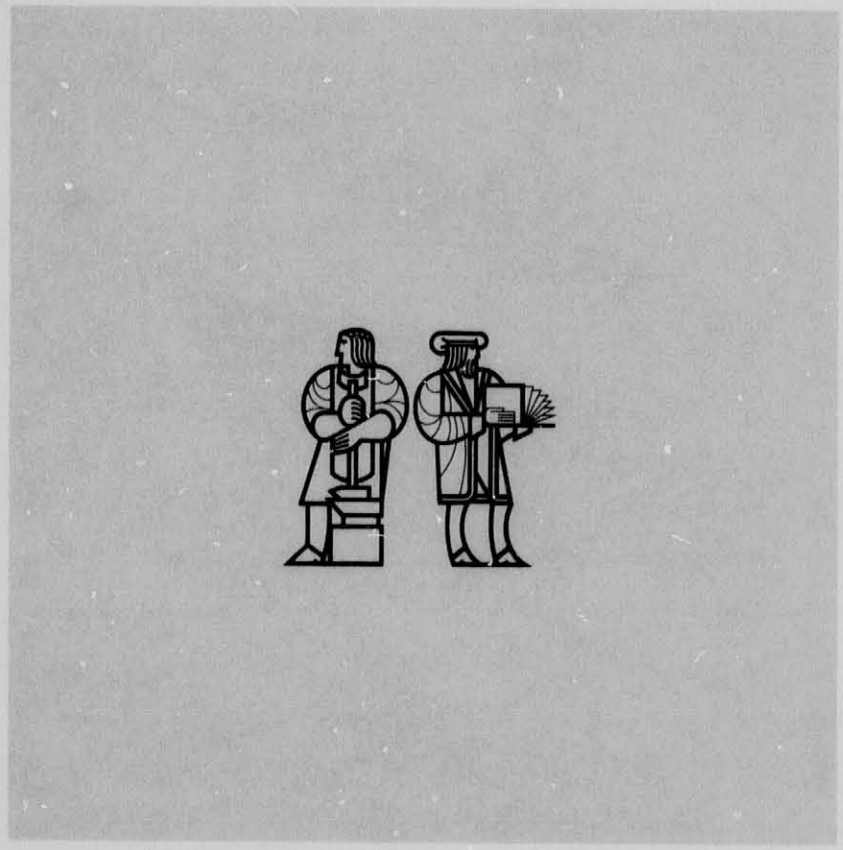
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ACADEMIC CALENDAR

1971

SEPTEMBER 3	FRESHMAN ORIENTATION
SEPTEMBER 13	REGISTRATION DAY, FIRST TERM
SEPTEMBER 14	CLASSES BEGIN
OCTOBER 11	COLUMBUS DAY (*holiday*)
OCTOBER 23 *through* OCTOBER 26	VACATION, VETERANS DAY
NOVEMBER 25 *through* NOVEMBER 28	THANKSGIVING VACATION
DECEMBER 13	LAST EXERCISES IN SUBJECTS WITH A FINAL EXAM
DECEMBER 15	LAST EXERCISES IN SUBJECTS WITH NO FINAL EXAM
DECEMBER 16 *through* DECEMBER 22	EXAMINATION PERIOD
DECEMBER 23 *through* JANUARY 4	CHRISTMAS VACATION

1972

JANUARY 5 *through* JANUARY 28	INDEPENDENT ACTIVITIES PERIOD
JANUARY 29 *through* FEBRUARY 1	VACATION
FEBRUARY 2	REGISTRATION DAY, SECOND TERM
FEBRUARY 3	CLASSES BEGIN
FEBRUARY 19 *through* FEBRUARY 22	VACATION, WASHINGTON'S BIRTHDAY
MARCH 25 *through* APRIL 2	SPRING VACATION
APRIL 15 *through* APRIL 18	VACATION, PATRIOTS' DAY
MAY 17	LAST EXERCISES IN SUBJECTS WITH A FINAL EXAM
MAY 19	LAST EXERCISES IN SUBJECTS WITH NO FINAL EXAM
MAY 22 *through* MAY 26	EXAMINATION PERIOD
MAY 29	MEMORIAL DAY (*holiday*)
JUNE 2	COMMENCEMENT DAY
JUNE 12	SUMMER SESSION BEGINS

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ALAN HILDRETH BARRETT, PH.D.
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Professor of Physics

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HAROLD ADOLPH LUNDQUIST
JAN ORSULA
THOMAS JOSEPH WHITE, JR.

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Professor of Physics, Emeritus; Senior Lecturer

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Dean of the School of Science, Emeritus

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Harry B. Higgins Professor of the Solid State, Emeritus

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Professor of Physics, Emeritus; Senior Lecturer

JERROLD REINACH ZACHARIAS, PH.D., L.H.D., SC.D.
Institute Professor, Emeritus; Professor of Physics, Emeritus;
Senior Lecturer; Director of the Education Research Center

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Center for Advanced Visual Studies

GYORGY KEPES, M.A.
Director

Center for International Studies

EVERETT EINAR HAGEN, PH.D.
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Associate Director

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GUSTAV SCHONFELD, M.D.
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Francis Bitter National Magnet Laboratory

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DONALD THOMAS STEVENSON, PH.D.
Assistant Director

ELMER WILBUR LAURENCE DAVIS, S.B.
Assistant Director for Administration

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Director

JOINT CENTER FOR URBAN STUDIES OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY AND HARVARD UNIVERSITY

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Director of Drama

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Director of Music

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Conductor of the M.I.T. Glee Club

JOHN COOK, MUS.B.
Organist

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MARY DALY HOWE, A.M.
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Director of the Office of Aerospace Studies

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Major, U.S. Air Force
Technical Instructor

RAYMOND HORACE GRENIER, B.A.
Major, U.S. Air Force
Technical Instructor

GEORGE W. HOAGE
Staff Sergeant, U.S. Air Force
Technical Instructor

ARTHUR H. VERVILLE
Sergeant, U.S. Air Force
Technical Instructor

Military Science

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Colonel, Infantry
Visiting Professor of Military Science;
Director of the Office of Military Science
(until January 31, 1972)

JOE F. ELLIOTT, S.M.
Colonel, Infantry
Technical Instructor (until January 31, 1972)
Visiting Professor of Military Science;
Director of the Office of Military Science
(beginning February 1, 1972)

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Technical Instructor

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Technical Instructor

LEIGHTON JOHN EVANS, JR.
SP/4, U.S. Army
Administrative Assistant

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WILLIAM ROBERT PORTER, PH.D.
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Professor of Naval Architecture

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Commander, U.S. Navy
Technical Instructor

JOHN D. FEDOR, M.S.
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Technical Instructor

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Chief Storekeeper, U.S. Navy
Technical Instructor

HOWARD WAYNE GAIN
Yeoman Third Class, U.S. Navy
Technical Instructor

Science has provided mankind with four priceless gifts which have allowed us to move far from the frightened, superstitious, hungry state of just a few centuries ago. These gifts include an understanding of the physical world in which we live and of the forces of nature which we must contend to survive. Research has provided us with deep insights into living organisms including ourselves; it has given us some understanding of the complex societies in which men live together; and it has provided the basis of tools with which we can compete more effectively with nature for the means of survival.

These great achievements of the human mind have been a source of optimism and pride, a source of the hope that increased understanding would bring a happier life. Yet at the moment many among us have lost this hope and have become so frightened of the future prospects that they would, if they could, stop technological change and the scientific discoveries on which the future depends.

To me it is evident that without new technology, to enhance man's muscle and brain power, we could not continue the quest of a free and decent society for everyone.

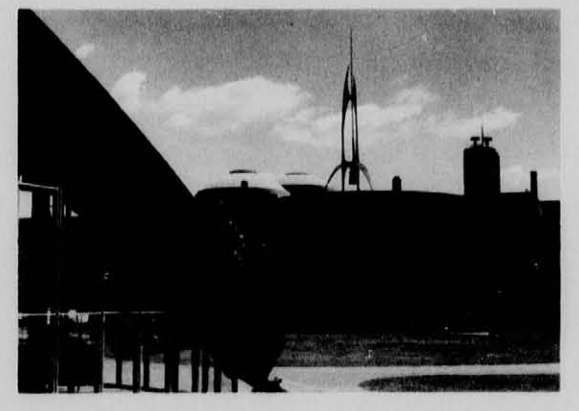
The contemporary multicrisis we face is basically the consequence of an ever-increasing disparity between man's growing mastery of the physical world on the one hand, and his lack of understanding of the profound impact of his actions on himself and his social institutions, on the other. It is, as well, a consequence of the lack of effective means, thus far, for guiding the man-induced social evolution. The effects of this incongruence between a growing ability to change the world and the inability to shape it to fit our hopes can be seen all around us.

It is generally believed that we have the means to provide the opportunity for a decent life for everyone. It is the bittersweet character of the modern world, the contrast between the world that is and the world that could be, that leads to the disenchantment that we see on all sides and to an almost universal inclination to blame most of the current ills on bad management or the influence of special groups.

The first responsibility of universities must always be a dedication to rationality and scholarship in science and engineering, social science, the arts, and the professions. But at this moment universities must do more. We are called upon to become leaders in an effort through new educational, research, and action programs to relate man's humanistic needs to the choices available in technology, social organization, and ecology. M.I.T.'s history is one of dedication to society's need and we are committed to a major effort to help solve these pressing problems.

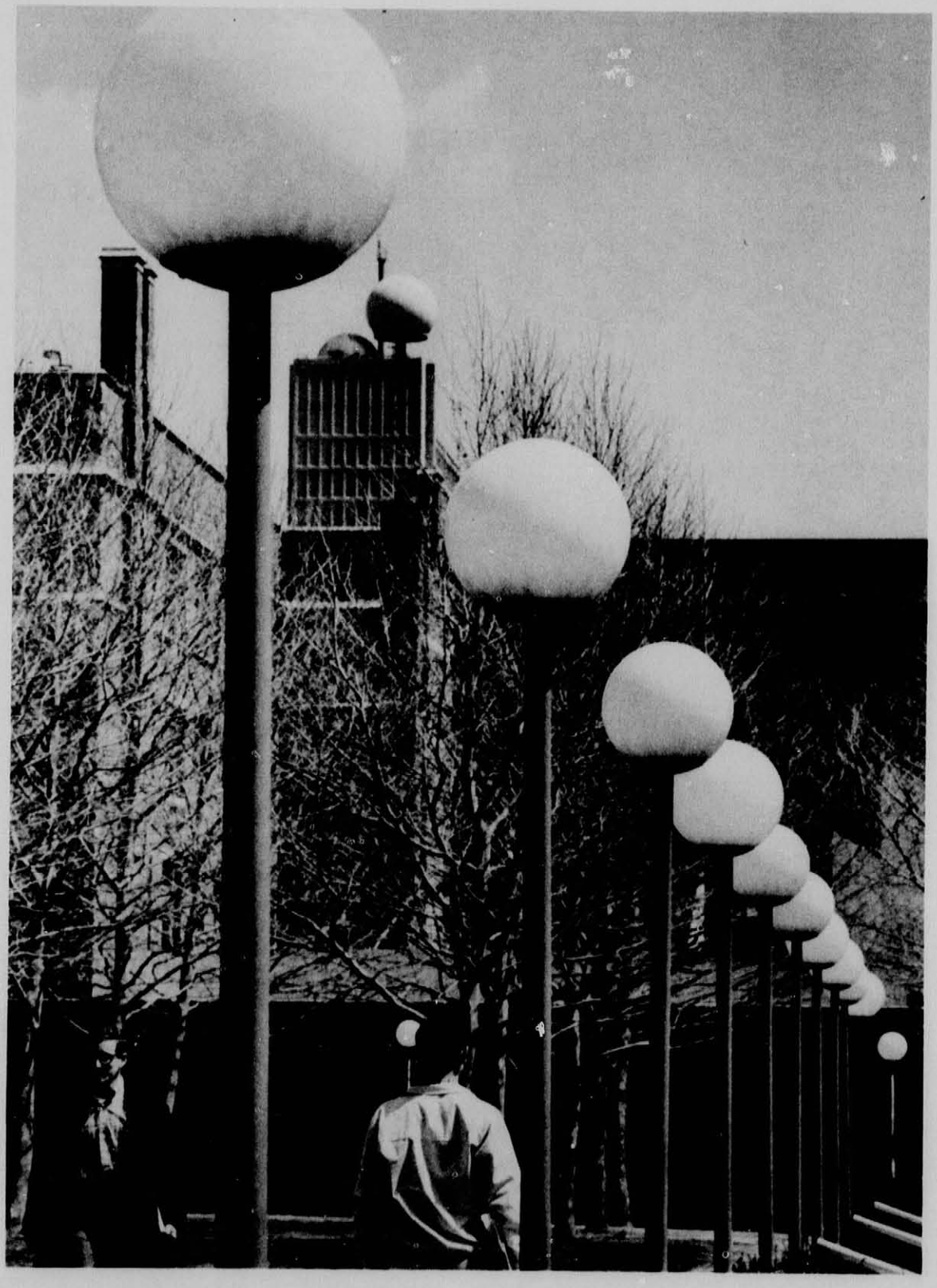
JEROME B. WIESNER
President







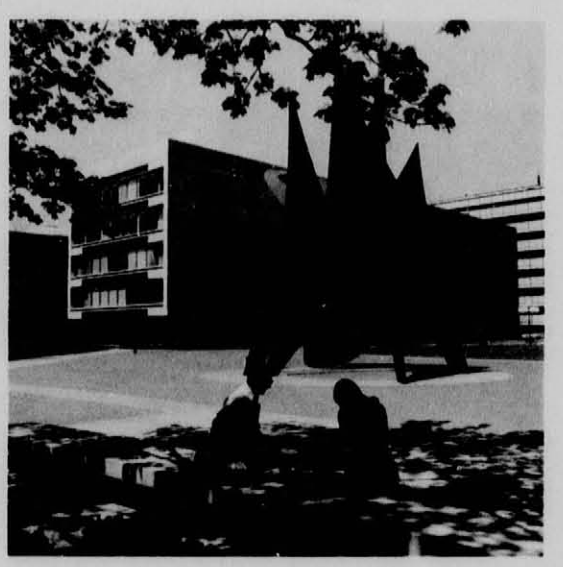


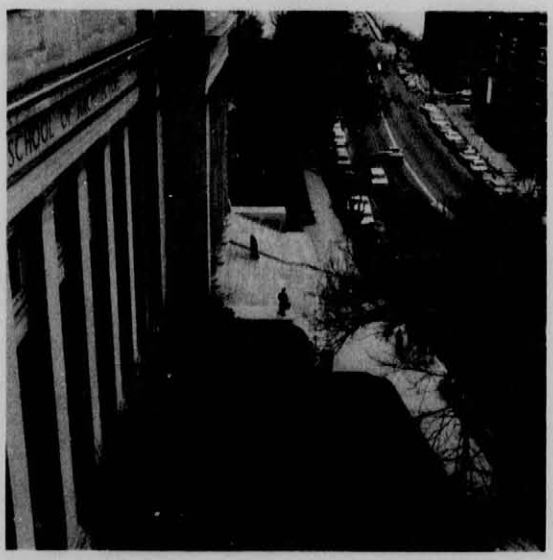

















M.I.T.















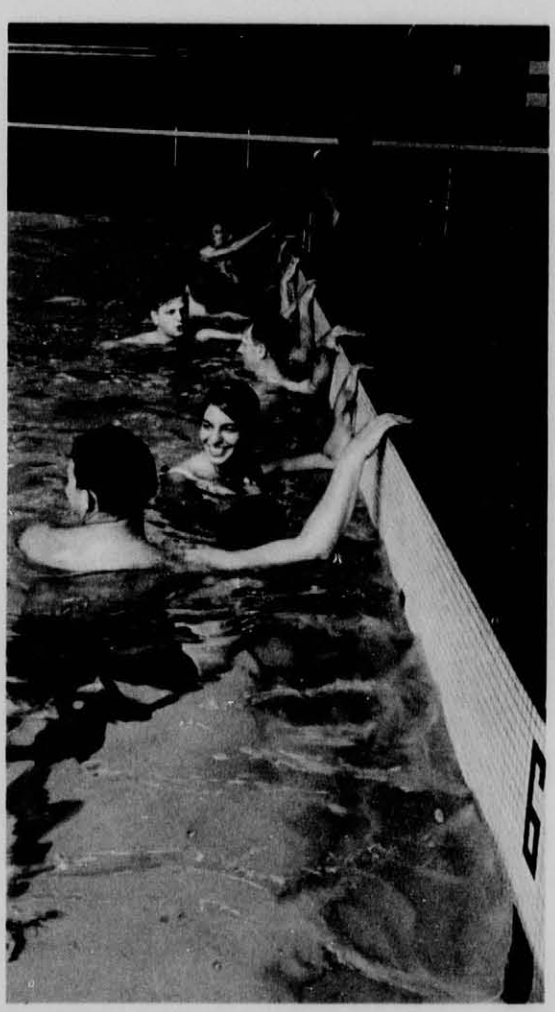




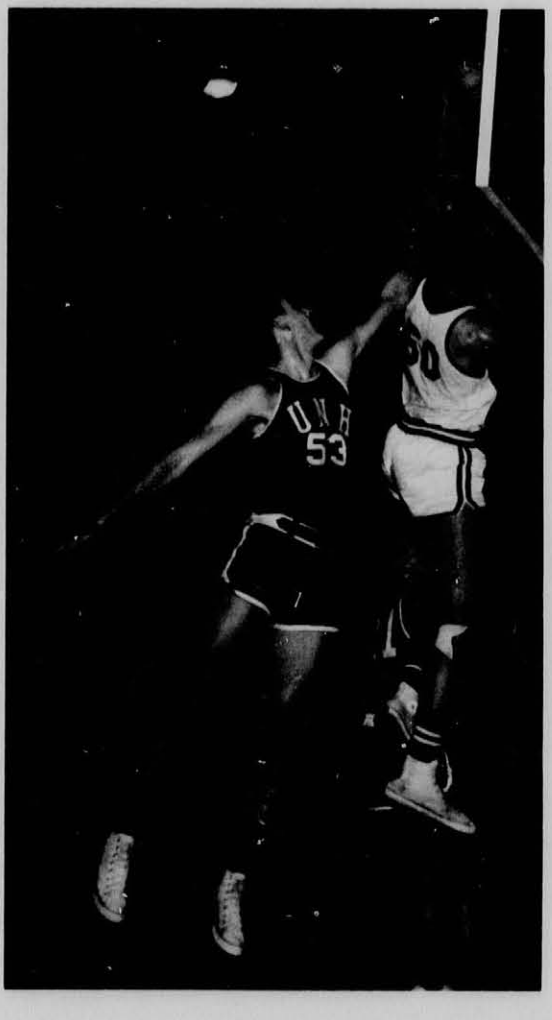











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A Modern University Centered in Science

The Massachusetts Institute of Technology is an independent, coeducational, endowed institution committed by charter and plan to the extension of knowledge through teaching and research. It is organized into five academic schools — Architecture and Planning, Engineering, Humanities and Social Science, Management, and Science — and a number of interdisciplinary groups. There are about 7,800 students (including about 600 women), more than 4,100 of them studying for undergraduate degrees; about 1,000 members of the faculty; and a supporting teaching staff of about 700. The Institute is located on a well-equipped residential campus of 125 acres fronting the Charles River in Cambridge, opposite Boston.

M.I.T. awards Bachelor's, Master's, professional (Engineer), and doctoral degrees, and it provides important programs of postdoctoral and postgraduate study in management, engineering, and the life sciences. From modest beginnings in 1861 as an institution "where young men could learn exactly and thoroughly the fundamental principles of positive science with their leading applications to the industrial arts," the Institute has grown to embrace teaching and research programs of distinction in engineering and the engineering sciences, the physical sciences, architecture and planning, the life sciences, management, and those of the humanities and social sciences most closely related by method or content to modern developments in engineering, science, and mathematics.

A Powerful Curiosity about Things Not Understood

The unique educational opportunities which the Institute presents to undergraduate and graduate students stem from concepts which underlie all its teaching programs and from special qualities which M.I.T.'s character imparts to its entire academic community.

Emphasis on fundamentals and on self-reliance are central in M.I.T.'s educational philosophy. Substantially every subject taught here is influenced by the environment of a scientific and technological institution: a strong sense of the quantitative and the analytical, a critical analysis of cause and effect, a demand for precision, and a powerful curiosity about things not understood enter every classroom. The Institute's faculty holds that this kind of education is relevant to any responsible role which its graduates may assume in a society increasingly influenced by technological progress.

The central purpose of the academic programs is to give students a sound command of basic principles, versatility of mind, insight and perspective concerning natural phenomena, the habit of continued learning, and the power that comes from a thorough and systematic method of attack. From these attributes comes the best assurance against professional obsolescence, especially in today's world of rapid technological change.

M.I.T. is widely known for its contributions to new knowledge, achievements of a remarkable research enterprise which is shared broadly by faculty and students. This interlocking of research and teaching gives M.I.T. an intellectual climate of extraordinary excitement and a spirit of ferment and creative innovation in which every student may share.

The Institute has always sought high professional standards for its teaching and research; there is a traditional and established role of stressing excellence. The continuing search for new methods of teaching, rapid assimilation of new knowledge into teaching programs, and constant emphasis on self-criticism are evidence of the faculty's commitment to maintain and extend the high quality of an M.I.T. education.

Singleness of Method, Diversity of Interest

The Institute has a single campus and a single faculty serving both undergraduate and graduate students. Most of its classrooms and laboratories are in an interconnected group of buildings which facilitate informal interchange between departments and disciplines. Members of the faculty group themselves for teaching and research very largely according to their interests, and there are interdisciplinary laboratories to provide support in many fields which go beyond the traditional boundaries of a single department. Students, too, though they register (except for freshmen and some sophomores) in specific departments, focus their work much

according to their interests, sharing the interdisciplinary activities of the faculty with whom they work.

Though registration and academic requirements tend of necessity to emphasize the procedural aspects of an M.I.T. education, it is important to understand that the academic programs of most students — both undergraduate and graduate — are flexible within broad limits, determined each year by each student himself (in collaboration with a faculty advisor) in response to his own interests and preparation.

Most undergraduates study in at least three of M.I.T.'s schools, many in four, and a few in all five during the four years of their undergraduate work. Graduate students frequently study in two or three of M.I.T.'s five academic schools. Advanced undergraduates often register with graduate students for at least one of their classes; and many undergraduates and almost all graduate students participate, often together, in advanced research. M.I.T. students come from every state in the United States and from 80 foreign nations; the proportion of foreign students at the Institute (about 15 per cent) is one of the highest in an American university.

The intermixing of ages, disciplines, and nationalities which is characteristic of the Institute deeply influences the life and experience of every member of this academic community, bringing together students and teachers, metallurgists and physicists, biologists and architects, humanists and engineers, young and old. The result is an academic environment unusual for its singleness of method and purpose and notable for its diversity of interest.

To Foster Qualities of Intellect and Character

The scope of M.I.T. has always been wider than its title, "institute of technology," might suggest, and today the Institute's commitments to the humanities and social sciences are providing an entirely new dimension of scholarship. The increasing impact of science upon our social institutions and upon the conduct of industry and government has been reflected at M.I.T. in the emergence of active teaching and research in fields in which the physical and social sciences most directly interact — fields such as economics, psychology, political science, linguistics, and the history and philosophy of science.

Every M.I.T. undergraduate takes approximately 20 per cent of his undergraduate work in the humanities program, averaging one subject each term. An undergraduate who wants more work in this area may register for a program which combines study in one field of humanities or social science with work in one science or engineering discipline, or for a program which permits concentration in humanities alone. Students are eligible for either option after satisfying the Institute requirements in science.

The Institute maintains a commitment to foster for its students those qualities of intellect and character which distinguish truly educated men and women, the qualities of responsibility and ethic which mark the professional estate. In turn, M.I.T. assumes in its students a commitment to adult values which is expressed by extending to them a large measure of responsible self-government and personal freedom.

"As a great educational institution," Dr. Julius Adams Stratton, former President of M.I.T., has said, "we shall be judged not only by the quality of our students' intellectual discipline but by the firmness of their moral fiber, by their attitudes toward the whole of learning, by the manner in which they speak and act, and by their understanding of the obligations of a citizen."

The Academic Program

The primary organization of the academic program is along the lines of the traditional disciplines. Each of the academic departments offers one or more degree programs, or Courses[1] of study, and every upperclass undergraduate student and every graduate student is registered in one of these Courses. Degrees are awarded on the basis of satisfactory completion of Courses.

But increasing numbers of students choose fields of concentration which cross regular departmental lines. Among these are programs in fields such as planetary and space science, space technology, communications, materials, computer science, operations research, instrumentation, and others. Some of these involve guidance for the student by standing or special committees; some consist of association with one of the interdepartmental activities.

[1] At the Institute the word *Course* refers to an organized curriculum leading to a specified degree. The word *subject*, on the other hand, refers to the individual classes. Each Course is designated by a Roman numeral; individual subjects are given Arabic numerals to correspond with the Course numbers. For example, Civil Engineering is Course I; the number 1.05 indicates a subject given in the Course in Civil Engineering.

Undergraduate Courses at M.I.T. lead to the degree of Bachelor of Science (S.B.). Graduate degrees awarded are Bachelor in Architecture (B.ARCH.), Master of Science (S.M.), Master in Architecture (M.ARCH.), Master in City Planning (M.C.P.), Engineer (each degree designating the field in which it is awarded),[2] Doctor of Philosophy (PH.D.), and Doctor of Science (SC.D.).

The chart on the following pages shows schools, departments, undergraduate and graduate Courses and degrees, and Course numbers. Undergraduate Courses, including Courses which provide periods of on-the-job experience in industry, require four years of full-time study for the Bachelor of Science degree.

Undergraduate Courses and degree requirements are described in Section 2 of this Catalogue; graduate fields of study and degree requirements, in Section 3. The statements of each department in Section 4 should be consulted for detailed information about the degrees offered.

Three departments (Aerospace Studies, Military Science, and Naval Science) offer undergraduate instruction to all eligible students but are not a part of any of the five Institute schools. Their programs are described in Section 2.

The Academic Calendar

The academic calendar is a feature of university life which affects every member of the academic community, sets a framework within which the educational endeavor takes place, and controls, to a large extent, the ebb and flow of campus life. As times change, so do educational institutions and the whole atmosphere surrounding the academic process. An academic calendar framework within which this process develops must, in essence, be flexible to meet the needs which ensue.

Beginning in September, 1970, a new academic calendar was put into effect at M.I.T. A basic outline of this plan encompasses:

1. A fall term beginning on the Monday after Labor Day in four of seven years, and the Wednesday after Labor Day in other years. Classes during this term will end just before Christmas vacation and are preceded by a reading and final examination period.
2. An approximately one month January independent activities period following the Christmas vacation.
3. A second term, beginning following a few days break after the January independent activities period, ending in May and preceded by a two-week reading and final examination period.

The January Independent Activities Period is one in which students are involved, with faculty guidance, in reading or research projects of their own choosing. The period is intended to provide opportunity for flexibility in learning and teaching styles. To complement the traditional term subject program, the faculty feels that students need to be given an opportunity to spend part of their time formulating and following plans of study suited to their own individual learning styles. Formulating and following such a plan is not easy to do, and a student cannot be expected to do it without help, but he may well learn more from making an attempt in this direction, even a not entirely successful one, than he would from spending the same period of time in a routine way on a prescribed sequence of topics.

Teaching and Research Resources

Teaching and research both fulfill M.I.T.'s purpose of advancing the frontiers of knowledge, and these activities carried on together have greater power than either performed alone. While advancing human knowledge and understanding, research makes special contributions to the Institute's educational program by providing experience in theory and experiment for both students and faculty and by assuring that classroom teaching is up-to-date; thus research is viewed at M.I.T. as an essential partner with classroom and laboratory instruction.

The Institute receives generous grants from both industry and government in support of research activities in which students and faculty participate, and it devotes substantial resources of its own to such undertakings. For this work M.I.T. has facilities unusual — and in some cases unique — among educational institutions. There are more than 70 special laboratories on the campus in Cambridge. In general, the Institute's policy is to make these facilities available to all scholars — undergraduate, graduate,

(*continued on page 6.*)

[2] The Engineer degrees include Chemical Engineer (CHEM.E.), Civil Engineer (C.E.), Electrical Engineer (E.E.), Engineer in Aeronautics and Astronautics (E.A.A.), Marine Mechanical Engineer (MAR.MECH.E.), Materials Engineer (MAT.E.), Mechanical Engineer (MECH.E.), Metallurgical Engineer (MET.E.), Mineral Engineer (MIN.E.), Naval Architect (NAV.ARCH.), Naval Engineer (NAV.E.), Nuclear Engineer (NUCL.E.), Ocean Engineer (OCEAN E.).

Schools, Departments, Courses, and Degrees

Schools and Departments	*Undergraduate Courses (and Course Numbers)*	*Bachelor's Degrees*	*Graduate Courses (and Course Numbers)*	*Graduate Degrees*
School of Architecture and Planning				
Department of Architecture	ARCHITECTURE[1] (IV)	S.B.	ARCHITECTURE (IV)	B.ARCH.
	ARCHITECTURE[1] (IV-B)	S.B.		M.ARCH
Department of Urban Studies and Planning	URBAN STUDIES (XI)	S.B.	URBAN STUDIES AND PLANNING (XI)	M.C.P. PH.D.
School of Engineering				
Department of Aeronautics and Astronautics	AERONAUTICS AND ASTRONAUTICS (XVI)	S.B.	AERONAUTICS AND ASTRONAUTICS[2] (XVI)	S.M., E.A.A., SC.D., PH.D.
	COOPERATIVE COURSE[1] (XVI-B)	S.B.		
Department of Chemical Engineering	CHEMICAL ENGINEERING (X)	S.B.	CHEMICAL ENGINEERING[2] (X)	S.M., CHEM.E., SC.D., PH.D.
	CHEMICAL ENGINEERING[1] (X-C)	S.B.	CHEMICAL ENGINEERING PRACTICE (X-A)	S.M.
Department of Civil Engineering	CIVIL ENGINEERING[1] (I)	S.B.	CIVIL ENGINEERING[2] (I)	S.M., C.E., SC.D., PH.D.
Department of Electrical Engineering	ELECTRICAL ENGINEERING (VI)	S.B.	ELECTRICAL ENGINEERING[2] (VI)	S.M., E.E., SC.D., PH.D.
	ELECTRICAL ENGINEERING (VI-A)	S.B.	ELECTRICAL ENGINEERING (VI-A)	S.M.
Department of Mechanical Engineering	MECHANICAL ENGINEERING (II)	S.B.	MECHANICAL ENGINEERING[2] (II)	S.M., MECH.E., SC.D., PH.D.
	MECHANICAL ENGINEERING[1] (II-A)	S.B.	TEXTILE TECHNOLOGY	S.M.
	COOPERATIVE COURSE[1] (II-B)	S.B.		
Department of Metallurgy and Materials Science	METALLURGY AND MATERIALS SCIENCE (III)	S.B.	METALLURGY (III)	S.M., MET.E., MIN.E., SC.D., PH.D.
	METALLURGY AND MATERIALS SCIENCE[1] (III-A)	S.B.	CERAMICS	S.M.

[1] See the Department's statement for complete information about the specific degrees offered.

[2] In the field of Materials Engineering, programs leading to the degrees of Materials Engineer (MAT.E.) or Doctor of Science or Doctor of Philosophy are offered under interdepartmental supervision.

[3] Five-year Course leading to Bachelor of Science and Master of Science degrees awarded simultaneously at the end of the graduate year.

[4] See the statement concerning the specific degrees offered by the Department, as well as the degrees offered by the Woods Hole Oceanographic Institution and M.I.T. in the Joint Program described at the end of Section 4.

Schools and Departments	*Undergraduate Courses (and Course Numbers)*	*Bachelor's Degrees*	*Graduate Courses (and Course Numbers)*	*Graduate Degrees*
Department of Nuclear Engineering			NUCLEAR ENGINEERING (XXII)	S.M., NUCL.E., SC.D., PH.D.
Department of Ocean Engineering	NAVAL ARCHITECTURE AND MARINE ENGINEERING (XIII)	S.B.	NAVAL ARCHITECTURE AND MARINE ENGINEERING (XIII)	S.M., NAV. ARCH., MAR. MECH.E., SC.D., PH.D.
	OCEAN ENGINEERING (XIII)	S.B.	OCEAN ENGINEERING[4]	S.M., OCEAN E.
	SHIPPING AND SHIP-BUILDING MANAGEMENT[1,3] (XIII-B)	S.B.	SHIPPING AND SHIP-BUILDING MANAGEMENT (XIII-B)	S.M.
			NAVAL CONSTRUCTION AND ENGINEERING[1] (XIII-A)	S.M., NAV.E.
School of Humanities and Social Science				
Department of Economics	ECONOMICS (XIV)	S.B.	ECONOMICS (XIV)	S.M., PH.D.
Department of Foreign Literatures and Linguistics			LINGUISTICS (XXIII)	PH.D.
Department of Humanities	HUMANITIES AND ENGINEERING (XXI-A)	S.B.		
	HUMANITIES AND SCIENCE (XXI-B)	S.B.		
Department of Philosophy	PHILOSOPHY (XXIV)	S.B.	PHILOSOPHY (XXIV)	PH. D.
Department of Political Science	POLITICAL SCIENCE (XVII)	S.B.	POLITICAL SCIENCE (XVII)	S.M., PH.D.
Department of Psychology			PSYCHOLOGY (IX)	S. M., PH.D.
Alfred P. Sloan School of Management	MANAGEMENT (XV)	S.B.	MANAGEMENT (XV)	S.M., PH.D.
School of Science				
Department of Biology	LIFE SCIENCES (VII)	S.B.	BIOLOGY[1,4] (VII)	S.M., PH.D., SC.D.
	LIFE SCIENCES[2] (VII-A)	S.B.		
Department of Chemistry	CHEMISTRY (V)	S.B.	CHEMISTRY (V)	S.M., PH.D., SC.D.
Department of Earth and Planetary Sciences	EARTH AND PLANETARY SCIENCES (XII)	S.B.	EARTH AND PLANETARY SCIENCES (XII)	S.M., PH.D., SC.D.
	EARTH AND PLANETARY SCIENCES[3] (XII-A)	S.B.	EARTH AND PLANETARY SCIENCES[3] (XII-A)	S.M.
	PHYSICAL SCIENCES[1] (XII-B)	S.B.	OCEANOGRAPHY[4]	S.M., PH.D. SC.D.
Department of Mathematics	MATHEMATICS (XVIII)	S.B.	MATHEMATICS (XVIII)	S.M., PH.D., SC.D.
Department of Meteorology			METEOROLOGY (XIX)	S.M., PH.D., SC.D.
			OCEANOGRAPHY[4]	S.M., PH.D., SC.D.
Department of Nutrition and Food Science			NUTRITION AND FOOD SCIENCE[1] (XX)	S.M., PH.D., SC.D.
Department of Physics	PHYSICS (VIII)	S.B.	PHYSICS (VIII)	S.M., PH.D., SC.D.

and postdoctoral — whenever they have a legitimate educational need for them, with the result that nearly all of M.I.T.'s laboratories are shared by undergraduates, graduate students, and faculty members working together.

Most of these research facilities are described elsewhere in this book by the departments which operate them. Typical are the nuclear reactor (Department of Nuclear Engineering); the supersonic wind tunnels (Department of Aeronautics and Astronautics); the Electronic Systems Laboratory (Department of Electrical Engineering); and several departmental computation facilities operated by the Departments of Civil, Electrical, and Mechanical Engineering, and the Alfred P. Sloan School of Management.

In addition to laboratories and facilities organized within departments, there are an increasing number of laboratories of an interdepartmental nature, established to facilitate work in fields which cross the lines of traditional disciplines. The most important of these interdisciplinary research and teaching activities are described in Chapter 5.

Supporting both the teaching and research activities at the Institute are the libraries on campus and the information processing services. These facilities are described here.

The Libraries

With holdings in excess of one million volumes, the M.I.T. Libraries are a vital resource for the support of both teaching and research. Over 15,000 current journals and serials, together with extensive back files, provide comprehensive holdings in all major fields. These are enriched by numerous small collections, including a large group of technical reports and the Institute archives.

The library system, with headquarters in the Charles Hayden Memorial Library building, includes five school libraries, three branches, and six reading rooms: the Rotch Library of Architecture and Planning; the Dewey Library (economics, industrial management, industrial relations, and political science); the Barker Engineering Library (with a separate Aeronautics and Astronautics Library branch, Materials Center Reading Room, and Space Center Reading Room); the Humanities Library (with a branch Music Library and a Reserve Book Room); the Science Library (with the Lindgren Library branch for the earth and planetary sciences, Chemistry Reading Room, and Physics Reading Room); and the Student Center Library.

All the services offered by a fine research library are available: reference and information, interlibrary loans, and microfilms, photoprints, and quick copies of works here or in other libraries.

The libraries serve primarily Institute students, faculty, staff members, and their families. Others wishing to use the facilities may apply to the Head, Extramural Services, Room 14S-200, for a library privilege card.

Information Processing Services

At M.I.T., the computer and techniques for the processing of information each serve as subjects of study and as specific tools in programs of teaching, research, and administration. Many programs are in progress that seek to contribute to our understanding of the structure of computer systems and languages and to the application of new techniques to computer design and organization, to the development of operating systems and programming languages, and to applications.

The demonstrated and potential contributions that the computer can make to the advancement of essentially every field of human endeavor are well recognized. While it frequently is viewed primarily as a device to perform calculations in scientific research, the computer serves increasingly as a tool that opens up totally new ways to process information and presents an opportunity to formulate and think through both old and current problems in wholly different ways. As a result of the application of the computer, new disciplines are emerging and established disciplines are being significantly transformed.

Students, both undergraduate and graduate, are intimately involved in much of this activity. A large majority of students begin to use the computer early in their programs of study and many continue to do so on into graduate work. Opportunities to pursue programs of study oriented toward computer sciences are available and are described elsewhere in this Catalogue. Within each department, specific research programs are under way in either the development or utilization of the computer.

Information processing facilities at M.I.T. fall into two groups: those provided within the Information Processing Center, which serves as a large, versatile central computing facility to meet the teaching and research needs of the

Institute community; and those provided through the local departmental and laboratory computer facilities, which provide somewhat specialized information processing requirements to meet specific needs.

The Information Processing Center offers its users a broad spectrum of services, including high-performance job-stream processing, remote-job-entry, systems for experimentation, research and development, general purpose, interactive time-sharing, programming assistance, and documentation.

The Center provides its users with four major computer environments:

OPERATING SYSTEM/360 A large, complex job-stream facility is available operating currently on an IBM System/360, Model 65, and providing a full spectrum of local and remotely-accessible services. A wide variety of programming languages and applications software is available to each user, together with consulting services and other user-oriented facilities and services. Although the principal use of this service is on a local basis, a considerable and growing fraction of the total work load of this system is generated through Remote Job Entry over telecommunication connections to several locations on the M.I.T. campus and to several other universities in the greater Boston area. This system currently processes approximately 1,000 jobs per day.

CP/67 This system, running on an IBM System/360, Model 67, provides an operating environment oriented towards systems research experimentation and development; and, under the CMS monitor, interactive time sharing. Using a virtual machine concept, this system provides each simultaneous user with a simulated computer and the tools to develop a system to operate upon it. The current configuration accommodates approximately thirty simultaneous users.

MULTIPLEXED INFORMATION AND COMPUTING SERVICE (MULTICS) This system, currently implemented on the GE-645, was developed by a cooperative effort between the Institute's Project MAC, the General Electric Company, and the Bell Telephone Laboratories. This system, which has been generally available to the campus since the fall of 1969, provides the most advanced and sophisticated remote access service currently available. It offers a system environment and a developing set of tools not only to the novice programmer with limited applications but also for faculty and students performing the most advanced research in computer science and subsystem development. The maximum number of simultaneous users is now fifty-five and will eventually be increased to ninety.

COMPATIBLE TIME-SHARING SYSTEM (CTSS) This general purpose, M.I.T.-developed time-sharing system operates on a specially-modified 7094 and has served as the Institute's primary time-sharing facility for the last seven years. The system serves thirty simultaneous users and has become the most widely publicized effort in multiple access computing. It encompasses about one hundred commands and a large number of publicly-available user-written programs.

Other Teaching Facilities

The Institute's philosophy of "learning by doing" sometimes carries its teaching program beyond the Cambridge campus. Three departments (Aeronautics and Astronautics, Electrical Engineering, and Mechanical Engineering) have programs of study combining academic work at M.I.T. with on-the-job practice in industry. In chemical engineering, the School of Chemical Engineering Practice operates stations for undergraduates and graduate students at the Bound Brook, New Jersey, plant of the American Cyanamid Company and at the Oak Ridge National Laboratory and it also provides other opportunities for students to obtain practical experience in industry.

In a very real sense, these activities extend the M.I.T. campus into a number of industrial plants throughout the country.

Organization of the Institute

The governing body of the Institute is a board of trustees known as the Corporation, over which the Chairman presides. Its members include 80 distinguished leaders of science, engineering, industry, and education and (*ex officio*) the President, the Chancellor, and the Vice President and Treasurer of the Institute. Between quarterly meetings the Corporation functions through its officers and Executive Committee.

The Corporation appoints Visiting Committees for each department and for certain of the other major activities of the Institute. Members of these Committees, leaders in their respective professions, serve as counselors to the departments and in turn make recommendations to the Corporation concerning departmental activities.

The Institute's chief executive office is the President. The Chancellor acts as deputy to the

President on all matters. In addition, senior officers of the Institute include the Provost, the Dean for Institute Relations, and eight Vice Presidents. The academic program is directed by the President, the Chancellor, the Provost, and five deans, each responsible for the undergraduate and graduate programs in one of the five academic schools.

The Dean for Student Affairs is directly concerned with all aspects of student life, and the Dean of the Graduate School is concerned with coordinating educational policies of the graduate program. Officers concerned with the administration of academic affairs meet regularly in the Academic Council. Other administrative officers join them to form the Administrative Council.

The management of research activities which are financed through contracts with government and industry is centered in the Division of Sponsored Research. The Industrial Liaison Office and the M.I.T. Associates Office are responsible for fulfilling the contractual obligations of the Institute to a group of leading American companies which make special grants in support of M.I.T.'s program in research and education.

The President presides over the Faculty of the Institute, which consists of all professors, associate professors, assistant professors, certain professors emeriti, certain designated instructors and research associates, and a number of administrative officers (*ex officiis*).

The academic staff of the Institute totals about 3,800.

The Campus

M.I.T.'s 125-acre campus extends for more than a mile along the Cambridge side of the broad Charles River Basin facing the city of Boston. Most academic activities are brought together in a group of interconnected buildings designed to permit maximum flexibility and easy communication among the departments and schools. The extensive athletic plant and playing fields are on the campus, as are the recreational buildings, dormitories, and dining halls. This convenient arrangement contributes greatly to the sense of unity and interdisciplinary involvement that characterize the Institute.

At the eastern end of the campus are the Alfred P. Sloan Building and the distinctive Grover M. Hermann Building, which house activities in management, economics, international studies, and political science. Adjacent to them is Eastgate, a 30-story apartment tower for married students and faculty.

A commanding feature of East Campus is McDermott Court, in which a great sculpture by Alexander Calder rises in bold contrast against the facade of the 20-story Center for Earth Sciences, the Cecil and Ida Green Building. Surrounding McDermott Court are student residences, Walker Memorial, Hayden Library, and the Camille Edouard Dreyfus Chemistry Building.

The Institute's main buildings, enclosing the Great Court, were designed by Welles Bosworth '89 and were dedicated in 1916. Banked by magnificent rhododendrons and lined with tall shade trees, the Great Court opens to a wide prospect of the Charles River, the low brick buildings of old Boston and the concrete and glass towers that rise above them.

Interconnected with these central buildings are the Center for Life Sciences (the Dorrance and the Uncas A. and Helen F. Whitaker Buildings), the Karl Taylor Compton Laboratories (electronics and nuclear science), the Center for Materials Science and Engineering (the Vannevar Bush Building), the Information Processing Center, the Center for Space Research, the Sloan Laboratory, the Guggenheim Laboratory, and the Center for Advanced Engineering Study.

Across Massachusetts Avenue, on West Campus, is the Student Center, the Julius Adams Stratton Building, which contains social rooms, restaurants, offices for student activities, music rooms, a spacious library, and recreational and commercial facilities.

The Student Center plaza, which is the focus of social activities at the Institute, is bounded on the west and south by Kresge Auditorium and the Chapel. Both buildings were designed by Eero Saarinen. The auditorium contains a large concert hall seating 1,200, a little theater, and offices and rehearsal rooms. The Chapel is used regularly for religious services by all faiths and is open throughout the day for meditation. The Chapel's unusual design includes an exterior moat that reflects light in changing patterns on the interior walls. Adjacent to the Chapel is the Center for Advanced Visual Studies.

Along Memorial Drive and facing out on the Charles River are additional student residences, among them the serpentine Baker House, which was designed by the Finnish architect Alvar Aalto. Westgate, an apartment complex for married students, is at the westernmost end of the campus.

Also on West Campus are playing fields for soccer, lacrosse, baseball, softball, touch football, rugby, cricket, track, and tennis. Here, too, are Rockwell Athletic Cage, Briggs Field House, an outdoor skating rink, and the David Flett du Pont Athletic Center.

The Charles River Basin, which is two miles long and a third of a mile wide, is a major feature of M.I.T.'s physical environment, and the Pierce Boathouse and the Sailing Pavilion provide means for extensive activity in crew and sailing.

Endicott House

Endicott House, a former private estate at 80 Haven Street in Dedham, is M.I.T.'s center for off-campus educational and administrative conferences. Set in spacious grounds, the House has meeting and dining rooms for 75 guests and overnight accommodations for 31.

Talbot House

Near Woodstock, Vermont, Talbot House is an attractive old New England farm home furnished to accommodate groups of students and faculty for conferences and recreational weekends in the Vermont countryside.

Associated Organizations

Organizations associated with the Institute include:

Alumni Association

The M.I.T. Alumni Association has a comprehensive program for keeping 58,000 former students informed of M.I.T. affairs. For example, the Alumni Association publishes *Technology Review*, a nationally circulated journal of contemporary affairs in science, engineering, and other fields represented among M.I.T. alumni. There are nearly one hundred regional M.I.T. clubs throughout the world, and the Alumni Fund, through which alumni contribute to the financial mainstream of the Institute, ranks annually in the country's top half-dozen. Other alumni activities include Alumni Day, class reunions, alumni seminars, and conferences in Cambridge and major cities throughout the United States as well as a program of communications and directories.

Association of M.I.T. Alumnae

The Association of M.I.T. Alumnae is an organization of former M.I.T. women students with a continuing interest in women currently studying at the Institute. The group maintains and administers its own funds for special financial aid to women students.

Lowell Institute School

The Trustee of the Lowell Institute established this free evening school in 1903, under the auspices of M.I.T. The program is designed to bring systematic engineering study within the reach of young people in industry who would otherwise be denied these opportunities. The school is presently offering a two-year program in computer technology. For further information, write to the Director of the Lowell Institute School, Room 5-113, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

Lowell Institute Cooperative Broadcasting Council

The Institute is associated with other Boston educational and cultural organizations in the Lowell Institute Cooperative Broadcasting Council. Boston's non-commercial educational stations, WGBH-FM (89.7 mc.), WGBH-TV (Channel 2), and WGBX (Channel 44), are operated with the advice and cooperation of the Council.

M.I.T. participation in programming is coordinated by the Institute Information Service.

The M.I.T. Press

Since The M.I.T. Press became a wholly independent university press in 1962, it has grown to the point that it is now among the few largest scholarly publishers in the United States. About 1,000 books have been published under the M.I.T. imprint since the Press was founded in 1933. At the present time approximately 150 new books are issued by the Press each year.

The Press, which is located in new quarters at 28 Carleton Street, consists of three operating divisions: information acquisition and evaluation, information processing, and information dissemination. The Director of the Press is responsible to the office of the President and Chancellor. Editorial and management boards consisting of faculty and officers of the Institute advise the Press in its policy and operations. The editorial board is charged with administering the imprint of the Press; book projects must be accepted by the board before they are published by the Press.

The M.I.T. Press is a principal agency for the execution of the Institute's responsibility to teach not only a residential student body but

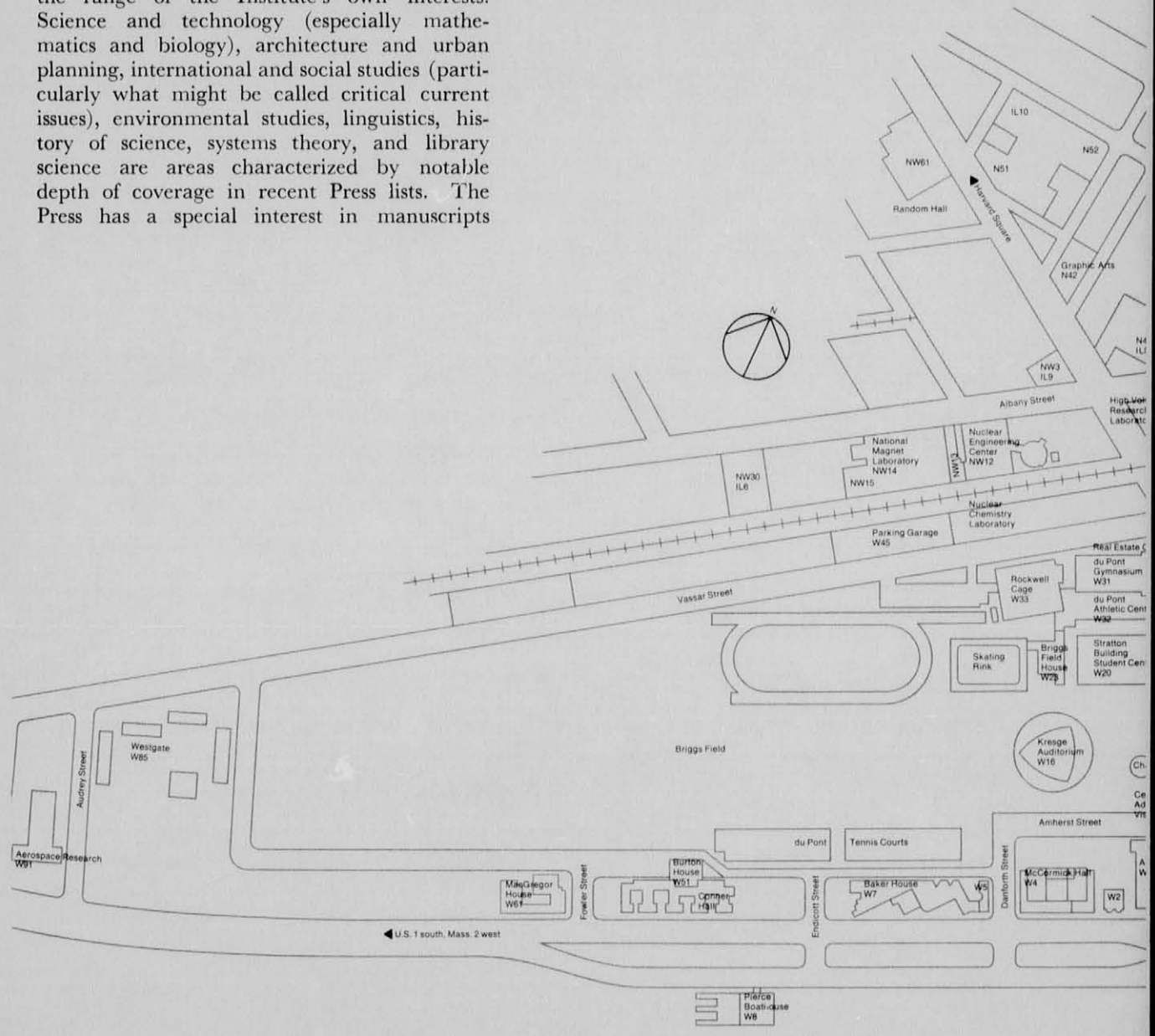
M.I.T.: A Modern University

MAP OF THE INSTITUTE

the world at large. The Press has world-wide distribution; its books and other educational materials bearing its imprint convey to a broad audience of scholars a sense of the quality of the Institute and its concern with learning. Books published by the Press have won many awards, including the National Book Award and a wide variety of citations for graphic excellence.

In general, the range of publication parallels the range of the Institute's own interests. Science and technology (especially mathematics and biology), architecture and urban planning, international and social studies (particularly what might be called critical current issues), environmental studies, linguistics, history of science, systems theory, and library science are areas characterized by notable depth of coverage in recent Press lists. The Press has a special interest in manuscripts originating at the Institute itself; among its authors, however, are members of faculties of many other universities in the United States and abroad.

Some of the books published by the Press are sharply specialized, others are of broad general interest; some are topical, others are of lasting concern; some are hardcover originals, others are popular paperback reprints. To achieve its function of disseminating learning, the Press



makes increasing use of a variety of other media besides the printed book, often as elements of a media package that is organized about a volume or set of volumes. It should be noted that no book published by the Press ever in the passage of time becomes unavailable to the individual purchaser or library: a reproduction service operated in conjunction with the Microreproduction Laboratory provides copies on special order.

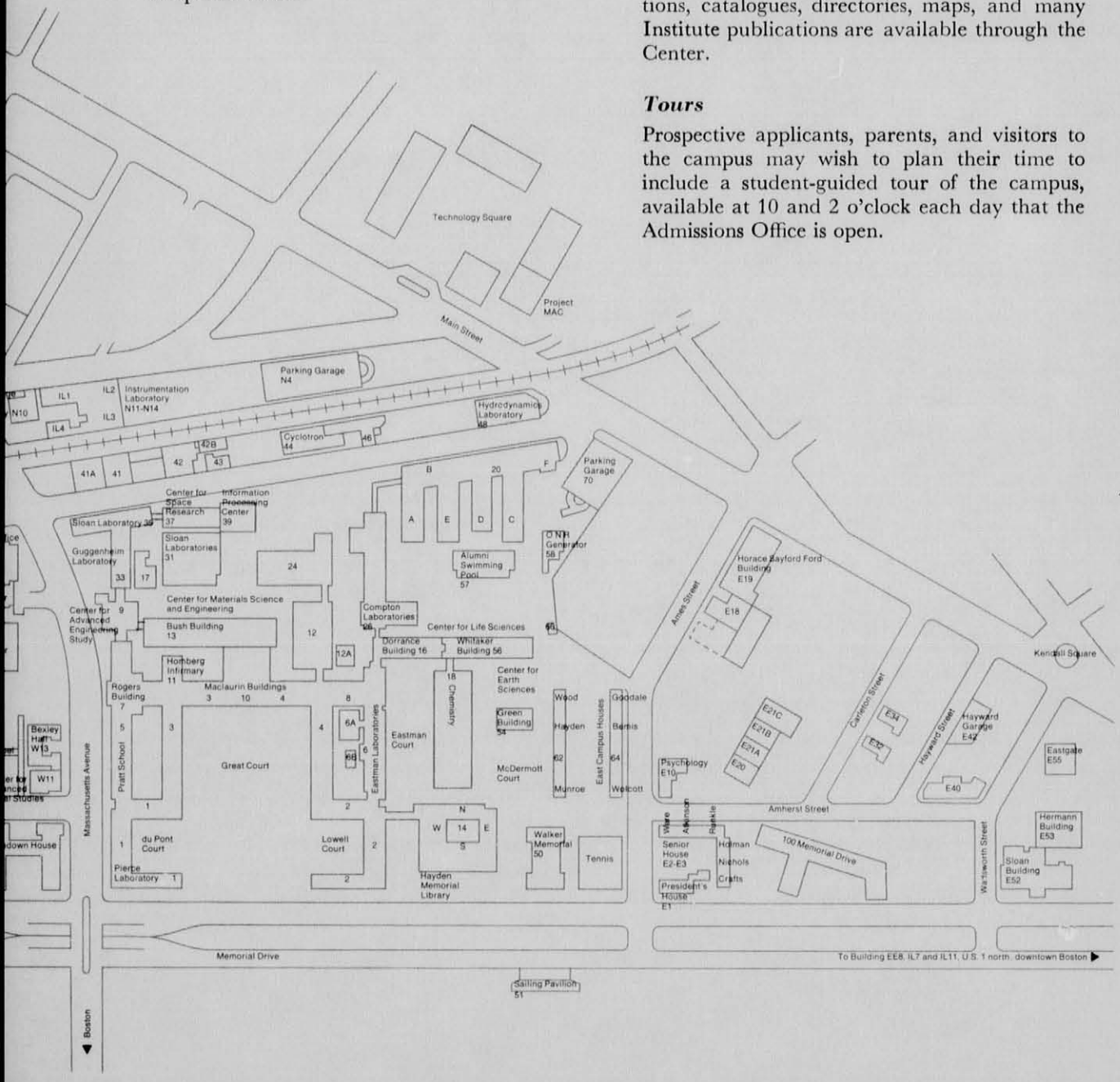
A complete descriptive catalogue of publications is available upon request addressed to the M.I.T. Press, Cambridge, Massachusetts 02142.

Information Center

This office (Room 7-111) is located in the main lobby at the 77 Massachusetts Avenue entrance. General information about Institute activities as well as directions to various M.I.T. destinations, catalogues, directories, maps, and many Institute publications are available through the Center.

Tours

Prospective applicants, parents, and visitors to the campus may wish to plan their time to include a student-guided tour of the campus, available at 10 and 2 o'clock each day that the Admissions Office is open.





A Tradition of Excellence

The Massachusetts Institute of Technology maintains a tradition of excellence in preparing its undergraduates for creative graduate work or professional activity. Because standards of admission are high, the educational program is set at a level which offers to students the opportunity to acquire deep understanding of basic scientific principles and to develop habits of thought characteristic of leaders in science and engineering.

Engineering, science, architecture and planning, management, and humanities and the social sciences are the fields of principal concentration in undergraduate education at M.I.T. The underlying themes are the purposeful application of science through engineering, the study of science for its own sake, and the awareness of the impact of engineering and science upon our physical environment and upon our conduct of industry, government, and society. An integrated program of studies in the humanities and social sciences extends through the undergraduate years, developing powers of judgment and taste and strengthening the student's ability both to meet the basic requirements of his profession and to assume effectively wide responsibilities in public and private life.

Each Course curriculum leading to a Bachelor's degree consists of two major divisions: the General Institute Requirements and a Departmental Program.

The General Institute Requirements consist of certain specific subjects in science, science distribution subjects in at least three fields, project-type laboratory subjects, and humanities and social science offerings. Among these offerings, each student may exercise a considerable range of individual choice.

Each Departmental Program consists, in part, of a grouping of subjects in the areas of professional interest to the Course or Courses represented by that particular department and, in part, of additional opportunities for the student to take subjects of his choice. By Institute rule, considerable time for electives is available to every student throughout the four years.

A student may use these elective opportunities to follow special interests or to deepen and broaden his educational background. Alternatively, he may use his elective time to prepare for advanced study in some professional field, such as medicine or law; for graduate study in some area in which M.I.T. gives no undergraduate degree, such as meteorology or oceanography; or for advanced study in a field which is interdisciplinary, such as astrophysics, communication science, or space science and technology.

The pattern for the Bachelor's degree program provides a basis for education in rapidly developing and growing fields of knowledge; it is excellent for those who will follow professions in architecture, engineering, science, economics, political science, or management; and it offers a sound foundation for careers partly or wholly unrelated to these professions.

The Undergraduate Programs

The undergraduate subjects are planned and coordinated to give each student an understanding of scientific and technological knowledge through a variety of alternative paths. Each subject attempts to give undergraduates an opportunity to explore the intrinsic intellectual excitement of its contents; to stimulate an aggressive rather than a passive involvement in the subject matter; and to provide motivation for creative work and continuing self-education.

An undergraduate at M.I.T. may choose his major field of study from among many Courses; a complete list of undergraduate Courses and degrees is given in Section 1 of this Catalogue. The program for the Bachelor of Science degree normally requires four years of full-time study.

To complete work for a Bachelor's degree in any Course, each student must fulfill the General Institute Requirements and must complete the Departmental Program specified by that Course. However, each student in every Course has considerable freedom in planning his academic program. Within limits imposed by the prerequisites, each student may schedule his own sequence of subjects in consultation with his Faculty Counselor. Flexibility in the choice of electives and subjects fulfilling the Science Distribution and Laboratory Requirements and, for superior students, the opportunity to take examinations for advanced standing, all permit a

student to design a program around his own particular background, interests, abilities, and future goals.

Furthermore, in some cases, a student may substitute other subjects for certain of those specified by his Course. To assure that such substitutions be well thought out and not haphazardly chosen, a student must obtain permission from his Faculty Counselor, during his junior year, to embark on a program involving a "major departure" from an approved curriculum. (The term "major departure" is understood to signify substitutions not-in-kind for more than one required subject, or substitutions of any sort for more than two required subjects.)

Each undergraduate Course offers the degree of Bachelor of Science with the field of the degree specified, as for instance Bachelor of Science in Electrical Engineering. Some departments also offer in addition an undesignated degree of Bachelor of Science. The purpose of this arrangement is to provide further flexibility by making available curricula which may cross disciplinary and departmental lines. While the undergraduate curriculum for an undesignated Bachelor of Science degree, as listed by a Department, may have its own unique features, each individual program must be laid out in consultation with a departmental representative to assure that it is meaningful in structure and challenging in content.

In the first year, most students concentrate on a program centered around mathematics, physics, chemistry, and humanities.

During the second year, studies are ordinarily continued with subjects meeting the Science Distribution, Laboratory, and humanities requirements and with the beginning subjects in the Departmental Programs. In the third and fourth years, there is increasing diversity among the Courses as the students concentrate on their Departmental Programs.

The curricula for all the Courses are given in Section 4 of this Catalogue, where descriptions of the departments in each school are arranged alphabetically by school. The General Institute Requirements are set forth in the next few pages, and the Departmental Programs are listed by each department.

Selection of Courses

Many entering students have a well-defined preference for a specific field, while others have interests in several areas and have not yet decided upon a field of concentration. Experience shows that a substantial percentage of those who do enter with a decided preference find other areas to be more to their liking, and therefore every student should be prepared to examine with an open mind the various Courses available at the Institute. Students are encouraged to attend departmental orientation programs and to seek out and talk with faculty and others who have experience in fields of potential interest to them. They also are urged to select electives which will help them in deciding about their future careers. For many students this thoughtful consideration of available possibilities will reinforce existing convictions, while for others it will open up new avenues of interest; in either instance the result will be beneficial.

The faculty recognizes that the most effective educational ally it can have is the creative interest of a student in the material he is studying. It believes, therefore, that the primary aim of each student in choosing a Course of study should be to find that area which holds maximum challenge and rewarding satisfaction for him. Each of the undergraduate Courses combines the study of basic principles with the study of their application in particular situations. From the interest aroused by this combination of principles and applications studied in depth in a particular Course comes the motivation for the continuing learning which leads to professional competence.

A student may enroll in a Course as early as the end of his first year, and he must do so by the end of his second year. This arrangement affords the opportunity for early concentration by a student who has settled on his Course and, at the same time, provides time for others to explore their interests, assess their abilities, and choose a Course which satisfies both.

Each student entering M.I.T. is assigned an advisor, a member of the faculty or staff who assists the student in designing an effective program of study appropriate to his interests and aspirations. The selection of electives is one of the important problems on which each student should work in detail with his advisor. For example, if a student has not decided on a specific Course, he may wish to register for electives and Science Distribution Subjects which are relevant to the Courses he is considering. It is important that these subjects be selected with care because each department has different recommendations for Science Distribution Sub-

jects, and an inappropriate choice may delay graduation in some instances because of scheduling difficulties, or it may decrease elective freedom in the third and fourth years. Advisors can help students utilize most effectively the elective freedoms which are assured in all M.I.T. curricula.

Other Study Opportunities

Premedical Education

In recent years an increasing number of students has entered medical school upon graduation from M.I.T. Aeronautics and astronautics, biology, chemistry, electrical engineering, chemical engineering, physics, mathematics, political science, as well as other fields in science, engineering, and the humanities are regularly represented. Since no formal program of premedical studies exists at M.I.T., students have great flexibility in their choice of major fields. Specific medical school entrance requirements can be met in almost any of the Institute's Courses by proper selection of electives. The broad premedical programs that result fully meet the specifications of the Association of American Medical Colleges.

A Premedical Advisory Committee — whose members are directly involved in medical practice, related medical research, and student counseling — provides information to students interested in medical careers. Each student is encouraged to take advantage of the flexibility and diversity of the available academic programs. The Program is administered for the Committee by Professor Emily L. Wick, Associate Dean for Student Affairs, who maintains liaison among the student, his Faculty Counselor, and the Premedical Advisors.

Education and Teaching

The professional field of education, including teaching at the elementary and high school levels, has interested an increasing number of students. The Institute offers no regular or professional degrees or certification in education. However, there is a series of courses, teaching opportunities, and placement possibilities available to undergraduates. A teaching program in one of the Cambridge high schools is available as a credit seminar. Courses in political science, humanities, and management deal with specific educational problems, and through special project courses in several departments students may work with faculty members on special problems of education from curriculum development to psychology of learning.

Some of the course work offered at the Institute is designed to give academic support to the several educational activities carried on by students on a volunteer basis. These activities include the M.I.T. High School Studies Program, the Urban Action tutoring programs, Upward Bound, and other student-initiated programs.

The Education Research Center is a focus of interest for students and faculty who are concerning themselves with curriculum development at both the high school and university levels. Students interested in curriculum activities should contact the Education Research Center.

The Career Planning and Placement Office, under the direction of Dean Robert K. Weatherall, concerns itself with the placement of students in teaching positions upon graduation. This office has information on teaching credentials and other pertinent information.

Overseeing these and related activities is a group of faculty members who serve as counsellors to students interested in teaching or graduate work in education. Students are encouraged to seek out any member of this Advisory Committee on Education. For further information, students should contact the Assistant to the Provost, Louis Menand III, who maintains liaison efforts among the various programs and faculty involved.

Biomedical Engineering

An area of study which is of increasing interest to undergraduate and graduate students alike lies at the interface between the engineering and life and health sciences. Investigations on such varied topics as artificial organs, biological control systems, and mechanisms of sensory perception, to name only a few, involve faculty and students from most of the engineering departments. Much of this research is carried out in interdepartmental laboratories in collaboration with workers from medical centers in the Boston area. The undergraduate wishing to explore this developing area will have ample opportunity within his regular departmental major through elective subjects, special laboratory projects, and the senior thesis. These studies should be of special interest to students who are enrolled in a premedical curriculum. Graduate study in biomedical engineering is open to students with appropriate undergraduate background in either the engineering or biological sciences. The

Committee on Biomedical Engineering serves as an advisory body which can assist students in setting up interdepartmental programs. Recently a new Program in Health Sciences and Technology has been established collaboratively by M.I.T. and Harvard University (see Interdisciplinary Programs). For further information write to the Committee on Biomedical Engineering, Room 16-512, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

Prelaw Education

A small number of students enter law schools from M.I.T. each year. Although law schools do not prescribe particular undergraduate preparation as a condition of admission, a showing of thorough learning in some area of study, such as economics, science, government, or mathematics, is viewed favorably. While a typical M.I.T. education fits well with the preferences of the leading schools, students may wish to consult Stanley M. Jacks, the Institute's Prelaw Advisor, regarding preparation for law school. He maintains a list of accredited law schools, the dates of the law school admission test, and other information pertaining to the study of law.

Program for the Bachelor's and Master's Degrees

Any regular undergraduate student may undertake a program of study leading to the simultaneous award of the Bachelor's and Master's degrees, provided his departments recommend him to the Dean of the Graduate School as a candidate for the Master's degree. He must be enrolled at least one term as a graduate student and complete the requirements for both the Bachelor's and Master's degrees, including a Master's thesis. With departmental acceptance to graduate status, a student may work for the simultaneous award of the S.B. in Art and Design and the graduate B.Arch. degree. A student wishing to pursue this program should submit a petition approved by the undergraduate Faculty Counselor and the graduate Registration Officer. The requirements for the various honors and other designated five-year Courses leading to the S.B. and S.M. degrees are specified under the appropriate department statements.

Program for Two Bachelor's Degrees

A student may work for a second Bachelor's degree to be received separately or concurrently. A petition which describes his planned academic program must be approved by Faculty Counselors in each of the two departments concerned at least two full terms before he would normally receive the second of the two S.B. degrees. The S.B. requirements of each department must be satisfied and the combined program must contain at least 450 units. From the time his petition is approved until he receives the first of the two S.B. degrees, the student must register in both departments and his program and all changes in it must be approved by both Faculty Counselors.

Overseas Study

Many opportunities exist for M.I.T. undergraduates to experience the stimulation and expanded horizons associated with a "junior year abroad." Through participation in any of the well-organized and well-established programs administered by existing organizations and other colleges, an M.I.T. student has a wide choice of country and program. Although almost any field can be studied abroad, most students find it advisable to plan their total undergraduate programs to emphasize professional work at M.I.T. Thus, the year abroad can become a major experience in another culture by emphasizing the language, literature, history, and culture of the host country, for which substantial academic credit is normally granted toward the M.I.T. degree. For science or engineering majors a science course or two can provide the flavor of such work in the foreign scene.

For a mature student with exceptional competence in the language and some previous experience in the culture, an individually arranged independent program may not be too demanding of time and effort, but careful planning is essential.

A junior-year-abroad student maintains official M.I.T. registration as "undergraduate on foreign study" and has thereby maintained his student aid and Selective Service status. Total costs, including travel, have proved to be no more than expenses for a year at the Institute.

Effective working command of the language of instruction is vital. A student without prior study can, by conscientious work in the subjects available here, achieve such command of a Western European language if he begins by the second term of his freshman year. Early planning is obviously important.

Because of important differences in academic practices and levels among foreign universities, there are no general rules for obtaining academic

credit for work and study overseas toward M.I.T. degree requirements. However, M.I.T. student experience has been good, especially after careful advance planning with faculty advisors. It is the responsibility of each student to work out with his own department and Faculty Counselor the arrangements for academic credit for work he proposes to undertake overseas.

Professor Harold L. Hazen, Dean Emeritus of the Graduate School, is the Foreign Study Advisor, and he is prepared to discuss opportunities with students and to assist them in planning their programs. Students interested in overseas study should consult him as early as possible for help in organizing their objectives and plans of study, selecting their overseas institutions, and preparing in language studies and in obtaining departmental and other approvals prerequisite to registration as "undergraduate on foreign study." M.I.T. is cooperating with a number of international student agencies which contribute greatly in the areas of travel, housing, and hospitality.

Domestic "Junior Year Away"

A domestic "junior year away" for study at another U.S. institution has been approved by the faculty as a three-year experiment for limited numbers during 1970–73. M.I.T. registration as "undergraduate on leave" without M.I.T. tuition is contingent upon certification by the student's major department that the planned program draws on resources not generally available at M.I.T. or through its established cross registration privileges. Anyone interested should consult Professor Hazen (see Overseas Study above) on procedures and conditions for official approval.

Interdisciplinary Programs

With the development of interdepartmental and interdisciplinary activities in a wide range of disciplines, undergraduate students have continued to arrange their academic programs to undertake work in these areas, such as operations research, astronomy, environmental studies, and biomedical engineering.

Section 5 of this Catalogue includes a directory of the programs and facilities directed toward interdisciplinary study.

Research

Undergraduate students are encouraged to explore research experiences at an early point in their studies. To encourage such activity, academic credit may be granted for research.

To support this developing trend, a *Directory of Research Opportunities* is published each term listing current opportunities for undergraduates to participate in the ongoing research of the Institute faculty. Each academic department, in addition, has an Undergraduate Research Coordinator to answer questions and to assist students in identifying suitable opportunities.

Further information about this program may be obtained by contacting Professor Margaret MacVicar, Education Research Center, M.I.T.

Cooperative Programs

Harvard University

A limited number of M.I.T. undergraduates are permitted to take one or two subjects at Harvard University (Faculty of Arts and Sciences) for degree credit and at no extra charge, provided the subjects are not offered regularly at M.I.T. Except in rare instances, applicants must be third- or fourth-year students with excellent academic records. Arrangements are made through the Department of Humanities prior to or at the regular M.I.T. registration periods. A Harvard subject may not be added after the third week of the term.

Wellesley College

In the fall of 1968, Wellesley College and M.I.T. inaugurated a five-year experimental cross-registration program for undergraduates. The purpose of the program is to extend and diversify the educational programs now available to students in the curricula and environments of both institutions. Under this program, M.I.T. students may substitute subjects taken at Wellesley for M.I.T. subjects. Details on the exchange, including the rules governing the substitution of required subjects, are provided in a publication entitled *Wellesley-M.I.T. Exchange: Guide for M.I.T. Students*. New issues of the *Guide* are mailed to all undergraduates each term: in April for the fall term, and in December for the spring term. Copies of the most recent *Guide* are available in the Information Office and the office of the Dean for Student Affairs. Bus transportation between Wellesley and M.I.T. for academic purposes is provided to cross-registered students without cost.

Deadlines for cross-registration are in May for the following September and in December or January for the spring term. The deadline date for each term is announced in the latest *Guide*.

The Basic First-Year Program

With the exception of about ten percent of the class who elect to join the optional programs described further on, freshmen will take a program commonly consisting of electives and required subjects in mathematics, physics, chemistry or biology, and humanities. These subjects provide an appropriate preparation for all the courses of undergraduate study offered at M.I.T. Classes typically meet one to four times a week in some combination of lecture and recitation modes, with laboratory and tutorial sessions depending on the subject and method of organization.

For students entering with only the preparation implied by the entrance requirements, a typical schedule for the two terms of the first year is as follows:

First Term

		Units		
	CHEMISTRY *or* BIOLOGY	5	0	7
8.01	PHYSICS I	5	0	7
18.01	CALCULUS	4	0	8
	HUMANITIES	3	0	6
	SEMINAR		6	
			51	

Second Term

8.02	PHYSICS II	5	0	7
18.02	CALCULUS	4	0	8
	HUMANITIES	3	0	6
	SEMINAR		6	
	Elective		9	
			48	

The units notation is of the form C-L-P, where C, L, and P are, respectively, the number of hours of class, laboratory, and outside preparation each week. These subjects are partially described later in this section and in more detail in the Descriptions section at the back.

Many other programs are appropriate, depending on the individual student's preparation and interests. To fulfill the Institute Requirements, freshmen in the Class of 1975 may choose between two sequences in mathematics from among five subjects in the chemistry/biology area and from among four sequences in physics and eight in humanities.

Entering students with degree credit in one or more of the first-year subjects may substitute more advanced subjects in the same areas or may use the time thus made available for electives or science distribution subjects. The procedures by which degree credit at entrance is earned are described in the section of this Catalogue dealing with admission to the Institute.

Electives

Any subject offered by the Institute is open to the freshman, provided he can satisfy the prerequisites. Including Undergraduate Seminars, there are more than one hundred subjects without prerequisites and an additional 15 to 20 with prerequisites or corequisites that most freshmen can satisfy at least by the second term. Except for the seminars, these subjects are described with the complete descriptions of subjects.

The Undergraduate Seminars differ from other electives in that they are designed expressly to allow students to work in small groups in close association with faculty members. Less formally organized than customary classroom or laboratory subjects, they offer an opportunity for study with a high degree of individual responsibility and freedom in planning and executing a selected program. The seminars cover a wide range of topics and involve many different types of study. A list of those available is supplied to first-year students during the summer. These seminars can also be taken for credit as electives by upperclass undergraduates.

Electives can be used for several different purposes. For example, many students who are undecided about their eventual course of study will use part or all of their elective time to get more information about the various departments or fields they are considering. Other students who are more certain of their professional goals will use elective time to explore areas of secondary interest. Still others will choose to begin work on departmental or Institute requirements, deferring subjects of a more supplemental nature until a later year. The study of a language may be started, or continued, and most of the R.O.T.C. programs are normally begun as electives in the first year. Before deciding which electives to take, most freshmen will find it helpful to ask themselves which of these uses of electives best suit their individual needs.

Pass/Fail

Freshmen presently receive grades of either Pass or Fail in all subjects they take. Pass/fail grading for freshmen was introduced experimentally in 1968 with a variety of objectives, among them a reduction of the non-functional stresses of the first year (anxiety about time, class rank, the failure to do "A" work) and the development of more mature attitudes about learning and about managing one's time. At the middle and end of each term the freshmen and their instructors, in turn, are asked to complete written evaluations

in each subject. This process usually provides the student with a more comprehensive and useful evaluation of his work than A-F grades alone communicated under the conventional system.

For most freshmen a normal subject load consists of four or five subjects totalling 45-54 units of credit (nominally equivalent to that many hours of time spent per week). Compared to an A-F grading system, pass/fail offers the freshman more choice of how he spends his time, often permitting him to take an additional subject for credit. At the same time the Faculty supports this means to a broader program, they continue primarily to value the depth which comes from a rigorous approach to each subject.

The Freshman Handbook

This relatively brief overview of the first-year academic program is meant to convey the nature and scope of the options available, but it is hardly a sufficient basis for the individual freshman to plan his year. Shortly after they are admitted to M.I.T., the freshmen receive the Freshman Handbook, a compendium of detailed information on academics, athletics, extra curricular activities, housing, the advisory system, and an outline of Residence/Orientation Week. Distributed also to the freshman advisors, the Handbook is a primary reference document for the first year.

Options Within the First Two Years

Currently there are three experimental programs, each accommodating 30-40 self-selected freshmen. Two of the programs, the Experimental Study Group and the Unified Science Study Program, have been in operation several years and also include a similar number of sophomores, most of whom joined the groups in their freshman year. The three programs differ from one another but share a common objective, namely, that of offering a meaningful alternative to the more traditional lecture-recitation, subject-by-subject format. Students continue to be responsible for satisfying the General Institute Requirements, and many opportunities for fulfilling these requirements are provided within the context of the programs. Opportunities for close student-faculty interaction are inherent in the structures. Every effort is made to help the student prepare for a smooth re-entry into the standard program at the end of his first or second year.

Experimental Study Group

This program is open to a limited number of freshmen; it appeals to those who prefer independent study and who are willing to accept the attendant risks.

The freshmen, together with upperclassmen, graduate students, and faculty members, work together to educate themselves and one another. Freshmen are expected to do a good deal of their learning independently of formal instruction; help by more experienced members is available when needed.

Freshmen are expected to set their own programs as much as they can. Those who have compelling intellectual interests may follow those interests; those who desire to fulfill the Institute required subjects (math, physics, chemistry, humanities) are encouraged to study these subjects and are helped to do so by informal seminars.

There are other seminars, organized from time to time by members of the group on subjects which interest them (for instance, on the sun, on circuit-theory, on history considered as a science).

Group activity is available for those who like it but is not required of all students. There is, however, a general meeting held once a week for the purpose of governing the group, and most students and faculty members find it advantageous to attend these meetings.

Freshmen are expected to learn how to learn; no restrictions are placed on the method of learning adopted. It is permissible for freshmen to sign up for regular M.I.T. subjects, but these should not constitute the major fraction of their programs. There is a small workshop on the premises, but those freshmen who like experimental work have in the past preferred to work part-time in one of M.I.T.'s research laboratories; these freshmen members of the Experimental Study Group are helped to find places in such laboratories (see Directory of Undergraduate Research Opportunities). Other resources of M.I.T. which are normally available to freshmen are also available to E.S.G. freshmen.

Students reside with the regular M.I.T. living groups. The Experimental Study Group has its own work area, including reading, seminar, study, and music rooms, a work-shop and a library, and a commons area with a kitchen.

This program provides an opportunity for a student to take the initiative for learning; along with this, however, goes an element of risk. A student who joins the program but lacks the desire to take the necessary initiatives may find

after a year that he has learned little. This possibility should be squarely faced by any student who considers joining the program.

For more information write to Experimental Study Group, Room 24-612, M.I.T.

Unified Science Study Program

The Unified Science Study Program (U.S.S.P.) is a complete fulltime curriculum for freshmen and sophomores. The U.S.S.P. is an alternative approach to the undergraduate curriculum, questioning most of the traditional constraints of higher education, blurring disciplinary lines, and constructed mainly around student-initiated projects based upon real problems. A limited number of freshmen are admitted each year to this program, and they find in it a great freedom in selecting their own educational goals and the means to achieve them. The U.S.S.P. staff works closely with individual students, and to some extent students are expected to teach each other and to help each other achieve their goals. For more information about the U.S.S.P., students should contact the U.S.S.P. headquarters in Room 20C-105, M.I.T.

Concourse Experiment

The Concourse Experiment, beginning in September, 1971, will explore a new mode of undergraduate education for the first two years at M.I.T. carried out by a faculty group from widely different professional disciplines acting in close collaboration. This program will be characterized by intense and continuous interaction of ideas and techniques from engineering, science, social science, and humanities. Concourse expects to bring to students the diversity of disciplines and research and the activities of the Institute departments and laboratories in a naturally balanced and related way. A description of the program in detail is available from the Freshman Advisory Council.

Degree Requirements

To be recommended for the degree of Bachelor of Science, a student must have attended the Institute not less than one academic year, which ordinarily must be the year of his graduation. He must have completed satisfactorily a program of study approved in accordance with the rules and regulations of the faculty, including the General Institute Requirements and the Departmental Program of the Course in which his degree is to be awarded. A student must petition the Committee on Curricula for any substitutions in the General Institute Requirements. Departures from the Departmental Programs are permitted with the consent of the Faculty Counselor. The Departmental Program and the total number of units required are shown for each Course in Section 4 of this Catalogue.

Effective for the Class of 1973, the General Institute Requirements include:

1. Completion of one of the following subjects: CHEMISTRY OF THE SOLID STATE (3.091), CHEMISTRY (5.01), INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM (5.41), CHEMICAL EQUILIBRIUM (5.60) or GENERAL BIOLOGY (7.01); the physics requirement (8.01 or 8.011 or 8.012 or 8.013 and 8.02 or 8.021 or 8.022 or 8.023); and the calculus requirement (18.01 or 18.012 or 18.014 and 18.02 or 18.022 or 18.024).
2. Completion of the requirements in humanities and social sciences, described on pages 21–26 of this Catalogue.
3. Completion of the Science Distribution Requirement, described on pages 19–20 of this Catalogue.
4. Completion of the Laboratory Requirement, described on pages 20–21 of this Catalogue.
5. Completion of the physical education requirements described on page 21 of this Catalogue.

In summary, to be recommended for the degree of Bachelor of Science, a student must have satisfactorily completed the following units:

		Total Units
GENERAL INSTITUTE REQUIREMENTS		
Science Requirement:		
CHEMISTRY/BIOLOGY (3.091 or 5.01 or 5.41 or 5.60 or 7.01)	12	
PHYSICS (8.01 or 8.011 or 8.012 or 8.013 and 8.02 or 8.021 or 8.022 or 8.023)	24	
CALCULUS (18.01 or 18.012 or 18.014 and 18.02 or 18.022 or 18.024)	24	
Humanities:		
First- and second-year humanities	36	
Third- and fourth-year humanities	36[1]	
		132
Science Distribution and Laboratory Subjects:		
Science Distribution Subjects		**36[2]**
Laboratory Subjects		**12[2]**
DEPARTMENTAL PROGRAM		
As specified for each Course, a minimum of		**180[3,4]**
Total units required for the S.B. degree, at least		**360[5]**

[1] The requirement for classes of '72 is 32 units.
[2] Each department may specify some of the Science Distribution and Laboratory Subjects.
[3] Departments may require up to 205 units (leading to a total of 385 units) for graduation.
[4] Departmental Programs include at least 36 units of electives, usually more.
[5] This total does not include R.O.T.C. subjects, if elected.

The Science Distribution Requirement

The Science Distribution Requirement of 36 units is met by taking subjects especially designed for this purpose. Available subjects are listed below. To fulfill the requirement, students must study subjects totaling 36 units of which no more than 12 units may be taken in subjects offered by a student's own department. If 5.41 or 5.60 or 7.01 is used to satisfy the General Institute Requirement in Chemistry/Biology, then it cannot be used for the Science Distribution Requirement. The combination of subjects chosen must be approved by the student's Faculty Counselor. Science Distribution Subjects are normally taken in the second year, but students who have the proper prerequisites may take them in the first year. The prerequisites for these subjects are given with the descriptions.

1.00 INFORMATION SYSTEMS (3–3–6)
1.02 ENGINEERING MATERIALS (3–3–6)
1.07 ANALYSIS OF UNCERTAINTY (3–1–8)
1.08 GEOTECHNOLOGY (3–3–6)
1.11 INTRODUCTION TO SYSTEMS ANALYSIS (3–3–6)
1.13 BEHAVIOR OF PHYSICAL SYSTEMS (3–3–6)
1.40 INTRODUCTION TO ELECTRON MICROSCOPY (1–3–2)
2.00 INTRODUCTION TO ENGINEERING SYSTEMS (3–3–6)
2.01 MECHANICS OF SOLIDS (4–0–8)
2.02 INTRODUCTION TO SYSTEM DYNAMICS (3–1–8)
2.101 COMPUTER MODELS OF PHYSICAL AND ENGINEERING SYSTEMS I (3–3–6)
2.403 THERMODYNAMICS (4–0–8)
2.42 ELEMENTS OF CLASSICAL AND STATISTICAL THERMODYNAMICS (4–0–8)
2.901 POLYMER MATERIALS SCIENCE (3–0–9)
3.00 THERMODYNAMICS OF MATERIALS (4–0–8)
3.10 ELECTRONS AND ATOMS IN SOLIDS (4–0–8)
3.11 MECHANICS OF MATERIALS (4–0–8)
3.12 PRINCIPLES OF CRYSTALLOGRAPHY AND X-RAY DIFFRACTION (4–3–5)
3.141 SCIENCE OF MATERIALS (4–3–5)
4.30 BASIC STRUCTURAL THEORY (3–3–6)
4.43 ENVIRONMENTAL CONTROL-ACOUSTICS (3–0–5)
5.121J PLANETARY PHYSICS AND CHEMISTRY I (3–0–9)
5.122J PLANETARY PHYSICS AND CHEMISTRY II (3–0–9)
5.41 [1]INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM (5–0–7)
5.60 [1]CHEMICAL EQUILIBRIUM (4–0–8)
5.61 PHYSICAL CHEMISTRY (4–0–8)
6.00 INTRODUCTION TO COMPUTATION (4–3–5)
6.01 INTRODUCTORY NETWORK THEORY (4–0–8)
6.14 INTRODUCTION TO ELECTRONICS (4–2–6)
6.231 PROGRAMMING LINGUISTICS (4–1–7)
6.251 DIGITAL COMPUTER PROGRAMMING SYSTEMS (3–2–7)
6.28 PROBABILISTIC SYSTEMS ANALYSIS (4–0–8)
7.01 [1]GENERAL BIOLOGY (4–0–8)
7.51 ORGAN AND SYSTEM PHYSIOLOGY (3–0–6)
8.03 PHYSICS III (5–0–7)
8.291J PLANETARY PHYSICS AND CHEMISTRY I (3–0–9)
8.292J PLANETARY PHYSICS AND CHEMISTRY II (3–0–9)
10.12 STAGED CASCADES IN CHEMICAL PROCESSING (3–3–6)
10.13 CHEMICAL ENGINEERING THERMODYNAMICS (4–0–8)
10.17 COMBUSTION AND AIR POLLUTION (2–0–4)
11.04 MODELS AND METROPOLIS (4–0–8)
12.00 EVOLUTION OF THE EARTH (2–0–4)
12.001 INTRODUCTORY OCEANOGRAPHY — THE SEA FLOOR (2–0–4)
12.002 THE EARTH AND THE PLANETS (2–0–4)
12.01 EARTH SURFACE PROCESSES (2–2–2)
12.02 PHYSICS AND CHEMISTRY OF GEOLOGICAL MATERIALS (3–4–5)
12.051 CRYSTALLOGRAPHY (2–2–4)
12.052 THEORETICAL CRYSTALLOGRAPHY (2–0–4)
12.111 ASTRONOMY I (2–0–4)
12.112 ASTRONOMY II (2–0–4)
12.131J PLANETARY PHYSICS AND CHEMISTRY I (3–0–9)
12.132J PLANETARY PHYSICS AND CHEMISTRY II (3–0–9)
12.21 PHYSICAL OCEANOGRAPHY (3–0–9)
12.30 SURVEY OF THE EARTH AND PLANETARY SCIENCES (3–3–6)
13.001 INTRODUCTION TO MARINE APPLIED MECHANICS (4–0–8)
13.64J WATER, AIR AND INTERFACE VEHICLES (2–0–6)
14.30 INTRODUCTION TO STATISTICAL METHOD IN ECONOMICS (4–0–8)
15.053 QUANTITATIVE METHODS FOR MANAGEMENT (4–0–8)
15.852 PRINCIPLES OF DYNAMIC SYSTEMS I (3–0–9)
16.001 THERMODYNAMICS AND STATISTICAL MECHANICS (4–0–8)
16.01 DYNAMICS (4–2–6)
16.20 MECHANICS OF SOLIDS (4–2–6)
16.84 AEROSPACE ENGINEERING (3–2–7)
18.03 DIFFERENTIAL EQUATIONS (3–0–9)
18.031 INTRODUCTION TO LINEAR ALGEBRA AND APPLICATIONS (3–0–9)
18.051 THE WORLD OF MATHEMATICS (3–0–9)
18.303 APPLICATIONS OF PROBABILITY AND RANDOM VARIABLES (3–0–9)
18.304 PROBABILITY AND STATISTICS (3–0–9)
18.420 INTRODUCTION TO THE MATHEMATICAL THEORY OF COMPUTATION (3–0–9)
18.700 LINEAR ALGEBRA (3–0–9)
18.703 BASIC ALGEBRA (3–0–9)
19.02 DESCRIPTIVE METEOROLOGY (3–2–7)
19.43 SYNOPTIC METEOROLOGY I (2–2–5)
19.83 PHYSICAL OCEANOGRAPHY (3–0–9)
20.30 PHYSIOLOGICAL AND NUTRITIONAL BIOCHEMISTRY (4–0–8)
20.48 THE MATHEMATICAL ASPECTS OF ECOLOGY (3–0–6)
22.01 INTRODUCTION TO NUCLEAR REACTOR ENGINEERING (3–0–9)

[1] Not acceptable as Science Distribution Subject, if taken to fulfill the General Institute Requirement in Chemistry/Biology.

Through Science Distribution Subjects the student can broaden and deepen his educational foundation in basic science begun in his first-year program. These subjects are designed to give each student the opportunity to proceed further in areas already studied, or to explore other areas of potential interest.

The available Science Distribution Subjects vary among themselves in approach and emphasis. Some give a systematic introduction to the fundamental concepts and principles of a field; others illustrate, through examples, some

of the attitudes, concerns, and methods that are characteristic of professional work in a field.

Most Departmental Programs occupy 48 units in the second year. In many cases, subjects required by a department are also on the list of Science Distribution or Laboratory Subjects. Thus students following a particular Departmental Program may satisfy simultaneously part or all of the Science Distribution or Laboratory Requirements. This provides additional flexibility in the planning of a second-year program.

The Laboratory Requirement

The Laboratory Requirement of 12 units may be met by enrolling in one or two laboratory subjects expressly designed for this purpose. Available subjects are listed below. The Laboratory Requirement is normally fulfilled in the first two years, but some students may choose to postpone it. The Laboratory Subjects must be approved by the student's Faculty Counselor.

1.10 CIVIL ENGINEERING LABORATORY (0–6–6)
2.654 PHYSICAL MEASUREMENT AND ANALYSIS (2–6–4)
2.67 URBAN LABORATORY IN MECHANICAL ENGINEERING (3–6–3)
2.672 EXPERIMENTAL ENGINEERING I (2–3–1)
2.673 EXPERIMENTAL ENGINEERING II (0–4–2)
2.86 MANUFACTURING PROJECT LABORATORY (2–3–1)
2.861 [1]ENGINEERING DESIGN AND MANUFACTURE (4–4–4)
3.05 MATERIALS RESEARCH LABORATORY (2–6–4)
5.20 LABORATORY PROBLEMS IN CHEMISTRY (1–3–2)
5.21 LABORATORY PROBLEMS IN CHEMISTRY (1–6–5)
5.31 INTRODUCTION TO CHEMICAL EXPERIMENTATION (2–8–2)
6.272 DIGITAL SYSTEMS PROJECT LABORATORY (2–8–2)
6.702 BIOELECTRONICS PROJECT LABORATORY (2–8–2)
6.71 ELECTRONIC CIRCUITS AND SIGNALS LABORATORY (1–4–1)
6.711 DIGITAL SYSTEMS PROJECT LABORATORY (3–7–2)
6.714 STROBE PROJECT LABORATORY (2–8–2)
6.715 POWER SYSTEMS PROJECT LABORATORY (2–8–2)
6.716 PARTICLE OPTICS PROJECT LABORATORY (2–8–2)
6.717 AUDIO FREQUENCY COMMUNICATIONS PROJECT LABORATORY (2–8–2)
6.718 PSYCHOACOUSTICS PROJECT LABORATORY (3–4–5)
6.719 MICROELECTRONICS PROJECT LABORATORY (2–8–2)
6.721 OPTICAL SEMICONDUCTOR DEVICES PROJECT LABORATORY (2–8–2)
6.722 MODERN OPTICS PROJECT LABORATORY (2–8–2)
6.723 IMAGE TRANSMISSION SYSTEMS PROJECT LABORATORY (0–12–0)
6.724 CONTROL SYSTEMS PROJECT LABORATORY (2–8–2)
7.02 EXPERIMENTS IN BIOLOGY (1–8–3)
7.031 EXPERIMENTAL GENETICS AND MICROBIOLOGY (2–16–6)
7.041 EXPERIMENTAL CELL BIOLOGY (2–16–6)
7.051 EXPERIMENTAL BIOCHEMISTRY (2–16–6)
7.061 EXPERIMENTAL PHYSIOLOGY (2–16–6)
8.11 PHYSICS PROJECT LABORATORY I (1–6–5)
8.12 PHYSICS PROJECT LABORATORY II (1–6–5)
8.13 EXPERIMENTAL ATOMIC PHYSICS I (1–6–5)
9.50 RESEARCH IN PSYCHOLOGY (Arr. — minimum 6 units)
10.91 EXPERIMENTAL RESEARCH PROBLEM (Arr. — minimum 6 units)
11.801 URBAN STUDIES LABORATORY I (2–5–5)
12.114 WORKSHOP IN ASTRONOMY (0–8–0)
13.90 OCEAN ENGINEERING LABORATORY (0–12–0)
14.31 ECONOMETRICS (3–4–5)
15.307 BEHAVIORAL SCIENCE RESEARCH PRACTICUM (2–8–8)
16.62 EXPERIMENTAL PROJECTS (2–6–4)
17.01 POLITICAL SCIENCE LABORATORY (2–6–4)
20.02 NUTRITION AND FOOD SCIENCE PROJECTS LABORATORY (1–8–3)

[1] Students taking 2.861 (12 units) receive 6 units of laboratory credit.

Typically, a Laboratory Subject consists of an experimental investigation, including an analysis of the problem and evaluation of results. Assumptions based on book knowledge or intuition are experimentally tested against the real world. A student analyzes his results, relating them to his assumptions and methods, and a faculty member participates in the evaluation of the experiment. The Laboratory Subjects call for a major commitment of the student's attention to one or a few experimental problems and emphasize as much as possible work of project type rather than routine experimental exercises. They are designed to stimulate the student's resourcefulness and his own ideas.

The Laboratory Requirement is not intended to teach specific basic techniques for later experimental work, to provide broad coverage of a particular field, or to be a complement to a specific lecture subject. The Laboratory Subjects are planned to give each student, at an early stage of his educational experience at M.I.T., an opportunity to work on one or a few experimental problems, exercising the same type of initiative and resourcefulness as a professional man would in similar circumstances.

The Physical Education Requirement

The Institute expects each student to gain experience in recreational athletics during his first two years at M.I.T.; by the end of this period each male student must have compiled at least 8 points of athletic credit. These points may be acquired by participating in a physical education class (2 points per quarter) or by membership on one of the 21 freshman or varsity teams (2 points for fall or spring sports, 4 points for winter sports).

The program consists of both individual and team activities with the major emphasis placed on the development of interests which can be carried on in later life. A student who elects in-

dividual sports such as golf, tennis, sailing, or squash will receive a strong background in the fundamentals of the sport. Instruction in physical education classes often leads to intercollegiate participation.

Physical education classes for the year are divided into four quarters, with these activities:
First quarter — September to mid-November: archery, development class, golf, gymnastics, touch football, lacrosse, sailing, beginning swimming, pistol, beginning tennis, and intermediate tennis, modern dance, and sculling.
Second quarter — mid-November through fall term: badminton, basketball, bowling, development class, fencing, judo, karate, scuba diving, skating, skiing, squash, rifle, beginning swimming, intermediate swimming, Red Cross senior life saving, and modern dance.
Third quarter — February through March: development class, diving, fencing, judo, karate, skating, skiing, squash, beginning swimming, volleyball, pistol, scuba diving, and Red Cross senior life saving and instruction.
Fourth quarter — April through May: archery, development class, beginning golf, intermediate golf, sailing, soccer, softball, beginning swimming, scuba diving, beginning tennis, intermediate tennis, rifle, sculling, and Red Cross instructors' program (continued from the third quarter).

Upon entering M.I.T. each male student must submit a record of a medical examination and take a swimming test. Students who fail the swimming test are expected to take beginning swimming. If the medical examination indicates any disability which might limit physical activities, the athletic requirements may be modified.

Although there are no specific requirements for women students, facilities are provided for many activities of their choice, and women may participate in many physical education classes.

The Undergraduate Program in Humanities and Social Sciences

The M.I.T. program in humanities and social sciences has several objectives. It seeks first to develop attitudes and skills basic to a life of effective thought, action, and appreciation as a responsible citizen and broadly educated human being. Second, it seeks to provide some understanding of man's experience at key points in his history and of the human problems which must be the concern of every civilized man. Third, it seeks to provide some sense of the intellectual discipline involved in a particular area in the humanities or social sciences, some study in depth in a field outside the student's professional specialization. Finally, it seeks to develop skill in accurately and effectively communicating facts and ideas orally and in writing.

Every candidate for a Bachelor's degree must take eight term subjects in the humanities and social sciences; normally one subject is taken during each of the eight terms of residence.

During the first year, each student takes one of nine two-term sequences: THE WESTERN TRADITION: THE CLASSICAL HERITAGE (21.011) and THE WESTERN TRADITION: THE EUROPEAN HERITAGE (21.012); or SELF-DEFINITION: WRITING AND THINKING (21.013) and SELF-DEFINITION: WRITING AND THINKING (21.014); or CULTURE AND SOCIETY IN AMERICA: THE RISE OF A TECHNOLOGICAL CIVILIZATION (21.017) and CULTURE AND SOCIETY IN AMERICA: THE TECHNOLOGICAL SOCIETY (21.018); or THREE MAJOR TEXTS: THE BIBLE, PLATO AND MARX (21.019) and THREE MAJOR TEXTS: THE BIBLE, PLATO AND MARX (21.020); or THE WESTERN TRADITION: THE CLASSICAL HERITAGE (21.021) and THE WESTERN TRADITION: THE EUROPEAN HERITAGE (21.022); or THE WESTERN TRADITION: THE CLASSICAL HERITAGE (21.023) and THE WESTERN TRADITION: THE EUROPEAN HERITAGE (21.024); or IDENTITY AND PURPOSE IN BLACK AMERICA (21.025) and IDENTITY AND PURPOSE IN BLACK AMERICA (21.026); or THE GREEK TRADITION (23.011) and THE JUDAEO-CHRISTIAN TRADITION (23.021); or CONTEMPORARY MORAL ISSUES (24.015) and CONTEMPORARY MORAL ISSUES (24.016). The subject matter of the freshman curriculum is drawn in each case from the several disciplines of the Humanities and directed toward certain major achievements of Western intellect, imagination or social development. The interdisciplinary emphasis of the freshman year is followed by a sophomore curriculum in which the student is asked to examine the perspective and the distinctive languages of two separate disciplines in the School of Humanities and Social Science. The sophomore has a choice between two sets of options. In the first set he is asked to elect either APPROACHES TO LITERATURE (21.03); or THE LANGUAGE OF MUSIC (21.07); or THE NATURE OF LITERATURE (23.031); or PHILOSOPHY: CLASSIC AND CONTEMPORARY (24.11). In the second option he is asked to

make a choice between SOCIETY AND MAN (17.02); or THE TWENTIETH CENTURY: REVOLUTION AND TOTALITARIANISM (21.05); or RATIONALISM AND RADICALISM: THE DILEMMA OF LIBERAL SOCIETY (21.051); or THE DYNAMICS OF IMPERIALISM (21.052); or MODERN WORLD HISTORY (21.053); or MODERN WORLD HISTORY (21.054); or AN INTRODUCTION TO ANTHROPOLOGY (21.06); or THE FRENCH ENLIGHTENMENT (23.051). Frequent written exercises, with criticism from instructors and scheduled conferences, give each student an opportunity to improve his capacity for clear, critical writing. Students with insufficient training or other language handicaps are urged to take advantage of small group remedial instruction; for those who are seriously deficient such instruction is required.

Humanities Fields and Subjects

FIRST YEAR[1]

One of the following combinations of subjects:
THE WESTERN TRADITION: THE CLASSICAL HERITAGE (21.011) *and*
THE WESTERN TRADITION: THE EUROPEAN HERITAGE (21.012)
or
SELF-DEFINITION: WRITING AND THINKING (21.013) *and*
SELF-DEFINITION: WRITING AND THINKING (21.014)
or
CULTURE AND SOCIETY IN AMERICA: THE RISE OF A TECHNOLOGICAL CIVILIZATION (21.017) *and*
CULTURE AND SOCIETY IN AMERICA: THE TECHNOLOGICAL SOCIETY (21.018)
or
THREE MAJOR TEXTS: THE BIBLE, PLATO AND MARX (21.019) *and*
THREE MAJOR TEXTS: THE BIBLE, PLATO AND MARX (21.020)
or
THE WESTERN TRADITION: THE CLASSICAL HERITAGE (21.021) *and*
THE WESTERN TRADITION: THE EUROPEAN HERITAGE (21.022)
or
THE WESTERN TRADITION: THE CLASSICAL HERITAGE (21.023) *and*
THE WESTERN TRADITION: THE EUROPEAN HERITAGE (21.024)
or
IDENTITY AND PURPOSE IN BLACK AMERICA (21.025) *and*
IDENTITY AND PURPOSE IN BLACK AMERICA (21.026)
or
THE GREEK TRADITION (23.011) *and*
THE JUDAEO-CHRISTIAN TRADITION (23.021)
or
CONTEMPORARY MORAL ISSUES (24.01) *and*
CONTEMPORARY MORAL ISSUES (24.02)

SECOND YEAR
One of the following subjects:
APPROACHES TO LITERATURE (21.03)
PHILOSOPHY: CLASSIC AND CONTEMPORARY (24.11)
THE NATURE OF LITERATURE (23.031)
THE LANGUAGE OF MUSIC (21.07)
and one of the following subjects:
SOCIETY AND MAN (17.02)
THE TWENTIETH CENTURY: REVOLUTION AND TOTALITARIANISM (21.05)
RATIONALISM AND RADICALISM: THE DILEMMA OF LIBERAL SOCIETY (21.051)
THE DYNAMICS OF IMPERIALISM (21.052)
MODERN WORLD HISTORY (21.053)
MODERN WORLD HISTORY (21.054)
AN INTRODUCTION TO ANTHROPOLOGY (21.06)
THE FRENCH ENLIGHTENMENT (23.051)

THIRD AND FOURTH YEARS[1]

Any one of the following combinations of subjects may be taken without the approval of a humanities advisor. Other combinations are not prohibited but must be specifically approved by a humanities advisor. Subjects indicated by a dagger (†) may be taken as a single subject to satisfy the distributional requirement.

[1] Each subject in the program for the first and second years carries 3–0–6 units of credit. Each subject in the program for the third and fourth years carries 9 units of credit, unless otherwise specified.

[2] Open only to students having an adequate background in French.

FIELD ONE: HISTORY

(For additional and related subjects see the special Interdisciplinary Sequence on page 25.)

Any three of the following:
HISTORY OF ENGINEERING (21.411)†
HISTORY OF ENGINEERING (21.412)†
HISTORY OF MATERIALS (21.414J)†
(*Same subject as* 3.78J)
TECHNOLOGY AND ECONOMIC GROWTH (21.415)†
SCIENCE AND TECHNOLOGY IN THE AMERICAN ENLIGHTENMENT (21.416)†
SCIENCE, TECHNOLOGY, AND WAR IN THE AMERICAN EXPERIENCE (21.417)†
DEVELOPMENT OF AMERICAN ECONOMIC INSTITUTIONS (21.421)†
HISTORY OF TRANSPORTATION IN THE UNITED STATES (21.422)†
HISTORY OF THE AUTOMOBILE (21.423)†
THE BUSINESSMAN IN AMERICAN HISTORY (21.424)†
HISTORY OF TECHNOLOGY IN THE UNITED STATES (21.426)†
ECONOMIC DEVELOPMENT, POLITICAL STRUCTURE, IMPERIALISM, AND SOCIAL DISCONTENT IN LOW INCOME COUNTRIES (21.428J)†
REVOLUTION IN TWENTIETH-CENTURY LATIN AMERICA (21.461)†
THE EMERGENCE OF MODERN AFRICA (21.463)†
ROME: REALITY AND IDEA (21.473)†
CULTURE AND SOCIETY IN MEDIEVAL EUROPE (21.475)†
THE ITALIAN RENAISSANCE (21.476)†
THE NORTHERN RENAISSANCE AND THE REFORMATION (21.478)†
SOCIAL CRITICISM AND SOCIAL SCIENCE IN AMERICA (21.482)†
DISSENT AND REFORM IN TWENTIETH-CENTURY AMERICA (21.483)†
URBAN AMERICAN HISTORY (21.484J)†
(*same subject as* 11.561J)
URBAN AMERICAN HISTORY (21.485J)†
(*same subject as* 11.562J)
RELIGION AND AMERICAN CULTURE (21.486)†
THE CITY IN AMERICAN HISTORY (21.488)†
THE FAMILY IN TECHNOLOGICAL SOCIETY (21.489)†
SOCIETY AND CULTURE IN THE EIGHTEENTH CENTURY (21.514)†
INTELLECTUAL HISTORY OF MODERN EUROPE (21.515)†

RUSSIA: ORTHODOXY, AUTOCRACY, AND REBELLION (21.517)†
ANARCHISM (21.518)†
MARX, DARWIN, AND FREUD (21.522)†
POST-FREUDIAN SOCIAL THOUGHT (21.523)†
HISTORY AND PSYCHOANALYSIS (21.524)†
POLITICS OF THE SELF: CONCEPTIONS OF MAN AND SOCIETY IN AMERICAN SOCIAL SCIENCE (21.526)†
AMERICAN INTELLECTUAL HISTORY (21.531)†
AMERICAN IDEAS AND INSTITUTIONS (21.532)†
AMERICAN CONSTITUTIONAL HISTORY (21.533)
THE AMERICAN REVOLUTION (21.541)†
POLITICAL IDEAS AND INDUSTRIAL SOCIETY (21.542J)†
CHINA, JAPAN, AND THE WEST (21.543)†
WAR AND THE MILITARY INSTITUTIONS OF THE MODERN STATE (21.545)†
THE EXPORT OF THE EUROPEAN ARMY (21.546)†
VIENNA AND VERSAILLES (21.548)†
COMPARATIVE REVOLUTION (21.549)†
NATIONALISM IN AFRICA (21.551J)†
THE SOVIET UNION: AN INDUSTRIAL SOCIETY IN HISTORICAL PERSPECTIVE (21.552)†
THE RISE OF EUROPEAN SOCIALISM, 1864–1914 (21.553)†
SPANISH CIVIL WAR, 1936–1939 (21.554)†
SOCIALISM AND COMMUNISM IN EUROPE 1917–1941 (21.555)†
SOVIET-AMERICAN DIPLOMACY (21.556)†
RECONSTRUCTION OF EUROPE, 1945–1965 (21.558)†
COLD WAR SEMINAR (21.559)†
NINETEENTH CENTURY EUROPEAN LIBERALISM: ITS DECLINE AND TRANSFORMATION (21.574)†
VARIETIES OF FASCISM: ORIGINS AND COMPARATIVE DEVELOPMENT IN GERMANY AND FRANCE, 1900–1945 (21.576)†
CULTURES AND SOCIETIES OF MODERN MEXICO (21.621)†
ARCHEOLOGY OF TECHNOLOGY (21.642)†
COMPARATIVE ANCIENT TECHNOLOGIES (21.643)†
ARCHEOLOGY OF URBANIZATION (21.651)†
AMERICAN INDIAN POLICY (21.671)†
ECONOMIC ANTHROPOLOGY (21.681)†
ARCHEOLOGICAL THEORY AND METHODS (21.682)†
LANGUAGE AND CULTURE (21.683)†
PEASANT SOCIETY (21.684)†

FIELD TWO: PHILOSOPHY

(For additional and related subjects see the Special Interdisciplinary sequence on page 25.)

Any three of the following:
HISTORY OF PHILOSOPHY I (24.201)†
HISTORY OF PHILOSOPHY II (24.202)†
THEORY OF KNOWLEDGE (24.211)†
METAPHYSICS (24.221)†
ETHICS (24.231)†
LIBERTY AND EQUALITY (24.232)†
SYMBOLIC LOGIC (24.241)†
PHILOSOPHY OF SCIENCE (24.251)†
NATURAL THEOLOGY (24.261)†
PHENOMENOLOGY (24.271)†
EXISTENTIALISM (24.272)†
MODERN SOCIAL THOUGHT (24.302)†
PHILOSOPHY OF EDUCATION (24.311)†
PHILOSOPHY OF THE ARTS (24.321)†
PHILOSOPHY IN LITERATURE (24.322)†
CLASSICS IN THE PHILOSOPHY OF SCIENCE (24.331)†
TRADITION AND INNOVATION IN TWENTIETH-CENTURY PHYSICS (24.332)†
PHILOSOPHICAL ANTHROPOLOGY (24.341)†
RELIGIOUS PHILOSOPHY IN THE WEST (24.351)†
PHILOSOPHIES AND RELIGIONS OF ASIA (24.352)†
CONTEMPORARY PHILOSOPHY AND THEOLOGY (24.353)†

FIELD THREE: LITERATURE

(For additional and related subjects see the Special Interdisciplinary sequence on page 25.)
LITERARY ANALYSIS (21.11)††‡

plus any two of the following:
SCIENTIFIC AND ENGINEERING WRITING (21.10)†
WRITING WORKSHOP (21.101)†
THE WRITING OF FICTION (21.102)†
THE WRITING OF POETRY (21.103)†
PLAYWRITING (21.104)†
THE WRITING OF PROSE (21.105)†
PROSE WRITING (21.106)†
THE EPIC (21.13)†
THE BIBLE: FORM AND CONTENT (21.14)†
SHAKESPEARE (21.15)†
SHAKESPEAREAN TRAGEDY (21.151)†
CHAUCER (21.16)†
LITERATURE OF THE ENGLISH RENAISSANCE (21.17)†
ADVENTURE IN FICTION (21.25)†
READINGS IN MODERN ENGLISH AND AMERICAN POETRY (21.251)†
CULTURE AND EMPIRE (21.269)†
NARRATIVE FICTION (21.27)†
UTOPIAN LITERATURE (21.271)†
NARRATIVE AND THE NOVEL (21.272)†
LYRIC POETRY: PRACTICE AND THEORY (21.273)†
LITERATURE AND THE ORIGINS OF AMERICAN EMPIRE (21.274)†
THE SHORT STORY (21.276)†
THE POLITICS OF THE NOVEL (21.277)†
BAUDELAIRE, MALLARME, AND YEATS (21.278)†
THEATER ARTS: ELEMENTARY STAGECRAFT AND PRODUCTION STUDIES (21.28)†
MODERN DRAMA (21.281)†
SATIRE (21.282)†
TRAGEDY (21.283)†
COMEDY (21.284)†
THE SEXUAL ORDER (21.286)†
DOSTOEVSKY, TOLSTOI, CHEKHOV: RUSSIA AND THE MODERN AGE (21.29)†
CHINESE LITERATURE (21.302)†
STUDIES IN MODERN FICTION (21.31)†
THE RETURN OF THE REPRESSED (21.312)†
MAJOR AUTHORS: FRIEDRICH NIETZSCHE (21.313)†
MAJOR AUTHORS: CHARLES DICKENS (21.314)†
LANGUAGE AND ITS STRUCTURE (21.315J)†
(*Same subject as* 23.700J)
STUDIES IN LITERATURE AND NATIONAL VALUES (21.317)†
THE NINETEENTH CENTURY: AESTHETICISM AND CONSCIENCE (21.32)†
POPULAR CULTURE AND MASS MEDIA (21.33)†
LITERATURE AND PROPAGANDA (21.34)†
SOCIAL VISION IN LITERARY ART: SHAW, LAWRENCE, FAULKNER (21.35)†
WOMEN AND LITERATURE (21.36)†
REVOLUTIONARY ATTITUDES (21.381)†
THE IDEA OF CULTURE (21.383)†
LYRIC AND DISCOURSE (21.385)†
LITERATURE AND INTERPERSONAL RELATIONSHIPS (21.386)†
METAPHOR (21.387)†
DANTE I (23.87)†
DANTE II (23.88)†
THE ART OF STORY-TELLING IN RUSSIAN LITERATURE (23.975)†
CHEKHOV AS PROSE WRITER (23.976)†
SOVIET RUSSIAN LITERATURE (23.991)§†
GOGOL AND LITERARY METHODOLOGY IN RUSSIA (23.992)§†
TOLSTOI'S "WAR AND PEACE" (23.993)§†

‡ Students who elect 21.03 or 23.031 in partial fulfillment of their second-year humanities requirement are to take three subjects, in place of two, from the list in Field Three: Literature. If 21.03 or 23.031 are taken, 21.11 may not be taken for credit.
¶ Accepted as one subject in the humanities and social sciences.
§ Readings in English; conducted in English.

MAYAKOVSKY AND PASTERNAK (23.994) §†
THE PROSE OF A SOLZHENICYN (23.995) †
THE RUSSIAN SHORT STORY (23.996) §†
NINETEENTH-CENTURY RUSSIAN LITERATURE (23.997) §†
DOSTOEVSKY (23.998) §†
REVOLUTION AND WAR IN CONTEMPORARY RUSSIAN AND POLISH LITERATURE (23.999) †

FIELD FOUR: FOREIGN LITERATURES

Group A — German

ADVANCED GERMAN (23.14) ¶†
or
LITERARY ANALYSIS (21.11) †‡
plus any two of the following:
INTRODUCTION TO GERMAN POETRY (23.141) †
GERMAN CIVILIZATION (23.142) †
GOETHE'S POETRY (23.15) †
GERMAN ROMANTICISM (23.16) †
GOETHE'S "FAUST" (23.19) †
SEMINAR IN GERMAN POETRY (23.20) †
MODERN GERMAN DRAMA (23.21) †
MODERN GERMAN FICTION (23.22) †

Group B — French

ADVANCED FRENCH (23.54) ¶†
or
LITERARY ANALYSIS (21.11) †‡
plus any two of the following:
FRENCH CIVILIZATION I (23.541) †
FRENCH CIVILIZATION II (23.543) †
SEMINAR ON VOLTAIRE (23.58) †
CONTEMPORARY FRENCH DRAMA (23.61) †
FRENCH ROMANTICISM (23.62) †
FRENCH PROSE FICTION I (23.632) †
FRENCH PROSE FICTION II (23.634) †
FRENCH PROSE FICTION III (23.631) †
SEMINAR IN FRENCH LITERATURE (23.64) †
CLASSICAL FRENCH DRAMA (23.65) †
MODERN FRENCH POETRY (23.66) †

Group C — Russian

ADVANCED RUSSIAN (23.94) †
or
LITERARY ANALYSIS (21.11) †‡
plus any two of the following:
RUSSIAN CIVILIZATION (23.951) †
INTRODUCTION TO RUSSIAN LITERATURE (23.980) †
MODERN RUSSIAN POETRY (23.981) †
SEMINAR ON PUSHKIN AND RUSSIAN ROMANTICISM (23.982) †
STUDIES IN RUSSIAN PROSE: GOGOL (23.983) †
SELECTED PROBLEMS IN SOVIET LITERATURE (23.985) †

Group D — Spanish

INTRODUCTION TO SPANISH LITERATURE (23.41) †
or
LITERARY ANALYSIS (21.11) †‡
plus any two of the following:
SPANISH DRAMA (23.35) †
TWENTIETH-CENTURY SPANISH LITERATURE (23.36) †
MASTERPIECES OF SPANISH LITERATURE (23.42) †

Group E — Comparative Literature

DANTE I (23.87) †
DANTE II (23.88) †
plus any literature subject

FIELD FIVE: MUSIC

THE SYMPHONY (21.81) †
plus one of the following:
MUSIC THEORY I (21.821) †
MUSIC THEORY II (21.822) †
MUSIC THEORY III (21.823) †
MUSIC THEORY IV (21.824) †
ORCHESTRATION (21.825) †
PROBLEMS AND TECHNIQUES OF MUSIC RESEARCH (21.826) †
ANALYSIS OF MUSICAL STRUCTURE (21.827) †
MUSIC IN THE MIDDLE AGES (21.83) †
MUSIC IN THE RENAISSANCE (21.831) †
MUSIC IN THE BAROQUE ERA (21.84) †
J. S. BACH (21.841) †
MUSIC IN THE CLASSIC ERA (21.85) †
MOZART (21.851) †
MUSIC IN THE ROMANTIC ERA (21.86) †
BEETHOVEN (21.861) †
TWENTIETH-CENTURY MUSIC (21.871) †
TWENTIETH-CENTURY MUSIC: SCHOENBERG, BERG AND WEBERN (21.872) †
THE OPERA (21.88)
SEMINAR IN MUSIC (21.881) †
SEMINAR IN MUSIC (21.882) †
NON-WESTERN MUSIC (21.883) †

FIELD SIX: ECONOMICS

ECONOMIC PRINCIPLES I (14.01) †
and
ECONOMIC PRINCIPLES II (14.02)
and one of the following:
PRICES AND PRODUCTION (14.03)
ECONOMIC FLUCTUATIONS AND GROWTH (14.05)
INDUSTRIAL ORGANIZATION AND PUBLIC POLICY (14.20)
DISTRIBUTION OF INCOME AND EMPLOYMENT OPPORTUNITY (14.41)
URBAN ECONOMICS (14.51)
ECONOMICS OF THE SOVIET UNION (14.52)
COMPARATIVE ECONOMIC SYSTEMS (14.53)
LABOR ECONOMICS AND PUBLIC POLICY (14.64)
ECONOMIC HISTORY (14.71)
ECONOMIC GROWTH AND DEVELOPMENT (14.74)

FIELD SEVEN: POLITICAL SCIENCE

Any three of the following subjects:
POWER, INFLUENCE, AND POLICY DECISIONS (17.03)
MATHEMATICAL POLITICS (17.04)
INTRODUCTION TO NORMATIVE POLITICAL THEORY (17.11)
POLITICAL IDEAS AND INDUSTRIAL SOCIETY (17.12J)
CRITIQUES OF TECHNOLOGICAL SOCIETY (17.13)
REVOLUTION AND THE THEORY OF POLITICS (17.14)
INTRODUCTION TO THE AMERICAN POLITICAL PROCESS (17.21)
POLITICAL PARTIES (17.22)
JUDICIAL PROCESS (17.23)
THE PRESIDENT AND THE CONGRESS: THE SEPARATION AND
POLITICS AND TELEVISION (17.24)
BUREAUCRACY (17.25)
THE POLITICS OF NATIONAL ECONOMIC CONTROL (17.26)
URBAN POLITICS (17.31)
THE GOVERNANCE OF CAMBRIDGE (17.34)
POLITICS OF POVERTY AND COMMUNITY ACTION (17.35)
POLITICS OF URBAN EDUCATION (17.36)
GOVERNMENT, POLITICS AND TECHNOLOGY (17.41)
CONGRESS AND POLICY FOR SCIENCE AND TECHNOLOGY (17.42)
EVOLUTION OF STRATEGIC NUCLEAR SYSTEMS (17.43)
EVOLUTION OF FORCES FOR LIMITED WAR (17.44)
POLITICAL PSYCHOLOGY (17.46)
EGO AND YOUTH (17.47)
INTRODUCTION TO POLITICAL DEVELOPMENT (17.51)
COMPARATIVE POLITICAL SYSTEMS (17.52)
POLITICAL AND ECONOMIC DEVELOPMENT OF TROPICAL AFRICA (17.53)
ECONOMIC DEVELOPMENT, POLITICAL STRUCTURE, IMPERIALISM, AND SOCIAL DISCONTENT IN LOW INCOME COUNTRIES (17.54J)
NATIONALISM IN AFRICA (17.55J)
INTERNATIONAL RELATIONS (17.56)
PRINCIPLES AND PROBLEMS OF AMERICAN FOREIGN POLICY (17.57)
SEMINAR IN INTERNATIONAL POLITICS (17.58)

ARMS CONTROL, DISARMAMENT, AND FOREIGN POLICY (17.59)
CAUSES OF WAR (17.60)

FIELD EIGHT: LABOR RELATIONS

Group A

ECONOMIC PRINCIPLES I (14.01)†
and
LABOR RELATIONS (14.63)†
and
LABOR ECONOMICS AND PUBLIC POLICY (14.64)

Group B

LABOR RELATIONS (14.63)†
and
LABOR ECONOMICS AND PUBLIC POLICY (14.64)
and
DISTRIBUTION OF INCOME AND EMPLOYMENT OPPORTUNITY (14.41)

FIELD NINE: PSYCHOLOGY

INTRODUCTION TO PSYCHOLOGY AND BRAIN SCIENCE (9.00)†
and any two of the following subjects:
PHYSIOLOGICAL PSYCHOLOGY (9.01)
NEURAL MECHANISMS OF LEARNING AND MOTIVATION (9.03)
COMPARATIVE PSYCHOLOGY (9.30)
PSYCHOLOGY OF PERCEPTION (9.35)
COLOR SCIENCE AND COLOR VISION (9.37)
LEARNING (9.40)
PROBLEM SOLVING (9.45)
PSYCHOLOGY OF LANGUAGE AND COMMUNICATION (9.59)
PERSONALITY STRUCTURE AND DEVELOPMENT (9.60)
SOCIAL PSYCHOLOGY (9.70)
BEHAVIOR IN GROUPS (9.80)
DEVELOPMENTAL PSYCHOLOGY (9.89)
ADVANCED PSYCHOLOGY SEMINAR (9.92)

FIELD TEN: VISUAL ARTS

Three subjects: selections within both groups required

Group A

VISUAL DESIGN PROBLEMS I (4.021)
VISUAL DESIGN PROBLEMS II (4.022)
CREATIVE PHOTOGRAPHY I (4.051)†
CREATIVE PHOTOGRAPHY II (4.052)
PAINTING (4.071)
INTRODUCTION TO FILM MAKING (4.091)
MOVIES: AN INTRODUCTION I (4.096)
MOVIES: AN INTRODUCTION II (4.097)

Group B

EVALUATING PHOTOGRAPHY (4.056)
TOPICAL STUDIES IN THE HISTORY AND THEORY OF ART (4.601)†
INTRODUCTION TO MODERN ART (4.602)†
PAINTING AND SCULPTURE IN THE MIDDLE OF THE NINETEENTH CENTURY (4.603)†
MODERN ART FROM POST-IMPRESSIONISM TO CUBISM (4.604)†
PAINTING IN THE TWENTIETH CENTURY (4.605)†
SCULPTURE IN THE TWENTIETH CENTURY (4.606)†
STUDIES: ARCHITECTURE IN THE ANCIENT WORLD (4.61)†
STUDIES: ARCHITECTURE 1400–1750 (4.62)†
STUDIES: ARCHITECTURE IN THE MIDDLE AGES (4.63)†
STUDIES: ARCHITECTURE FROM 1750 TO THE PRESENT (4.64)†

SPECIAL INTERDISCIPLINARY SUBJECTS‡

SPECIAL TOPICS IN INTERDISCIPLINARY STUDIES (21.901)§
SPECIAL TOPICS IN INTERDISCIPLINARY STUDIES (21.902)§
MUSICAL ACOUSTICS (21.92J)†
(*Same subject as* 6.38J)
SEMINAR IN TECHNOLOGY AND SOCIETY: ETHICAL AND SOCIAL ISSUES IN BIO-MEDICINE (21.941J)†
(*Same subject as* 7.09J)
THE ELEMENTS: A SEMINAR (21.943J)†
(*Same subject as 8.287J*)
POETIC AND SCIENTIFIC DISCOURSE IN CLASSICAL LITERATURE (21.948)†
CLASSICAL PHILOSOPHY: COSMOLOGY AND ETHICS (21.949)†
INTRODUCTION TO THE FAR EAST (21.951)†
SEMINAR IN CHINESE CULTURE (21.952)†
MARX AND MARXISM (21.953)
WORKSHOP IN CRITICAL AND CREATIVE EXPERIENCE (21.954J)
(*Same subject as* 4.099J)
CHINESE SCIENCE AND NATURAL PHILOSOPHY (21.955)
SEMINAR ON THE AMERICAN UNIVERSITY (21.956)†
EDUCATION AND SOCIETY I (21.958)†
EDUCATION AND SOCIETY II (21.959)†
CONTEMPORARY PHILOSOPHY AND THEOLOGY (21.96)†
SEMINAR ON TECHNOLOGY AND SOCIETY (21.961)†
TECHNOLOGY, VALUES AND SOCIAL CHOICE (21.963)†
SEMINAR IN URBAN EDUCATION (21.967)†
SEMINAR IN URBAN EDUCATION (21.968)†
BLACK LITERATURE IN AMERICA (21.971)†
BLACK LITERATURE II (21.972)†
THE PHILOSOPHY AND CRITIQUE OF THE BLACK MOVEMENT (21.973)†
TRADITION AND INNOVATION IN TWENTIETH-CENTURY PHYSICS (21.992)†
INTELLECTUALS AND SOCIAL CHANGE (21.995)†
AMERICAN VALUES OF THE 1920's (21.997)†
AMERICAN VALUES OF THE 1930's (21.998)†
GROUP BEHAVIOR AND THE CULTURAL PROCESS (21.999)†

Undergraduates who are interested in Urban Studies or Social Inquiry may work out a program of three or four subjects offered in different fields or departments and request approval by petition for such a program of concentration from the Department of Humanities.

For students with suitable preparation, special variations of the first- and second-year humanities subjects are conducted in French by the Department of Foreign Literatures and Linguistics.

Every undergraduate is required to take a concentration of three humanities or social science subjects in one of ten fields, and a fourth or distributional subject in another field; these subjects are usually taken in the third and fourth years. The fields in which they are grouped are: History, Philosophy, Literature, Foreign Literatures, Music, Economics, Political Science, Labor Relations, Psychology, and Visual Arts. In addition, some special interdisciplinary subjects are available, mainly serving as distributional subjects.

§ A "time arranged" subject. At least 9 units must be taken to be accepted as one subject in the humanities and social sciences.
‡ Subjects in this category are additional subjects which may be taken to satisfy the Humanities distribution requirement; but they may also be combined, by petition to the Department of Humanities, with other elective subjects in the above ten fields to satisfy the concentration requirement of three subjects in a single field.

The humanities or social science field is selected on a basis of particular interest, except that students enrolled in Shipping and Shipbuilding Management (Course XIII-B) or Economics (Course XIV) may not select either the Economics or Labor Relations fields; and those in Political Science (Course XVII) may not select the Political Science field. Students in Architecture (Courses IV and IV-B) may not select certain subjects to satisfy the humanities and social science program, as specified under the curricula for these Courses.

The subject offerings are described on the preceding pages. At least some of the work in each concentration must be of higher than elementary level. Although elementary language subjects may not be counted as junior-senior humanities, qualified students are encouraged to build on previous training in modern languages by taking subjects in French, German, or Russian literature.

ECONOMIC PRINCIPLES I (14.01) is a subject which must be taken by undergraduates in the School of Engineering in Ocean Engineering (Course XIII). It may be taken either as the distributional subject or as part of an appropriate three-term concentration.

Military Science, Aerospace Studies, and Naval Science

The general purpose of the Reserve Officers' Training Corps is to qualify students as officers in the active and reserve forces, as well as for positions of leadership in civilian pursuits. The Army, Navy, and Air Force each conducts a program at M.I.T. for this purpose.

THE ARMY R.O.T.C. PROGRAM

All full-time freshmen male students with four years of school remaining may enroll in the four-year R.O.T.C. program, and selected undergraduate and graduate students with less than four years of school remaining may apply for enrollment in the two-year R.O.T.C. program. Successful completion of the program described below and a six-week Advanced Summer Camp qualify students for commissions upon graduation.

During each school year, Military Science students are required to take the Military Science subjects and an Institute subject from the list below. The Military Science subjects are taught in both semesters, and the list of Institute subjects includes subjects from each semester so that the student, with the help of his advisor, can determine the best sequence in completing the requirements for the R.O.T.C. program. For example, a student may decide to take both the Military Science subject and an Institute subject selected from the list in the same semester or to take one requisite in each semester. There will be a one-hour class in leadership development both terms.

The Institute subjects are primarily from four fields: Political Science, History, Management, and Psychology. The subjects, designated by the Director of Military Science, are felt to be those which will develop in the student a balanced appreciation of the development and dynamics of military and social institutions and their interrelationship with society, as well as an understanding of the interactions and management of individuals in groups. The groupings are not final and other subjects may be substituted upon approval.

Between the third and fourth year, the student attends a six-week Advanced Summer Camp conducted within a military environment. Reinforcement of classroom instruction is accomplished through the use of practical field training. Major emphasis is given to leadership development by placing the student into leadership positions.

Students receive $50 per month during their final two years in the program at M.I.T. They are also paid for the summer camp according to the current active duty pay scale. Mileage allowances are paid for travel to and from the summer camp.

One, two, three, and four-year scholarships covering full tuition, fees, and a monthly stipend of $50 are available on a competitive basis. Details may be obtained by writing to the Director of Military Science.

Program of Instruction: One Institute subject listed for each year and all Military Science subjects are required.

FIRST YEAR

14.53 COMPARATIVE ECONOMIC SYSTEMS (3–0–6)
17.21 INTRODUCTION TO THE AMERICAN POLITICAL PROCESS (3–0–6)
17.41 GOVERNMENT, POLITICS, AND TECHNOLOGY (4–0–8)
17.52 COMPARATIVE POLITICAL SYSTEMS (3–0–6)
17.56 INTERNATIONAL RELATIONS (3–0–6)
17.57 PRINCIPLES AND PROBLEMS OF AMERICAN FOREIGN POLICY (3–0–6)
MS11 MILITARY ORGANIZATION, TACTICS, AND COMMUNICATION (2–0–1) (No M.I.T. credit)
MS111 LEADERSHIP DEVELOPMENT (0–1–0) (No M.I.T. credit)
MS121 UNITED STATES MILITARY HISTORY (0–1–0) (No M.I.T. credit)

SECOND YEAR

17.43 EVOLUTION OF STRATEGIC NUCLEAR SYSTEMS (3–0–6)
17.44 EVOLUTION OF FORCES FOR LIMITED WAR (3–0–6)
17.58 SEMINAR IN INTERNATIONAL POLITICS (3–0–6)
17.59 ARMS CONTROL, DISARMAMENT AND FOREIGN POLICY (3–0–6)
21.541 AMERICAN REVOLUTION (3–0–6)
21.545 WAR AND THE MILITARY INSTITUTIONS OF THE MODERN STATE (3–0–6)
21.556 SOVIET-AMERICAN DIPLOMACY (3–0–6)
MS21 PRINCIPLES OF LEADERSHIP (2–0–1) (No M.I.T. credit)
MS211 LEADERSHIP DEVELOPMENT (0–1–0) (No M.I.T. credit)
MS221 LEADERSHIP DEVELOPMENT (0–1–0) (No M.I.T. credit)

THIRD YEAR

9.45 PROBLEM SOLVING (3–0–6)
15.053 QUANTITATIVE METHODS OF MANAGEMENT (4–0–8)
15.309 ADMINISTRATIVE THEORY AND PRACTICE (3–0–6)
15.501 INFORMATION AND DECISION SYSTEMS I (4–0–8)
15.854 DESIGN OF INFORMATION AND CONTROL SYSTEMS FOR RESEARCH MANAGEMENT (3–0–6)
15.903 INTRODUCTION TO INDUSTRIAL MANAGEMENT (3–0–6)
15.905 INFORMATION AND DECISION SYSTEMS II (4–0–8)
MS31 PRINCIPLES OF MILITARY MANAGEMENT, OPERATION, AND LOGISTICS (2–0–1) (No M.I.T. credit)
MS311 LEADERSHIP DEVELOPMENT (0–1–0) (No M.I.T. credit)
MS321 LEADERSHIP DEVELOPMENT (0–1–0) (No M.I.T. credit)

FOURTH YEAR

9.70 SOCIAL PSYCHOLOGY (3–0–6)
9.80 BEHAVIOR IN GROUPS (3–0–6)
15.301 MANAGERIAL PSYCHOLOGY (3–0–6)
15.302 SOCIAL PSYCHOLOGY (3–0–6)
15.304 COMPLEX ORGANIZATIONS (3–0–6)
17.03 POWER, INFLUENCE, AND POLICY DECISION (3–0–6)
17.46 POLITICAL PSYCHOLOGY (2–1–6)
MS41 PRINCIPLES AND APPLICATIONS OF MILITARY LAW AND ADMINISTRATION (2–0–1) (No M.I.T. credit)
MS411 LEADERSHIP DEVELOPMENT (0–1–0) (No M.I.T. credit)
MS421 LEADERSHIP DEVELOPMENT (0–1–0) (No M.I.T. credit)

Application Procedure For Four-Year Program

Application is effected by enrollment in MS111. This is accomplished in the same manner as in other Institute subjects. The student should contact the Office of Military Science if additional information is desired.

The Two-Year Program

Students interested in the two-year program should apply through the Military Science Office during the year preceding the year in which they desire to be enrolled. Selections are based on nation-wide competition with initial processing in January of each school year. To be eligible, the student must pass an Army physical examination and be reasonably certain that he will remain in school for two more years. Further details may be obtained from the Office of Military Science.

THE AIR FORCE R.O.T.C. PROGRAM

The Air Force R.O.T.C. program is designed to prepare students for commissions in the United States Air Force upon successful completion of an M.I.T. Course. The Office of Aerospace Studies offers two programs — one of four years and one of two years — for M.I.T. students to qualify for commissions.

The Four-Year Program

The four-year program consists of classroom and corps training work during the four undergraduate years and one summer training period of four weeks between the sophomore and junior years at a United States Air Force base.

During the first two years, the program acquaints students with organization of the United States Air Force and the Department of Defense. The roles of these forces are related to national defense policy, including organization and role of the military instrument of national policy, general and limited war, alliances, and the strategies and policies of countries that constitute a potential threat. The course includes a review of the making of defense policy and the contribution of U.S. defense policies to national objectives. Leadership training is also begun. During the last two years, emphasis is placed on personal development. Students increase their ability to communicate their thoughts to others both orally and in writing by discussing military and aerospace technological advances and current research and development activities. Understanding of people and interpersonal relationships are also stressed. Students increase their leadership ability by assuming positions of responsibility in the Cadet Corps and in the required summer training.

While in Air Force R.O.T.C. students are furnished uniforms and equipment required for the program. Students enrolled in the four year program who are undergraduate students are offered an opportunity to compete, on a nationwide basis, in the college scholarship program. These scholarships provide full coverage for tuition and laboratory fees plus $50 monthly for subsistence and an allowance for books. Students who do not qualify for scholarships will receive $50 monthly for subsistence during their junior and senior years.

At the beginning of the junior year each student is required to sign a formal agreement that he will complete the last two years of Air Force R.O.T.C. and accept a commission as a Second Lieutenant in the United States Air

Force when he has been granted his degree from M.I.T. The term of active duty commitment after commissioning varies depending upon the professional area chosen. For those entering research and development, engineering, or any other non-flying field, the term of service is four years. If the student is physically qualified and desires to become a pilot or navigator, the required term of service is six years.

The Two-Year Program

The two-year program is for those students who do not complete the first two years of the four-year Air Force R.O.T.C. program. Such students may apply as undergraduates during their sophomore year or as graduates if they have a minimum of two years remaining in their graduate academic program. In lieu of completing the freshman and sophomore years of the four-year program, these students will receive six weeks of field training at an Air Force base during the summer preceding their entry into Air Force R.O.T.C. at M.I.T. They will receive $50 a month in subsistence allowance and complete the same academic program required of the upperclass four-year students.

General Information on Both Programs

The program of instruction is as follows:

FIRST YEAR

21.19 SCIENTIFIC AND ENGINEERING WRITING (2–0–7)
AS11 U.S. MILITARY FORCES (1–0–1) (No M.I.T. credit)
AS111 CORPS TRAINING (0–1–0) (No M.I.T. credit)
AS121 CORPS TRAINING (0–1–0) (No. M.I.T. credit)

SECOND YEAR

17.43 EVOLUTION OF STRATEGIC NUCLEAR SYSTEMS (3–0–6)
or
17.56 INTERNATIONAL RELATIONS (3–0–6)
or
21.545 WAR AND THE MILITARY INSTITUTIONS OF THE MODERN STATE (3–0–6)
AS21 INTRODUCTION TO DEFENSE POLICY (1–0–1) (No M.I.T. credit)
AS211 CORPS TRAINING (0–1–0) (No M.I.T. credit)
AS221 CORPS TRAINING (0–1–0) (No M.I.T. credit)

THIRD YEAR

17.57 PRINCIPLES AND PROBLEMS OF AMERICAN FOREIGN POLICY (3–0–6)
or
17.59 ARMS CONTROL, DISARMAMENT AND FOREIGN POLICY (3–0–6)
or
21.05 THE TWENTIETH CENTURY: REVOLUTION AND TOTALITARIANISM (3–0–6)
or
21.556 SOVIET-AMERICAN DIPLOMACY (3–0–6)
AS31 SEMINAR IN GROWTH AND DEVELOPMENT OF AEROSPACE POWER (3–0–3) (No M.I.T. credit)
AS311 CORPS TRAINING (0–1–0) (No. M.I.T. credit)
AS321 CORPS TRAINING (0–1–0) (No M.I.T. credit)

FOURTH YEAR

AS41 SEMINAR IN AIR FORCE LEADERSHIP (3–0–3) (No M.I.T. credit)
AS42 SEMINAR IN MANAGEMENT PRINCIPLES (3–0–3) (No. M.I.T. credit)
AS411 CORPS TRAINING (0–1–0) (No M.I.T. credit)
AS421 CORPS TRAINING (0–1–0) (No M.I.T. credit)

Adjustments in the curriculum will be made to accommodate students enrolling in an honors or cooperative course. Students who are eligible for graduate training or who desire to continue their graduate work may request a delay in reporting for active duty until completing graduate training.

Eligibility Requirements

To be eligible for the Air Force R.O.T.C. program a student must be:

1. A citizen of the United States.
2. Physically qualified for commission in the United States Air Force in accordance with existing Air Force regulations.
3. Not more than 30 years of age upon commissioning.
4. Planning to pursue work at M.I.T. leading to at least a Bachelor's degree in any Course offered by the Institute.
5. Willing to sign a formal agreement and enlist in the Air Force Reserve at the beginning of the junior year, which obligates him to remain in the R.O.T.C. program for the two final years, to accept a commission, and to serve the required period in the Air Force upon graduation.

Application Procedure

Eligible students should apply for admission to the Air Force R.O.T.C. after they have been notified of admission to the Institute. Application should be made direct to the Professor of Aerospace Studies, either by mail or by personal visit as soon as possible. Further information, including physical standards, will be furnished upon receipt of the initial inquiry.

THE NAVAL R.O.T.C. PROGRAM

The purpose of the Naval R.O.T.C. program is to provide instruction and training in essential Naval Science subjects, which, when coupled with the prescribed M.I.T. engineering or science curricula, will qualify selected male students for commissions as Naval Reserve Officers in the restricted line category (engineering duty).

The M.I.T. Navy unit is the only one of the nation-wide Naval R.O.T.C. programs designed to produce "engineering duty" officers. Graduates of this program may serve their obligatory active duty as engineering officers aboard ship, in naval shipyards, or in other technical assignments. Students may apply for the Navy Nuclear Power Program or for Submarine or Flight Training, or they may request that they be commissioned in the Civil Engineer Corps of the Navy, if qualified. Postgraduate work leading to a Master's degree prior to active

duty assignment is allowed when the quality of the student's work and the technical specialty involved warrant. The work for the advanced degrees need not be taken at M.I.T.

The Naval R.O.T.C. instruction and training consists of one catalogue course each year and one Naval Science laboratory each term. One summer period of six weeks is devoted to practical engineering and seamanship training at sea aboard a naval ship. This period is scheduled during the summer between the third and fourth academic years.

While in an undergraduate status, the Naval R.O.T.C. student is furnished all necessary text and reference books required for the Naval Science course and all uniforms and uniform equipment, and in addition he receives retainer pay of $50 per month during his third and fourth academic years. Transportation to and from the port of embarkation for the summer cruise is furnished by the Navy, and the student is paid at the current rate of $225.30 per month while on the cruise. Upon completion of the program and receipt of a Bachelor of Science degree from M.I.T., the student is commissioned as an Ensign (ED), U.S. Naval Reserve; he is ordered to active duty in engineering duty billets either afloat or ashore for a period of three years, unless he plans to attend graduate school, as noted above. At the end of this three-year period he may be released to inactive duty, but he must retain his commission as a Reserve Officer for a total of six years from the date of its original acceptance.

Eligibility Requirements

To be eligible for the four-year Naval R.O.T.C. program, an entering student must be:

1. A male citizen of the United States.

2. At least 17 years of age and not more than 21 years of age by June 30 of the year in which enrolled in the program. The lower age limit may be reduced to 16 years if the student is considered of sufficient maturity to take Naval Science courses.

3. Physically qualified in accordance with the standards for entrance to the Naval Academy, except that total visual acuity must meet the current standards, correctable to 20–20 by the use of lenses. M.I.T. students are permitted considerable latitude in the visual requirements. Certain types of color blindness are acceptable.

4. Planning to pursue work at M.I.T. leading to a Bachelor's degree in any Course except the following: Cooperative Courses II-B, VI-A, and XVI-B. Students in Architecture, Life Sciences, Economics, Political Science and Humanities will be considered eligible provided they complete as part of their elective and science distribution subjects at least eight subjects from the required core curriculum for an S.B. degree in any single department within the Schools of Science and Engineering.

5. Willing to sign a contract with the Navy which obligates the student, after completing the requirements for a commission, to fulfill the following additional requirements: to accept a commission, to serve on active duty for a period of three years subsequent to graduation, and to retain the commission for a period of six years from the date of original acceptance.

The Four-Year Program

Students in the Naval R.O.T.C. program must, while completing degree requirements in one of the acceptable Courses, take the following required subjects:[1]

FIRST YEAR

NS11 NAVAL ORGANIZATION AND HISTORY (0–2–0)
(No M.I.T. credit)
NS12 NAVAL ENGINEERING (0–3–0)
(No M.I.T. credit)
13,64J HYDROSPACE VEHICLES (2–0–6)

SECOND YEAR

NS21 NAVAL WEAPONS SYSTEM (0–3–0)
(No M.I.T. credit)
NS22 SEAPOWER AND MARITIME AFFAIRS (0–2–0)
(No M.I.T. credit)
21.545 WAR AND THE MILITARY INSTITUTIONS OF THE MODERN STATE (3–0–6)

THIRD YEAR

NS31 NAVAL OPERATIONS AND NAVIGATION (0–2–0)
(No M.I.T. credit)
NS32 NAVAL OPERATIONS AND NAVIGATION LABORATORY (0–3–0)
(No M.I.T. credit)
17.43 EVOLUTION OF STRATEGIC NUCLEAR SYSTEMS (3–0–6)

FOURTH YEAR

NS41 DEFENSE MANAGEMENT (0–2–0)
(No M.I.T. credit)
NS42 NAVAL MANAGEMENT (0–3–0)
(No M.I.T. credit)
15.501 INFORMATION AND DECISION SYSTEMS I (4–0–8)

Application Procedure

Eligible students should apply for admission to the Naval R.O.T.C. program as soon as they have been notified of their admission to the Institute. Applications should be made directly to the Commanding Officer of the Naval R.O.T.C. Unit, either by mail or by personal visit by Registration Day or as soon as possible thereafter.

The Naval R.O.T.C. program at M.I.T. is not open to students selected under the nationwide Navy scholarship program known as the Regular N.R.O.T.C. or Holloway Plan. Further inquiries regarding the M.I.T. program should be addressed to the Commanding Officer, N.R.O.T.C. and Naval Administrative Unit, M.I.T.

[1]Alternate catalogue courses are available for schedule conflicts.

Creativity and Intellectual Independence

Study and research for advanced degrees have held a prominent place at M.I.T. for more than 80 years.

The Graduate School seeks to promote the best environment for advanced study and for intimate association among creative workers, both faculty and students, as a community of scholars, and to extend the boundaries of knowledge in their fields of study.

Through the Graduate School, the departments collaborate to establish overall requirements for admission, for character and quality of programs, and for degrees. Each student's program is guided by a department and its faculty in accord with these overall standards.

Of first importance to any graduate school is the quality and productivity of its faculty. Faculty strength is needed over a wide range of fields to serve varied student interests. National, indeed international, recognition as a productive scholar and authority in his field is normally expected of each faculty member. Satisfaction in his work and in his association with students characterizes the effective teacher. M.I.T. is proud of its faculty as judged by these criteria.

An outstanding characteristic, indeed a major asset, of graduate education at M.I.T. is the atmosphere of intellectual independence and individual creativity combined with a strong sense of group unity and cooperation.

Our primary aim is to develop in each student the realization that his intellectual growth and his subsequent success are directly related to the depth of his command of basic principles. Although graduate study is often popularly associated only with a high degree of specialization, M.I.T. believes that such specialization, while valuable, is secondary to extending intellectual and humanistic horizons, producing new orientations, and developing growth in intellectual courage and in depth of understanding and social responsibility. Achieving mastery of basic principles develops the mind as no mere acquisition of specialized knowledge can; it provides the power to attack unsolved problems with success and to explore new areas of knowledge with confidence.

Successful graduate study is also closely associated with the ability to organize and express important ideas in clear and simple terms. Thus graduate students find assignments as teaching assistants rewarding and stimulating as an integral part of their graduate education. These and similar positions as research assistants offer the student professional assignments with an approach to financial self-sufficiency. At M.I.T., graduate students are in a very real sense junior partners of the faculty in study, in teaching, and in pioneering research. They have the responsibilities of mature students and independent professional workers.

For almost 50 years, the Institute has consistently awarded the largest number of Master's and doctor's degrees in engineering in the nation, and in recent years M.I.T. has ranked very near the top in doctoral output in the physical sciences and mathematics. In addition, more recent programs in the life sciences, social sciences and humanities, architecture and city planning, and management have now assumed an integral role in the Graduate School of the Institute. Enrollment of Regular Graduate Students now stands at approximately 3,200. About 1,000 students enter the Graduate School each year, more than 900 of them coming to M.I.T. with baccalaureate degrees from about 200 other American colleges and universities. Some 70 foreign countries and more than 100 foreign universities are typically represented among the 800 foreign students enrolled in the Graduate School.

Resources for Graduate Study

Extensive resources for graduate study have developed naturally at M.I.T. from a long tradition of emphasis on contributions to new knowledge in fields of the Institute's interest. M.I.T.'s high productivity of advanced degrees is the result of these pioneering interests of its faculty that have generated both demand and support for advanced research. The wealth and diversity of teaching and research resources, described in this Catalogue, particularly by the individual departments in their respective sections, are a direct result. Graduate students — and, in appreciable numbers, undergraduate students — have central roles in all of the Insti-

tute's wide-ranging research activities; this participation is vital to the educational experience of both students and faculty and to the success of the research itself.

Interdisciplinary developments are especially vigorous. For example, in the Research Laboratory of Electronics graduate students and faculty from 12 departments, ranging from physics and life sciences to modern languages and economics, find an effective and congenial environment for their creative work. The rapidly evolving and productive interaction between science and engineering in the field of materials has generated both a standing interdepartmental committee for the guidance of doctoral work and a large interdisciplinary Center for Materials Science and Engineering. The new Urban Systems Laboratory relates to many graduate departments. These and other interdepartmental teaching and research groups are described in Section 5.

Although most graduate students find their interests served by programs available within a single department, some elect to work in interdisciplinary fields which reach into two or more departments. In general, each graduate student's program can be designed to fulfill his own particular interests, subject to the general requirement that the field thus defined has scope and depth appropriate for an advanced degree regardless of whether or not its boundaries happen to fall within the scope of a single department. Most important, the faculty tends to regard departmental organization more as an administrative convenience than as a limit to the bounds of their scholarly interests.

The M.I.T. Libraries, described in detail in Section 1 of this Catalogue, provide a major resource for graduate study. They serve New England as a depository for unclassified reports of the Department of Defense, the Atomic Energy Commission, the National Aeronautics and Space Administration, and the Rand Corporation. The collections are notably strong in science and technology of the U.S.S.R.

Another significant resource for graduate study is the cooperative cross-registration privilege with Harvard University, Wellesley College, Brandeis University, Tufts University, Boston University, and the Woods Hole Oceanographic Institution, used by graduate students of these institutions.

While the graduate student tends normally toward intensive preoccupation with his professional field, M.I.T. encourages breadth of experience as well. Leaders in many areas of knowledge give lectures and seminars on the campus, and in general these are open to all members of the Institute community.

The cultural and social life and recreational facilities of the M.I.T. campus, described in Section 1 and Section 6 of this Catalogue under the headings The Campus, Campus Activities, and Student Housing, are shared alike by undergraduate and graduate students. Concerts and dramatic performances are frequent on the campus, given by both Institute groups and professional performers, and Greater Boston is an outstanding cultural and intellectual center. Many graduate students take advantage of these exceptional opportunities for extending interests to new fields.

Graduate students are encouraged to use all of M.I.T.'s extensive athletic facilities; a number of informal teams composed of both undergraduate and graduate students schedule intercollegiate competitions, and graduate student entries are frequently successful in the intramural athletic program. The Nautical Association also welcomes graduate students.

Degrees and Fields of Study

Graduate students may pursue work leading to any of the following degrees:

Doctor of Philosophy, PH.D.
Doctor of Science, SC.D.
Engineer Degrees (See page 36)
Master of Science, S.M.
Master in Architecture, M.ARCH.
Master in City Planning, M.C.P.
Bachelor in Architecture, B.ARCH.

The major fields for graduate study are listed below. Each graduate program is described by the department concerned, in its statement on graduate education given later in this Catalogue, and these statements should be consulted for more specific information.

School of Architecture and Planning

Department of Architecture
ARCHITECTURE, Course IV

Department of Urban Studies and Planning
URBAN STUDIES AND PLANNING, Course XI

School of Engineering

Department of Aeronautics and Astronautics
AERONAUTICS AND ASTRONAUTICS, Course XVI
Areodynamics and gas dynamics
Aeroelasticity
Aeronautical and astronautical engineering

Flight transportation
Fluid mechanics
Instrumentation
Instrumentation and automatic control
Materials engineering
Physics of fluids
Plasma physics and space sciences
Propulsion
Space mechanics
Structures
Vehicle design

Department of Chemical Engineering
CHEMICAL ENGINEERING, Course X
Applied chemistry
Biochemical engineering
Biomedical engineering
Catalysis and reactor engineering
Engineering operations
Fuel engineering
Materials
Materials engineering
Polymers and plastics
CHEMICAL ENGINEERING PRACTICE, Course X-A

Department of Civil Engineering
CIVIL ENGINEERING, Course I
Applied earth science
Civil engineering
Civil engineering systems
Construction and operations
Hydrodynamics
Materials
Materials engineering
Ocean engineering
Operations research
Planning and design
Soil mechanics
Structural mechanics
Structures
Transportation
Urban engineering
Urban systems
Water resources

Department of Electrical Engineering
ELECTRICAL ENGINEERING, Course VI
Communications
Communications bio-engineering
Computer science
Control engineering
Electrical engineering
Electrical science and engineering
Electromagnetic theory
Electronics
Energy processing
Materials engineering
Operations research
Quantum electronics
Solid-state electronics
Systems science

Department of Mechanical Engineering
MECHANICAL ENGINEERING, Course II
Materials engineering
Mechanical engineering

Department of Metallurgy and Materials Science
METALLURGY AND MATERIALS SCIENCE, Course III
Ceramics
Materials science
Metallurgy

Department of Ocean Engineering
NAVAL ARCHITECTURE AND MARINE ENGINEERING, Course XIII
Acoustics
Hydrodynamics
Naval engineering
Ocean engineering
Ocean engineering (Joint Program with Woods Hole Oceanographic Institution)
Operations research
Ship propulsion
Ship systems
Structural mechanics
NAVAL CONSTRUCTION AND ENGINEERING (USN and USCG), Course XIII-A
SHIPPING AND SHIPBUILDING MANAGEMENT, Course XIII-B

Department of Nuclear Engineering
NUCLEAR ENGINEERING, Course XXII
Applied plasma physics
Fission technology

School of Humanities and Social Science

Department of Economics
ECONOMICS, Course XIV

Department of Humanities
HUMANITIES, Course XXI

Department of Philosophy
PHILOSOPHY, Course XXIV

Department of Foreign Literatures and Linguistics
LINGUISTICS, Course XXIII
Linguistics

Department of Political Science
POLITICAL SCIENCE, Course XVII

Department of Psychology
PSYCHOLOGY, Course IX
General experimental psychology
Physiological psychology
Social-developmental psychology

Alfred P. Sloan School of Management
MANAGEMENT, Course XV

School of Science

Department of Biology
BIOLOGY, Course VII
Biochemistry
Biophysics
Cell biology
Microbiology
Physiology
Biological Oceanography (Joint Program with Woods Hole Oceanographic Institution)

Department of Chemistry
CHEMISTRY, Course V
Analytical chemistry

Biophysical chemistry
Chemical physics
Geological chemistry
Inorganic chemistry
Nuclear chemistry
Organic chemistry
Physical chemistry

Department of Earth and Planetary Sciences
EARTH AND PLANETARY SCIENCES, Course XII
Geochemistry
Geology (classical geology, theoretical geology)
Geophysics
Oceanography
Oceanography (Joint Program with Woods Hole Oceanographic Institution)
Planetary Sciences

Department of Mathematics
MATHEMATICS, Course XVIII

Department of Meteorology
METEOROLOGY, Course XIX
Oceanography
Oceanography (Joint Program with Woods Hole Oceanographic Institution)

Department of Nutrition and Food Science
NUTRITION AND FOOD SCIENCE, Course XX
Biochemical engineering
Clinical nutrition
Food engineering
Food science and technology
Food toxicology
Nutritional animal pathology
Nutritional biochemistry and metabolism
Oral biology

Department of Physics
PHYSICS, Course VIII

Each graduate student is officially enrolled in one department or Course. His program is not limited, however, to subjects offered in a single department. Subjects and research programs may be chosen from several departments, with the aid and counsel of the staff, as long as the overall program is integrated and well balanced with respect to a major field of study.

In addition to specialized professional competence, graduate students are expected to have a background in the humanities and social sciences. The faculty believes that those who receive advanced degrees should have the breadth of interests and understanding which tend to promote qualities of leadership and an awareness of professional, social, and moral responsibility, along with specialized competence. To further this objective, graduate students may take electives offered by the School of Humanities and Social Science or by Harvard University.

INTERDEPARTMENTAL DOCTORAL PROGRAMS

Many recent developments in the physical and social sciences and engineering reflect interdisciplinary trends. Team research is one result of this; another result is that individual interests now frequently span several conventionally defined fields. Thus a number of graduate students now desire doctoral programs in fields that may be adequate in both scope and depth to meet doctoral standards but whose boundaries overlap substantially two or more departments. In certain areas, such as materials engineering, instrumentation, operations research, economics and urban studies, public systems engineering, bioengineering, special continuing committees provide guidance. In other fields, interdepartmental doctoral programs are normally administered by *ad hoc* committees appointed for each student by the Dean of the Graduate School. Details of this procedure are found in the *Graduate School Manual.*

Descriptions of the major interdisciplinary research facilities and academic programs are in Section 5 of this Catalogue.

Cooperative Programs

Harvard University

A graduate student at M.I.T. or Harvard University who is engaged full time in study or in a combination of study and academic staff duties equivalent to full time may, by permission, enroll for advanced study (exclusive of research) at the other institution without paying additional tuition, provided that this exchange enrollment does not exceed one-half of his total registration for the term. Included in the above category are full-time Special Graduate Students who are registered at M.I.T. This cooperative arrangement is applicable only to the regular academic terms and not to the Summer Session.

Requests for registration under this cooperative arrangement should be confined to subjects which are not offered at the student's own institution; if there is an apparent duplication of a requested subject in the two schools, acceptable reasons for the request must be presented. Students will not be allowed to attend classes which are so crowded that additional registration puts an undue load on the instructors.

The procedures to be followed and deadlines to be observed by both M.I.T. and Harvard students wishing to enroll in subjects under this cooperative arrangement are given in the *Graduate School Manual.*

Boston University

An arrangement analogous to that described for Harvard has been made between the M.I.T. Departments of Economics and Political Science and the African Studies Program at Boston University. Details of the procedures to be followed, which are similar to those for Harvard-M.I.T. cross-registration, are given in the *Graduate School Manual*.

Brandeis University

A similar cooperative arrangement also exists between the M.I.T. Department of Urban Studies and Planning and the Florence Heller Graduate School for Advanced Studies in Social Welfare at Brandeis University. Cross-registration is restricted to one or two subjects per term in the area of social welfare at Brandeis and urban studies at M.I.T.

Tufts University

A cooperative arrangement exists between the M.I.T. Department of Nutrition and Food Science and the School of Dental Medicine at Tufts University. The program is restricted to specific graduate subjects at each institution.

Wellesley College

Graduate students are eligible to participate in the Wellesley-M.I.T. Exchange Program. Information concerning the details of this program may be found in a publication entitled *Wellesley-M.I.T. Exchange: Guide for M.I.T. Students*. This booklet is available in the Office of the Dean of the Graduate School, as well as the Information Office. Applications are available in the Information Office and the Office of the Dean for Student Affairs.

Woods Hole Oceanographic Institution

Information regarding the program in Oceanography may be obtained from the Department of Earth and Planetary Sciences or from the Department of Meteorology at M.I.T. The Department of Ocean Engineering at M.I.T. can provide information about the program in Ocean Engineering and the Department of Biology can provide information regarding the program in Biological Oceanography. The Woods Hole Oceanographic Institution may be consulted also for information concerning all these programs.

A general description of these programs is included in Section 4 of this Catalogue.

Requirements for Degrees

Candidates for advanced degrees must satisfactorily complete an approved program of study and research, including an appropriate portion done in residence, before being recommended for a degree. The amount of time required to attain any one degree varies; candidates who lack undergraduate prerequisites for graduate work may be permitted to make up these deficiencies in the course of their graduate work, but those who do so must expect to spend a longer period of time in the Graduate School than is otherwise required for the degree. All the general requirements for the different degrees, as well as the residence requirements, are described in the following paragraphs.

A student who expects to come to M.I.T. for an advanced degree after earning an undergraduate degree elsewhere should give careful attention to undergraduate subjects prerequisite for the advanced work which he intends to undertake; these requirements are outlined by each department in following sections of this Catalogue. For advice on such subjects, a student should write to the chairman of the Committee on Graduate Students of the department in which he wishes to enroll.

Degrees are awarded by the Corporation of the Institute upon the recommendation of the faculty. Favorable faculty action is based upon approval by the Committee on Graduate School Policy on recommendations from the appropriate departmental Committees on Graduate Students.

THE DEGREE OF BACHELOR IN ARCHITECTURE

The graduate degree of Bachelor in Architecture is awarded upon the satisfactory completion of a program of study of at least 164 subject units approved by the Department of Architecture, of which 96 units must be in "A" subjects, and the completion of a thesis acceptable to the Department. ("A" subjects are those intended primarily for graduate students; they are indicated in the Descriptions of Subjects given at the back of this Catalogue.)

A student who has obtained the degree of Bachelor of Science in Art and Design at the Institute or an equivalent degree at another institution may attain the degree of Bachelor in Architecture in two years. A student who enters without previous experience in a department of architecture may take four years.

With departmental acceptance to graduate status, a student may work for the simultaneous award of the S.B. in Art and Design and the graduate B. Arch. degree.

THE MASTER'S DEGREES

A student who has a Bachelor's degree from the Institute in the same department in which he enrolls for the Master's degree, or who has had equivalent preparation elsewhere, may attain the Master's degree in one year. Others with less direct or extensive preparation will require a longer time.

A student who completes the requirements for the Bachelor's degree at the Institute with substantial extra advanced credits in graduate subjects may, upon application, be granted a relaxation of the normal residence requirement (apart from thesis) and may be recommended for the Master's degree upon completion of the academic requirements.

Degree Requirements

The degrees Master of Science, Master in Architecture, and Master in City Planning are awarded upon the satisfactory completion of an approved program of study of at least 66 subject units, of which 42 units must be in "A" subjects, and the completion of an acceptable thesis.

The choice of field of specialization must be approved by the Committee on Graduate Students of the department in which the student is enrolled. Approval of the entire program must be obtained from this Committee and from the student's Registration Officer. A special interdepartmental committee may be appointed by the Dean of the Graduate School to supervise a program in a field which spans two or more departments.

To be recommended for a Master's degree, a student must have, in addition to a clear record in a program of graduate study and research as defined above, a scholastic standing of a distinctly high grade.

Degrees With and Without Specification

In an approved program for a Master of Science degree, if 34 units of "A" subjects and the thesis are in a single field of science or engineering (as determined by a departmental Committee on Graduate Students), the degree is recommended with specification in the field in which the student has thus specialized; otherwise, the degree is recommended without specification. The same high standard of academic performance is required in either case.

Programs for the Simultaneous Award of the Bachelor's and Master's Degrees

Information concerning the opportunity for programs of study leading to the simultaneous award of the Bachelor's and Master's degrees is given under "The Undergraduate Programs" in Section 2 of this Catalogue.

Program for Two Master's Degrees

Occasionally, a graduate student seeks two Master's degrees simultaneously or in sequence in different departments. Such a procedure is permissible provided a program of study comprising at least 66 subject units (exclusive of thesis units) and a thesis is completed to the satisfaction of each department. A common thesis may be submitted for both degrees if not less than 60 subject units are unique to each program; if separate theses are submitted, not less than 30 subject units must be unique to each program. Registration shall be in one department at a time. For simultaneous degrees, a petition must be filed with the Registrar by the end of the term before graduation, stating the expected program in both departments.

Interdepartmental Master's Degree Program

Any approved interdepartmental graduate program leading to the Doctor's degree is approved as a Master's program. A list of these appears in Section 5. Because degree requirements differ, those interested should seek specific advice from the program headquarters.

THE ENGINEER DEGREES

The objective of a program leading to an Engineer degree is a more advanced level and a broader range of competence in engineering and science than that required for the Master's degree, but with less emphasis on creative research than that characterizing a doctoral program. In general, the Master's degree requires a minimum of one academic year and the Engineer degree two academic years beyond a baccalaureate in the same field.

The following Engineer degrees are awarded: Chemical Engineer (CHEM.E.), Civil Engineer (C.E.), Electrical Engineer (E.E.), Engineer in Aeronautics and Astronautics (E.A.A.), Marine Mechanical Engineer (MAR.MECH.E.), Materials Engineer (MAT.E.), Mechanical Engineer (MECH. E.), Metallurgical Engineer (MET.E.), Naval Architect (NAV.ARCH.), Naval Engineer (NAV.E.),

Nuclear Engineer (NUC.E.), and Ocean Engineer (OCEAN E.).

The requirement for such a degree is the satisfactory completion of a program of advanced study and research approved by the appropriate department of the School of Engineering. The minimum program consists of at least 162 subject units (exclusive of thesis units) and the completion of an acceptable thesis. A department may accept a Master's thesis of superior quality for the Engineer degree.

A graduate of the Institute who enrolls for an Engineer degree in the same department in which he received his Bachelor's degree, or others with equivalent preparation, may complete the requirements for that degree in two years; a student with less direct or extensive preparation will require a longer time.

The Thesis for the Master's and Engineer Degrees

The caliber and scope of the Master's and Engineer theses are, in general, such as to require the equivalent of the full time of a student for at least a half of a term. Many theses may require a somewhat longer time. Every degree candidate working on a thesis is expected to register for thesis in all periods during which his thesis research is actually in progress.

THE DOCTORATES

M.I.T. offers the degrees of Doctor of Science and Doctor of Philosophy interchangeably in branches of science and engineering, and the degree of Doctor of Philosophy alone in urban studies and planning, economics, political science, biology, psychology, philosophy, linguistics, and management. These degrees certify to performance of original research of high grade and to creditable completion of an approved program of advanced study, principally at the Institute.

The two basic requirements for a doctorate are:

1. Completion of a program of advanced study, including a general examination.
2. Completion and oral defense of a thesis on original research.

Experience has clearly indicated that the purposes of doctoral work are effectively served only by full-time effort in formal study or by a combination of formal study and relevant work as an academic staff appointee.

The Program of Advanced Study

The program of advanced study and research may be selected in any field approved by the department in which the student is enrolled. The thesis is in this same field. The program often comprises subject areas reaching into several departments. If the field requires substantial participation by two or more departments, an interdepartmental faculty committee may be appointed by the Dean of the Graduate School to advise with a Graduate Registration Officer in the administration of the student's program.

Each doctoral candidate will have a general examination in his field at such time and in such manner as his departmental or interdepartmental committee approves. This examination consists of both oral and written parts.

The Thesis

The caliber and scope of the doctoral thesis are such as to require, in all but very exceptional cases, the equivalent of at least one full-time academic year of research. Many doctoral researches require a substantially longer time. Each doctoral candidate is expected to register for thesis in all periods during which work pertaining thereto is actually in progress.

The investigation must be carried out under the supervision of an M.I.T. faculty member or senior staff member approved by the department. Work already accomplished elsewhere which has not been under the supervision of an Institute faculty member cannot be accepted in partial fulfillment of the thesis requirement, nor can credit be granted for thesis research done *in absentia*, except under very special conditions and with specific prior approval by the Committee on Graduate School Policy. A full statement of policy on thesis research *in absentia* is given in the *Graduate School Manual*.

A final oral examination on the thesis and its field will be held after the thesis has been submitted and tentatively evaluated by the examiners.

Minor Program

The Institute believes that candidates for the doctor's degree should be aware of the context of their special field in the spectrum of human knowledge. Although there is no Institute requirement of a Minor for the doctor's degree, certain departments require that candidates

take a number of subjects outside their major field.

Language Proficiency

Scholars from different countries should have the means of communicating with one another. The American scholar is fortunate in that much foreign professional literature is now written in English, or readily available in English, and many foreign scholars speak English. Nevertheless the American scholar should have studied other languages enough to be able to communicate with foreign scholars in a spirit of reciprocity. There will also be times when the knowledge of a foreign language will be important to him in his work.

Although there is no Institute language requirement, prospective doctoral students are urged to include language study in their college preparation. Several departments have a language requirement for the doctorate, normally the requirement that a candidate be able to read or speak one or two foreign languages with intermediate competence. Typically, a student may satisfy the requirement in three ways:

1. He may satisfy the requirement before entrance by passing one or more intermediate or advanced courses with a grade of C or better.
2. He may be examined by the Department of Foreign Literatures and Linguistics.
3. He may take a two-term subject in the language or languages concerned offered by the Department of Foreign Literatures and Linguistics. Depending on student demand, the Department of Foreign Literatures and Linguistics offers a choice of two-term language subjects, stressing the ability to read or to speak, in French, German, Russian or Spanish.

The Department of Foreign Literatures and Linguistics gives, for the purpose of 2 above, written and oral examinations in French, German, Russian, and Spanish twice a year at the end of each term. Written and oral examinations in other approved languages are arranged individually upon request. A student who requests a written or oral examination in French, German, Russian or Spanish at an unscheduled time, or in any other language at any time, is required to submit with his application a receipt from the Bursar indicating that he has paid a special fee of $30 for this purpose. *Any student who fails to appear for a predoctoral language examination is subject to a fine of $10.*

Further information concerning the above and other departmental requirements may be obtained from the individual departments.

RESIDENCE REQUIREMENTS

M.I.T. degrees are "residence" degrees in the sense that a major portion of the work for which each is awarded must be done with opportunity for full-time association with the faculty, other graduate students, and the Institute community. In this academic environment a student lives and works in a stimulating and scholarly atmosphere; he enjoys free and unhampered discussion with his colleagues, both faculty and students, within his professional field and over a broad range of other subjects. This environment includes easy access to libraries and reference sources, to the educational opportunities offered by other disciplines, and also to recreational, cultural, religious, and athletic opportunities. Experienced together, these offer the challenge and inspiration of being a working member of a team mutually striving for professional growth and advancement and transmission of knowledge.

All thesis work must be done under the supervision of an authorized member of the Institute's academic staff.

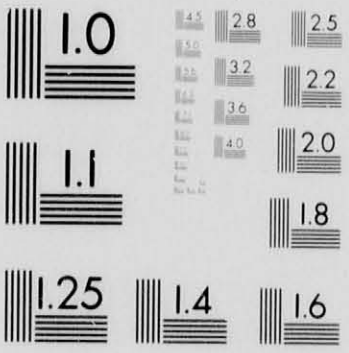
For all Master's degrees the minimum residence requirement is one full academic term.

For the Engineer degrees, two terms of full-time graduate work must be completed with residence credit.

For the doctor's degree, the course of advanced study must be pursued under the direction of the Committee on Graduate School Policy for at least two academic years of full-time graduate work, including the research for and writing of a thesis, normally with residence credit. In the case of students who satisfy the Committee that they have successfully accomplished at another institution advanced work of a grade similar to that required at the Institute, the required period of residence may be reduced. In no case may the required period of residence be reduced to less than the equivalent of three full-time academic terms, not more than one of which may be a summer term.

Organization of the Graduate School

The administration of the Graduate School rests with the President, the Chancellor, and the Provost of the Institute; the Dean, Associate



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Dean, Assistant Dean, and Executive Officer of the Graduate School; and the Committee on Graduate School Policy, comprised of a faculty member from each department offering graduate degrees and two representatives from the Graduate Student Council. The Institute Faculty is the same for undergraduate and graduate instruction.

Each department exercises a large measure of responsibility for its graduate program under a policy established for the Institute as a whole. Under the general responsibility of the Department Head, each department has a departmental Committee on Graduate Students, which, with one or more Graduate Registration Officers, administers departmental graduate activities. The Graduate Registration Officer advises and assists individual students in all aspects of their graduate work. The membership of the Committee on Graduate School Policy is listed with that of other faculty committees at the back of this Catalogue.

Because this catalogue statement is necessarily abridged, the *definitive* statement of organization, policies, and procedures of the Graduate School is given in the *Graduate School Manual*. (Copies are available from the Graduate School Office and from departmental Graduate Registration Officers.) Each graduate student is expected to be familiar with this manual in order that he may know his privileges and his obligations and be familiar with operations of the School.

SCHOOL OF ARCHITECTURE AND PLANNING

A statement by the Dean of the School of Architecture and Planning.

Architecture and planning both began as professions concerned with the art of design as applied to the built-in physical environment. Architects worked with structures and spaces at a fairly intimate scale requiring close control over the means of construction, planners in the larger framework of urban form, with a technology that leaned increasingly on the social sciences.

These professions are now rapidly enlarging their roles in society. Architects perceive that buildings form only a part of the constructed and natural environment, all parts of which should have a balanced relationship; this cannot be imposed arbitrarily, but must represent all the unfolding needs of man as a social animal that can be met in his immediate surroundings. City planners perceive that concern for urban form is at the edge of a larger problem, the viability of urban life in America. The environmental problems of modern cities have become so urgent and so interrelated that one cannot address them singly. Knowing how to create physical systems such as housing and transportation is of high importance, but more important still is to know whether and when investment in such systems can be justified as compared to other policies that may not involve built-in systems. Urban planning is tending today toward a loose federation of interests united by a complete involvement in the urban problem. These disciplines are concerned not only with concepts of urban form but with race and poverty, with the phenomenon of squatter urbanization, with the intervention of government in urban change, and with neighborhood participation in planning decisions.

Both architecture and planning are being profoundly influenced by the new information revolution, which opens up new possibilities for the ordering of complex data for use in design and in policy making. The School benefits enormously from its placement in a scientific university.

Reinforcing the importance of cultural and aesthetic insights, an important section in the School is concerned with a broad perspective of the visual arts. This includes the scholarly study of the history and criticism of art and architecture as well as studio experiences in several forms of direct visual expression. The presence of this nucleus attracts students from every part of the Institute and offers possibilities for undergraduate concentration in the visual arts.

The overriding challenge of architecture and planning today is not in individual, isolated works of design; it is in bending the total environment to

make a cohesive and satisfying background for modern urban life, in shaping individual creativity to fit into an ongoing social process of great complexity and dynamism. That is why these professions are now seeking to understand all the forces that are brought to bear in giving form to the physical environment.

THE UNDERGRADUATE CURRICULA IN THE SCHOOL OF ARCHITECTURE AND PLANNING

The S.B. curricula in the School of Architecture and Planning consist of a program of general education, emphasizing science, mathematics, and the humanities and social sciences (the General Institute Requirements), and a concentration in one of a number of programs appropriate to architecture, urban planning, and the visual arts (the Departmental Programs). The Departmental Programs are given by each department on the following pages.

Each student arranges his program of studies with the advice and consent of a Faculty Counselor. Typical Course Schedules are issued each term by the Registrar with the Class Schedules. R.O.T.C. subjects may be used according to the specifications in Section 2.

Department of Architecture

Architecture is an art; only creative insight may achieve it. Yet technology is the means to architecture, and architecture satisfies wants related to many areas of human affairs. Thus it has become the American preference that schools of architecture be lodged in universities, where the art of design can be fortified by scholarship and research in humanities, science, and engineering.

Contained within an institution especially alert to technology's potential for improving human life, M.I.T.'s Department of Architecture is dedicated to the search for a physical environment which expresses our culture, which encompasses the scientific outlook, and which uses modern industrial methods and materials while giving full satisfaction to our hunger for aesthetic fulfillment.

THE UNDERGRADUATE CURRICULA

The Department offers two undergraduate courses of study: Course IV, leading to the degree of Bachelor of Science in Art and Design; and Course IV-B, leading to the degree of Bachelor of Science.

Course IV is a flexible program for students whose primary interest falls within the subject area of the Department. There are four possible areas of concentration: visual studies (including visual design, photography, and film making); architecture and urban design; building technology (including structures, building process, and environmental control); and history, theory and criticism of art and architecture. Within a broad framework, each student develops an individual course of study best suited to his needs.

Course IV-B is offered for students who find that their basic intellectual commitments are to subjects within the Department of Architecture but whose educational interests and goals cut across departmental boundaries. These students may, with the approval of the Department, plan a course of study that directly suits their interests, while including the fundamental areas within the Department.

Students in the Department of Architecture may, upon consultation with a Faculty Advisor, exercise flexibility in scheduling completion of General Institute Requirements. Deferment of a portion of the General Institute Requirements in the first year will allow those who so choose to elect appropriate subjects of professional interest within the Department of Architecture and other departments of the Institute. It should be emphasized, however, that any program of studies that involves postponing first-year physics and mathematics will limit the possibilities of easy transfer from the Department of Architecture to those departments of the Institute that, within a four-year sequence, presuppose the completion of most of the science and mathematics portions of the General Institute Requirements by the end of the sophomore year. In addition, some advanced subjects in departments other than Architecture presume the knowledge acquired in fulfilling General Institute Requirements. Registration in subjects of interest in those departments may be precluded or postponed by deferment of General Institute Requirements.

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE IN ART AND DESIGN

Architecture (Course IV)

Each student shall discuss his educational interests and plans with his faculty counselor not later than the beginning of the fall term of his junior year. In addition, he shall submit to the Department, no later than the beginning of the spring term of his junior year, a statement of his educational goals and a list of the restricted and planned electives selected to achieve these goals. Subsequent to approval of this list by the Department, substitutions of subjects of similar content may be permitted by the student's faculty counselor.

GENERAL INSTITUTE REQUIREMENTS	*Total units*
Specific science and humanities and social science subjects.[2]	132[1]
ECONOMIC PRINCIPLES I (14.01) is recommended in the upperclass humanities and social science program.	
Science Distribution Requirement	36
Laboratory Requirement	12

Architecture

DEPARTMENT OF ARCHITECTURE

DEPARTMENTAL PROGRAM

Restricted Electives

Three of the following introductory subjects:

4.031	FORM AND DESIGN I	2	4	6
4.121	ARCHITECTURAL DESIGN	2	5	5
4.30	[3]BASIC STRUCTURAL THEORY	3	3	6
	or			
4.402	BUILDING PROCESS	3	3	6
4.601	TOPICAL STUDIES IN THE HISTORY AND THEORY OF ART	3	0	6
11.05	URBAN SOCIAL STRUCTURE AND PROCESS	2	0	6
	or			
11.07	ECONOMIC ISSUES IN URBAN PLANNING	2	0	6
	or			
11.11	COMPONENTS OF THE URBAN ENVIRONMENT	3	0	6
		29 to 36		

Subjects within the School of Architecture and Planning which are neither on the list of introductory subjects above nor in the student's chosen area of concentration	31 to 24	**60**
Planned Electives		**60**

A coherent selection of subjects (in addition to the introductory subject in the area of concentration) within one of the following areas of concentration which, together with other parts of the student's program, is aimed at a well-defined educational goal. Each program must be approved by the Department.

- Visual Studies, the 4.0 series
- Architecture and Urban Design, the 4.1 series
- Building Technology, the 4.3, 4.4 and 4.5 series
- History, Theory and Criticism of Art and Architecture, the 4.6 series

Unrestricted Electives	**60**
Total Units Required for the S.B. Degree	**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] The following subjects may *not* be used for the humanities and social science requirement: for areas of concentration in architecture and urban design and in building technology, those subjects in Field 10 used in fulfillment of the Departmental Program; for areas of concentration in visual studies and history, theory and criticism of art and architecture, all subjects in Field 10.

[3] BASIC STRUCTURAL THEORY (4.30) is accepted as partially fulfilling this requirement, and will also be credited towards the Science Distribution Requirement, thereby providing 12 additional units of Unrestricted Elective.

Students who plan to continue their studies for the graduate degree, Bachelor in Architecture, must apply for admission to the graduate B.Arch. program. Students who have fulfilled the requirements for the S.B. degree in Art and Design will normally be able to satisfy the requirements for the B.Arch. degree in two years if they include the following subjects in their undergraduate programs: ENGINEERING MATERIALS (1.02); visual studies, 24 units which include FORM AND DESIGN I (4.031); architectural design, 52 units in the undergraduate 4.1 series; INTRODUCTION TO INFORMATION PROCESSING (4.20); structures, 28 units in the 4.3 series which includes BASIC STRUCTURAL THEORY (4.30); BUILDING PROCESS (4.402); TOPICAL STUDIES IN THE HISTORY AND THEORY OF ART (4.601); history of architecture, 18 units in the 4.6 (not 4.60–) series; ARCHITECTURAL COMMUNICATION (4.701); and URBAN SOCIAL STRUCTURE AND PROCESS (11.05) or ECONOMIC ISSUES IN URBAN PLANNING (11.07) or COMPONENTS OF THE URBAN ENVIRONMENT (11.11). Both 1.02 and 4.30 can be used to satisfy the Science Distribution Requirement for the S.B. degree in Art and Design.

The following subjects are recommended for an undergraduate program in history, theory and criticism of art and architecture as adequate preparation for graduate study: TOPICAL STUDIES IN THE HISTORY AND THEORY OF ART (4.601); INTRODUCTION TO MODERN ART (4.602); THEORY AND METHOD IN THE HISTORY OF ART AND ARCHITECTURE (4.681); a sub-concentration in either the history of painting and sculpture (4.60 series) or the history of architecture (4.6 series), 36 units; one subject from the sub-concentration not chosen, 9 units; design (12 units) subjects from the 4.0 or 4.1 series, 24 units; and building technology, 24 units in the 4.3, 4.4 and 4.5 series. ARCHITECTURAL DESIGN (4.121 and 4.122) are recommended for students taking the sub-concentration in the history of architecture. The ability to read art historical literature in either French or German is required by most graduate schools. Attention is directed to the Archeology subjects in the Department of Humanities.

Because of the breadth of choices available, the area of concentration in building technology is not narrowly specified, but is purposely left flexible to fit each student's objectives. Nevertheless, the program for each student is expected to be coherent and to include the fundamentals of architectural design and building technology. At least 24 units in architectural design (the 4.1

series) are highly recommended together with a selection of subjects in building processes (4.402 and the 4.5 series), structures (the 4.3 series) and environmental control (the 4.4 series). Beyond this, the student may elect to concentrate more deeply on one of the above three sub-concentrations by a carefully selected group of subjects in the Department and other Departments as appropriate to his objectives. The choice of subjects within the area of concentration should be made in consultation with an appropriate member of the faculty.

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE

Architecture (Course IV-B)

The wide range of offerings within the Department of Architecture and their numerous possible relationships with those of other departments may suggest to a student a coherent program of study which includes subjects in these other departments. For instance, there are many subjects in the department which might be profitably combined with subjects in urban studies and planning, computer sciences, systems analysis, etc. In order to meet this condition, the Department offers to a limited number of students a curriculum composed of the Institute core, departmental restricted electives and planned electives selected by the student. A student desiring to follow this curriculum must submit to the Department, not later than the beginning of the fall term of the junior year, a statement of his educational goals and a list of the restricted, planned, and unrestricted electives selected to achieve these goals. At an earlier date, such students should discuss their interests and intended programs with one or more of the faculty of the Department.

		Total units
GENERAL INSTITUTE REQUIREMENTS		
Specific science and humanities and social science subjects.[2]		**132**[1]
ECONOMIC PRINCIPLES I (14.01) is recommended in the upperclass humanities and social science program.		
Science Distribution Requirement		**36**
Laboratory Requirement		**12**
DEPARTMENTAL PROGRAM		
Restricted Electives		
Design subjects of at least 12 units each in the 4.0 or 4.1 series	24	
Building technological subjects in the 4.3, 4.4 or 4.5 series[3]	12	
One history subject in the 4.6 series	9	
One of the following subjects in the Department of Urban Studies and Planning: 11.05, 11.07 or 11.11	8 or 9	
	53 or 54	
Planned Electives		
A coherent selection which, together with other parts of the student's program, is aimed at a well-defined educational goal. Each program must be approved by the undergraduate curriculum committee or the Department.		**72**
Unrestricted Electives		**55 or 54**
Total units required for the S.B. degree		**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] The following subjects may *not* be used for the humanities and social science requirement: those subjects in Field 10 used in fulfillment of the Departmental Program.
[3] BASIC STRUCTURAL THEORY (4.30) or ENVIRONMENTAL CONTROL-ACOUSTICS (4.43) is accepted as partially fulfilling this requirement, and will also be credited toward the Science Distribution Requirement, thereby providing additional units of Unrestricted Elective.

GRADUATE STUDY IN ARCHITECTURE

The Department offers graduate study programs at two levels: Bachelor in Architecture and Master in Architecture. B.Arch. is the degree awarded to students who complete a program, accredited by the profession, that is an essential step toward licensure for architectural practice. M.Arch. is a second professional degree awarded to students who extend their studies beyond the B.Arch. Both programs are designed as preparation for practice, although they may also attract students preparing for teaching, writing, or research.

ENTRANCE REQUIREMENTS FOR GRADUATE STUDY

Undergraduate preparation in architecture usually differs from that leading to advanced studies for scientific and engineering degrees. The following requirements apply to those seeking the advanced degree in architecture.

Mathematics and Science. Four term subjects at college level in mathematics and/or the physical sciences.

Humanities. Six term subjects in the humanities and/or the social sciences.

Professional Preparation. M.I.T. Students who have fulfilled the requirements for the S.B. degree in Art and Design will normally be able to satisfy the requirements for the Graduate B.Arch. degree in two years if they have taken the special program in architecture and urban design specified.

The Graduate Degrees

BACHELOR IN ARCHITECTURE

The degree of Bachelor in Architecture is awarded upon the satisfactory completion of an approved program of at least 164 units, of which 96 units must be in "A" subjects, and an accept-

able thesis. Completion ordinarily requires two years of residence beyond the Institute's undergraduate degree of Bachelor of Science in Art and Design.

A substantial number of candidates are admitted with a Bachelor's degree from other institutions; those who have not yet studied in a department of architecture will usually require four years of residence to fulfill the requirements for the B.Arch. degree.

MASTER IN ARCHITECTURE

This program, open only to students who have already earned the first professional degree, is designed to promote study in depth; candidates with degrees from other institutions will be required to be in residence for two academic years, and to complete approved programs substantially greater than the minimal requirements stated below. Candidates with the Institute's degree of B.Arch., having already completed 96 units of "A" subjects, can fulfill the requirements for the degree M.Arch. upon the satisfactory completion of the following additional requirements: an approved program of 66 units, of which 42 units must be in "A" subjects including one term of architectural design, and an acceptable thesis.

Department of Urban Studies and Planning

In the last decade, the concerns of planners have changed significantly. Emphasis has expanded from a focus on the physical environment — analysis, design, and control of land uses, circulation systems, and community facilities — to a broader and more explicit interest in such issues as environmental quality, poverty, race, health, education, ecology, and techniques and goals of social and economic development, as well as problems of public participation and the distribution of power. Research and action now focus on tasks such as the formulation of international and national as well as regional and local development strategies for improving the environment in cities and regions; the interactions between the physical environment and the behavior, attitudes, and satisfaction of various client groups; and the fashioning of more comprehensive and more powerful analytical methods for understanding and designing solutions to the problems of mobility and communication. The Department of Urban Studies and Planning seeks to increase competence in dealing with these and other problems and to train professionals and scholars who as managers or advisors will be able to deal with the processes of urban and regional development as well as advocate the interests of underrepresented constituencies.

A student has several options in training himself for work in these fields. He may focus on some special area or approach to urban studies or he may pursue a broader program and develop a competence as more of a general practitioner. However, the core knowledge expected of all students includes the following elements:

1. A general understanding of the interactions between the social, economic, spatial, and political aspects of contemporary urban society.
2. Techniques for analyzing the needs of urban and regional communities and planning for change in the operations of economic and political structures, spatial patterns, and social service delivery systems.
3. Skill in the synthesis of urban policy, including the statement of problems, the formulation of objectives, the generation and evaluation of alternative plans and policies, the implementation and management of social, economic, and environmental programs, and the monitoring and evaluation of feedback.

Subjects offered by the Department of Urban Studies and Planning are listed elsewhere in this catalogue under the heading of introductory integrative concepts or under several commonly selected areas of specialization. Students can also take relevant subjects in other M.I.T. departments and cross-register at Harvard University, and thus take advantage of other subjects not available at M.I.T.

OPPORTUNITIES FOR SPECIALIZATION

Social Policy and Governmental Institutions: A concentration is available focusing on the design and evaluation of complex urban programs involving both social and environmental action, with emphasis on problems of poverty, race, and citizen participation. Subjects dealt with include the governmental, legal, and institutional setting for policy-making; and specialized work in the fields of health planning, educational planning, income maintenance, and the social components of housing policy.

Housing, Community Development, and Urban Economics: The Department offers a special concentration in the area of housing and community development. Course work includes the study of housing programs and policies, housing technologies and the housing production system, land development economics, real estate and housing markets, client analysis and user involvement in housing design. A special focus on urban economics is encouraged through work jointly with the Department of Economics. Linkages between the problems of housing design and development and the provision of community services, transportation planning, and the regulation of land use patterns receive attention.

Planning Problems of the Developing Countries of the World: This specialization is for students interested in the problems of cities and regions in developing countries. Special consideration is given to migration and social change, the problems of squatters, the social and cultural

transformation implied by urbanization and economic development, and the various policy issues posed by these trends.

City Design and Spatial Policy: The Department offers training in the field of city design — the spatial organization of activities and the shaping of the physical environment at the city and regional scale, with special reference to its esthetic and sensuous qualities, and to the importance of behavioral and psychological processes. Our training and research in this area offer a focus on the city rather than on the architectural project. We seek to develop a basic competence in city planning and in the methods of design at the city scale as well as a more special competence in understanding and analyzing the experimental and ecological consequences of city form. Environmental management and the recognition of users needs are stressed. This specialization may include course work in the Department of Architecture.

Quantitative Methods and Techniques for Urban Analysis, Planning, and Design: New problems and programs in urban affairs require the development and refinement of new quantitative and analytical approaches to planning, design, and urban problem-solving. Students entering with some mathematical background may be particularly interested in subjects and seminars in the development of information systems, decision theory, modeling of social systems, programming, and computer-aided design. The computer facilities in the Institute and the School provide essential resources for this work.

Students have the option of selecting and shaping still other areas of specialization (in consultation with members of the faculty) consistent with their academic background, practical experience, and career objectives. For example, a student interested in regional planning might select a range of subjects including Regional Economic Analysis, Models of the Metropolis, National and Regional Growth Issues in Developing Countries, Metropolitan Planning in Developing Countries, as well as pursue independent reading and research in conjunction with members of the Urban Studies and Planning staff as well as members of the Department of Economics faculty. A specialization focusing on the problems of minorities in the city might be arranged drawing together such subjects as Issues and Strategies in Community Development, Social Policy, Planning and Poverty, Urban Social Structure and Process, Institutional Change in Urban America, Educational Policy and the Community as well as additional course work in the Departments of Political Science, Humanities, and Economics.

In 1968 the Department established a Laboratory for Environmental Studies. The Laboratory operates on a modest basis. It involves departmental faculty members from other departments (e.g., Architecture, Political Science, Economics, Humanities, and the Sloan School of Management). To the extent that resources permit, the Laboratory supports faculty members engaged in research as well as students who participate in its activities as research assistants. The Laboratory is currently involved in several innovative research enterprises: (a) the study of policy options and implementation mechanisms related to urban growth strategies; (b) the educative city — analysis of the ways in which the educative qualities of urban environments can be enhanced; (c) computer-aided planning and design — the development of new hardware and software to enhance the capability of the planner and to increase the access of a wide range of participants in the planning process to technical information.

THE UNDERGRADUATE CURRICULUM
(*Urban Studies — Course XI*)

Introduction

A program leading to the S.B. in Urban Studies is open to qualified undergraduates. The program has several purposes: (1) to provide a foundation upon which students can build a course of graduate study in urban planning, law, the welfare professions, or the social and environmental sciences; (2) to provide a general but systematic background for students who intend to assume positions in the urban professions without further formal study; (3) to provide undergraduates with an opportunity to test the feasibility of a variety of social change and social service strategies.

In addition to studies of urban environments and exploratory analyses of alternative directions for urban policy, the course in Urban Studies directs its efforts toward adapting the concepts and techniques of many disciplines to work on contemporary urban problems.

Areas of specialization within the Program generally fall into three groups: Urban Studies, Environmental Planning, and Social Policy. The Urban Studies emphasis is the one linked most closely to the disciplines of Sociology,

Economics, and Political Science. It builds appropriately toward graduate study in one of the traditional academic disciplines, or toward graduate preparation in law or medicine. The Environmental Planning concentration encompasses such specializations as housing, transportation, land use planning, city design, data management and information systems, and environmental quality control. It is a means of preparing for graduate education in environmental engineering, city planning, or public administration, or for immediate employment after college. The Social Policy area includes possible concentrations in the design of social service systems (e.g., the planning of health services or educational programs), the study of deliberate social change or community organization strategies. It is designed for students who wish to work with community action programs or in health planning, social work, or community development or who plan to pursue graduate studies in social planning.

Whatever area of specialization a student may choose, his work in the program is intended to prepare him in such matters as the significance of cities in society and culture, the interrelationships between the many processes which affect urban environments, the methods and techniques which now exist for understanding the city and for evaluating urban policy.

The Curriculum

Students will be required to take the junior and senior urban studies colloquia offered for undergraduate majors in the Department. The junior year colloquium, "Perspectives on Urban Issues," offers various analytical and normative views of "urban problems" and is designed to help each student develop a perspective of his own based on work in his field of specialization. In the senior year, each student will participate in the senior colloquium, "Urban Problems in American Society: Responses and Strategies," which deals with the study of national policies and programs aimed at guiding urban growth and ameliorating urban social problems.

Each student will be expected to complete at least four subjects from the list of core subjects (the restricted electives). These are intended to outline the scope and methods of urban studies and to provide a basis for choosing an area of concentration. In addition, each student will be required to complete at least six subjects in a specific area of concentration, defined in close cooperation with his advisor. Work in a student's field of concentration can include field research, independent study, action-planning, and community service. During the senior year each undergraduate urban studies major will prepare a thesis. The senior thesis is intended to focus the various parts of the student's program on a particular problem or aspect of urban studies. Consideration of possible topics should normally begin early in the junior year.

Course XI leads to the degree of Bachelor of Science in Urban Studies. The normal curriculum requirements for the degree are summarized below:

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science, humanities, and social science subjects				**132**[1]
	Science Distribution Requirement				**36**
	Laboratory Requirement				**12**
DEPARTMENTAL PROGRAM					
	Required Subjects				
11.02	PERSPECTIVES IN URBAN ISSUES	3	0	6	
11.03	URBAN PROBLEMS IN AMERICAN SOCIETY: RESPONSES AND STRATEGIES	3	0	6	
	THESIS		14		
					32
	Restricted Electives				
	At least four of the following:				
11.04	MODELS AND THE METROPOLIS	4	0	8	
11.05	URBAN SOCIAL STRUCTURE AND PROCESS	3	0	6	
11.07	ECONOMIC ISSUES IN URBAN PLANNING	3	0	6	
11.09	TECHNOLOGY AND THE CITY	3	0	6	
11.11	COMPONENTS OF THE URBAN ENVIRONMENT	4	0	8	
11.20	INTRODUCTION TO HOUSING PROBLEMS	3	0	6	
11.30	INTRODUCTION TO CITY DESIGN AND SPATIAL POLICY	3	0	6	
11.55	PLANNING AND POVERTY	2	0	7	
11.561J	URBAN AMERICAN HISTORY	3	0	6	
11.571	URBAN LEGAL ISSUES	2	0	7	
11.70	REPRESENTATION	1	3	5	
11.711	COMMUNITY AND REGIONAL PLANNING METHODS		*Arr.*		
17.31	URBAN POLITICS	3	0	6	
					at least **36**
	Planned Electives				
	A coherent selection which, together with other parts of the student's program, is aimed at a field of concentration. Each program must be developed in cooperation with a faculty advisor.				
					at least **48**
Unrestricted Electives					up to **64**
Total units required for the S.B. degree					**360**

[1]The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

SPECIAL FEATURES OF THE PROGRAM

The Advisory System: The problem-solving and integrative nature of the field of urban studies

calls for a considerable degree of student initiative, both in the selection of specific subjects and in the determination of a suitable program in a given field of concentration. An advisory system has been designed which encourages student initiative while at the same time insuring that each student develops a rigorous and coherent program and receives continuing guidance in carrying out independent work.

Field Work: Field work or internships with agencies and programs in the Boston area, while not a requirement, may be an important aspect of the experience of most Urban Studies majors. Part time, carefully supervised field opportunities are available through the Department. Students are encouraged and aided in securing urban-related positions during the summer. In some cases, students can identify relevant jobs for more extended periods, taking a leave of absence for a semester or longer.

Research: Independent student research and research activities associated with on-going departmental projects are also important program components. There is a Departmental Undergraduate Research Commission which approves and funds student-initiated projects.

IMPLEMENTATION OF THE UNDERGRADUATE PROGRAM

The Undergraduate Urban Studies Program was initiated in September 1970. Enrollment is still limited. A number of subjects offered by the Department have been modified to make them compatible with the overall intent and structure of the undergraduate program. Various new subjects are being developed.

The Undergraduate Urban Studies Program is experimental in nature through 1971–72. Each undergraduate in the program is expected to contribute to the on-going evaluation and development of the Urban Studies curriculum.

Students considering Course XI should consult with the Department of Urban Studies during their freshman year and obtain a copy of the Department's suggestions for meeting the General Institute Requirements.

GRADUATE STUDY

The Department of Urban Studies and Planning offers graduate work leading to the degrees of Master in City Planning and Doctor of Philosophy. The Course is open to students with varying backgrounds; urban studies, architecture, landscape architecture, civil engineering, economics, sociology, law, management, and public administration all offer suitable preparation. Applicants from other fields are also accepted.

ENTRANCE REQUIREMENTS FOR GRADUATE STUDY

Undergraduate preparation for urban studies and planning usually differs from that required for the scientific degrees. The following are prerequisites for graduate study:

Mathematics and Science. Four one-term college subjects in one or more of the fields of mathematics and the physical and natural sciences.

Humanities. At least six terms of work in English, history, economics (or allied subjects), and other humanities subjects equivalent in scope to those included in the undergraduate curricula of the Institute.

General. A broad, sound general education, with competence in communication through oral, written, and graphic expression and through mathematics, and a previous specialization in some related field are both desirable.

Deficiencies in any of the above areas may be removed by taking comparable subjects at M.I.T.

MASTER IN CITY PLANNING

The typical program leading to the degree of Master in City Planning requires two to two and a half years of study at M.I.T., depending both upon prior preparation and upon the specialization chosen.

No program of required subjects is prescribed. Each student, whether through previous experience, formal subjects, or independent study, is expected to acquire an understanding of a core of fundamental knowledge and skills, and to develop competence in some more specialized area. Most students who have not earned undergraduate degrees in interdisciplinary urban studies or planning programs will need to include the equivalent of between one and two terms of undergraduate course work such as is listed above under "Restricted Electives" for the S.B. degree. Each student sets his own program in collaboration with a faculty advisor in the light of his particular background and interests. Students may choose one of the fields described under Opportunities for Specialization, or some other area related to urban or regional development in which this department, or other M.I.T. departments, can offer advanced work. An original thesis is required, occupying at least one term and often longer.

DOCTOR OF PHILOSOPHY

Advanced students seeking research or teaching careers in city and regional planning or in urban studies may be accepted as candidates for the doctorate. Prerequisites are substantially the same as for the Master's degree. The general requirements for the Ph.D. degree are specified in Section 3 of this Catalogue.

Subject to the approval of a special advisory committee, a doctoral candidate engages in a course of studies which provides a broad background of urban studies and equips him for advanced work in some area of specialization. This area may be in any field related to urban studies or planning in which this Department or other M.I.T. departments offer strong support.

After successful completion of doctoral examinations, the student is required to prepare a written doctoral thesis evidencing the capacity to do independent research.

No stated number of graduate subjects is required. Doctoral candidates who already hold the M.C.P. degree will require at least two terms of study in residence before beginning their theses. Other candidates may require up to six terms, depending on their prior preparation.

Interested and qualified students can undertake joint doctoral programs with the Department of Political Science and the Department of Economics. Doctoral students in urban studies may be associated with the research program of the M.I.T.-Harvard Joint Center, the Urban Systems Laboratory, as well as the Department's Laboratory for Environmental Studies.

COMMUNITY FELLOWS PROGRAM (CFP)

The Community Fellows Program provides an opportunity for a limited number of especially capable persons to spend a year at M.I.T. studying aspects of institutional innovation, program administration, and the management of social change. Each Fellow will be expected to develop a specific proposal or program aimed at dealing with a particular problem or meeting a critical need in his or her organization or community. The program is oriented primarily toward independent study and it is deliberately flexible. Fellows will be registered officially as special non-degree students in the Department of Urban Studies and Planning. Academic credit will be awarded, if desired, for coursework taken.

The program is designed for mature individuals who have already embarked upon their careers and who have had significant experience in the problem areas most relevant to the needs of minority communities. The program is open to men and women throughout the United States, although approximately half the Fellows accepted each year will be from the greater Boston metropolitan area. The interests and experience of prospective Fellows may be in such diverse fields as community organization, housing development and renovation, health planning, educational planning, social services delivery, food technology, communications and public media, or environmental management. Principal criteria for admission are each individual's ability and experience. Applicants need not have a college degree.

The primary objective of the Community Fellows Program is to assist each Fellow in developing a specific community-or-agency-related program or proposal. To this end, the formal and informal resources of M.I.T. will be made available to participants in the Program. Each Fellow will have a faculty advisor. Fellows will also participate in two special seminars: the first, during the fall term, will deal with community development issues and strategies; the second, during the spring term, will focus on the individual projects of the participants.

SPECIAL PROGRAM FOR URBAN AND REGIONAL STUDIES OF DEVELOPING AREAS (SPURS)

This program provides an opportunity for a small number of unusually qualified persons to carry out a program of study and research for one academic year outside the regular degree requirements. The work of this group of Fellows is focused on the problems of urban and regional change within the broad context of national development. The main aim is to make it possible for some of the persons who will be shaping policy in the developing nations in the years to come to enhance their capacity to cope with these problems.

The non-degree program is designed to serve mature individuals who are now occupying or are likely to occupy significant positions in private or public organizations. They may be drawn from such varied fields as architecture, engineering, sociology or economics, from government or business, from any field in which there is a concern with problems of urban and regional development. Preference is given to persons from the developing countries, but some participants come from Western Europe or the United States. The principal criteria for admis-

sion are the exceptional ability, experience and position of the individual. All applicants must have a thorough command of English.

The program is flexible. Fellows are encouraged to tailor their work to their own individual requirements. They are generally permitted to select subjects offered at M.I.T. normally available to graduate students, subject to the approval of the instructor. Fellows may also pursue their own research or, when feasible, participate in ongoing research programs in the Department.

SCHOOL OF ENGINEERING

The Dean of the School of Engineering describes the role of the engineer and M.I.T.'s program of education for leadership in engineering.

It is the engineer who is bringing about the great revolution in technology. Largely by his efforts we are at last achieving the technical potential for the creation of a society free from want.

Increasingly the achievements of our engineering leaders derive more from a mature and imaginative exploitation of today's scientific knowledge than from ingenuity or tinkering, no matter how skillful these may be. Through a coupling of deep scientific skill with purposeful engineering motivation, engineers have provided, for example, a host of new machines and new materials; spectacular systems of transportation, communication, power and propulsion; and the tools for the automated mass production of consumer goods of many kinds. As engineers continue to enrich our society by conceiving, designing, building, and managing our great engineering and industrial systems, they are instigators of rapid change not only in engineering itself but also in the economic, social, and cultural environment of the world.

Although engineers deal extensively with facts and scientific principles, they also must carry out their work as leaders of men. Their ultimate stature, therefore, often finds expression in those situations where judgment and wisdom weave the elements of scientific knowledge into the whole fabric of society. In the future, the engineer will be called upon to participate with increasing frequency and in greater depth in programs that cut across a wide spectrum of disciplines and involve an increasing number of social and economic factors. The opportunities for the engineer to provide leadership in these areas are vast. Accordingly, the educational plan at M.I.T. interlaces a sequence of studies in science, engineering, and the humanities with involvement in research, in a manner that embraces all the elements of a truly liberal education.

Among M.I.T.'s 34,000 engineering alumni are many who have become independent professional consultants, college or university professors, or entrepreneurs responsible for their own businesses. The majority of them, however, are either on the staffs of industries, where they perform technical work of a highly varied and challenging character, or are members or leaders of management in industry. As the impact of engineering in world affairs accelerates, M.I.T. engineers in ever-increasing numbers have the distinction of serving as advisors to government on many important issues.

The various curricula within the School of Engineering are sufficiently general to assure that no student is confined to a narrow specialization. In fact, specialized knowledge is now of such quantity and its application is so sophisticated that it cannot be mastered in four, five, or even six years. Further-

more, the engineer and the scientist, working in concert, are setting such a pace in technological change that specialization is often outmoded several times within the span of a professional lifetime.

It is not enough merely to prepare an engineer to keep abreast of a particular contemporary technology. Accordingly, the goal of the School is to equip its students with an understanding of the basic sciences — mathematics, physics and chemistry — and of the engineering of science; and to develop in them a versatility of mind and an ability to learn anew so that, as professional engineers, they will work at the frontiers of their field and bring forth new technologies, the very nature of which may be essentially unknown during the period of their formal education.

The curriculum of the freshman year encompasses study of the basic sciences, mathematics, and humanities. In the sophomore year, the student normally continues these studies with subjects leading to the fulfillment of the Science Distribution, Laboratory, and Humanities requirements. While some technical and professional subjects that lead to a major field may begin in the sophomore year, the majority of these subjects are taken in the later years.

Mature professional education may begin during the senior year but finds its full expression only in the graduate years. The student who decides early in his program on the broad field of his major may enter a department at the beginning of the sophomore year. In most instances this student may elect, for about one-fourth of his sophomore studies, subjects that are a definite part of his major program. On the other hand, the student who wishes to postpone his choice of department until the end of the sophomore year need not necessarily delay his graduation beyond four years, because any sequence of elective subjects he chooses to fill the elective time of the sophomore year will be credited to his total degree requirements.

The basis of choice among engineering fields should lie within — rather than outside — each student's mind and personality. When assessing the question of becoming identified with a particular engineering field during a period of study, a student is wise to choose the one which provides an immediate, potent source of motivation and inspiration rather than to attempt to foresee what his permanent area of professional activity may be. To find expression for one's gifts and to carry one's education as far as those gifts justify are the essential purposes of higher education.

The undergraduate programs of each department of the School of Engineering are built upon a strong scientific base to give knowledge of enduring value. Each program leads to a wide range of choice of a career and serves as preparation for continued on-the-job study following graduation, or further formal graduate study in a broad spectrum of fields. A student may thus safely follow his own intuition with the conviction that his training will equip him for the unknown future, whatever the details of his professional career may be.

THE UNDERGRADUATE CURRICULA IN THE SCHOOL OF ENGINEERING

The S.B. curricula in the School of Engineering consist of a common program of general education emphasizing science, mathematics, and the humanities and social sciences (the General Institute Requirements) and groupings of subjects appropriate to particular engineering fields (the Departmental Programs). The Departmental Programs are given by each department in the following pages.

Each student arranges his program of studies with the advice and consent of a Faculty Counselor. Examples of Course Schedules are issued each term by the Registrar with the Class Schedules. R.O.T.C. subjects may be used according to the specifications in Section 2.

INTERDISCIPLINARY PROGRAMS

The School of Engineering offers a wide range of interdisciplinary programs on both the undergraduate and graduate level. A student interested in obtaining greater breadth in an area of interest will find the flexible curricula of the Departments of the School of Engineering designed to satisfy his goals. For example, a student interested in studying materials would find appropriate subjects in all of the School's eight departments. Thus, with the faculty and resources of all the departments available to him, the student is able to develop a program that satisfies his own intellectual and professional objectives. Interdisciplinary programs can also be developed in power engineering, ocean engineering, transportation, computers and information systems, bio-engineering, or in other areas not exclusively covered by an individual department. The student interested in an interdisciplinary program will find it helpful to study the departmental descriptions and also to read Section 5, which covers interdisciplinary opportunities that combine, in various manners and degree, disciplines from the Schools of Science, Management, Humanities and Social Science, and Architecture and Planning with those of the School of Engineering.

Department of Aeronautics and Astronautics

The engineer is sometimes described as a builder of bridges between science on the one hand and the needs of society on the other. The engineer practicing in the fields of aeronautics and astronautics bridges science with the specific social needs of transportation, national defense and the exploration of space. Aeronautics embraces the atmospheric flight of vehicles ranging from VTOL (Vertical Takeoff and Landing) aircraft, including helicopters, to supersonic transport and hypersonic aircraft. Astronautics involves the flight of long-range ballistic vehicles, moon and earth satellites, and interplanetary spacecraft beyond the atmosphere in the vast airless regions of space. The objective of the education offered by the Department of Aeronautics and Astronautics is to prepare its graduates for leadership in the processes of research, development and operation as they relate to aeronautical and astronautical systems. To serve these objectives the Department curriculum, in addition to the Institute core offerings in humanities, science and mathematics, embraces the engineering sciences and technologies which are regarded as fundamental to contemporary aeronautics and astronautics. There is at the same time a strong emphasis on systems subjects, available as electives, which are superimposed upon the several disciplinary subjects and act as a means for giving the student an awareness of the relations among them and a feeling for the interconnected whole.

The interests and fields of specialty of the faculty of the Department range from the aeronautical and space sciences and technologies on the one hand to systems engineering on the other. This variety in background and interest makes it possible for the Department to offer a balanced education in aeronautics and astronautics with flexibility to meet student desires and to encourage maximum development of individual abilities. Engineering science electives are offered to those interested primarily in research, while professional engineering subjects are available to those attracted to engineering development and operations. Throughout the Department's offerings, the view is taken that it is less important for the student to learn specialized knowledge in detail than it is to acquire the attitudes of applying science to achieve engineering objectives; to learn how to explore new technical ideas, express and test them and examine their implications; and to develop a feeling for the innovations, compromises, judgments and attention to detail required for technological advancement. Every subject taught by the Department is regarded as an instrument to instill these attitudes in its students.

In order to deal effectively with the range of subjects underlying the processes of research, development and operations, the Department faculty is presently divided into five major divisions of instruction. Each division includes faculty members and subject offerings which are fundamental to both aeronautics and astronautics. The five divisions are the following: mechanics and physics of fluids; materials, structures and aeroelasticity; propulsion and space power; aeronautical and astronautical systems; instrumentation, control and guidance. Many faculty members work with more than one division, thereby promoting a broader understanding within the faculty of the conditions associated with the research, development and operation of flight vehicle systems. Because of the exceptionally stringent character of these conditions, the small design margins that separate success from failure make the problems of flight vehicle engineering among man's most difficult and challenging.

Progress in aeronautics and astronautics continues to be so rapid that effective education must deal not only with the circumstances of today but also those to be expected in the future. Faculty service with government and industry advisory committees and consulting on significant aerospace problems help fulfill the need for coupling education with current practice. Another means for insuring that faculty members continue to be well informed and retain leadership in their professional areas is active personal participation in research. An important characteristic of the Department is that, on the basis of his own free choice, each faculty member may be associated with research work in either academic facilities or laboratories

assisted by outside sponsorship. Experience and information gained from such research is generally incorporated first in graduate subjects and is then applied to the updating of all subjects offered by the Department. The laboratories also make it possible for undergraduates at all levels, including freshmen, for graduates, and for postgraduates to work with faculty members on a wide variety of advanced projects. Students frequently assist with laboratory work, carry out special projects, and use laboratory facilities; they have the advantage of advice from the laboratory staff on undergraduate and graduate theses. The laboratories also have funds to pay for service not associated with academic credit, so that students often can earn money toward academic expenses while gaining valuable professional experience.

The Department is organized for research into two divisions, each with several sections. The Aerospace Research Division includes the Aeroelastic and Structures Research Laboratory, the Aerophysics Research Laboratory, the Flight Transportation Laboratory, the Fluid Dynamics Research Laboratory, the Gas Turbine Laboratory, the Man-Vehicle Laboratory, the Measurements Systems Laboratory, the Plasma Physics and Space Sciences Laboratory, the Space Propulsion Laboratory, the Wright Brothers Wind Tunnel, and various facilities used for individual research by faculty members. The Instrumentation Division includes the guidance systems section, the guidance component section, and the guidance test facilities sections.

The Aerospace Research Division has equipment for research in all regions of flight, from hovering to interplanetary operations. Gas dynamic research is carried out in the hypersonic wind tunnel (Mach number 7.5) and in the supersonic wind tunnel of the Aerophysics Research Laboratory. Fluid mechanics research occupies a low-speed, low-turbulence wind tunnel. Two larger low-speed wind tunnels are used for airplane and VTOL research. High-vacuum spheres and molecular-beam techniques are employed in the Fluid Dynamics Research Laboratory to simulate low-density space environments and study interactions of the environment with vehicle surfaces. Structural dynamics research, including blast and high-velocity impact effects, is carried on in the Aeroelastic and Structures Research Laboratory. Facilities for ion propulsion studies are available in the Space Propulsion Laboratory, while the Gas Turbine Laboratory, manned jointly with the Department of Mechanical Engineering, conducts research on the aerodynamics of turbines, compressors, combustion, and mixing jets. The Measurements Systems Laboratory is engaged in research on interplanetary navigation systems and in research and flight-testing of systems for celestial observations from stations in the upper atmosphere. Simulator equipment is used for studying human reactions in the Man-Vehicle Control Laboratory. The Flight Transportation Laboratory carries out research studies on the technological, operational, and economic problems associated with present and future flight transportation systems covering areas such as vehicle design and operation, air traffic control, airport design and operation, and management and institutional factors.

The Instrumentation Division pioneers in the development of control and guidance equipment for aircraft, missiles, and space vehicles. Inertial guidance receives special attention, and the Laboratory is equipped with advanced facilities for research on all phases of control and guidance. Projects dealing with systems for helicopters, airplanes, submarines, satellites, and manned lunar craft are currently in progress and offer many kinds of student participation.

In addition to the research facilities described, a Projects Laboratory is maintained for the purpose of allowing students to carry out experiments which they themselves conceive and design. Students who have acquired reasonable levels of skill in the Projects Laboratory usually move into other laboratories of the Department.

Seminars on topics of historic and current general interest in aeronautics and astronautics, conducted by leaders in their fields, are held on Tuesday afternoons throughout the school year. Because of their educational value, seniors and graduate students are expected to join the staff in attending these seminars.

THE UNDERGRADUATE CURRICULUM

Aeronautics and Astronautics (Course XVI)

Undergraduate study in the Department leads to the degree of Bachelor of Science in Aeronautics and Astronautics at the end of four years. The curriculum provides flexibility to meet the needs of careers in aerospace activity ranging from scientific research to responsible engineering direction of large enterprises. Each

Engineering

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

student elects an individual program tailored to his interests, built on firm grounding in science and on a broad base in the engineering sciences, from a wide selection of available subjects. With the advice of his Faculty Counselor, he plans an undergraduate program which is reviewed each term and which may be changed at any time. The curriculum requirements for the Bachelor of Science degree are as follows:

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				**132**[1]
	The subjects 8.03, 16.20, and 18.03, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.				
	The subject 16.62, which is required in the Departmental Program, appears on the list of Laboratory Subjects and can be used to satisfy the Laboratory Requirement.				
DEPARTMENTAL PROGRAM					
	Required Subjects				
16.001	THERMODYNAMICS AND STATISTICAL MECHANICS	4	0	8	
8.03	PHYSICS III	5	0	7	
16.20	SOLID MECHANICS I	4	2	6	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
3.141	SCIENCE OF MATERIALS	4	3	5	
6.14	INTRODUCTION TO ELECTRONICS	4	2	6	
16.01	DYNAMICS	4	2	6	
16.02	AERODYNAMICS	4	2	6	
16.201[2]	STRUCTURAL MECHANICS	4	0	6	
16.62	EXPERIMENTAL PROJECTS	2	6	4	
					118
	Restricted Electives[3]				
	1. *Either*				
16.30	PRINCIPLES OF AUTOMATIC CONTROL	3	0	9	
	or				
16.40	PRINCIPLES OF FLIGHT GUIDANCE	3	1	8	
	2. *Either*				
16.53	ROCKET PROPULSION				
	or	3	0	6	
16.54	AIRCRAFT ENGINES				
	3. *Either*				
16.71	FLIGHT VEHICLE ENGINEERING	2	3	7	
	or				
16.73	SPACE SYSTEMS ENGINEERING	4	0	8	
					33
	Unrestricted Electives[4]				**77**
Total units required for the S.B. degree					**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] This is a restricted elective for Classes of '72 and '73.

[3] Classes of '72 and '73 may elect three of five restricted electives, the alternatives listed, 16.201 and 16.031 or 16.11. Thus they are left with 84 to 92 units of unrestricted electives.

[4] Schedules of students in Course XVI may always be arranged to leave available 24 units of unrestricted elective in the second year.

During the first two years, subjects elected by the student will be mainly in the areas of science and engineering science. If he wishes to specialize as fully as possible in his education in aeronautics and astronautics, he will choose subjects recommended by the Department, thereby gaining flexibility and elective freedom in his upper years. These subjects are in varied fields, in keeping with the wide range of the Department's interests, so that this course of action is consistent with a desire for program diversity and breadth.

Many freshmen interested in this course elect to take departmental freshmen electives, 16.81 or 16.82, or both. Usually a student begins to follow the program in aeronautics and astronautics in the fall of his second year. During that year, he is advised to take the first four subjects listed above, namely 8.03, 18.03, 16.001 and 16.20. He may also, with profit, elect 3.141, if he has not already done so as a freshman. Other desirable choices would include mathematics beyond 18.03, physics beyond 8.03, or, from the above list, 16.01 or 6.14.

A student who elects Course XVI at the end of his second year can arrange an acceptable program by using some of the elective freedom available in the upper years to satisfy the departmental subject requirements. However, such a program will be correspondingly limited in depth.

During the first two years and apart from science and engineering science subjects, many students will wish to obtain a broad view of the aerospace field or a deeper insight into one of its aspects under the tutelage of an experienced engineer or scientist. Undergraduate electives and seminars meet this need.

During the third and fourth years programs may be drawn from a wide range of subjects depending on a student's interests. As a base, he may use some of his elective freedom to take more of the restricted electives listed above or additional departmental undergraduate elective subjects. He will still have opportunity to choose continuing subjects in the Department's varied fields of interest. Any student may elect to do a Bachelor's thesis in his fourth year.

Aeronautics and Astronautics (Cooperative Course) (Course XVI-B)

The cooperative program for Aeronautics and Astronautics undergraduates provides the opportunity to spend about seven months in an aerospace organization before the senior year. This length of industrial practice enables the student to advance to more interesting and professionally rewarding experience than can be gained in summer employment. The program permits

completion of requirements for the Bachelor's degree in four years.

Students in the program become regular employees during their period of employment and are subject to the regulations of the company. Cooperating companies in the aerospace industry pay students at prevailing rates during their period of employment. Students pay their own expenses while away from the Institute.

A student interested in the program should apply to the professor in charge for particulars and an interview and also should, with his Faculty Counselor, arrange a schedule which permits his absence from Cambridge during the second term of the third year. This should be done before January of the sophomore year since subject choices in the second term of the second year may be affected.

CURRICULUM IN THE COOPERATIVE COURSE (COURSE XVI-B)

The Cooperative Course leads to the degree of Bachelor of Science in Aeronautics and Astronautics. The curriculum requirements for this degree are the same as for Course XVI, except for the addition of required plant work in place of 8 units of elective:

16.85	INDUSTRIAL PRACTICE	0	8	0

GRADUATE STUDY IN AERONAUTICS AND ASTRONAUTICS

Graduate students in the Department of Aeronautics and Astronautics study and conduct research in the engineering and scientific aspects of many problems of flight transportation. Fields of endeavor may be fairly general; programs may be oriented either to aeronautical or astronautical engineering or to the related sciences with less emphasis on engineering applications. Major fields of specialization include:

Aerodynamics and gasdynamics
Aeroelasticity
Aeronautical and astronautical systems
Automatic control
Flight guidance
Flight transportation systems
Fluid mechanics
Instrumentation
Man vehicle interactions
Physics of fluids
Plasma physics and space sciences
Propulsion
Space mechanics
Structures
Vehicle design

Advanced study in the Department leads to the degrees of Master of Science in Aeronautics and Astronautics; Engineer in Aeronautics and Astronautics; Materials Engineer; Doctor of Science or Doctor of Philosophy.

Entrance Requirements for Graduate Study

In addition to the general requirements for admission to the Graduate School, all applicants must have a strong undergraduate background in fundamentals of mechanics, thermodynamics, and electrical science. Additional undergraduate preparation is a prerequisite for specialization in particular fields. Some prerequisites may be completed early in a graduate program.

The Graduate Degrees

MASTER OF SCIENCE IN AERONAUTICS AND ASTRONAUTICS

The general requirements for the Master's degree are given in Section 3. To complete the requirements of at least 66 subject units, of which 42 units must be in "A" subjects, and an acceptable thesis generally takes one academic year. Two terms of advanced mathematics beyond DIFFERENTIAL EQUATIONS (18.03) or its equivalent must be included.

Although excessive sp cialization is undesirable, it is expected that most candidates for this degree will concentrate in a single professional field, not seeking the breadth of educational background implied by the Engineer degree.

ENGINEER IN AERONAUTICS AND ASTRONAUTICS

The general requirements for the Engineer degree are given in Section 3. The minimum program of 162 subject units and an acceptable thesis usually takes at least two years for completion. The Department's program is reserved for those who possess demonstrable capability for excellence in engineering. This includes a capacity for pursuing rigorous advanced training in the disciplines upon which engineering is based, as well as the judgment and skill needed to apply technology to the synthesis of the complex operational systems used by mankind. In order to obtain the breadth of knowledge required for an engineering career, this degree program requires exposure to graduate-level subjects in each of the Department's five Divisions of Instruction.

Requirements for admission to candidacy for the degree of Engineer in Aeronautics and Astronautics are more rigorous than for the degree of Master of Science in Aeronautics and Astro-

nautics. Specific description of these requirements is published in a pamphlet obtainable from the Department's Graduate Office.

DOCTOR OF SCIENCE (OR PHILOSOPHY)

The general requirements for the doctor's degree are given in Section 3. To be recommended for this degree by the Department of Aeronautics and Astronautics, the student must complete an approved program, including a thesis. Such a program probes more deeply into a special field than the program for the Engineer degree and does not necessarily include the same breadth of engineering applications. Competence must be demonstrated by a Qualifying Examination designed to test the candidate's grasp of the principles of mathematics and physics and their application to simple situations. A Minor program and foreign language are required. A General Examination later tests the depth of the candidate's understanding of his major field of study. The thesis must demonstrate the student's ability to carry out independent original research of high quality on a problem of aeronautical or astronautical science or engineering.

SPECIALIZATION IN THE FIELD OF INSTRUMENTATION

For the doctor's degree, the student is required to complete an approved program and a thesis in one of the interrelated fields of instrumentation which include automatic control; navigation and guidance of vehicles; optimum control principles and their application to various types of plants; information systems, and system components. This program involves study in and participation by the Departments of Aeronautics and Astronautics, Electrical Engineering, Mechanical Engineering, Mathematics, and Physics. It is administered, for registration purposes, by the Department of Aeronautics and Astronautics. Competence must be demonstrated by a Qualifying Examination designed to test the candidate's grasp of the principles of mathematics, physics and control theory. A foreign language is required. The General Examination includes both written and oral parts. The thesis must demonstrate the ability of the student to do original research of high grade on a problem of instrumentation or aerospace systems engineering.

SPECIALIZATION IN THE FIELD OF MATERIALS ENGINEERING

There has arisen in recent years a very strong interaction between the field of materials and flight vehicle development. It may be said that material properties impose limitations on either the performance or efficiency of most flight vehicles and their propulsion systems. Graduates who have preparation in the combined fields of aeronautics and astronautics and materials science are required in increasing numbers to deal with these important interdisciplinary problems.

Graduate students with undergraduate backgrounds in aeronautics and astronautics may pursue programs leading to the degrees of Materials Engineer or Doctor of Science or Doctor of Philosophy. The same general requirements for the completion of these degrees are applicable as for the corresponding degrees in Aeronautics and Astronautics.

Programs of study leading to the degrees of Materials Engineer and Doctor of Science or Doctor of Philosophy are arranged on an individual basis, depending upon the preparation of the student. In general, such programs will involve a substantial number of subjects in the fields of metallurgy, physics, and chemistry in addition to subjects within the Department.

Language Requirement

There is no language requirement for candidates for the Master of Science or Engineer degrees. A candidate for a doctoral degree is normally required to fulfill the departmental language requirement of competence in one foreign language before his third year in residence. The language choice must have prior approval of his Graduate Registration Officer.

Financial Assistance for Graduate Study

The Department offers several fellowships for full-time study in aeronautics and astronautics.

The assistantship program provides a unique opportunity to progress toward a graduate degree through combined registration for academic subjects and research leading to the thesis. The research assistant works with a faculty supervisor on a specific research assignment. The experience gained in organizing work, in learning and applying new experimental techniques and analytical tools, and in technical writing, is invaluable in any career in engineering. In most cases, a student can be placed in the technical area in which he desires to concentrate his study and to carry on his thesis research.

The Department also offers a limited number of teaching assistantships.

Department of Chemical Engineering

(Including the School of Chemical Engineering Practice)

Chemical Engineering is the most broadly based of all engineering disciplines. This breadth results from a very deep involvement with chemistry in addition to the applications of physics and mathematics which are common to all engineering disciplines.

In its broadest sense, chemical engineering is the creative application of chemistry to the solution of significant problems; chemical engineering is making unparalleled contributions to the provision of adequate food supplies, to the re-creation of proper ecological balances, to the advancement of medical/engineering science, and to the economic production of material goods. In order to participate meaningfully in these activities, the engineer requires a thorough grounding in chemistry, mathematics, and physics. At M.I.T., the Department of Chemical Engineering achieves this objective in two undergraduate programs: Chemical Engineering (Course X), leading to the degree Bachelor of Science in Chemical Engineering; and Chemical Engineering (Course X-C), leading to the degree Bachelor of Science. The latter requires less study in formal chemical engineering subjects and results in additional elective time. In the past, Course X-C has proven to be especially attractive to students who wished to specialize in chemistry, physics, biology, or management while simultaneously gaining a broad exposure to the engineering attitude in solving problems.

The Department offers a wide selection of graduate subjects and research areas leading to advanced degrees in chemical engineering. Important subject areas include polymer chemistry, surface and colloid chemistry, biomedical engineering, chemical process development, transport processes, and environmental engineering. Many of our current undergraduates find it attractive in the upperclass years to take a variety of these graduate level subjects. This exposure is invaluable in identifying potential independent research interests for the student. Other students find these subjects to be fruitful as terminal technical studies prior to moving on to work in the social sciences, teaching, or management.

The School of Chemical Engineering Practice involves one term of work under the direction of Institute faculty at the Practice School Stations. There each student has a unique opportunity to develop the ability to apply basic professional principles to the solution of practical problems in industry. Study at the field stations is generally included in a program for a Master's degree.

THE UNDERGRADUATE CURRICULA

The undergraduate subjects provide basic studies in physics and mathematics, a major concentration in chemistry, and a strong core of chemical engineering. The four-year undergraduate programs, designed to develop judgment, initiative, and responsibility, give each student considerable latitude in arranging a selection of subjects that will best fit his needs and develop his aptitudes. Those who expect to go on to graduate school may therefore elect subjects which will strengthen their preparation for advanced work.

In addition to work in science and engineering, students take an integrated sequence of subjects in the humanities and social sciences. The chemical engineer's progress and accomplishments are not determined solely by technological competence; fully as important are his breadth of outlook and understanding of society.

The curriculum is designed to give undergraduates a sound basis for further developing their aptitudes and interests through industrial work, independent study, or graduate work.

In order to permit different undergraduate programs, a wide latitude of free choice of subjects within the chemical and chemical engineering areas is provided. Consequently, each student should plan, with the aid of his Faculty Counselor, a program which fits his interests and capabilities. It is especially important that he recognize early the extent of his interest in graduate work.

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE IN CHEMICAL ENGINEERING

Chemical Engineering (Course X)

The Course in Chemical Engineering leads to the degree of Bachelor of Science in Chemical

Engineering

DEPARTMENT OF CHEMICAL ENGINEERING

Engineering. The curriculum requirements for the degree are given below:

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				132[1]
	The subjects 10.12, 18.03 and either 5.41 or 5.60, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.				
	Laboratory Requirement.				12
DEPARTMENTAL PROGRAM					
	Required Subjects				
5.41	[2]INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM	4	0	8	
5.60	[2]CHEMICAL EQUILIBRIUM	4	0	8	
5.62	PHYSICAL CHEMISTRY	4	0	8	
10.12	STAGED CASCADES IN CHEMICAL PROCESSING	3	3	6	
10.13	CHEMICAL ENGINEERING THERMODYNAMICS	4	0	8	
10.15	[3]THESIS REPORTS	0	4	0	
10.26	CHEMICAL ENGINEERING LABORATORY	0	10	0	
10.301	MODES OF HEAT AND MASS TRANSFER	4	0	6	
10.37	CHEMICAL KINETICS AND REACTOR DESIGN	3	0	6	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
	THESIS		12		117
	Restricted Electives				
	Chemistry or Biology (in addition to the above required subjects)			at least	24
	Chemical Engineering (in addition to the above required subjects)			at least	24
	Laboratory work (within the above categories of electives, at least 6 units in addition to the General Institute Laboratory Requirement, 10.12, 10.26, and THESIS)				
	Unrestricted Electives[4]			up to	51
Total units required for the S.B. degree					360

[1]The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] Students in the class of '73 and later classes who take either 5.41 or 5.60 to fulfill the General Institute Requirement in Chemistry/Biology must take 12 additional units of Unrestricted Elective.

[3] 10.15 is a "time-arranged" subject.

[4] Schedules of students in Course x may always be arranged to leave available 12 units of unrestricted elective in the second year. The Unrestricted Electives must be at least 48 units.

Electives in chemistry are normally selected from the following: a second term of organic chemistry (5.42); a further term of physical chemistry (5.63); a term of inorganic chemistry (5.03); and relevant laboratory subjects. Electives in chemical engineering normally include most of the following: engineering operations (10.302 or 10.311, and 10.312); structure and properties of non-metallic substances (10.21) and industrial chemistry (10.18).

Additional opportunity for experimental research, with considerable flexibility in scheduling, is provided in Experimental Research Problem (10.91), 12 units of which satisfy the General Institute Laboratory Requirement. Students with a strong interest in a professional minor may satisfy this interest by use of the scheduled free elective time.

The student who decides early to major in chemical engineering is encouraged to begin taking professional subjects right away. For example, 5.41 or 5.60 satisfies the Institute requirement in Chemistry. Both are required in the Departmental Program and either one or both may be taken in the freshman year. In the second year, the Chemical Engineering subjects (10.12 and 10.13), Physical Chemistry (5.62), and additional mathematics may be taken. The student would then be in an excellent position for professional work in some depth in the third and fourth years.

Some students may wish to defer choice of major field until the end of two years; or they may decide upon chemical engineering early but still wish, because of strong secondary interest in other engineering or scientific areas, to exercise maximum freedom in the first two years. They will have 12 units of elective time in the first year and, if their second year includes two subjects in humanities and a third term of mathematics, 60 units will remain to be chosen. If two of the Science Distribution Subjects chosen are in the field of fluid mechanics, thermodynamics, chemistry, biology, chemical engineering (examples: 2.403, 3.00, 5.41, 5.60, 7.01, 10.12), a student can generally complete the requirements for a degree in chemical engineering in two more years. This leaves 36 hours to his own choosing in the second year; but he will have sacrificed some of his elective freedom of the third and fourth years. He is advised to discuss his proposed program with a Course x Faculty Counselor as soon as he becomes interested in a degree in chemical engineering.

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE
Chemical Engineering (Course X-C)

The degree allows a student to plan a program involving basic subjects in chemistry and chemical engineering, but instead of continuing in depth in these areas, he can arrange for study in other fields (such as other engineering disciplines, biology, biomedical engineering, economics, and management).

The student planning to follow this curriculum should discuss his interest in such a degree

with a member of the faculty of the Department. No later than the first term of his junior year, he should submit to the Department a statement of his goals and a program of subjects which will achieve these objectives. The student will be assigned a member of the department faculty as his advisor.

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				**132**[1]
	The Science Distribution Requirement will be satisfied by 10.12 and either 5.41 or 5.60, which are required in the Departmental Program, plus appropriate subjects totaling				**12**
	Laboratory Requirement.				**12**
DEPARTMENTAL PROGRAM					
	Required Subjects				
5.41	[3]INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM	4	0	8	
5.60	[3]CHEMICAL EQUILIBRIUM	4	0	8	
10.12	STAGED CASCADES IN CHEMICAL PROCESSING	3	3	6	
10.13	CHEMICAL ENGINEERING THERMODYNAMICS	4	0	8	
					48
	Restricted Electives				
	A coherent program of subjects, with at least 24 units in chemical engineering, in addition to those in the Departmental Program, designed to achieve a specific educational goal. The program is to be planned by the student in consultation with a designated Faculty Counselor in the Department of Chemical Engineering.			at least	**100**
	Unrestricted Electives[3]			up to	**56**
Total units required for the S.B. degree					**360**

[1] The requirement for Class of '72 is 128, the Unrestricted Elective units being increased by 4.
[2] Students in the class of '73 and later classes who take either 5.41 or 5.60 to fulfill the General Institute Requirement in Chemistry/Biology, must take 12 additional units of Unrestricted Elective.
[3] The Unrestricted Electives must be at least 36 units.

Five-Year Programs

In addition to offering separate programs leading to the Bachelor of Science and Master of Science degrees in Chemical Engineering, the Department offers a program leading to the simultaneous award of both degrees at the end of five years.

For Chemical Engineering students interested in nuclear applications, the Department of Chemical Engineering offers jointly with the Department of Nuclear Engineering a five-year program leading to the joint degrees of S.B. in Chemical Engineering and S.M. in Nuclear Engineering. Such programs are approved on an individual basis between the registration officers of the two departments.

GRADUATE STUDY IN CHEMICAL ENGINEERING

Because of the breadth of the field of chemical engineering, the undergraduate Course must be devoted primarily to training in fundamentals; strictly professional subjects are necessarily elementary in character. Postgraduate study is therefore of particular importance and value to the chemical engineer.

The following advanced degrees are offered in chemical engineering: Master of Science in Chemical Engineering, Master of Science in Chemical Engineering Practice, Chemical Engineer, Materials Engineer, Doctor of Science or Doctor of Philosophy. Programs for the Master of Science degree are usually arranged as a continuation of undergraduate professional training on a more mature basis. Work for the Engineer and doctoral degrees is more specific in character, and the Department offers coordinated programs in nine fields: applied chemistry, biochemical engineering, biomedical engineering, catalysis and reactor engineering, engineering operations, environmental engineering, fuel engineering, materials engineering and polymers and plastics. Special programs are developed for individual cases.

Entrance Requirements for Graduate Study

In addition to the general requirements for admission to the Graduate School set forth in Section 8 of this Catalogue, preparation in physical chemistry and organic chemistry equivalent to CHEMICAL EQUILIBRIUM (5.60) and PHYSICAL CHEMISTRY (5.62) and ORGANIC CHEMISTRY (5.41, 5.42) is normally essential.

Requirements for Advanced Degrees

The general requirements for the various degrees are specified in Section 3. A Minor is required by the Department.

Fields of Study

The technology of chemical engineering in the process industries falls loosely into two categories: physical and chemical. While both types are encountered in many industrial problems, graduate subjects of instruction and research are logically grouped in the corresponding fields of engineering operations and applied chemistry. Most graduate students take some work in each field, and in the School of Chemical Engineering Practice the problem assignments involve fundamentals in both areas.

Engineering

DEPARTMENT OF CHEMICAL ENGINEERING

ENGINEERING OPERATIONS (PROCESS ENGINEERING)

The variety of graduate offerings provides opportunity for programs in heat transfer, fluid mechanics, and the separation processes based on mass transfer — subjects which are basic in process engineering. The topics include thermodynamics, applied mathematics, molecular transport properties, fluid mechanics and the interrelation of mass, momentum and heat transfer, distillation, mass transfer between phases, combustion, economic balance, and plant design. Opportunities for research of an advanced nature are available.

Relevant subjects offered by the Department include:

ANALYTICAL TREATMENT OF CHEMICAL ENGINEERING PROCESSES (10.33)
CHEMICAL ENGINEERING THERMODYNAMICS (10.40)
DISTILLATION (10.41)
ION EXCHANGE (10.47)
HEAT AND MASS TRANSFER (10.50)
MECHANICS OF FLUIDS (10.52)
CHEMICAL ENGINEERING DESIGN (10.53)
ADVANCED TOPICS IN MASS TRANSFER (10.54)
PRINCIPLES OF COMBUSTION (10.70)

Programs may also include advanced subjects in mathematics, instrumentation, fluid mechanics, metallurgy, and others offered in other departments.

APPLIED CHEMISTRY

The Department offers a diversified program in applied chemistry, designed for the student who wants to broaden his competence in the chemical aspects of chemical engineering. This program provides subjects in industrial chemistry and chemical thermodynamics; in chemical kinetics and theory of rate-processes, with emphasis on heterogeneous and catalytic processes; and in the physical chemistry of ion-exchange, adsorption, and chromatography. The subjects listed under Materials Science and Engineering (below) also include several on applied chemistry. Much of the Department's research activity falls into these areas, and unique laboratory facilities are provided.

Relevant subjects offered by the Department include:

INDUSTRIAL CHEMISTRY (10.25)
ION EXCHANGE (10.47)
CHEMICAL ENGINEERING IN MEDICINE (10.56)
PROPERTIES OF GASES AND LIQUIDS (10.59)
CATALYSIS (10.602)
ELECTROCHEMISTRY (10.62)
CHEMICAL ENGINEERING KINETICS (10.65)

A well-rounded program in applied chemistry might also include subjects given by other departments in advanced organic, inorganic, or physical chemistry; in biochemistry, enzymology, or bacteriology; and in physical metallurgy, electrochemistry, corrosion, or ceramics.

BIOMEDICAL ENGINEERING

The application of Chemical Engineering to problems in the life sciences and medicine has become an increasingly important and meaningful area of research. The broad background of the Chemical Engineer, spanning both fundamental and applied aspects of chemistry and physics, makes him uniquely qualified to handle such tasks. Students interested in this area have the opportunity to draw upon the Department's diverse offering of courses in the Chemical Engineering sciences. Relevant subjects offered include:

STRUCTURES AND PROPERTIES OF MATTER (10.21)
ANALYTICAL TREATMENT OF CHEMICAL ENGINEERING PROCESSES (10.33)
CHEMICAL ENGINEERING THERMODYNAMICS (10.40)
HEAT AND MASS TRANSFER (10.50)
MECHANICS OF FLUIDS (10.52)
ADVANCED TOPICS IN MASS TRANSFER (10.54)
CHEMICAL ENGINEERING IN MEDICINE (10.56)
PHYSICS AND CHEMISTRY OF SURFACES (10.61)
ELECTROCHEMISTRY (10.62)
STRUCTURE AND PROPERTIES OF POLYMERS (10.64)
CHEMICAL ENGINEERING KINETICS (10.65)
SURFACE SCIENCE AND ENGINEERING (10.66)
PHYSICAL CHEMISTRY OF POLYMERS (10.68)

Well-rounded programs may also include introductory and advanced courses in biology, biochemistry, physiology, biophysics, bacteriology, and biophysical chemistry offered by other departments.

The Department's active graduate research program in biomedically related areas is characterized by an interdisciplinary approach to both fundamental and applied problems. Many projects involve collaboration with physicians, surgeons, and life scientists in other departments and in local hospitals associated with Harvard Medical School. Research topics include the rheology of non-Newtonian biological fluids, mass transfer in blood and in artificial organs, such as the artificial kidney and blood oxygenator, synthesis of blood-compatible synthetic biomaterials, membrane transport phenomena, synthetic replacement of the lung surfactant, physical properties of biopolymers, and ultrafiltration of solutions of biological macromolecules.

MATERIALS SCIENCE AND ENGINEERING

The Department maintains an active and diversified graduate research program in surface and colloid chemistry, polymer chemistry, and polymer physics and offers a coordinated instruc-

tional program in these areas. Students whose interests lie in the direction of surface phenomena or polymeric materials thus have a rare opportunity to develop specialized skills in these areas in an atmosphere where the focus of attention is on the applied, as well as the basic, scientific aspects. Specific subjects offered are:

PHYSICS AND CHEMISTRY OF SURFACES (10.61)
STRUCTURE AND PROPERTIES OF POLYMERS (10.64)
SURFACE SCIENCE AND ENGINEERING (10.66)
PHYSICAL CHEMISTRY OF POLYMERS (10.68)
POLYMERIZATION PROCESSES (10.69)

Graduate research activities in these fields include topics such as the rheology of polymer solutions and particulate dispersions, molecular transport phenomena in polymers, structure and properties of microcrystalline thermoplasts, permselective membranes, chemisorption on semiconductors, fluid transport in microporous solids, crystal growth kinetics, and wetting processes. Collaboration between Chemical Engineering and many other departments in the supervision of these research projects brings an interdisciplinary approach to the entire program.

For students with strong interest in materials and an adequate background in chemistry or chemical engineering, the Department offers special graduate curricula leading to the degrees of Materials Engineer and Doctor of Science or Doctor of Philosophy. These curricula are designed to provide a properly integrated background in the science and engineering of the major classes of materials (metals, ceramics, and polymers) and also to specialize in some depth in a selected area of the field. Specific graduate programs are suggested by, and subject to the approval of, an interdepartmental committee on materials engineering. Further details may be obtained by consulting the Department Graduate Registration Officer.

ENVIRONMENTAL ENGINEERING

Most processes which generate pollutants are chemical in nature. A broad chemical engineering background therefore provides an excellent preparation for attacking many aspects of environmental engineering. Problems in air and water pollution control and in solid waste disposal can be analyzed and modified by applying chemical engineering fundamentals. Furthermore, the versatility of the chemical engineer — in terms of his understanding of both chemical and physical aspects of engineering — makes him particularly well-qualified to handle the more complex interrelationships which are part of the broader environmental problems.

In addition to graduate courses in thermodynamics, industrial chemistry, and transport phenomena, students interested in pursuing graduate programs in environmental engineering are encouraged to take some additional courses in process design, kinetics, catalysis, combustion, and separation processes. Specific courses in environmental problem areas include 10.72, Seminar in Air Pollution Control; 10.39, Principles of Combustion and Air Pollution; the Environmental Projects Laboratory course; as well as courses in water resources (civil engineering), mesometeorology (meteorology), microbiology (biology) and biochemical engineering (nutrition and food science). The Department also offers a number of research assistantships and thesis topics in air pollution, water pollution, and solid waste disposal (contact Department for current listing).

FUEL ENGINEERING

Among all the chemical reactions, combustion is the one most widely used — in chemical synthesis, chemical and metallurgical processing, and power production. An integrated program in this field would typically include subjects in heat, momentum and mass transfer, thermodynamics, kinetics, combustion, radiation, a seminar in combustion, and a research problem in fuel processing or combustion. The Department's Fuels Research Laboratory provides excellent facilities for research on a wide range of problems, from small-scale studies of fuel processing or combustion kinetics to research in high-output combustion in rockets, ramjets, and gas turbines requiring use of the Laboratory's 2,000 kw compressors to simulate altitudes to 80,000 feet and flight Mach numbers to 2.5.

Subjects commonly taken are:

CHEMICAL ENGINEERING THERMODYNAMICS (10.40)
MECHANICS OF FLUIDS (10.52)
CHEMICAL ENGINEERING KINETICS (10.65)
PRINCIPLES OF COMBUSTION (10.70)
SEMINAR IN AIR POLLUTION CONTROL (10.72)
RADIATIVE TRANSFER (10.74)

SCHOOL OF CHEMICAL ENGINEERING PRACTICE

In the School of Chemical Engineering Practice, selected groups of graduate students spend a term at two field stations located at the American Cyanamid Company plant in Bound Brook, New Jersey, and the Oak Ridge National Laboratory of the Atomic Energy Commission, in Oak Ridge, Tennessee. At each field station, the student groups operate under the direction of two members of the Institute staff. The

facilities of the plant constitute their laboratory. The program's chief objective is to develop students' ability to apply theory to practical engineering accomplishment. Staff guidance emphasizes resourcefulness and effectiveness in cooperative effort under industrial conditions.

Quantitative aspects of chemical engineering are intensively studied in the Practice School. Plant investigations are carried out by the students on special phases of unit operations and on problems of industrial chemistry. Oral and written presentation of plans, results, and recommendations for action are stressed.

Bachelor's graduates of this Department ordinarily meet the requirements for the S.M. degree in Chemical Engineering Practice (Course X-A) in two terms. Starting in the September following graduation, students are at the field stations until the end of January, and then return to the Institute to complete the program for the Master's degree during the spring term. Practice School experience (10.82 and 10.83; or 10.86 and 10.87) may be substituted for the S.M. thesis in Course X. A similar Practice School field program starts in February and extends to early June.

For students who have graduated in chemical engineering from other institutions, the usual program of study for the Master's degree in Chemical Engineering Practice involves one or two terms at the Institute followed by the field station work in the Practice School. Graduates in chemistry from other institutions normally require an additional term. Students are usually not admitted to the Practice School until they have spent at least one term at the Institute.

Department of Civil Engineering

Creating the complex systems of constructed facilities required to meet such public and private objectives as economic development, environmental protection, and quality of life is the purpose of civil engineering. Billions of dollars are invested each year by governments and industries throughout the world to meet the rapidly expanding demand for facilities for transportation, communication, energy, defense, water resource utilization, urban development, housing, recreation, manufacturing, etc. Civil engineering has long been the principal instrument for focusing man's scientific and technological skills on these problems and for bringing together the necessary teams of engineering, architectural, and managerial specialists. It has become clear, however, that significant progress toward meeting the stated objectives in the face of society's rapidly expanding complexity and changing values requires not only excellent technology but also an awareness and consideration of a whole fabric of social, political, economic, and institutional constraints leading to the identification of a range of feasible alternatives and criteria for their evaluation. This suggests expanded future roles for the civil engineer wherein he will be increasingly responsible for the design and evaluation of entire systems of facilities — systems which in addition to performing their particular function serve the broader interests of society as well.

Reflecting this expanded professional challenge, the undergraduate program of the Department of Civil Engineering is designed to balance the problem-formulation and problem-solving needs for a broad range of careers. The core of the program is designed to provide first, an overall appreciation for the issues and structure of civil engineering problems and for the skills required to achieve solutions, and second, the fundamental methods for formulating, solving, and evaluating problems of physical behavior and of complex system performance. The program then promotes the study of an applications area in some depth, as much for the self-discipline and self-confidence to be gained from thoroughness of understanding as for the particular knowledge itself.

At the graduate level, research and education go hand-in-hand. Recognizing the continuing demand for pioneering technology while responding to the new need for an understanding of broad interactions, we provide two basic tracks. The student may be interested in physical processes or in the analysis and design of component facilities and hence will work in a fundamental area such as soil, water, structures, or materials. On the other hand, he may study the planning, design, and operation of large scale systems of facilities in fields such as transportation, water resources, and other public services, including their interaction with their physical and social environment.

Both the educational and research programs are supported by extensive experimental and computational facilities. Access to the facilities of other groups within the Institute further extends this capability. In all such activities, both undergraduate and graduate students participate to the fullest degree, working together with faculty who are widely known for their engineering accomplishments.

FACILITIES AND SPECIAL PROGRAMS

Educational and research facilities and special programs within the Department are described below.

LABORATORIES

The *Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics* was dedicated in October, 1970, as a major unit for research in the water environment. It contains more than 40,000 square feet of classrooms, laboratories, shops, computer facilities, and offices. A large collection of literature in this field is also available for reference. The experimental equipment includes numerous tanks, channels, and basins for the study of waves, tides, and currents on coastlines and in estuaries, for investigations in sediment transport and water quality control. Specialized equipment exists for the study of cavitation, hydro-elastic vibrations, turbulence, stratified flows, thermal pollution, dispersion in porous media, surface runoff, and many other phenomena of vital importance in water resources engineering. In addition, the Labora-

tory provides extensive supporting facilities for instrument development and calibration, for data recording, reduction, and analysis.

The *Soil Research Laboratory* conducts applied and fundamental research on the engineering properties of soil and rock. Areas of concentration are earthquake engineering, behavior of jointed rock, fabric of clays, frost action, soil stabilization, stress-strain behavior of clays, lunar soil mechanics, and the measurement of soil properties for a variety of field projects involving buildings on the M.I.T. campus, braced subway excavations, highway embankments and earth dams. A data acquisition system serves the experimental facilities, which include plane strain and high pressure triaxial apparatus, controlled loading consolidation cells, freezing units, X-ray diffraction apparatus, and equipment for dynamic testing. A models laboratory investigates the bearing capacity of cohesive soils, soil structure interaction during earthquakes, and provides students with models of earthdams and retaining walls. New field measurement devices and improved methods of field data acquisition and processing are being developed.

The *Structures Laboratory* is an educational facility for the study of the behavior of structural elements and structural systems. The laboratory assists the student in relating theoretical predictions to actual response, and in visualizing the behavior of complex systems.

The *Materials Research Laboratory* staff includes civil, chemical, and mechanical engineers, metallurgists, and electronics specialists; its mission is research on materials which are useful to the practice of civil engineering. Among the latter are concrete and cementitious compounds, metallic reinforcements, metals, natural and synthetic polymers, glasses, asphalt and bituminous materials, wood, and various composites containing combinations of these. The research programs are directed toward understanding of composition-structure-property relationships, the control of properties for enhanced usefulness, and the experimental measurement of properties to facilitate best engineering design. As a consequence, considerable and varied equipment for the production, fabrication, and evaluation of materials is available, with new apparatus continually being developed. Cooperation exists with other similar groups in the Institute.

The *Civil Engineering Systems Laboratory* (CESL) is primarily concerned with the analysis and design of large-scale, integrated civil engineering facilities and public services. CESL is founded on the proposition that computers represent a technological change which, by increasing the engineer's ability to manipulate data by several orders of magnitude, will lead to fundamental alterations in the way engineering is carried out. Research and instruction is directed toward the application of the most modern computer-based analytic, design, and management techniques to civil engineering systems.

CESL is widely recognized for the development of the Integrated Civil Engineering System (ICES), a set of problem-oriented languages in the several fields of civil engineering. This computer system, like the earlier CESL efforts COGO and STRESS, has been adopted by about 1,000 engineering offices throughout the world.

Faculty and students associated with CESL are now jointly attempting to develop a common understanding of how the many systems analysis techniques made practical by the computer should be fitted into the design process. Specific areas of emphasis are: probabilistic methods, optimization techniques, and multi-dimensional evaluation procedures. As part of its research with the future shape of the design process, CESL is also concerned with how information generated in the distinct design phases (planning, analysis, design, construction, management) can be shared using the computer as an integrating mechanism.

CESL maintains a high level of computer capabilities through its research and educational program. The laboratory itself has a medium-size computer facility with a 16K IBM 1130 surrounded by a high speed printer, an Intercomp disk drive, plotter, and an ARDS storage tube graphics device. CESL also supports terminals which have access to M.I.T.'s time sharing IBM 360/67 and the GE Multics system.

INTERDISCIPLINARY PROGRAMS

As new problem areas emerge, they increasingly fail to fall within the traditional interest area of a single academic department at M.I.T. The Department of Civil Engineering is responding to this situation in two ways.

First, we have broadened the interest and capability within the Department by adding faculty with training and professional experience in law, management, economics, political science, and sociology as well as in mechanical and electrical engineering and in geology. Accordingly, we have developed departmental research

and subject offerings in many interdisciplinary areas of current and future importance such as environmental control, public service systems, urban engineering, engineering and public policy, project evaluation, and management. Undergraduates and graduate students build educational programs in these and other areas either through use of the liberal elective provisions of the curricula leading to degrees designated as being in Civil Engineering or by formulating a special program leading to a degree without designation. In any case, the subjects chosen may be selected from among the offerings of all the Departments of the Institute, including Urban Planning, Architecture, Management, Mathematics, Economics, Political Science, the Life and Earth Sciences, and the other fields of engineering.

A second mechanism exists for addressing interdisciplinary problems at the graduate level and consists of programs administered by special and standing interdepartmental committees. Those of particular interest to students from civil engineering are in environmental engineering, transportation, materials, applied earth sciences, operations research, computers and information systems, ocean engineering, public systems, construction management, and the social applications of technology.

In short, each student's educational and research program may be explicitly arranged to best reflect his personal motives and professional goals, whether they are intensive or extensive in nature.

THE INTER-AMERICAN PROGRAM IN CIVIL ENGINEERING

In cooperation with selected universities in Latin America, research programs on civil engineering problems are performed by small groups composed of M.I.T. and Latin American faculty and students; both undergraduate and graduate students of the Department may be eligible to participate in these activities. Each project extends over an appreciable time interval, thus affording opportunities for location field studies in Latin America where the social, economic, political, and technical factors involved in the problems may be observed. Experimental work, model studies, design evaluations, and other research activities are performed at the Institute, where the entire group is located during the major portion of the project.

The projects studied may be characterized as ones profiting from the use of modern technology and new scientific information in a research manner. The results of the work are presented in seminars in Latin America, to which interested local groups are invited.

THE UNDERGRADUATE PROGRAM
Civil Engineering (Course I)

The Department of Civil Engineering offers two undergraduate curricula for students seeking a strong base for careers in civil engineering or related fields. The first curriculum, which leads to the degree of Bachelor of Science in Civil Engineering, is designed for students having educational goals which fall substantially within the scope of civil engineering. The second curriculum, which leads to the degree of Bachelor of Science is designed for students having another well-defined educational goal, the attainment of which requires a specially formulated program of study.

Each of these curricula provides sufficient flexibility to permit each student to develop his own special interests either within the Department or through subjects offered by other departments. Undergraduates are encouraged to participate in the research and development activities of the Department and in many cases can obtain degree credit for such work.

Often there are academic advantages to planning programs for the third and fourth years so as to dovetail with possible graduate study. This is readily accomplished for those students who embark on the Departmental program in their second year. In addition, selected students may be admitted to a special program permitting them to work simultaneously toward undergraduate and graduate degrees. The undergraduate degree will be awarded upon completion of the requirements for that degree.

With the exception of two subjects in basic physics and mathematics, all core subjects are taught by faculty of the Department using examples drawn from their own experiences. However, the subjects in mechanics, materials, geology, and mathematics are compatible and, when necessary, interchangeable with corresponding subjects offered by other departments.

THE DEGREE: BACHELOR OF SCIENCE IN CIVIL ENGINEERING

It is the objective of this curriculum to help the student develop problem-solving and decision-making abilities within the framework of civil engineering problems. It aims to provide him with the basic techniques for exercising these abilities and with a useful knowledge of one area

Engineering

DEPARTMENT OF CIVIL ENGINEERING

of civil engineering in depth while at the same time understanding the interrelationship of the various disciplines which contribute to the profession. The five-subject core of this curriculum begins with an introduction to the issues, problems, methods, and personalities of civil engineering and then builds a foundation of applied mechanics, applied probability, economic analysis, and systems engineering. In doing so it stresses the common nature of their application to problems from across the breadth of the profession. The core is followed by a set of planned electives designed to provide the student with useful knowledge of some particular area of civil engineering in depth and also to give an appreciation for the role of related disciplines.

CURRICULUM FOR S.B. DEGREE IN CIVIL ENGINEERING

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				132[1]
	The Science Distribution Requirement will be satisfied by 1.11, which is required in the Departmental Program, plus appropriate subjects totaling[2]				24
	Laboratory Requirement[3]				12
DEPARTMENTAL PROGRAM					
	Required Subjects				
1.07	ANALYSIS OF UNCERTAINTY	3	1	8	
1.11	ENGINEERING SYSTEMS ANALYSIS	3	3	6	
1.12	CIVIL ENGINEERING	4	0	8	
1.13	BEHAVIOR OF PHYSICAL SYSTEMS	3	3	6	
1.14	ECONOMICS FOR ENGINEERS	3	0	9	
					60
	Planned Electives				
	Primary Program A coherent selection of three subjects within one of the following areas: Structural Systems, Building Systems, Engineering Mechanics, Geotechnical Engineering, Materials of Construction, Transportation Systems, and Water Resources Systems.				at least 33
	Secondary Program At least two subjects, chosen from among those offered by the Department of Civil Engineering, which add breadth to the overall program.				at least 18
					51
	Unrestricted Electives[4]				up to 81
Total units for the S.B. degree					360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] This requirement is to be fulfilled by taking, in addition to 1.11, one mathematics and one physical science subject offered by a department other than Civil Engineering.
[3] 1.10 CIVIL ENGINEERING LABORATORY is recommended but not required.
[4] Credit for the Unrestricted Electives must total at least 36 units.

THE DEGREE: BACHELOR OF SCIENCE

This curriculum is provided for those students with a general interest in the objectives of civil engineering but whose specific and clearly defined educational goal cannot be achieved by following the requirements for the degree Bachelor of Science in Civil Engineering. The core of the program is identical with that required for the Bachelor of Science in Civil Engineering but the planned electives are not constrained to a presently identified subdiscipline of civil engineering. Under this program, students interested in urban affairs, environmental control, project management, public systems, etc. may develop sequences of planned electives including subjects from within and without the Department.

A student desiring to enter this program must first define his educational objective, and then, through conversations with members of the faculty, find a professor in the department with similar interests, to be designated as his Program Advisor, who will agree to assist the student in outlining a curriculum and will endorse it as a recommendation for departmental approval.

CURRICULUM FOR S.B. DEGREE

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				132[1]
	The Science Distribution Requirement will be satisfied by 1.11, which is required in the Departmental Program, plus appropriate subjects totaling[2]				24
	Laboratory Requirement[3]				12
DEPARTMENTAL PROGRAM					
	Required Subjects				
1.07	ANALYSIS OF UNCERTAINTY	3	1	8	
1.11	ENGINEERING SYSTEMS ANALYSIS	3	3	6	
1.12	CIVIL ENGINEERING	4	0	8	
1.13	BEHAVIOR OF PHYSICAL SYSTEMS	3	3	6	
1.14	ECONOMICS FOR ENGINEERS	3	0	9	
					60
	Planned Electives				
	At least seven subjects, three of which are offered by the Department of Civil Engineering, which will lead to a well-defined educational goal.				at least 72
	Unrestricted Electives[4]				60
Total units required for the S.B. degree					360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] This requirement is to be fulfilled by taking, in addition to 1.11, one mathematics and one physical science subject offered by a department other than Civil Engineering.
[3] 1.10 CIVIL ENGINEERING LABORATORY is recommended but not required.
[4] Credit for the Unrestricted Electives must total at least 36 units.

ELECTIVE SUBJECTS

Undergraduate elective subjects offered by the Department include the following:

1.00	INFORMATION SYSTEMS	3	3	6
1.02	ENGINEERING MATERIALS	3	3	6
1.03	ENGINEERING ANALYSIS	4	0	8
1.05	FLUID DYNAMICS	3	3	6
1.06	SOIL MECHANICS	3	3	6
1.08	GEOTECHNOLOGY	3	3	6
1.09	CIVIL ENGINEERING	0	6	12
1.10	CIVIL ENGINEERING LABORATORY	0	6	6
1.20	TRANSPORTATION LABORATORY	2	6	4
1.21	TRANSPORTATION SYSTEMS PLANNING AND DESIGN	4	0	8
1.40	INTRODUCTION TO ELECTRON MICROSCOPY	1	3	2
1.501	INTRODUCTION TO STRUCTURAL ENGINEERING	3	3	6
1.502	STRUCTURAL ANALYSIS AND DESIGN	3	2	7
1.503	ENGINEERING MECHANICS	4	0	8
1.60	INTRODUCTION TO WATER RESOURCES	3	0	6
1.991	SPECIAL STUDIES IN CIVIL ENGINEERING	*Arr.*		
1.998	SPECIAL STUDIES IN CIVIL ENGINEERING	*Arr.*		
1.999	SPECIAL STUDIES IN CIVIL ENGINEERING	*Arr.*		

By the fourth year, students will have the prerequisites for a variety of graduate subjects offered by the Department. Descriptions of typical sequences of subjects in these areas may be obtained from Faculty Counselors.

Students wishing to work closely with a faculty member in his research may obtain permission to register for thesis or to enroll in SPECIAL STUDIES IN CIVIL ENGINEERING (1.999).

Students are encouraged to consider appropriate subjects offered by other departments as part of their elective programs.

GRADUATE STUDY IN CIVIL ENGINEERING

The Graduate Degrees

The Department grants the following advanced degrees:

Master of Science in Civil Engineering
Civil Engineer
Materials Engineer
Doctor of Science
Doctor of Philosophy

The general requirements for the various degrees are indicated in Section 3.

Entrance Requirements for Graduate Study

In addition to the admission requirements noted in Section 8, applicants must present evidence of appropriate training for graduate study in the areas of their interest, though this preparation need not have been in Civil Engineering. Increasing opportunities exist for those having non-traditional backgrounds to continue their education at the graduate level in Civil Engineering. This has come about partly through a broadening of concerns within the Department and partly through the growth of interdepartmental research and degree programs which are bringing people of diverse backgrounds together in search of solutions to the major problems of our society. For example, where decisions on project justification were once made solely on the basis of economic efficiency as determined by benefit-cost analysis, ways are now being sought to incorporate into the decision making the values of the affected community and the impacts of the project upon environmental quality. This creates the need for professionals with training in the social sciences as well as engineering on the one hand, and in the physical sciences as well as engineering on the other hand. Consequently, we are finding it increasingly necessary and desirable to bring into our civil engineering community at M.I.T. graduate students and faculty having prior education and experience in such diverse fields as economics, political science, sociology, architecture, urban and regional planning, management, biology, geology, oceanography, etc. The primary requirement is for a basic capability and interest in quantitative approaches to real problems. Normally students may make up deficiencies in prerequisites for graduate subjects while pursuing a program of graduate work; prerequisite subjects are indicated with the description of each subject in this Catalogue.

Fields of Advanced Study

The Department has integrated programs for graduate study in the following areas: environment control, water resources and hydrodynamics, soil mechanics and foundation engineering, materials, structural engineering and building systems, construction and project management, transportation systems, urban systems, engineering public systems, civil engineering systems. Each of these is described briefly below. For major fields for doctoral theses, students should refer to the Civil Engineering list in Section 3 of this Catalogue. Fields other than those listed must be approved by the Department Graduate Registration Officer and by the Dean of the Graduate School.

ENVIRONMENT CONTROL

In recent years recognition has grown rapidly that man's very survival on this planet is threatened by population growth, air and water pollution, and resource depletion. It is necessary that we understand the dimensions of these problems and the extent to which technology

and changes in social attitudes may contribute to their solution.

Efforts are directed toward identification of the major threats, public policy formulation and examination of the technological, legal, economic, and managerial methods for implementation of these policies.

WATER RESOURCES AND HYDRODYNAMICS

The educational and research program is centered on four major areas of engineering in the water environment: (1) theoretical and experimental studies of the physical processes governing the occurrence, distribution, quality, and movement of water in the environment; (2) analysis of the hydraulic behavior of individual and interconnected elements in constructed water facilities; (3) mathematical simulation of physical systems to study the behavior, operation, and management of existing or proposed engineering works; and (4) water resource planning and management with multiple objectives, multiple alternatives, and chance.

Basic applications of fluid mechanics and of systems engineering are involved in hydraulic engineering, water quality control, coastal and ocean engineering, hydrologic analysis, and the planning of water resource systems.

The educational and research program is designed to accommodate a broad range of interests and backgrounds. For example, the objective may be the development of a mathematical model for the simulation of a physical system or such a model may be the beginning of work in water resource planning, optimization, and decision making. Students in the area of water resources and environmental problems may have backgrounds in the biochemical or geophysical sciences, mathematics, economics, as well as in civil or other branches of engineering.

Extensive research activities in the Ralph M. Parsons Laboratory for Water Resources and Hydrodynamics are closely coupled with the educational program. Within the hydrodynamics area the major interests center on studies in turbulence and boundary resistance, free surface flow, wave motion, tidal dynamics in estuaries and embayments, flows with density stratification, diffusion and mixing processes, sediment transport, and flow in porous media.

The planning and development of water resources is based on the analysis and synthesis of hydrologic and hydraulic systems and the integration of physical, economic, and social factors. Emphasis is placed on case studies and opportunities are provided for experience in water resource planning studies for various parts of the world.

Within the area of water quality management and control, a major concern is with the development of water quality simulation models for lakes, reservoirs, rivers, estuaries, and coastal regions. The objectives are to combine the hydrodynamic aspects of fluid transport processes with the chemical and biological aspects of the ecological system.

The research program now active, as in the recent past, includes the following topics: evaluation of precipitation measuring systems; evaluation of physical scale modeling of surface runoff; optimum linear synthesis of urban runoff; error analysis of mathematical models of surface runoff and streamflow; problem oriented computer languages for hydrology and hydraulic engineering; non-linear shallow water waves on uneven bottoms; wave scattering by large objects; wave shoaling, breaking, stability, mass transport in inshore and foreshore zones; effects of topography on storm or earthquake generated waves; mechanics of water-wave transmission past breakwaters; containment and collection of oil spills on the seas; mechanics of transport of suspended sediment; determination of sediment concentration by laser techniques; interaction of turbulent flow with porous boundaries; Hele-Shaw model study of the Long Island ground water system; effects of density stratification on mixing in aquifers; prediction and control of temperature distribution due to heated effluents from thermal power stations; thermal stratification and reservoir water quality; dispersion of wastes due to tidal motion and salinity intrusion in estuaries; tidal, salinity, and sedimentation problems in Lake Maracaibo Channel, Venezuela; water resource planning for new communities; planning for capacity expansion of water distribution systems; testing of new standards for economic evaluation of water resource projects; planning models for the development of water resources in the Republic of Argentina; management aspects of thermal pollution control; mathematical modeling of estuarine water quality.

Interdepartmental programs in Ocean Engineering may be arranged through the Department of Civil Engineering.

Subjects in the chemistry and biology of water may be taken through cross-registration in the Department of Environmental Science and Engineering at Harvard University.

SOIL MECHANICS AND FOUNDATION ENGINEERING

The civil engineer uses soil as a foundation material for a wide variety of structures, such as buildings, bridges, pavements, and retaining walls, and also uses it as a construction material for embankments, dams, roads, canal linings, etc. The graduate program in soils emphasizes the development and evaluation of techniques for practical design and for incorporating foundation considerations into the planning phase of overall project development. It is supported by major efforts in the analysis of deformation, stability, and flow problems, the measurement of the engineering properties of soil in the field and laboratory, and the measurement and evaluation of the field performance of structures during and after construction.

In addition to the comprehensive treatment of theoretical soil mechanics, soil properties, earth dams and foundations, there are advanced subjects in soil dynamics engineering geology, rock mechanics and soil stabilization. These subjects, together with thesis research and other studies utilizing the unique laboratory and field facilities of the Department, offer students excellent opportunities to work closely with the faculty in the study of such problems as the behavior of levees and embankments on soft ground; the behavior of deep braced cuts; the measurement and analysis of foundations of buildings on the M.I.T. campus; the use of theoretical and computer techniques to solve stress distribution, deformation, stability, and flow problems; soil stabilization; the effect of local soil conditions upon earthquake ground motions; the behavior of jointed rock masses; frost action; and the effects of stress systems on the strength and creep characteristics of soft clays.

MATERIALS

Civil engineers are the largest users of materials in any area of technology and the entire field of structural materials is undergoing rapid changes at the present time. These two facts impart unique characteristics to our teaching and research programs related to materials. On the one hand, the origin of properties, in terms of composition and internal structure, must be clearly understood. Equally important is the ability to utilize these properties effectively, economically, and imaginatively, to fulfill engineering needs. The property-composition-internal-structure relationships are treated in a number of fundamental subjects, some of which deal with broad classes or families of materials to illustrate the principles involved. Related to these subjects are research programs employing basic techniques and tools such as optical and electron microscopy, X-ray diffraction, single crystal studies and microstructural examinations; students acquire operational skill with the latter both through their subject work and in their research activities.

The application of materials to civil engineering needs, in a rational and quantitative fashion, represents the second main component of our effort. In this area are found subjects and research dealing with structural composites, fracture mechanics, viscoelasticity and rheology, mechanics of materials, and the mechanical behavior of metals. Again, considerable reinforcement between teaching and research takes place and the most modern testing and computational equipment and techniques are employed.

Students are also given opportunity to pursue studies in materials engineering, under interdepartmental supervision, leading to the degrees of Materials Engineer or Doctor of Science or Doctor of Philosophy. There is no standard curriculum in this field, and each student arranges a program of study and research uniquely suited to his interests and professional goals.

STRUCTURAL ENGINEERING AND BUILDING SYSTEMS

Society, today more than ever, has a great demand for constructed facilities, particularly buildings. In some cases, such as nuclear power plants to meet the needs for new energy sources, the challenge is to devise new ways to provide functional and safe structures. Usually, however, the challenge is to reduce both the direct and indirect costs of the facilities. To meet these challenges will require engineers who are prepared to improve design practice in the face of changing needs and values and to better integrate structural design into total project planning.

The educational program in structural engineering is based upon study of the fundamentals of structural mechanics, analysis of structural systems, and structural planning and design. Advanced areas of study include application of finite element techniques, computer systems for

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structural design, and engineering for earthquake and wind loadings. The program also includes study of optimization, reliability, and information flow in the total planning-design-construction process.

The research program, in which students naturally become involved, is broadly aimed at development of (1) rational methods of analysis of the total building system, (2) improved procedures for management of the total process, including information processing, (3) better criteria for performance of the system with regard to building function as well as structure, and (4) new uses of materials, structural systems, and construction techniques.

Specific research projects now underway include: optimization methods for the design of urban housing, study of wind-induced building motion, optimum seismic protection for new building construction in eastern metropolitan areas, seismic risk analysis, statistically-based serviceability criteria for building design, computer-aided structural design in a time-sharing environment, development of an evaluation program for proposed building systems, and transfer of information within and beyond the design phase of building projects.

CONSTRUCTION AND PROJECT MANAGEMENT

Integrated management of the total process by which facilities are created, from conception of need through planning, finance, design, construction and operation, is becoming increasingly important in reducing the time and cost of facilities. Current research is exploring the mechanisms for implementing this integration in the housing industry.

Other major research projects in the Department are centered around the construction and post-construction phases of this process. The approach is to predict some aspect of the performance of a structure on the basis of theory, and laboratory or field tests; instrument the structure; observe its behavior during and after construction; and evaluate the performance of the structure and the techniques used for predicting the performance. The students who work on these projects have the opportunity to learn firsthand about the problems of construction. The research leads to the improvement of old techniques or the development of new techniques of analysis, testing, and construction, and in this way not only advances the profession but has an immediate impact on the formal subjects taught in the Department.

TRANSPORTATION SYSTEMS

The essential focus of teaching and research in transportation is on systems planning, especially multimode systems. The program builds upon basic knowledge of the properties of transportation systems components, and the ability to analyze interactions among these components and between the transportation system and its environment. The basic approach is that of rational decision making about engineered systems, using where appropriate such techniques of systems analysis as economics, mathematical optimization, and computer models. Close relation to an extensive body of research supports and stimulates the academic program. Subjects of instruction offered include fundamentals of transportation systems, transportation systems analysis, transport systems design, urban transportation systems, flight transportation, traffic flow theory, decision theory, system simulations, mathematical programming, network flow, economic analysis, probabilistic analysis, and substantive applications to highway, air, rail, and sea transport. The Transportation Systems Division is a major participant in the work of the Civil Engineering Systems Laboratory, the Urban Systems Laboratory, the Commodity Transportation and Economic Development Laboratory, and the Flight Transportation Laboratory.

URBAN SYSTEMS ENGINEERING

A majority of civil engineering projects are located in metropolitan areas. Their design must therefore take into consideration not only the physical loads that will be imposed upon them, but also the strong interaction between these facilities and the complex economic and social forces of the urban environment.

Urban systems engineering applies modern computer-aided analytic techniques, tempered by an appreciation for relevant human issues, to the creative solution of urban civil engineering problems. The academic program thus integrates three complementary lines of study: methods of systems analysis, an application area such as transportation, construction or water resources, and the social, economic, and political aspects of the urban context.

Research in urban systems engineering is supported by the interdepartmental Urban Systems Laboratory and the Civil Engineering Systems Laboratory.

PUBLIC SYSTEMS

Research and education in public systems attempts to define how technology can be harnessed to serve the needs of public facilities. Particular emphasis is directed toward understanding how quantitative techniques can be used in the analysis and subsequent design of large-scale service systems such as mass transit, airports, and post office facilities.

Special attention is directed to the definition of the central issues, technical and ethical, in the application of technology. Subjects are offered in both the critical analysis of the applications of operations research and in the legal and political implications of alternative technological approaches to problems.

CIVIL ENGINEERING SYSTEMS

Advanced study and research in civil engineering systems focuses on the significant qualitative changes that are taking place in engineering practice. These result from technological advances brought about by computing systems which increase the engineer's ability to manipulate information by several orders of magnitude.

Particular attention is directed to the application of systems analysis techniques to the solution of large-scale civil engineering problems. A broad range of subjects in systems methodology is offered, which covers computer systems, optimization techniques and their use as a means to define areas of desirable design, probabilistic methods ranging from simulation to the analysis of stochastic systems and statistical inference for the development of systems models, and evaluation procedures including multidimensional analyses and decision theoretic approaches. In the belief that a full understanding of the strengths and limitations of tools and theory only come from the practice of learning how to mesh them with the structure of specific problems, each student is expected to focus his research and academic program on a particular application area such as transportation, water resources, building design, or public systems.

Current research focuses on the use of advanced techniques in the design of large projects such as the new billion dollar water supply system for New York City; the development of CARS, a new public transportation system; and the design of airport systems for major metropolitan areas.

Research Assistants

The research of the Department is an integral part of the study program, and approximately one hundred graduate students each year receive appointments as research assistants. In addition to the financial support so gained, such appointments provide valuable educational experience and outstanding thesis opportunities. Information about these appointments, and other forms of financial assistance, may be obtained by writing to the Head of the Department; but consideration for awards cannot be given before students have been assured of admission to the Graduate School.

Department of Electrical Engineering

Starting from a relatively modest beginning about one hundred years ago, the field of electrical engineering has become one of great variety and scope. Its products and services directly influence the daily living of most of the world's population. Its generators, motors, and other energy-processing devices provide the large quantities of inexpensive power needed in the industrialized and developing modern world. Its instruments for detecting, observing, and measuring electrical signals give it a unique role in supporting the advance of all other branches of science and engineering. Its conceptual models of detection, communication, and automatic control have influenced the development of such fields as economics, industrial management, psychology, and linguistics. Most recently its digital computers have revolutionized experimental techniques throughout the natural and behavioral sciences, engineering, and management and have provided models and tools for the study of the brain.

In a field with the rapid rate of change of modern electric technology, no one can describe with confidence the devices and systems of 15 years hence. However, it is certain that their development and understanding will require a firm grounding in the application of physics and mathematics to the design and analysis of "real" systems. "Real" systems include the obvious physical entities such as motors, transistors, lasers, etc. and the larger physical systems of which they are components: power systems, communication systems, computers, etc. "Real" systems that the engineer must deal with also include abstract entities such as data structures and information. The undergraduate curricula in Electrical Engineering are designed to provide the student with the intellectual tools and skills that will serve two purposes: 1) permit him to enter into professional work and 2) provide the basis for the continuous study and learning that marks the career of an engineer who leads his profession. In the undergraduate core curriculum, and in many of the subjects offered for graduate students, the emphasis is on the physical and mathematical principles and the techniques of applying them to real problems. In addition, however, elective subjects dealing with specialized techniques in a variety of fields are offered.

THE UNDERGRADUATE CURRICULA

There are four undergraduate programs in the Department of Electrical Engineering: two in Course VI (Program 1 — Electrical Engineering, and Program 3 — Computer Science and Engineering); and in Course VI-A, the cooperative versions of these two programs. The two VI-A programs permit the student to combine study with industrial engineering practice. In any program, a student who is admitted to graduate work may combine the Bachelor's and Master's thesis and receive the Bachelor of Science and the Master of Science degrees simultaneously at the end of five years of study. The common objective of all of these programs is to provide the intellectual and practical foundations on which can be based a large number of interesting careers.

Program 1 prepares students for industrial, teaching or research careers in electrical engineering or allied fields. Through a proper selection of elective subjects, they may get a good start in a specialized branch of electrical engineering or they may prepare themselves for graduate study in engineering or in such fields as physics, mathematics, industrial management, and the social sciences.

Program 1 requires two terms of mathematics and two terms of physics beyond the General Institute Requirements, introducing the student to differential equations, theory of functions of a complex variable, electricity and magnetism, and quantum mechanics. In this program the physics and mathematics background is used in a group of six core electrical engineering subjects in linear circuits, electronics, electromagnetic fields and waves, signal analysis and transform theory, and statistical mechanics and thermodynamics. These core subjects use lecture demonstrations, small sections, carefully developed homework assignments, and individual weekly conferences with each student to make sure that the points brought out in the homework are fully mastered.

Program 3 is designed to give students a background in the computer sciences and

related fields, upon which they may build careers in advanced computer systems development, in sophisticated applications of computers to technical or organizational problems, and in the further development of the computer sciences themselves. Although this program is not intended for students whose sole interest lies in the techniques and mechanics of programming or computer design, a selection of subjects from the curriculum may provide a good introduction to these areas for students majoring in other departments.

The curriculum of Program 3 has three major components. The first deals with the design and use of programming languages and computing systems. It includes the study of algorithms, information structures, and the organization of programs and information processing systems. The second component provides an introduction to the areas of mathematics that are most relevant to the computation and information sciences. It includes subjects in linear algebra, modern algebra, combinatorial analysis or probability, and mathematical models for computation. The third component is intended to provide the student with an introduction to a cohesive area of study outside of, but related to, the science and engineering of computation. It includes subjects in the theory of networks and systems. Other selections of subjects meeting the same objective can be arranged when appropriate.

For some students, especially those whose interests are centered on the hardware aspects of computation, a program of studies involving a combination of subjects from Programs 1 and 3 may be appropriate. Such combined programs should be arranged through the student's departmental Faculty Counselor.

The Electrical Engineering programs allow the student to take a considerable number of unrestricted elective subjects without overload. Students may use these as they see fit: they may take additional humanities subjects, science subjects, or use them to get a start in specialized branches of electrical engineering. To provide students with a chance to specialize in several of the current disciplines of electrical engineering, and to bring them into contact with current graduate research in these areas, sequences of electrical engineering electives have been developed.

The different engineering disciplines which students may enter through these elective sequences are: control, computer science, digital systems, electronic materials and devices, electromagnetics and dynamics, communications, bioengineering, and energy systems. Students should consult with their Faculty Counselors about these specialized elective sequences.

The Department of Electrical Engineering recommends that all undergraduates get some industrial experience during their program at M.I.T. There are two reasons for this recommendation. First, many aspects of the education of an engineer can be learned much more effectively and realistically on a job than by listening to lectures about them in the classroom. Second, most students get a great deal of pleasure from the discovery that the knowledge they have gained at M.I.T., which may have seemed rather abstract, does in fact help them to solve real and important engineering problems. This experience may be gained either through summer jobs or by participation in Course VI-A.

PRE-MEDICINE AND BIOMEDICAL ENGINEERING

Electrical Engineering provides an appropriate undergraduate preparation for certain types of careers in medicine and biomedical engineering. Although the Department has no formal curriculum in biomedical engineering, programs of study can be individually arranged within the regular curricula by combining subjects in the life sciences and chemistry offered by other departments with Departmental electives in such areas as speech and hearing, electrophysiology, sensory aids, and biomedical instrumentation. More detailed information is available through the Faculty Counselors or from Professor William M. Siebert, Room 20B-231. (Students with a specific interest in attending medical school should also consult Dean Emily L. Wick and the Premedical Advisory Committee.)

PROJECT STUDY

The Department of Electrical Engineering offers the opportunity for an undergraduate to develop a close working relationship with an active research group. A series of elective subjects, 6.852–6.858, Project Study, has been established for this purpose. A student enrolls by permission of an Electrical Engineering faculty member to join his research group. Grading is Pass-Fail, but continued registration is subject to the approval of the faculty member. It is

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expected that an undergraduate student entering a research group will participate in several ways: by independent study of the literature of that specialized field, by assisting graduate thesis students in their research work, by undertaking investigations or engineering design problems assigned to him, by assisting students who enter the group after him, or by project work which may extend over several terms under the supervision of an individual faculty member.

Electrical Engineering (Course VI)

PROGRAM 1. ELECTRICAL ENGINEERING

This program leads to the degree of Bachelor of Science in Electrical Engineering. The curriculum, consisting of a core of required subjects and a number of elective subjects, allows a student to prepare himself for an industrial career or for teaching or research.

Since the General Institute Requirements for Science Distribution subjects and Laboratory are met by the program, a total of 72 units of upperclass elective time is available which the student may use for a number of purposes. He may, for example, elect eight additional upperclass subjects in the humanities and social sciences. He may take a substantial minor program in industrial management. He may elect elementary foreign language subjects, as well as advanced subjects in physics, mathematics, and electrical engineering, to prepare for a future doctoral program. He may take electives in transistor electronics, communications, control, computer systems, probability, and instrumentation to prepare for a career in the engineering of large-scale systems. He may explore fields such as biology, psychology, and linguistics, to develop an understanding of communications in a context which includes both men and machines.

The curriculum requirements for the Electrical Engineering Program are listed below.

PROGRAM 1. ELECTRICAL ENGINEERING CURRICULUM (COURSE VI)

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				**132**[1]
	The subjects 6.01, 8.03, and 18.03 or 18.031, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.				
	Laboratory Requirement.				**12**
DEPARTMENTAL PROGRAM					
	Required Subjects[2]				
6.01	INTRODUCTORY NETWORK THEORY	4	0	8	
6.02	ELECTRONIC DEVICES AND CIRCUITS	4	0	8	
6.03	ELECTROMAGNETIC FIELDS AND ENERGY	4	0	8	
6.04	ELECTRODYNAMICS	4	0	8	
6.05	SIGNALS AND SYSTEMS	4	0	8	
6.08	STATISTICAL MECHANICS AND THERMODYNAMICS	4	0	8	
8.03	PHYSICS III	5	0	7	
8.211	INTRODUCTION TO QUANTUM PHYSICS	4	0	8	
18.075	[3]ADVANCED CALCULUS FOR ENGINEERS	3	0	9	
	[4]THESIS		12		
					120
	Restricted Electives				
	1. *Either*				
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
	or				
18.031	INTRODUCTION TO LINEAR ALGEBRA AND APPLICATIONS	3	0	9	
			12		
	2. *Departmental Laboratory* Subjects selected from the list below (in addition to the General Institute Laboratory Requirement)		12		
					24
6.215	[5]FEEDBACK CONTROL LABORATORY	Arr.			
6.272	DIGITAL SYSTEMS PROJECT LABORATORY	2	8	2	
6.274	ADVANCED DIGITAL SYSTEMS PROJECT LABORATORY	2	8	2	
6.70	ELECTRONIC COMPONENTS AND MEASUREMENTS	1	4	1	
6.702	BIOELECTRONICS PROJECT LABORATORY	2	8	2	
6.71	ELECTRONIC CIRCUITS AND SIGNALS LABORATORY	1	4	1	
6.711	DIGITAL SYSTEMS PROJECT LABORATORY	2	8	2	
6.712	ADVANCED BIOELECTRONICS PROJECT LABORATORY	2	8	2	
6.714	STROBE PROJECT LABORATORY	2	8	2	
6.715	POWER SYSTEMS PROJECT LABORATORY	2	8	2	
6.716	PARTICLE OPTICS PROJECT LABORATORY	2	8	2	
6.717	AUDIO FREQUENCY COMMUNICATIONS PROJECT LABORATORY	2	8	2	
6.718	PSYCHOACOUSTICS PROJECT LABORATORY	3	4	5	
6.719	MICROELECTRONICS PROJECT LABORATORY	2	8	2	
6.721	OPTICAL SEMICONDUCTOR DEVICES PROJECT LABORATORY	2	8	2	
6.722	MODERN OPTICS PROJECT LABORATORY	2	8	2	
6.723	IMAGE TRANSMISSION SYSTEMS PROJECT LABORATORY	0	12	0	
6.724	CONTROL SYSTEMS PROJECT LABORATORY	2	8	2	
6.81	[5]ELECTRICAL ENGINEERING LABORATORY	Arr.			
	Unrestricted Electives[6]				**72**
Total units required for the S.B. degree					**360**

[1] The Requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] Under special circumstances, substitution of subjects of similar content may be permitted by petition to the Department.

[3] Students are encouraged to consider alternate subjects in mathematics, subject to the approval of their faculty counselor.

[4] A thesis of at least 12 units is required. Up to 18 additional units of thesis may be used as elective. Students who continue studies for the S.M. degree and receive the S.M. and S.B. degrees simultaneously may substitute

12 units of additional elective for the undergraduate thesis.

[5] Registration in 6.215 or 6.81 must consist of at least 6 units in order to satisfy a part of the Departmental Laboratory Elective Requirement.

[6] Schedules of students in Course VI, Program 1, may always be arranged to leave available 12 units of unrestricted elective in the second year.

The above requirements are not rigid. Some variations are routinely permitted, while others are considered on an individual basis. Well-motivated substitutions of substantially equivalent subjects are usually approved. Students may request substantial changes in program which involve more than substitution in kind. Departmental approval will be granted in general only to well-prepared students, whose proposed programs are comparable to the curriculum listed above in breadth, depth, and integrated approach to a well-defined educational objective.

PROGRAM 3. COMPUTER SCIENCE AND ENGINEERING

This program of studies provides a foundation in the structure of computer systems and languages and the allied mathematics, and in the ideas of circuits, devices, and signals encountered in electrical systems. With this background, a student may enter into any of the rapidly evolving fields of activity based on the digital computer, such as computer system design, the design of programming languages and compilers, mathematical theories of computation, and artificial intelligence.

Program 3 leads to the degree of Bachelor of Science in Electrical Engineering. The curriculum requirements are listed below. Although they are intended to meet the needs of most students whose major interest lies in computers and computation, these requirements are not rigid. Well motivated substitutions of essentially equivalent subjects are normally approved. Substantial changes may also be approved provided they result in a program of comparable breadth and depth and serve a well-defined educational objective.

PROGRAM 3. COMPUTER SCIENCE AND ENGINEERING CURRICULUM (COURSE VI)

				Total units
GENERAL INSTITUTE REQUIREMENTS				
	Specific science and humanities and social science subjects.			**132**[1]
	The Science Distribution Requirement will be satisfied by 6.01 and 18.031, which are required in the Departmental Program, plus appropriate subjects totaling			**12**
	Laboratory Requirement.			**12**
DEPARTMENTAL PROGRAM[2]				
	Required Subjects[3]			
6.01	INTRODUCTORY NETWORK THEORY	4	0	8
6.05	SIGNALS AND SYSTEMS	4	0	8
6.232	COMPUTATION STRUCTURES	4	0	8
6.233	INFORMATION SYSTEMS	4	0	8
6.261	INTRODUCTION TO MODERN ALGEBRA	4	0	8
18.031	INTRODUCTION TO LINEAR ALGEBRA AND APPLICATIONS	3	0	9
	[4]THESIS		12	
				84
	Restricted Electives[5]			
	1. *Either*			
6.02	ELECTRONIC DEVICES AND CIRCUITS	4	0	8
	or			
6.212	SYSTEMS, NETWORKS, AND COMPUTATION	3	0	9
	2. *Either*			
6.251	DIGITAL COMPUTER PROGRAMMING SYSTEMS	3	2	7
	or			
6.252	STRUCTURE AND TRANSLATION OF COMPUTER LANGUAGES	4	1	7
	or			
	3. *Either*			
6.262	COMPUTABILITY, FORMAL SYSTEMS, AND LOGIC	4	0	8
	or			
6.253	THEORETICAL MODELS FOR COMPUTATION	3	0	9
	4. *Either*			
6.256	APPLICATIONS OF COMBINATORIAL MATHEMATICS	3	0	9
	or			
6.28	PROBABILISTIC SYSTEMS ANALYSIS	4	0	8
	or			
18.304	PROBABILITY AND STATISTICS	3	0	9
	5. Elective subject in either quantum physics or thermodynamics or biochemistry		12	
	6. *Department Laboratory* Subjects selected from the list of laboratory subjects given under Course VI, Program 1 (in addition to the General Institute Laboratory Requirement).		12	
				72
	Unrestricted Electives[6]			**48**
Total units required for the S.B. degree				**360**

[1] The requirement for Class '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] Subjects 6.02 or 6.212, 6.05, and 18.031 may, when appropriate, be replaced by a well formulated minor program in another area.

[3] Under special circumstances, substitution of subjects of similar content may be permitted by petition to the Department.

[4] A thesis of at least 12 units is required. Up to 18 additional units of thesis may be used as elective. Students who continue studies for the S.M. degree and receive the S.M. and S.B. degrees simultaneously may substitute 12 units of additional elective for the undergraduate thesis.

[5] Subjects (except 6.28) taken in partial fulfillment of the restricted elective requirement which appear on the list of Science Distribution Subjects (see page 21) can be used to fulfill part of the Science Distribution Requirement, providing corresponding units of additional unrestricted elective.

[6] Schedules of students in Course VI, Program 3, may always be arranged to leave available 12 units of unrestricted elective in the second year.

Electrical Engineering Cooperative Program (Course VI-A)

The VI-A Program is a cooperative program

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which provides the student with a way of gaining industrial and research experience concurrently with his studies, while helping to pay part of his educational expenses through his earnings. This is done through a series of organized work assignments interleaved with regular study at M.I.T. Students in the VI-A programs are likely to receive more professionally rewarding assignments than the typical summer job may provide, because of continuing liaison between each participating company and a professor in the Department. The students can also spend more time on the job because the subjects taken while on job assignments and the academic credit received for work experience help meet the degree requirements.

Second-year students in good standing in any of the programs of Course VI may apply for admission to the Course VI-A cooperative program. Applications for admission to the VI-A Program are made at the Course VI-A office, Room 4-205, early in the spring term. The Department cannot guarantee the acceptance of a student by one of the participating companies; however most, but not all, of the interested students are placed. The program terminates in the normal four years if the student leaves M.I.T. with a Bachelor of Science degree; if he is admitted to the Graduate School, the program continues through a fifth year. Admission to the Graduate School is based on the student's scholastic record and personal qualifications.

Course VI-A students who are admitted for graduate study at M.I.T. normally have four terms of industrial practice. Three industrial-practice terms are normally required during the undergraduate program. In special cases, however, where students plan to leave M.I.T. upon receipt of their Bachelor of Science degree, they may be permitted to omit the third practice term. On entering the VI-A Program, a student must agree to stay with one company through his Bachelor's and/or Master's degree.

Taken together, the participating companies cover substantially the entire spectrum of electrical technology and the electrical industry. Although a student is associated only with one company for his work, his work assignments are arranged to provide broad experience with the affairs and operating procedures of industry, and with the kinds of work in which engineers are engaged. The level of technical sophistication and responsibility at the company is kept in step with each student's growing technical competence as he advances in his academic program.

The industrial companies — such as the AVCO Corporation, General Electric Company, General Radio Company, Hewlett-Packard Co., Honeywell, Inc., International Business Machines Corporation, R.C.A., and Raytheon Company — provide experience in testing, design, development, and research in various areas of electronics, power, communications, control, and computation fields. The Bell Telephone Laboratories afford the opportunity for experience in the development of communication apparatus, circuits, and equipment for the Bell Telephone System. The Naval Ordnance Laboratory provides opportunities to work with people from many technical disciplines, brought together in a large laboratory concerned with basic and applied research in many fields.

While at the companies, students are subject to the usual company regulations. They receive regular financial compensation for their work. At the conclusion of the program, students are not obligated to accept employment with the company, nor is the company obligated to offer employment.

These VI-A programs lead to the degree of Bachelor of Science in Electrical Engineering for four years of study, and may lead to the degree of Master of Science in Electrical Engineering, awarded simultaneously with the Bachelor's degree at the end of the graduate year, if the student is admitted to the Graduate School. The curriculum requirements for the Bachelor of Science degree are given below.

PROGRAM 1. ELECTRICAL ENGINEERING CURRICULUM (COURSE VI-A)

		Total units
GENERAL INSTITUTE REQUIREMENTS		
	Specific science and humanities and social science subjects.	132[1]
	The subjects 6.01, 8.03, and 18.03 or 18.031, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.	
	Laboratory Requirement.	12

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	Required Subjects[2]			
6.01	INTRODUCTORY NETWORK THEORY	4	0	8
6.02	ELECTRONIC DEVICES AND CIRCUITS	4	0	8
6.03	ELECTROMAGNETIC FIELDS AND ENERGY	4	0	8
6.04	ELECTRODYNAMICS	4	0	8
6.05	SIGNALS AND SYSTEMS	4	0	8
6.08	STATISTICAL MECHANICS AND THERMODYNAMICS	4	0	8
8.03	PHYSICS III	5	0	7
8.211	INTRODUCTION TO QUANTUM PHYSICS	4	0	8

18.075	[3]ADVANCED CALCULUS FOR ENGINEERS	3	0	9	
	[4]THESIS		12		
	[5]INDUSTRIAL PRACTICE		18		
					138
	Restricted Electives				
	1. *Either*				
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
	or				
18.031	INTRODUCTION TO LINEAR ALGEBRA AND APPLICATIONS	3	0	9	
	2. *Departmental Laboratory* Subjects selected from the list of laboratory subjects given under Course VI, Program 1 (in addition to the General Institute Laboratory Requirement).		12		
					24
	Unrestricted Electives[6]				54
Total units required for the S.B. degree					360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Under special circumstances, substitution of subjects of similar content may be permitted by petition to the Department.
[3] Students are encouraged to consider alternate subjects in mathematics, subject to the approval of their faculty counselor.
[4] A thesis of at least 12 units is required. Up to 18 additional units of thesis may be used as elective. Students who continue studies for the S.M. degree and receive the S.M. and the S.B. degrees simultaneously may substitute 12 units of additional elective for the underduate thesis.
[5] Credit for Industrial Practice subjects is limited to a maximum of 27 units and a minimum of 18 units.
[6] Schedules of students in Course VI-A, Program 1, may always be arranged to leave available 12 units of unrestricted elective in the second year.

PROGRAM 3. COMPUTER SCIENCE AND ENGINEERING CURRICULUM (COURSE VI-A)

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				132[1]
	The Science Distribution Requirement will be satisfied by 6.01 and 18.031, which is required in the Departmental Program, plus appropriate subjects totaling				12
	Laboratory Requirement.				12
DEPARTMENTAL PROGRAM[2]					
	Required Subjects[3]				
6.01	INTRODUCTORY NETWORK THEORY	4	0	8	
6.05	SIGNALS AND SYSTEMS	4	0	8	
6.232	COMPUTATION STRUCTURES	4	0	8	
6.233	INFORMATION SYSTEMS	4	0	8	
6.261	INTRODUCTION TO MODERN ALGEBRA	4	0	8	
18.031	INTRODUCTION TO LINEAR ALGEBRA AND APPLICATIONS	3	0	9	
	[4]THESIS		12		
	[5]INDUSTRIAL PRACTICE		18		
					102
	Restricted Electives				
	Same as listed for Course VI, Program 3				72
	Unrestricted Electives[6]				36
Total units required for the S.B. degree					366

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Subjects 6.02 or 6.212, 6.05, and 18.031 may, when appropriate, be replaced by a well formulated minor program in another area.
[3] Under special circumstances, substitution of subjects of similar content may be permitted by petition to the Department.
[4] A thesis of at least 12 units is required. Up to 18 additional units of thesis may be used as elective. Students who continue studies for the S.M. degree and receive the S.M. and S.B. degrees simultaneously may substitute 12 units of additional elective for the undergraduate thesis.
[5] Credit for Industrial Practice subjects is limited to a maximum of 27 units and a minimum of 18 units.
[6] Schedules of students in Course VI-A, Program 3, may always be arranged to leave available 12 units of unrestricted elective in the second year.

GRADUATE STUDY IN ELECTRICAL ENGINEERING

The program of graduate education in the Department of Electrical Engineering has three aspects. First, a variety of classroom subjects in physics, mathematics, and fundamental fields of electrical engineering is offered to permit students to develop a strong theoretical background. Second, more specialized classroom and laboratory subjects and a wide variety of colloquia and seminars introduce the student to the problems of current interest in many fields of research, and to the techniques which may be useful in attacking them. Third, each candidate for any advanced degree conducts research under the direct supervision of a member of the Faculty and reports his results in a thesis.

Three advanced degree programs are offered. A well-prepared student can obtain his Master of Science degree in one calendar year, including completion of a course of formal studies and the presentation of a satisfactory thesis. Students who need more classroom subjects before entering on thesis work, or who want to carry out a more substantial research or teaching program while gaining further graduate experience, may choose to complete their theses by the end of a two-year program and receive the Electrical Engineer and the Master of Science degrees concurrently. The doctoral programs take about four years to complete. Doctoral candidates are expected to perform thesis research which is a significant contribution to knowledge and to participate in the educational program of the Department. Most doctoral students complete the Master of Science degree requirements in the course of their doctoral programs.

There are no fixed programs of study for these degrees. Each student plans his program in consultation with his Graduate Counselor, a member of the faculty whose professional field is related to the student's interest. As the pro-

gram moves towards thesis research, it usually centers in one of a number of areas, each characterized by an active research program. Areas of interest in the Department which have active research programs and related graduate subjects include:

Circuits and signals
Communication and probabilistic systems
Communications bio-engineering
Computer science
Electromagnetic theory and antennas
Energy conversion devices and systems
High-voltage radiation engineering
Materials and devices
Operations research
Stroboscopic photography and underwater sound
Systems science and control engineering

Besides the graduate subjects in Electrical Engineering, many students find it profitable to study subjects in other departments, such as Biology, Economics, Modern Languages and Linguistics, Management, Mathematics, Physics, and Psychology.

The informal seminar is an important mechanism for knitting together members of the various research groups. There are about 16 that meet every week. In these, graduate students, faculty, and visitors report their research in an atmosphere of free discussion and criticism. For the new graduate student, these open seminars are excellent places to learn about the various research activities in the Department.

Research laboratories of extraordinary range and strength are sponsored by the Department. The principle of close integration between regular graduate studies and these research laboratories has proven very effective, yielding educational values beyond those of formal study alone. The Department regards active research as a dominant influence in its graduate program, and each project is conceived and administered so that graduate students can and do have full opportunity to associate with it while retaining their scientific individuality and initiative. Some of the research projects are mentioned in the following paragraphs.

In the *Electronic Systems Laboratory* a program of research and development in control, computer technology and applications, and instrumentation is closely coupled with graduate study in these areas. Faculty, students and full-time staff are engaged in research on topics which include modern control theory; chemical-process control; high-speed vehicle control for ground and space environments; analytical and experimental studies of analog, digital, and analog-digital data-processing systems; logic design; the application of computers to electrical network and mechanical design; library information retrieval; research in man-machine communication devices and techniques for time-shared computers; research in computer programming; and electronic and microwave sensing systems for the measurement of physical quantities and for exploratory purposes in the aerospace environment. Taken together, these research efforts provide excellent educational opportunities in system and circuit analysis and in the application of modern computational tools, design techniques, and circuit devices to a variety of dynamical systems.

The *Research Laboratory of Electronics* provides a basic research environment with participation of faculty and students from a dozen academic departments. Since the formation of the Laboratory in 1945, as an outgrowth of the M.I.T. Radiation Laboratory, the research program has evolved and broadened. At present, the activities of the Laboratory fall into three principal categories. These are general physics, plasma dynamics, and communication sciences. Among the research activities in general physics are: microwave, optical, and infrared spectroscopy, radio astronomy, molecular beam studies, microwave electronics, and lasers and coherent optics. The research in plasma dynamics includes basic studies of plasma physics and gaseous electronics, as well as applications such as controlled fusion for energy conversion, ion propulsion, and microwave devices.

The research in communication sciences involves studies of both living and man-made systems. The major areas of interest in living systems include sensory physiology and neurophysiology, auditory psychophysics, speech communication, linguistics, sensory aids, image processing, and pattern recognition. Work is also under way on the application of these and other studies to medical problems. Studies of man-made communication systems include information processing and transmission, statistical communication theory, artificial intelligence, circuit theory, and computer research.

Both graduate and undergraduate students participate in the full range of activities mentioned above.

Project MAC is an interdepartmental research laboratory in the field of computer science and engineering. The main focus of its interests is

human use of computers: improving the interaction between men and computers in problem solving and decision making and the design and organization of computers and computational processes to facilitate such interaction. Active research areas include theory of computation, design of multi-access systems, computer networks, computer graphics, computer languages, organizational information systems, modeling and simulation, applications to programming and to mathematical research, and effects upon society of advances in computer technology.

The Continuum Electromechanics Group is concerned with the fundamental processes resulting from continuum electromechanical interactions and their engineering applications.

A group in the *High Voltage Research Laboratory* is concerned with the techniques of producing high-energy particles and radiation, and with their application to the needs of science, medicine, and industry.

A considerable segment of the departmental faculty is engaged in research in the area of solid-state science and engineering. Most of this work is carried on by groups affiliated with the *Center for Materials Science and Engineering*. *The Semiconductor Materials and Devices Groups* are concerned with problems which range from the fundamental physics of semiconductors to the engineering problems encountered in semiconductor device development and analysis, including some of those relating to integrated circuits and the allied use of computers. *The Microwave and Quantum Magnetics Group* is involved in the study of magnetism in relation to crystal structure, in the development of new magnetic materials, and in the utilization of these materials in high-frequency and microwave electromagnetic and acoustic devices. *The Mass Spectroscopy Group* is measuring electron ionization cross sections, studying charged particle optics, and developing new experimental techniques. The single crystals needed for much of the foregoing research are provided by a *Crystal Physics Group*, which has its own active research program concerned with problems of crystal growth and the study of crystal structure and crystal imperfections. *The Materials Theory Group* is concerned with the theoretical description of the electrical, optical, and transport properties of semiconductors. In addition, it deals with the basic aspects of magnetic materials and superconductors.

The *Electric Power Systems Engineering Laboratory* is studying a wide variety of problems pertinent to the generation and distribution of electrical energy. Some of the research projects are the use of an MHD instability for arc interruption, study of a superconducting field system for a high-power alternator, computer estimation of power network behavior based upon discrete (and incomplete) measurements, and prediction of subharmonic resonances in super-high-voltage transmission lines.

Financial Aid

Studies toward an advanced degree can be supported by personal funds, by an award such as the National Science Foundation Fellowship which the student brings with him to M.I.T., by a fellowship or traineeship awarded by M.I.T., or by a graduate assistantship. Assistantships require participation in research or teaching in the Department or in one of the associated laboratories. Assistants may register for up to 24 units of scheduled classroom and laboratory work and may receive additional academic credit for their participation in the teaching or research program. Many assistants spend two years in a program which leads to the simultaneous award of the Master of Science and the Electrical Engineer degrees, and the Department encourages assistants to pursue such programs.

A brochure on *Research and Graduate Study in Electrical Engineering at M.I.T.*, describing research and teaching opportunities in detail, may be obtained from the Department.

Entrance Requirements for Graduate Study

The general requirements for admission are set forth in Section 8 of this Catalogue. Because the undergraduate backgrounds of our applicants are so varied (electrical engineering, physics, mathematics, computer science, biomedical engineering, for example), no specific admissions requirements can be listed. The background of each such applicant will be studied carefully to see that he has the principal prerequisites deemed necessary for his probable graduate program. Applicants with non-electrical engineering backgrounds are encouraged to communicate directly with faculty members in their proposed area of study for advice and further details. In any case, superior achievement in undergraduate mathematics and physics is considered particularly important.

Every regular graduate student in electrical engineering is required to complete a written

examination in February of his first year of graduate study. This examination is designed to explore the student's undergraduate preparation in his principal areas of interest; it is intended primarily to help the student evaluate his preparation and to help the faculty counsel him with respect to his graduate program. Special examinations will be arranged for those for whom the regular examination is inappropriate.

The Graduate Degrees

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

The general requirements for the Master's degree are given in Section 3. The Department requires that the program include at least four formal graduate-level classroom and laboratory subjects.

Students working full time for the Master's degree can take as many as four classroom subjects per term. Students who have graduate assistantships can take as many as two classroom subjects in addition to their teaching or research assignments. The subjects are wholly elective and are not restricted to those given by the Department of Electrical Engineering; however, the program of study must be well balanced, emphasizing one or more of the theoretical or experimental aspects of electrical engineering. A research thesis is required.

All of the four undergraduate programs, previously described, may lead to the degrees of Bachelor of Science and Master of Science in Electrical Engineering, awarded simultaneously at the end of the graduate year.

ENGINEER DEGREE

Able students who desire more extensive training than is possible within the Master's degree program are encouraged to study for the Electrical Engineer degree. The course of studies for this degree is elective, and a thesis is required. The program ordinarily requires at least four terms of graduate study beyond the Bachelor's degree level.

The general requirements for the Engineer degree are given in Section 3. The Department also requires that the program include at least eight formal graduate-level classroom and laboratory subjects.

DOCTOR OF SCIENCE OR DOCTOR OF PHILOSOPHY

The general requirements for the Doctor's degree are given in Section 3.

Only students who have shown promise of performing truly creative work in either engineering or engineering science are encouraged to study for the Doctor's degree. Doctoral candidates are expected to perform thesis research which is a significant contribution to knowledge, and to participate in the educational program of the Department. Students entering on graduate work in the Department without significant research experience are usually required to qualify first for the Master's or Electrical Engineer degree; the quality of the thesis submitted for these degrees is a major component in the decision to admit a student to the doctoral program. For most students the written examination required of all electrical engineering graduate students during their first graduate year is acceptable as the written part of the General Examination.

Each candidate for the doctorate in electrical engineering must demonstrate intermediate competence in speaking and reading one modern foreign language.

A Minor is required by the Department, and must have departmental approval.

Department of Mechanical Engineering

Perhaps the broadest in scope of all the engineering fields, mechanical engineering is not identified with nor restricted to a particular technology, a particular vehicle, a particular device, or a particular system. It is in fact concerned with so many areas of modern technology that the tasks of the mechanical engineer are most interesting and varied.

We live in an era when technology is changing so rapidly that the education of an engineer must prepare him with a sound base for working in fields which perhaps do not even exist at the time he gets his degree. The greatest strength of the undergraduate curriculum in mechanical engineering, which combines a broad scientific training with project-oriented work in the laboratory and in design, is that it is ideally suited to the education of an engineer for the times in which we live.

The broad scope of mechanical engineering can best be exemplified by listing some of the areas in which active research is proceeding in the Department of Mechanical Engineering at the forefront of one or another technology. These research areas are listed within the three main divisions into which the Department is organized.

1. *Mechanics and Materials*
Continuum mechanics: elasticity, plasticity, rheology
Physics and mechanics of deformation and fracture in materials
Dynamics, vibrations, acoustics
Surface physics, wear, lubrication, friction
Manufacturing processes, machines, materials and systems
Fibers, polymers, textiles
Biomechanics
Biomaterials

2. *Thermal and Fluid Sciences*
Thermodynamics, kinetic theory, statistical mechanics
Heat transfer, mass transfer
Gas-surface interactions
Aero-acoustics
Fluid mechanics, plasma dynamics
Combustion
Re-entry physics
Cryogenics
Power generation and transmission
Biomedical fluid mechanics and heat transfer
Air and water pollution
Water desalination

3. *Systems and Design*
Modeling, analysis, synthesis and management of systems
Control system theory and design
Man-machine systems
Instrumentation and measurement systems
Electromechanics
Biomechanics
Neural surgery
Sensory aids and prostheses
Societal systems design: transportation, underdeveloped technologies, urban problems
Fluidics and fluid power control
Computer-aided engineering: computer graphics, information storage and retrieval
Power and propulsion systems

There can be only one firm foundation for a career as diverse and challenging as that faced by the mechanical engineer. Starting with mathematics, physics and chemistry, he must acquire some mastery in the engineering sciences: dynamics, materials, fluid dynamics, heat and mass transport, thermodynamics and statistical mechanics, systems analysis, and controls. With this he must experience the ways in which scientific knowledge can be put to use in the development and design of useful devices and processes. This is the art of engineering. To teach this art, largely by project-oriented work of creative nature, is the primary object of subjects in laboratory and design. Laboratory experience, which takes many forms, is intended to show how the experimental method is used in the solution of engineering problems. Design experience includes devising means to perform certain specified tasks, such as the design of a device or the synthesis of a system made up of parts having known characteristics.

A field of this width and diversification cannot be learned and mastered in all its details in four college years. The objective of our undergraduate program is to provide a broad intellectual horizon for the graduate and to inculcate such habits and skills of study that he will learn new science as it appears and take the initiative in applying it.

THE UNDERGRADUATE PROGRAMS

Two undergraduate programs are available, one leading to the degree of Bachelor of Science in Mechanical Engineering (Course II), the other to the degree of Bachelor of Science (Course II-A).

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

Mechanical Engineering (Course II)

The requirements for the degree, Bachelor of Science in Mechanical Engineering, have been selected to provide a balanced background in

Engineering

DEPARTMENT OF MECHANICAL ENGINEERING

mechanical engineering while allowing students who defer entering the Department until the end of the second year to graduate in the normal four-year period. Students with a satisfactory academic record who have averaged 45 units per term, who have met the General Institute Requirements in chemistry, mathematics, and physics, and who have also taken Differential Equations (18.03) can graduate in four years.

The core curriculum for the degree Bachelor of Science in Mechanical Engineering provides many alternatives for a student who enters the Department at the end of the first year. He may, for example, elect additional upperclass subjects in the humanities and social sciences. He may take a substantial minor program in industrial management. He may elect advanced subjects in physics, mathematics, and mechanical engineering, to prepare for future graduate work. He may arrange his electives so that, as early as possible, he can focus on professional subjects — in some relatively specific area, such as system dynamics and control. Or he may explore allied fields — for instance, biology, if he is interested in biomedical engineering.

The curriculum requirements for the Degree of Bachelor of Science in Mechanical Engineering are given below.

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				132[1]
	The subjects 2.01, 8.03, and 18.03, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.				
	The subjects 2.672 and 2.673, which are required in the Departmental Program, appear on the list of Laboratory Subjects and can be used to satisfy the Laboratory Requirement.				
DEPARTMENTAL PROGRAM					
	Required Subjects[2]				
2.01	MECHANICS OF SOLIDS	4	0	8	
2.02	INTRODUCTION TO SYSTEM DYNAMICS	3	1	8	
2.03	DYNAMICS	3	0	6	
2.201	FLUID MECHANICS	4	0	8	
2.30	MECHANICAL BEHAVIOR OF MATERIALS	3	2	4	
2.60	APPLIED THERMODYNAMICS AND HEAT TRANSFER	3	0	6	
2.672	EXPERIMENTAL ENGINEERING I	1	3	2	
2.673	EXPERIMENTAL ENGINEERING II	0	4	2	
2.70	[3]ENGINEERING SYNTHESIS AND DESIGN	2	3	4	
2.73	[3]ENGINEERING DESIGN	2	3	4	
2.86	[3]MANUFACTURING PROJECT LABORATORY	2	3	1	
8.03	PHYSICS III	5	0	7	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
	[4]THESIS		9		
					132
	Restricted Electives[2]				
	Materials				
	One of the following subjects:				
3.13	MATERIALS SCIENCE I	4	3	5	
3.141	SCIENCE OF MATERIALS	4	3	5	
	Thermodynamics				
	One of the following subjects:				
2.403	THERMODYNAMICS	4	0	8	
2.42	ELEMENTS OF CLASSICAL AND STATISTICAL THERMODYNAMICS	4	0	8	
					24
	Unrestricted Electives[5]				72
Total units required for the S.B. degree					360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] Substitution of subjects of similar content may be permitted by petition to the Department.

[3] 2.731 and 2.861 may be substituted for the three subjects 2.70, 2.73, and 2.86.

[4] To foster substantial research and design achievement, the Department permits up to 6 units of additional thesis credit, subject to approval of the student's Faculty Counselor.

[5] Schedules of students in Course II may always be arranged to leave available 24 units of unrestricted elective in the second year.

RECOMMENDED ELECTIVE SUBJECTS

Each student is urged to consult the Department as soon as he has decided to enter Mechanical Engineering so that he can be assigned a Faculty Counselor. The student and his Faculty Counselor then can plan a program that will best utilize the 60 units of unrestricted electives available in the remaining three years. Although the selection of elective subjects is an individual decision, the faculty of the Department recommends the undergraduate elective subjects listed below according to fields of interest.

Core Electives for All Students

8.04 PRINCIPLES OF QUANTUM PHYSICS
6.14 INTRODUCTION TO ELECTRONICS

Electives by Fields

Mechanics
2.06 VIBRATIONS
2.071 INTRODUCTION TO SOLID MECHANICS
2.652 EXPERIMENTAL STRESS ANALYSIS

Manufacturing
2.862 MACHINE TOOL FUNDAMENTALS

Materials
2.398 RESEARCH IN MATERIALS

Fibers, Polymers, Textiles
2.901 POLYMER MATERIALS SCIENCE
2.902 MECHANOCHEMISTRY
*2.903 ELEMENTS OF TEXTILE MATERIALS AND PROCESSES
2.904 FIBER PROCESSING DYNAMICS

Fluid Mechanics
2.203 APPLICATIONS IN FLUID MECHANICS
2.23 ENVIRONMENTAL POLLUTION SEMINAR

Thermodynamics
2.404 INTRODUCTION TO MOLECULAR THERMODYNAMICS
2.41 THERMODYNAMICS OF POWER SYSTEMS

Heat Transfer
2.52 BIOMEDICAL HEAT AND MASS TRANSFER
2.53 PROBLEMS IN HEAT

Thermal Systems
2.643 AIR CONDITIONING
2.644 ENVIRONMENTAL CONTROL — AIR CONDITIONING
2.646 REFRIGERATION

System Dynamics and Control

2.14 CONTROL SYSTEM PRINCIPLES

Design

2.00 INTRODUCTION TO ENGINEERING SYSTEMS
*2.711 GEOMETRIC DESIGN
2.732 DESIGN CONCEPTS
2.733 SPECIAL PROBLEMS IN SYSTEMS AND DESIGN

Laboratory

2.654 PHYSICAL MEASUREMENT AND ANALYSIS
2.67 URBAN LABORATORY IN MECHANICAL ENGINEERING

Computer Modeling of Physical Systems

*2.10 ELEMENTARY PROGRAMMING AND MACHINE COMPUTATION
*2.101 COMPUTER MODELS OF PHYSICAL AND ENGINEERING SYSTEMS I
*2.11 ELEMENTARY PROGRAMMING AND MACHINE COMPUTATION
*2.724 NOMOGRAPHY

Mathematics

18.075 ADVANCED CALCULUS FOR ENGINEERS
18.076 ADVANCED CALCULUS FOR ENGINEERS

Biomedical Engineering

2.74 TOPICS IN BIOMEDICAL ENGINEERING

*Subjects with no prerequisites which are suitable for freshmen.

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE

Mechanical Engineering (Course II-A)

Many students have a defined goal which can best be met by organizing a curriculum specifically tailored to that goal. Such a curriculum may be significantly different from that required for the degree of Bachelor of Science in Mechanical Engineering or, for that matter, different from that required for a degree in any specified field at M.I.T. For instance, some students may wish to have a substantial component of biology and physiology in their programs, to prepare for biomedical engineering. Others may wish to combine knowledge of solids with knowledge of electrical circuits and devices, or knowledge of fluids with knowledge of physical chemistry and reaction kinetics.

To meet such needs, the Department offers the degree of Bachelor of Science, with a significant part of the curriculum made up of "planned electives." These are to be chosen by agreement between the student and a departmental officer in such a manner that the complete curriculum is coherent and in pursuit of a clear objective.

Students who wish to study for this degree must so advise the Department by the beginning of the junior year in order that there be adequate opportunity for planning the complete curriculum. Registration for this degree program requires approval in writing from the Registration officer in charge of Course II-A.

The curriculum requirements for this degree are given below.

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				132[1]
	The subjects 2.01, 8.03, and 18.03, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.				
	Laboratory Requirement				12
	The subjects 2.672 and 2.673, which are among the restricted electives, appear on the list of Laboratory Subjects and can be used to satisfy the Laboratory Requirement.				
DEPARTMENTAL PROGRAM					
	Required Subjects				
2.01	MECHANICS OF SOLIDS	4	0	8	
8.03	PHYSICS III	5	0	7	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
	THESIS		9		
					45
	Restricted Electives				
	Five of the following subjects:				
3.141	SCIENCE OF MATERIALS				
	or	4	3	5	
3.13	MATERIALS SCIENCE I				
2.02	INTRODUCTION TO SYSTEM DYNAMICS	3	1	8	
2.03	DYNAMICS	3	0	6	
2.201	FLUID MECHANICS	4	0	8	
2.30	MECHANICAL BEHAVIOR OF MATERIALS	3	2	4	
2.403	THERMODYNAMICS				
	or	4	0	8	
2.42	ELEMENTS OF CLASSICAL AND STATISTICAL THERMODYNAMICS				
2.60	APPLIED THERMODYNAMICS AND HEAT TRANSFER	3	0	6	
2.672	EXPERIMENTAL ENGINEERING I	1	3	2	
2.673	EXPERIMENTAL ENGINEERING II	0	4	2	
2.70	[2]ENGINEERING SYNTHESIS AND DESIGN	2	3	4	
2.73	[2]ENGINEERING DESIGN	2	3	4	
2.86	[2]MANUFACTURING PROJECT LABORATORY	2	3	1	
					at least 54
	Planned Electives				
	A coherent selection of at least five subjects which, together with the remaining portions of the student's program, is aimed at a well-defined educational goal. The planned electives are to be agreed upon between the student and a designated Faculty Counselor of the Department of Mechanical Engineering.				at least 57
	Unrestricted Electives[3]				up to 60
Total units required for the S.B. degree					360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] 2.731 and 2.861 may be substituted for the three subjects 2.70, 2.73, and 2.86.

[3] Schedules of students may always be arranged to leave available 12 units of unrestricted elective in the second year. The Unrestricted Electives must be at least 48 units.

Mechanical Engineering: Cooperative Program (Course II-B)

Students who wish to gain industrial experience

during their four-year undergraduate program may do so by electing to enroll in Course II-B. Experience in a wide variety of industries is available, in a great many geographical locations. Students interested in this program should contact their Faculty Counselor or the staff member in charge, preferably in the sophomore year.

CURRICULUM IN THE COOPERATIVE COURSE (COURSE II-B)

The Course degrees and curricular requirements are the same as for Courses II and II-A; however, in addition, provision is made for the students to be employed in the plants of the cooperative companies. The plant work is considered as equivalent to an 8-unit elective subject:

2.951	INDUSTRIAL PRACTICE	40 h.p.w.
2.952	INDUSTRIAL PRACTICE	0 8 0

The Undergraduate Honors Course

Towards the end of the junior year an opportunity is offered to a limited additional number of students of superior ability to join an Honors Course group, which provides a coordinated schedule of studies through the senior and a graduate year.

The Honors Course leads to the degrees of Bachelor of Science and Master of Science in Mechanical Engineering, awarded simultaneously at the end of the fifth year of study. The program must satisfy all the requirements for both degrees, but only a single thesis is required.

Program for the Bachelor's and Master's Degree

The department offers a program of study leading to the simultaneous award of the Bachelor's and Master's degrees. The program normally requires five years of study, but only a single thesis is required. The master's study may be in the department or in a cooperating department such as Nuclear Engineering.

GRADUATE STUDY IN MECHANICAL ENGINEERING

The Department provides opportunities for graduate work leading to the following degrees: Master of Science in Mechanical Engineering, Master of Science in Textile Technology, Mechanical Engineer, Materials Engineer, Doctor of Science or Doctor of Philosophy.

Entrance Requirements for Graduate Study

Students starting graduate study in mechanical engineering usually have received the equivalent of a Bachelor's degree in mechanical engineering at a recognized engineering school; however, in many cases they will have had their undergraduate preparation in some other branch of engineering or science. Generally, their background includes preparatory studies in some or all of the following areas: applied mechanics, fluid mechanics, dynamics, thermodynamics, electrical circuits, electromagnetic fields, and materials. The Department requirements for admission are not specific, since a capable student with a more general preparation has the opportunity to establish his background in mechanical engineering by taking the most advanced undergraduate subjects which his abilities and preparation will permit.

The fields of advanced study and research are those briefly listed on page 81. Well-equipped facilities are available in the following laboratories:

Acoustics and Vibrations Laboratory
Atomic and Molecular Kinetics Laboratory
Automotive Laboratory, Sloan
Combustion and Propulsion Laboratory
Computer
Cryogenic Engineering Laboratory
Energy Conversion Laboratory
Engineering Projects Laboratory
Environmental Control Laboratory
Fibers and Polymers Laboratory
Fluid Mechanics Laboratory
Fluid Power Control Laboratory
Gas Turbine Laboratory
Heat Transfer Laboratory
Man-Machine Systems Laboratory
Materials Laboratory
Materials Processing Laboratory
Power Systems Engineering Laboratory
Sensory Aids Center
Stress Analysis Laboratory
Surface Laboratory
Vacuum Laboratory

The Graduate Degrees

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

The general requirements for the degree are given in Section 3 of this Catalogue with the provision that the 66 required units be taken during the two regular terms or during the summer term not including the January Independent Activities Period.

The student working for the Master of Science in Mechanical Engineering follows a wholly elective program; his subjects are not restricted to those given by the Department of Mechanical Engineering. The selection of individual subjects is restricted only by the condition that the program must be substantial and

logical in the judgment of the faculty advisor. The program should be well balanced, emphasizing one or more of the analytical, economic, design, or experimental aspects of the field.

MASTER OF SCIENCE IN TEXTILE TECHNOLOGY

Candidates for the Master of Science in Textile Technology should have the training offered by the Institute (or equivalent training from another institution) in the fields of either chemical engineering, chemistry, mechanical engineering, business and engineering administration, or industrial physics. The program for the degree lasts from one to two years, depending upon preparation. Students who have graduated with high standing from technical or textile schools which offer less extensive preparation in science and engineering may be accepted for study, but should expect to spend at least two years to fulfill degree requirements.

MECHANICAL ENGINEER

In recent years, there has developed a need for leaders possessing knowledge in depth in a number of areas associated with mechanical engineering. For those who desire to prepare themselves for engineering practice at a high professional level, the degree of Mechanical Engineer is awarded for a program of study which is more advanced than that for the degree of Master of Science. The requirements for the degree include approximately one additional year of full-time class work. If the Master's degree was not taken at M.I.T., a thesis must be a part of the program. The general requirements for the degree are given in Section 3 of this Catalogue.

MATERIALS ENGINEER

Candidates interested in studying materials engineering in the Department of Mechanical Engineering should in general have training equivalent to that offered by the Institute in its undergraduate programs in any of several departments of engineering or science. The graduate program encompasses study in the areas of mathematics, physics, chemistry, electrical materials, continuum and dislocation mechanics, metallurgy, ceramics, elastomers, and plastics, as well as research. In general, two years are required for completion of the degree of Materials Engineer. General requirements for the degree of Materials Engineer include a qualifying examination, as described for the Mechanical Engineer degree.

DOCTOR OF SCIENCE OR DOCTOR OF PHILOSOPHY

Admission to the doctoral program is granted only after the candidate has passed a qualifying examination; this should be taken as soon as possible after completing the Master's degree program. The requirements for the Doctor's degree include a Program of Advanced Study, a Minor program, a thesis in the field of Mechanical Engineering or in the field of Materials Engineering, and the language requirement specified for the doctorates in Section 3 of this Catalogue.

The program of advanced study and research may be selected in any field of science or engineering approved by the Department Committee on Graduate Studies. While no fixed number of units is prescribed, the usual program includes a substantial number of subjects in the student's area of principal interest, in addition to those taken to satisfy the requirements for the Master's degree; these, with the Minor program, usually require an additional two terms of work beyond the Master's degree. The Minor program must be approved by the student's doctoral committee.

The qualifying examination must be completed before any program of research is undertaken. The language requirement should be fulfilled as early as possible in the program, so that the student will be capable of reading the foreign scientific literature on his proposed thesis subject before starting the actual research.

For his thesis, each candidate undertakes a program of research which will contribute significantly to his major field of interest. This contribution may be analytical, experimental, or design knowledge. The Program of Advanced Study and the thesis are under the supervision of a doctoral committee selected by the student and his thesis supervisor. The doctoral committee makes an annual evaluation of the candidate's progress and conducts a final examination based on the thesis. While no fixed number of units is prescribed, the research usually requires at least one year of registration.

Candidates entering this doctoral program following award of the Master's degree in textile technology must meet the foregoing requirements but with a thesis based on research in the field of fibrous materials.

Department of Metallurgy and Materials Science

The Department of Metallurgy and Materials Science is concerned with the principal engineering materials upon which modern civilization depends. These are the skeleton, or even the whole substance, of structures, machines and equipment, and mechanical and electrical devices. Modern society cannot satisfy its needs for materials from wood, cement, and crude metals alone. The mechanical, chemical, thermal, and electrical properties demanded of materials today require much greater sophistication in the selection, treatment, and assembly of a bewildering variety of substances designed for specific needs.

Fortunately, there is a key to the rational use and development of materials, simple or complex, which is the basic contribution of the metallurgist. It is an understanding of the relations between structure and properties and, equally important, the knowledge of how structure may be controlled to influence properties. Structure has many levels: atomic, electronic, crystal, and gross. Even the lack of crystalline structure, as in glasses and some polymers, the blending of gross structures, as in composites, and defects in crystalline structures, as in electronic materials, are important features in the development of properties.

The name of the Department has both historical and technical significance. There is more to metallurgy and materials science than structural chemistry and solid-state physics. The metallurgist is also an engineer who must prepare materials of very high purity and know how to blend or alloy them, how to change their structure by heat treatment, deformation, phase change, and joining. He must, in effect, design materials with the desired combinations of properties; this is one of the applied aspects of his work. Historically, the metallurgist takes his name from the oldest, most abundant, and most serviceable of all engineering materials. But today he must know the place of other materials, such as ceramics, plastics, and other nonmetallics, in the scheme of things. The same methods which have been so vital in the development of an extraordinary array of metals and alloys have been just as fruitful in the evolution of improved ceramics, plastics, and electronic materials.

Metallurgists and materials engineers must bring together many skills in coping with actual materials problems. Some specialize in the preparation of materials, for which a basic knowledge of chemistry and thermodynamics is most helpful. Others are concerned with the elucidation of structure-property relations, for which a background in solid-state science is more useful. Still others deal with the manipulation of shape and properties, for which an understanding of the mechanics of materials is critical. The versatile man can apply his basic knowledge to any of these areas, whether in research, development, production, or management.

Because the field of materials is so broad, the Department has chosen to concentrate its activities in metals, ceramics, electronic materials, and plastics, though it should be emphasized that the appropriate knowledge and methods can be applied successfully to the technology of any material.

Metallurgy and materials science are of vital importance to modern industry. The design and operation of propulsion units such as gas turbines and rocket motors, of energy producers such as nuclear reactors, or energy converters such as magnetohydrodynamic generators, and of electrical and mechanical devices are critically dependent on the availability of materials with the requisite blend of properties. Men with skills to design these materials are in great demand by industry and government. They find challenging opportunities in a large variety of positions in operations, development and research in the basic materials-producing industries, chemical and metallurgical, in the consumer industries, which make products ranging from automobiles to surgical instruments, and in the space and electronics industries.

THE UNDERGRADUATE PROGRAMS

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE IN METALLURGY AND MATERIALS SCIENCE

***Metallurgy and Materials Science* (*Course III*)**

The undergraduate program caters to the diverse needs of students who aim for a terminal

degree and those who intend to pursue graduate work, to those who are more inclined toward engineering application as well as those who prefer solid-state science. The decision to concentrate on the physics, chemistry, or engineering of materials may be reached by students as late as the sophomore year or even during the junior year.

For these reasons, the curriculum is flexible. Understanding of materials is developed from a foundation of physical and engineering science, a core of subjects in mechanics, thermodynamics, crystal structure, and structure-property relations. These essential subjects are taught within the Department, so that meaningful examples can be used to illustrate the material. However, appropriate substitutions of subjects taken in other departments are permitted and, indeed, encouraged when a student has somewhat different educational objectives.

The elective program, constituting more than 20 per cent of the student's time, is chosen, with the help of an advisor, to give depth in one or more technical areas such as the preparation and purification of materials, including the chemical process technology employed by steelmakers; the processing and fabrication of materials by deformation, heat treatment, and phase change; the study and control of structure-property relations in metallic, ceramic and polymeric materials; and the physics of solid materials generally. Many graduate subjects are open to undergraduates having the necessary preparation.

Other choices under the elective program are, of course, possible. A student may focus his elective time on modern production or research management techniques in the materials industry, or he may simply prepare for later graduate study.

Participation in laboratory work by undergraduates is an integral part of both engineering and research experience. Some laboratories are associated with particular subjects, but, especially in thesis work, the undergraduate has access to the extensive facilities for graduate research in materials described in a later section.

The teaching facilities, some of which are located in the Center for Materials Science and Engineering, include an electron-optics laboratory with X-ray and electron diffraction equipment; electron microscopes and microanalyzers; laboratories for microscopic studies, heat treatment, and physical testing of materials; and complete test apparatus for the study of mechanical, thermal, electrical, and magnetic properties. In the ceramics laboratories most types of refractory as well as electrical ceramics and glasses can be prepared or their properties studied. Facilities for the growth and characterization of metallic and non-metallic crystals are available in several laboratories. The chemical metallurgy laboratories contain equipment for the study of heat and mass flow and for thermodynamic and kinetic investigations at high temperatures. The materials processing laboratories are equipped for work on deformation, solidification, joining, and vapor deposition as processing techniques. Laboratories in surface chemistry and corrosion are also open to undergraduates. Other services include a complete analytical laboratory and computation facilities with remote consoles.

The Course leads to the degree of Bachelor of Science in Metallurgy and Materials Science. The curriculum requirements for the degree are given below:

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				**132**[1]
	ECONOMIC PRINCIPLES I (14.01) is recommended in the upperclass humanities and social science program.				
	The subjects 3.00, 8.03, and 18.03, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.				
	Laboratory Requirement.				**12**
DEPARTMENTAL PROGRAM					
	Required Subjects[2]				
3.00	THERMODYNAMICS OF MATERIALS	4	0	8	
3.01	THERMODYNAMICS AND STATISTICAL MECHANICS	3	0	9	
3.02	CHEMISTRY OF MATERIALS	3	3	6	
3.11	MECHANICS OF MATERIALS	4	0	8	
3.12	PRINCIPLES OF CRYSTALLOGRAPHY AND X-RAY DIFFRACTION	4	3	5	
3.13	MATERIALS SCIENCE I	4	3	5	
3.15	MATERIALS SCIENCE II	4	3	5	
8.03	PHYSICS III	5	0	7	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
	[4]THESIS		12		
					120
	Restricted Electives				**20 to 24**
	Physical Metallurgy *One of the following subjects:*				
3.14	PHYSICAL METALLURGY I	4	3	5	
3.144	PHYSICAL METALLURGY I	4	0	4	
	Materials Processing *One of the following subjects:*				
3.18	MATERIALS PROCESSING	4	3	5	
3.188	MATERIALS PROCESSING	4	0	4	
	Unrestricted Electives[3]				**76 to 72**
Total units required for the S.B. degree					**360**

Engineering

DEPARTMENT OF METALLURGY AND MATERIALS SCIENCE

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Substitution of subjects of similar content is permitted in some cases.
[3] Schedules of students in Course III may always be arranged to leave available 12 units of unrestricted elective in the second year.
[4] Up to 6 additional units of thesis may be used as elective.

Students who decide during the first year at M.I.T. to study Metallurgy and Materials Science can facilitate their later progress by ensuring that their second-year subjects include additional mathematics and physics as well as 3.00 and 3.11, or their equivalents. The third and fourth years may then be devoted to study, in some depth and with adequate preparation, of areas such as physical metallurgy, the physics of solids, chemical metallurgy, ceramics, or polymers through appropriate use of upperclass elective time.

Some students, on the other hand, do not wish to make a Course choice until the junior year or may wish to use their elective time to the fullest possible extent in the second year rather than in later years. Generally, it will still be possible to complete the Departmental Program and Institute Requirements in two more years, especially if one of the second-year Science Distribution Subjects is in thermodynamics or mechanics of solids; but some elective freedom, particularly in the fourth year, will have been sacrificed.

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE

Metallurgy and Materials Science (Course III-A)

Many desirable educational goals exceed the bounds of a departmental program, particularly in a thoroughly interdisciplinary field such as materials science. The student may wish, for instance, to combine biology with materials science to satisfy his interest in biomaterials, or may have a strong interest in the role of materials in the humanities, ocean engineering and deep sea submergence, the exploration of space, transportation and communication, electronic devices and digital computers, energy conversion, environmental systems, and other fields; he may wish to emphasize such important areas as polymers and polymer chemistry, concretes and cements or soils; he may be strongly interested in the problems and control of industrial pollution.

Generally, a curriculum may be set up to attain such goals. For this purpose the Department offers the degree of Bachelor of Science. If the student informs the Department of his intentions at the beginning of the junior year (or earlier), there is usually enough time for the student and a Faculty Advisor to plan a coherent program with a list of planned electives, and submit it to the Department for approval. Such a program can be much more effective if the student's aims are discussed, as early as possible, with the appropriate faculty members, and the Department urges the student to do so.

The curriculum requirements shown below are intended as a guide to students. A program involving more project work and with fewer formal subjects may also be undertaken.

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				**132**[1]
	ECONOMIC PRINCIPLES I (14.01) is recommended in the upperclass humanities and social science program.				
	Science Distribution Requirement. The subjects 3.00, 8.03, and 18.03, which are among the restricted electives, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.				**36**
	Laboratory Requirement.				**12**
DEPARTMENTAL PROGRAM					
	Restricted Electives[2]				
	Six of the following subjects:				
3.00	THERMODYNAMICS OF MATERIALS	4	0	8	
8.03	PHYSICS III	5	0	7	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
3.01	THERMODYNAMICS AND STATISTICAL MECHANICS	3	0	9	
3.02	CHEMISTRY OF MATERIALS	3	3	6	
3.11	MECHANICS OF MATERIALS	4	0	8	
3.12	PRINCIPLES OF CRYSTALLOGRAPHY AND X-RAY DIFFRACTION	4	3	5	
3.13	MATERIALS SCIENCE I	4	3	5	
3.15	MATERIALS SCIENCE II	4	3	5	
3.14	PHYSICAL METALLURGY I	4	3	5	
3.18	MATERIALS PROCESSING	4	3	5	
3.16	PHYSICAL METALLURGY II	2	4	4	
					72
	Planned Electives				
	At least six subjects which are selected by the student and Faculty Advisor; together with the restricted electives, these subjects should make up a program intended to attain the goal defined by the student.				at least **72**
	Unrestricted Electives[2]				up to **72**
	Total units required for the S.B. degree				**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Substitution of subjects of similar content is permitted in some cases. If 3.00, 8.03, or 18.03 are used to satisfy the Science Distribution Requirement, the total for Restricted Electives will be reduced accordingly and the total for Unrestricted Electives will be increased accordingly. The Unrestricted Electives must be at least 36 units.

GRADUATE STUDY IN METALLURGY, MINERAL ENGINEERING, CERAMICS, AND MATERIALS SCIENCE

The Department conducts a large and active fundamental research program on the structure and properties, preparation, and processing of materials, with emphasis on metals, ceramics, polymers and electronic materials. Graduate research is an important part of the educational process, and interaction between graduate and undergraduate is encouraged through participation in research. Students are allowed to choose research projects for which they have enthusiasm and generally work with an individual faculty advisor. Most research projects result in significant findings which are published in the scientific literature. Graduate subjects of instruction, in this and other departments, allow the student to pursue areas in depth but also afford the opportunity for a broad view of the field of metals and materials. Though there are many individual research laboratories in the Department, there is much interaction and sharing of experimental facilities between them. Such interaction extends to laboratories of other departments, and joint projects are common. Interdisciplinary research is facilitated by the Center for Materials Science and Engineering, of which this Department is an important part. The attention of students is drawn particularly to the interdisciplinary graduate study areas, such as polymeric materials and biomedical materials, described in Section 5.

STRUCTURE AND PROPERTIES OF MATERIALS

The detailed structure of materials may be related to their mechanical, thermal, optical, and electrical properties. The study of such relationships with mechanical properties is one of the principal concerns of the physical metallurgy laboratories. The methods of electron and X-ray diffraction and electron microscopy are used to examine microstructural lattice imperfections induced by plastic flow and phase transformations; a classic example is the investigation of strengthening mechanisms in steel. Thermodynamic techniques also contribute to such research and are extended to investigation of deformation, annealing, and radiation damage. The mechanism of flow and fracture at high temperatures is studied in the high-temperature metals laboratory which is also concerned with the properties of powders, metal, metal-oxide alloys. Deformation and fracture characteristics of ceramics are investigated in the ceramics laboratories. The mechanical properties of anisotropic and composite materials are also of interest from the structural viewpoint. Dislocation interactions in materials at low temperatures can be studied by the modern techniques available. An electron optics group is concerned with developing new tools such as micro-X-ray diffraction and the application of the electron microprobe to produce Kossel line patterns. Kinetic processes are not neglected; for example, there is important research on stress relief, recrystallization, flow and fracture, and diffusion under stress.

Work on electrical properties proceeds in various laboratories. The superconductivity of metals, alloys, compounds, and composites and the relationship of defect microstructures to superconducting properties are extensively studied. The surface characteristics of semiconductor compounds and the study of materials for thermionic emission are part of the research on electronic materials. Thermal, optical, and electrical properties of both crystalline and noncrystalline ceramic materials form one of the principal areas of research in ceramics. The structures and crystallization of polymers are also of interest and may be studied under high pressure in a special laboratory. Both polymers and metals for biological uses are of more recent interest. The effects of irradiation damage on spontaneous magnetization and the study of spin disorder in magnetic alloys are examples of work on magnetic properties.

Work on Fermi surfaces and fine X-ray structure studies are conducted by a group in the physics of solids. The same group conducts theoretical studies of inorganic and organic molecular structure and is one of the principal users of advanced diffraction techniques to characterize crystalline and amorphous materials.

PREPARATION OF MATERIALS

Much of the research in this area is concerned with establishing thermodynamic properties and studying the mechanism of interaction between substances. In the chemical metallurgy laboratories, studies are made of the thermodynamic properties of liquid and solid metals and alloys, utilizing such methods as high-temperature solution calorimetry, reversible electrochemical cells, measurement of vapor pressures, and equilibration between gases and condensed phases. There

are also studies of diffusion in liquid alloys and salts, on the kinetics of reactions between gases and liquid metals, and of electrode kinetics in high-temperature systems.

Separation of materials is an important part of preparation, and in the mineral engineering laboratories there are studies of surface chemistry, including contact angle hysteresis, the electrochemistry of solid-liquid interfaces, and the kinetics of leaching processes.

The reaction of materials with their environments extends to fundamental corrosion research, including the measurement of contact potentials and studies of polarization, passivity, the nature of surface films, and the mechanisms of oxidation, corrosion, and cracking under stress.

Other laboratories, for example ceramics and materials processing, require specific materials prepared by powder methods, vacuum melting and deposition, zone refining, and chemical vapor deposition.

PROCESSING OF MATERIALS

The processing of materials to influence shape and properties involves study of the fundamental processes of solidification, deposition, deformation, and joining.

Research on solidification is conducted on aqueous solutions, metals, and alloys. The detailed structures produced by directional and slow solidification, as in castings, and by rapid solidification, as in arc-deposition, are of particular interest. Deposition of materials from the vapor state and plasma spraying are also studied.

Research on deformation processing involves the fundamentals of flow, fracture, and fatigue as well as studies of friction and lubrication during deformation, plastic instability, and superplasticity.

Work on joining includes fundamental studies of heat flow and material properties in arc, electron-beam, and laser welding, of vapor processing and surface treatment, and of sintering and brazing. Processing work on other materials, such as polymers and ceramics, is often more specific in character, involving high temperatures or pressures.

EQUIPMENT

The latest research equipment is available for studies in all of these areas. Facilities include all types of high-temperature furnaces in chemical metallurgy and ceramics, vacuum induction and vacuum arc-melting furnaces, electron beam melting apparatus, and zone refining and crystal growing equipment in materials processing. In physical metallurgy and electron optics, the latest electron microscopes, electron diffraction apparatus, equipment for metallographic examination, X-ray diffraction apparatus for structural analysis and fine-structure studies, X-ray fluorescent analyzers, and electron probe microanalyzers are all available, in addition to specialized equipment. Equipment for testing mechanical properties at high and low temperatures under a variety of strain rates is available in physical metallurgy and materials processing. Materials can be deformed in many ways, and the heavier equipment includes rolling and forging apparatus. A completely equipped laboratory is available for fundamental solidification studies. The welding laboratory includes gas welding, plasma-arc melting, electron-beam, and laser apparatus. All the necessary equipment for electrochemical studies in the corrosion laboratory and counting equipment for tracer studies in mineral engineering are available.

More recent additions include ultra-high vacuum equipment, extensive metallic and semiconductor crystal-growing apparatus, equipment for Fermi surface studies and other specialized solid-state studies, a high-pressure laboratory, and scanning electron microscopes scanning electron-diffraction equipment, and interference-contrast microscopes.

The Department maintains an analytical laboratory, machine and instrument-making shops, a student machine shop, and remote computation consoles.

Requirements for Graduate Study

The general admission requirements are those given in Section 8 of this Catalogue. Students whose undergraduate preparation is in metallurgy will generally be familiar with the principles of heat and fluid flow, thermodynamics, and materials science, with the emphasis on metallurgy. Those whose undergraduate preparation is in other branches of science and engineering and who wish to enroll for advanced degrees in the Department may find it advantageous to take some undergraduate subjects during their first year of graduate study.

It is expected that those who do graduate work in metallurgy will have studied the following subjects or their equivalents:

THERMODYNAMICS AND STATISTICAL MECHANICS (3.01)
MATERIALS SCIENCE 1 (3.13)

Graduate students whose preparation does not include the above subjects, or their equivalents, are expected to complete them in the early part of their graduate work.

Students who wish to do graduate study in ceramics generally have varied backgrounds, and there are no special requirements. However, all entering graduate students are required to register for CERAMICS (3.06) unless they have had similar training elsewhere.

For students in materials science, the general Institute requirements for admission are sufficient. Programs are arranged on an individual basis depending on the preparation and interests of the student. Students who have not taken the following subjects or their equivalents are expected to complete them as early as possible.

THERMODYNAMICS AND STATISTICAL MECHANICS (3.01)
MATERIALS SCIENCE 1 (3.13)

The Graduate Degrees

The Department offers the following graduate degrees: Master of Science in Metallurgy; Master of Science in Ceramics; Metallurgical Engineer; Mineral Engineer; Doctor of Science or Doctor of Philosophy.

The graduate degree requirements are as set forth in Section 3 of this Catalogue. The Department requires that candidates for the doctoral degrees go through a qualifying procedure before continuing with their programs of study and research and satisfy a Minor requirement. Information on this examination and on the areas covered by the general examination is available from the Chairman of the Departmental Committee on Graduate Students.

Assistantships and Fellowships

The Department offers assistantships and fellowships for graduate study. Research and teaching assistantships are available in all of the fields in which the Department is active. Further information may be obtained from the Chairman of the Departmental Committee on Graduate Students.

Department of Nuclear Engineering

The Department of Nuclear Engineering provides advanced technical education for students interested in developing the peaceful applications of nuclear reactions, plasma physics, and related aspects of radiation. In keeping with M.I.T.'s traditional role in other branches of knowledge, the Department aims to educate the individuals who will make the key scientific and engineering advances in these fields. Although the technological problems of power generation by neutron-induced fission of heavy elements in nuclear reactors and fusion of light particles in thermonuclear plasmas receive primary emphasis in the Department, the totality of its interests is best described as the engineering physics of low-energy charged particles, neutrons and radiation.

Fission reactors are used to produce heat and electricity, to propel submarines and ships, and to transmute elements and produce radioisotopes. The most important development now occurring in the fission field is the rapid growth in the number and capacity of electric generating stations using nuclear fission reactors as heat sources. Nuclear power is already economically competitive with power from coal, oil, or gas in many regions of the United States and in many foreign countries. One challenging task facing today's nuclear engineers is reducing the capital cost of nuclear power stations and extending the life of nuclear fuels so that nuclear plants will become the most economic way of generating electricity in ever-widening regions of the world. These cost reductions can be realized by improving the performance of today's reactors, by development of better methods for designing tomorrow's reactors, and by conceiving types of reactors better than any now in use.

Another challenge to nuclear engineers is the development of economic nuclear power systems that regenerate or yield a net increase in their essential fuel. Foremost are breeder reactors which use regenerated plutonium or uranium-233 to make available all the latent fission energy of abundant uranium-238 or thorium instead of the relatively scarce isotope uranium-235, which is the principal fissionable material in presently operating reactors. Breeder reactors will provide an energy resource capable of supplying the needs of the world for millions of years.

Fission reactors find widespread use in research on the interaction of radiation and matter and in the production of radioisotopes and the transmutation of elements. Also, the large amount of energy obtainable per unit mass of fissile fuel and the fact that air is not needed to sustain the fission reaction make fission reactors especially valuable in submarine and space applications.

Another potential source of nuclear energy and neutrons is controlled fusion of light elements. Energy from such thermonuclear reactions would provide another practically inexhaustible supply of energy. These fusion reactions must be carried out in a fully ionized plasma heated to a temperature of many million degrees and confined under stable conditions by strong magnetic fields. Recent progress in confining plasmas increases the likelihood that controlled fusion will become a practical source of energy within the lifetime of today's engineering students. The use of fusion reactions for an economic supply of neutrons could be achieved even sooner. Attainment of a practical fusion energy source requires improved understanding of the fundamental behavior of plasmas in electric and magnetic fields, development of materials capable of withstanding high stresses and exposure to intense radiation and great engineering ingenuity in combining fusion power components into a practical and economic system. The Department is active in these three fields, the fundamentals of plasma behavior, materials for intense radiation fields, and the engineering of fusion systems.

Study of the fundamentals of plasma behavior leads to improved understanding of astrophysical and ionospheric phenomena, magnetohydrodynamic energy conversion, ion propulsion, direct-conversion thermionic diodes, and high-power gas lasers. The latter two topics are applications of particular present interest in the Department. Students of the Department concentrating on applied plasma physics therefore are trained not only to advance knowledge of controlled fusion and of the plasma field as a whole, but also to apply the fundamental science in other contexts of more immediate practical significance. In these

plasma activities, the Department is an active participant in M.I.T.'s broad, interdepartmental program of research and instruction in plasma physics and its varied applications.

The Department's involvement with reactors and sources of radiation has led to an applied radiation physics program concerned with the radiations these sources emit and with the uses to be made of radiation. This program deals in a unified manner with neutrons, charged particles, gamma rays, and light and other electromagnetic radiations. It is concerned with the production of neutrons and gamma rays by fission reactors, the production of alpha, beta and gamma rays by radioisotopes, the production of electrons, positive ions, neutrons and gamma rays in particle accelerators, and the production of coherent electromagnetic radiation by lasers. Topics treated include the detection and measurement of radiation, the interaction of radiation with matter, the use of radiation in processing materials, the design of irradiators, biological effects of radiation and the use of scattering experiments with neutrons and coherent light to determine the structure and molecular dynamics of solids, liquids, and dense gases.

To achieve the full potential of nuclear energy from either fission or fusion reactors, it will be necessary to develop materials capable of withstanding intense radiation for long periods of time. Nuclear reaction systems require novel materials processed in special ways. The Department's nuclear materials engineering program is concerned with effects of radiation on materials and development of improved radiation-resistant materials. It deals also with production and fabrication of enriched uranium, thorium, and plutonium to serve as fuel for fission reactors and with processes for recovering these materials from the highly radioactive spent fuel discharged from reactors.

In these programs, attention is focused on the technology of the fission reaction and plasma phenomena and on aspects of physical sciences and engineering which contribute importantly to the efficient development of these fields, as, for example, low-energy nuclear physics, plasma physics, nuclear materials, and high-flux heat transfer. The Department follows a broad interdisciplinary approach, making use of important segments of physics, chemistry, and metallurgy and drawing on the techniques of chemical, civil, electrical, and mechanical engineering where relevant to the solution of nuclear engineering problems. The programs in nuclear engineering at M.I.T. are open to students with undergraduate training in these and related fields. They aim to teach the basic principles of nuclear technology and applied plasma and radiation physics and to show each student how his field of undergraduate specialization may be applied to problems in these fields.

Graduate students and advanced undergraduates at M.I.T. who wish to learn how their major professional field may be utilized in nuclear developments will find certain subjects or groups of subjects offered by the Department of Nuclear Engineering to be of interest. Programs of study focused on nuclear power plant engineering are of especial interest to students of electrical or mechanical engineering. Programs focused on applied plasma or radiation physics are valuable for students in physics or electrical engineering.

The Department of Nuclear Engineering does not offer undergraduate degrees. It does, however, offer jointly with a number of M.I.T. departments five-year programs leading to a joint Bachelor of Science in an undergraduate department and a Master of Science in Nuclear Engineering. The M.I.T. departments currently participating in these programs are Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, and Physics.

UNDERGRADUATE PREPARATION FOR NUCLEAR ENGINEERING

An undergraduate degree in physics, engineering physics, chemistry, or metallurgy, or chemical, civil, electrical, mechanical, or nuclear engineering furnishes suitable preparation for graduate study in nuclear engineering. Optimum undergraduate preparation would include the following material:

Physics: At least two years, including mechanics, heat, light, electricity, and magnetism and an introduction to wave mechanics and modern physics, equivalent to M.I.T. subjects 8.01, 8.02, 8.03, and 8.04.

Students planning to follow the Department's program of graduate study in applied plasma physics or applied radiation physics should have more advanced preparation in theoretical physics, electricity and magnetism, equivalent to M.I.T. subjects 8.06 and 8.07.

Mathematics: At least two and a half years, including ordinary and partial differential equations, vector analysis, matrix algebra, orthogonal functions, Bessel and Legendre functions, Fourier and Laplace transforms, and an introduction to functions of a complex variable, equivalent to M.I.T. subjects 18.01, 18.02, 18.03, 18.075 and 18.076.

Chemistry: One term of general, inorganic, and physical chemistry, including the periodic table, valence, oxida-

tion-reduction potentials, equilibrium constants, and heterogeneous equilibrium.

Engineering Fundamentals: Mechanical properties of materials, fluid flow, heat transfer and engineering thermodynamics, equivalent to M.I.T. subjects 2.01, 2.201, 2.50 and 2.403. Students without this undergraduate preparation may obtain sufficient background in engineering fundamentals by taking nuclear engineering subject 22.311.

Prospective graduate students should make every effort to complete undergraduate preparation before starting graduate study. Students whose preparation is incomplete may make up their deficiencies after admission to graduate study, but they will need more time to complete the graduate program.

Students who expect to apply for admission to the graduate Course in Nuclear Engineering should discuss their undergraduate programs with the Department's Registration Officer, preferably before the end of their junior year. Applicants for admission are advised, but not required, to take the Graduate Record Examination.

GRADUATE STUDY IN NUCLEAR ENGINEERING (COURSE XXII)

Details of the requirements for graduate degrees are given in the following paragraphs.

MASTER OF SCIENCE IN NUCLEAR ENGINEERING

The object of the Master's degree program is to give the student as good a general knowledge of aspects of nuclear engineering as can be gained in one year of full-time graduate study. This will provide a good foundation either for productive work in the nuclear field or for more advanced graduate study. The general requirements for this degree are listed in Section 3 of this Catalogue. Subjects recommended for all Master degree candidates include:

NUCLEAR PHYSICS FOR ENGINEERS (22.111 and 22.112)
NUCLEAR REACTOR PHYSICS I (22.211)

Other subjects may be selected in accordance with the student's particular field of interest. Most Master's candidates specialize in one of four alternative fields: fission reactor technology, applied plasma physics, applied radiation physics or nuclear materials engineering.

For students specializing in fission reactor technology, additional subjects recommended are:

NUCLEAR REACTOR PHYSICS II (22.212)
NUCLEAR REACTOR MEASUREMENTS LABORATORY (22.29)
ENGINEERING OF NUCLEAR REACTORS (22.312)

Other subjects available to Master degree candidates specializing in fission reactor technology include:

ADVANCED ENGINEERING OF NUCLEAR REACTORS (22.313)
NUCLEAR REACTOR DESIGN (22.33)
ECONOMICS OF NUCLEAR POWER (22.34)
NUCLEAR REACTOR OPERATIONS (22.39)
RADIATION ENGINEERING (22.53)
PLASMAS AND CONTROLLED FUSION I (22.611)
NUCLEAR FUELS (22.72J)
NUCLEAR CHEMICAL ENGINEERING (22.76)

For students specializing in applied plasma physics, subjects recommended in addition to 22.111, 22.112 and 22.211 are:

PLASMAS AND CONTROLLED FUSION (22.611 and 22.612)
ENGINEERING PHYSICS OF PLASMA AND PARTICLE DEVICES (22.63)
PLASMA LABORATORY (22.69)

Students specializing in applied radiation physics should select subjects in addition to 22.111, 22.112 and 22.211 from

PHYSICS OF SOLIDS I (3.42J)
NUCLEAR REACTOR MEASUREMENTS LABORATORY (22.29)
ENGINEERING OF NUCLEAR REACTORS (22.312)
RADIATION ENGINEERING (22.53)
RADIATION DAMAGE IN CRYSTALLINE SOLIDS (22.73J)

Students specializing in nuclear materials engineering should select subjects in addition to 22.111, 22.112 and 22.211 from those listed immediately above and

METALLURGY FOR NUCLEAR ENGINEERS (22.71)
NUCLEAR FUELS (22.72J)
NUCLEAR CHEMICAL ENGINEERING (22.76)

Students with adequate undergraduate preparation normally need one full year to complete the requirements for the Master of Science degree.

NUCLEAR ENGINEER

The two-year program of study leading to the Nuclear Engineer degree provides deeper knowledge of nuclear engineering than is possible in the Master's program and is intended to train men for creative professional careers in engineering application or design.

General requirements for this degree, described in Section 3 of this Catalogue, include 162 units of subject credit plus a thesis. The Department requires that each student plan an individually selected program of study, to be approved in advance by his faculty adviser, and that he complete a substantial engineering project involving design and/or construction.

Three alternative fields in which a candidate for the Nuclear Engineer degree may plan his program of study are fission reactor engineering, plasma engineering, or nuclear materials engineering. A particular objective of the fission reactor engineering program is to train candidates for the engineering opportunities developing with manufacturers and construction firms building nuclear power reactors and power

companies operating them. Subjects of value to candidates for the Nuclear Engineer degree in fission reactor engineering include

NUCLEAR POWER REACTORS (22.32)
NUCLEAR FUEL MANAGEMENT (22.35)
NUMERICAL METHODS OF REACTOR ANALYSIS (22.42)

in addition to those suggested for Master's degree candidates in fission reactor technology.

The engineering project required of all candidates for the Nuclear Engineer degree will generally be the subject of an Engineer's thesis. A suitable Master's thesis may be accepted partly or wholly in place of the Engineer's thesis, and either thesis may be augmented by work done while registered for SPECIAL PROBLEMS IN NUCLEAR ENGINEERING (22.90).

DOCTOR OF SCIENCE OR DOCTOR OF PHILOSOPHY

The program of study leading to these degrees aims to give a comprehensive knowledge of nuclear engineering and to develop competence in advanced engineering research.

General requirements of the Institute for the doctorate are given in Section 3 of the General Catalogue and in the Graduate School Manual. The specific requirements of the Department of Nuclear Engineering are presented here. The four principal parts of the doctoral program are the Major program leading to the General Examination, the Minor program, the language requirement and the doctoral thesis. Upon a satisfactory completion of this program, the student will ordinarily receive the degree of Doctor of Science unless he requests the degree of Doctor of Philosophy. The requirements for both degrees are the same.

The object of the Major program is to give the student good general knowledge of nuclear engineering, together with detailed familiarity with the specific field in which he intends to undertake research. To this end, before the student may start his doctoral research, he is required to pass a general examination demonstrating adequate undergraduate preparation in physics, chemistry, mathematics and engineering fundamentals and comprehensive knowledge at the graduate level of his chosen field in nuclear engineering.

The alternative fields in which doctoral candidates may elect to study and for which they are examined are: fission reactor physics, fission reactor engineering, applied plasma physics, applied radiation physics, nuclear materials engineering or nuclear fuel management. Details of the doctoral examination in each of these fields are given in the information circular for doctoral candidates obtainable from the Nuclear Engineering Department.

The object of the Minor program is to broaden the student's knowledge. The Minor consists of completing satisfactorily two or more related subjects, totaling at least 24 credit units, in a field other than nuclear engineering and of a more advanced character than would have been required for the student's undergraduate degree. The Minor program should be arranged in consultation with the student's registration officer, and have his approval. Graduate level subjects taken at other schools may be used to satisfy the Minor requirement if the registration officer judges them to be substantially equivalent to M.I.T. graduate subjects.

The object of the language requirement is to ensure that the student has familiarity with some language other than English. Students whose native language is not English are presumed to have satisfied this requirement. Other students may satisfy it by successful completion of a one-year college-level sequence of foreign language subjects while undergraduates, or in the M.I.T. Department of Foreign Literatures and Linguistics, or at Harvard University or Wellesley College.

Doctoral research may be undertaken either in the Department of Nuclear Engineering or in a nuclear-related field in another department. Appropriate areas of research include the following: In fission reactor physics — physics of thermal reactors, physics of fast reactors, reactor dynamics, neutron transport theory, numerical methods of reactor analysis; in fission reactor engineering — high-flux heat transfer, two-phase flow in boiling systems, liquid-metal heat transfer, nuclear reactor safety, fuel cycle analysis, nuclear fuel management, power system economics; in applied plasma physics — plasma production and confinement, plasma kinetic theory, plasma diagnostics, charged particle transport theory, fusion power systems, thermionic energy conversion, gas laser technology; in applied radiation physics — chemical or biological effects of radiation, radiation processing of materials, neutron diffraction studies, neutron cross section correlations, studies of molecular dynamics by scattering of light or neutrons, shielding of gamma rays or neutrons; in nuclear materials engineering — properties of nuclear fuels, effect of radiation on reactor materials, solvent extraction of metals, isotope

separation, nuclear fuel reprocessing, treatment of radioactive wastes.

RESEARCH FACILITIES

The Department's educational program is supported by a number of outstanding experimental facilities for advanced research in nuclear engineering.

THE M.I.T RESEARCH REACTOR

The M.I.T. Research Reactor operates at a power of 5,000 kw. It is fueled with U-235 and cooled and moderated by heavy water. Completed late in the spring of 1958, it is one of the finest university research reactors in the world. It provides first-hand experience in the design, performance, and operation of nuclear reactors and serves as a source of radiations for use in laboratory instruction on radiation detection and measurement methods. A variety of research projects make use of the intense sources of neutrons and gamma rays produced by the reactor. Areas of research in which the reactor is being used include: neutron physics, cross-section measurements, reactor physics, solid-state studies based on neutron diffraction, radiochemistry, physics of neutron-capture processes, activation analysis, research with short-lived radioisotopes, radiation-catalyzed chemical reactions, radiation-induced biological effects, radiation therapy, and studies of radiation effects on materials.

EXPERIMENTAL PLASMA FACILITIES

The Department utilizes extensive experimental facilities for production and confinement of large volumes of highly ionized plasmas and for studies of plasma turbulence, particle motions, and other phenomena. High-power lasers and other equipment are available both for plasma diagnostics and for study of basic physical interactions. Experimental apparatus for thermionic conversion studies is also available. The Department has facilities to support a unique program of controlled fusion engineering studies and has its own well-equipped graduate laboratory for instruction in plasma laboratory techniques.

The Department has a major role in the design and operation of ALCATOR, a joint project of the Research Laboratory of Electronics and the National Magnet Laboratory. ALCATOR is expected to produce a dense, hot plasma approaching the regime of fusion interest. ALCATOR is a major plasma physics installation and is expected to function for many years as the plasma equivalent of the M.I.T. Research Reactor as an educational and research facility.

Most of the research on plasmas and controlled fusion is done in M.I.T.'s Research Laboratory of Electronics. This Laboratory is an association of faculty and graduate students from many departments, and it includes groups active in all aspects of plasma research.

OTHER RESEARCH FACILITIES

The Department has a well-equipped nuclear instrumentation laboratory, a 14 MeV neutron source, and two subcritical natural-uranium reactors, one moderated by water and the other by graphite. Laboratory space and shop facilities are available for research in all areas of nuclear engineering. M.I.T.'s IBM Type 7094 and 360/65 digital computers are used extensively in research and graduate instruction. The Department has its own liquid helium refrigeration unit.

FIVE-YEAR PROGRAMS WITH OTHER DEPARTMENTS

The five-year programs leading to a joint Bachelor of Science in Chemical Engineering, Civil Engineering, Electrical Engineering, Mechanical Engineering, or Physics, and a Master of Science in Nuclear Engineering are helpful to students who, early in their undergraduate studies, decide to pursue a graduate degree in nuclear engineering.

Students desiring to enter such a program must meet the graduate admission requirements of the Department of Nuclear Engineering. They must submit their applications for admission at the end of their junior year. If admitted, the student's program will be arranged between the registration officers of the two participating departments. For further information, interested students should contact either their undergraduate department or the Department of Nuclear Engineering.

Department of Ocean Engineering

The marine environment is the challenging and productive province of the ocean engineer. His systems must operate in this uniquely changeable and unforgiving environment. These systems primarily serve the following purposes: ocean transportation, exploration and development of ocean resources, and the support of ocean sciences. His concerns include the design of surface ships, of submersibles, of offshore platforms, of ocean harvesting and pollution control systems, of underwater sensing and communication devices.

These systems are characterized by a high degree of self-sufficiency. Typically, they must be able to operate alone for extended periods of time and they rely on various subsystems for power, life support, and for mobility. These subsystems must mesh and interact in a tightly confined space. From the earliest days of ships, the ocean engineer has never had the luxury of being able to design components separately. The trading off of subsystem characteristics against each other toward the overall system objective has had to be his forte, synthesizing his specialty. In so doing he has had to be and must continue to be a jack of the basic engineering disciplines and a master of most.

Historically, the Department of Ocean Engineering at M.I.T. evolved out of the Department of Naval Architecture. A typical example of an ocean engineer is the naval architect, and the Department is proud of its 77-year history as a leading center of ship research and design. The Pratt School of Naval Architecture and Marine Engineering, housed within the Department, continues to be one of the world's leading focal points of ship design, ship hydrodynamics and ship structural research, propeller and ship propulsion systems development, and sailing yacht design. Undergraduate and graduate programs leading to a complete spectrum of degrees in Naval Architecture and Marine Engineering continue to be offered. In short, the broadening of the Department's responsibilities to include all man-made systems relating to the oceans implies no slackening in M.I.T.'s ship related programs. Rather, the Department's long standing expertise in marine vehicles and selected engineering sciences forms a solid foundation upon which to base its broadened efforts throughout the marine environment.

The Department's broadened Ocean Engineering Program received its original impetus from the demands of the offshore oil industry. As a result, many of the departmental programs are closely allied with requirements for the preliminary survey and erection of large offshore platforms. From this rather limited beginning, the program has rapidly grown to meet the challenges of efficient ocean utilization. This includes the design of survey submersibles, the control of oil spills and effluent discharges, the design of ocean sensor arrays, the use of ocean mineral resources, the role of marine biologics and fisheries, the development of specialized power systems, the management and utilization of the coastal zone, and the design of underwater habitats.

The facilities of the Department include a highly sophisticated variable pressure propeller tunnel, a towing tank, a model shop, a structures laboratory, and an acoustics and vibrations laboratory.

One of the goals of the Department's curricula, whether they lead to ocean engineering or naval architecture degrees, is to develop men who are ready to conceive, initiate, carry through, and ultimately direct large scale engineering projects having to do with the oceans. Such a person requires (1) a firm foundation in the basic engineering disciplines: applied mathematics, hydrodynamics, structural mechanics, vibratory phenomena, energy conversion, materials, and electronics; and (2) the ability to synthesize and integrate this knowledge toward workable, efficient systems; and to place his systems into proper perspective within the economic and societal framework. All the Department's curricula are based on these two underlying needs and therefore comprise a combination of courses in engineering fundamentals, marine systems analysis, and creative project work in a laboratory environment.

In addition, the Department offers a variety of advanced programs which are at the cutting edge of technology in (1) marine hydrody-

namics, (2) marine structural mechanics, (3) underwater acoustics and communication, and (4) vehicle control. These programs permit the graduate student to prepare for a research career in these fields or in specialized advanced engineering work.

Once a student has attained the fundamental engineering skills, he is free to, and in fact encouraged to, design his own program in a manner consistent with his particular set of interests. In so doing, he may take advantage of all the educational resources at M.I.T. as well as the Institute's unique relationship with the Woods Hole Oceanographic Institution.

The Department's educational programs lead to a broad engineering and scientific competence in engineering for the ocean environment. A flexible curriculum, a departmental faculty with wide and continuing research and industrial experience, and unusually close faculty-student contact all contribute to a sound and effective education.

THE UNDERGRADUATE PROGRAMS

Ocean Engineering
Naval Architecture and Marine Engineering
(Course XIII)

These curricula are intended for students interested in the engineering and engineering science aspects of ocean sciences, ocean exploration, and the utilization of the oceans, both for transportation and their other resources. It also serves as highly suitable preparation for the spectrum of graduate programs which the Department offers.

All students take the same required subjects in mathematics, science, and engineering fundamentals, along with subjects to fulfill the General Institute Requirements in Humanities and Laboratory.

The elective program is divided into two nearly equal parts. Planned electives assure that the program meets the student's objective, while unrestricted electives may be used to enhance this objective by further study in specialized areas or, alternatively, to broaden the student's educational experience.

The Department is always ready to discuss substitutions for departmentally prescribed subjects in order to enhance student objectives. Furthermore, a curriculum without designation of field permits pursuit of broader marine-related interests.

Within departmental subjects, attention is focused on the flexible and creative application of science and engineering to real physical problems, with examples chosen principally from those occurring in ocean engineering in its broad sense; design or systems projects emphasize the underlying engineering principles.

The curriculum is so arranged that whatever program has been followed in the first two years at M.I.T., the departmental requirements can be met in a total of four years without unduly compromising electives. Also, many students find it profitable to follow a five-year program, leading to the simultaneous award of Bachelor's and Master's degrees.

The four-year Course leads to the degree of Bachelor of Science in Ocean Engineering, in Naval Architecture and Marine Engineering, or without designation of field. The curricula for the degrees are given below:

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				132[1]
	ECONOMIC PRINCIPLES I (14.01) is required in the upperclass humanities and social science program if another subject in the field of economics is not included in the elective program.				
	The subjects 2.403, 13.001, and 18.03, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.				
	Laboratory Requirement.				12
DEPARTMENTAL PROGRAM					
	Required Subjects[2 3]				
2.403	THERMODYNAMICS	4	0	8	
13.001	INTRODUCTION TO MARINE APPLIED MECHANICS	4	0	8	
13.002	MARINE APPLIED MECHANICS	4	0	8	
13.73	A SURVEY OF OCEAN ENGINEERING	1	0	1	
13.79	APPLIED OCEAN ENGINEERING	3	1	5	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
18.075	ADVANCED CALCULUS FOR ENGINEERS	3	0	9	
					71
	Planned Electives[3 4 5]				
	At least seven subjects which are selected by the student and his Faculty Counselor, chosen to attain the educational objective of preparation for a career in Ocean Engineering, in Naval Architecture and Marine Engineering, or an educational objective defined by the student.			at least	72
	Unrestricted Electives[6]				73
Total units required for the S.B. degree					360

[1] The requirement for Class of '72 is 128 units, the unrestricted elective units being increased by 4.

[2] The Department encourages substitution of subjects of similar content after consultation with and concurrence of the Faculty Counselor.

[3] For the degree without designation of field delete 13.79, APPLIED OCEAN ENGINEERING (3–1–5) from the list of required subjects and increase the unrestricted elective units by 9.

[4] For the degree in Ocean Engineering at least one planned elective subject must be selected in four of the following nine areas: Acoustics and Vibration, Design, Hydrodynamics, Instrumentation, Materials and Fabrication, Ocean Environment, Power and Propulsion, Probability, and Structures. A suitable Special Problem (of at least 9 units), 13.700–13.709 SPECIAL PROBLEMS IN OCEAN ENGINEERING must be included.
[5] For the degree in Naval Architecture and Marine Engineering, at least one suitable planned elective subject must be selected in each of the following areas: Design, Hydrodynamics, Materials and Fabrication, Power and Propulsion, and Structures. A suitable Special Problem (of at least 9 units), 13.700–13.709, SPECIAL PROBLEMS IN OCEAN ENGINEERING, must also be included.
[6] Schedules of students in Course XIII may always be arranged to leave available 24 units of unrestricted elective in the second year.

Interpretation of the various areas listed in footnotes 4 and 5 in the curriculum statement above may be assisted by reference to the list of similar areas in the section relating to graduate study which follows. This list indicates a few subjects in each area.

Shipping and Shipbuilding Management (Course XIII-B)

This five-year program is intended for students primarily interested in the business and management phases of the marine industry. Students entering professional work in this field must have a firm technical background; hence all the departmentally prescribed requirements of the undergraduate curriculum in Naval Architecture and Marine Engineering must be satisfied. Although students are not formally admitted to the program until the beginning of the fourth year, the elective program in earlier years should be arranged with the course objective in view.

The program leads to simultaneous award of the degrees Bachelor of Science in Naval Architecture and Marine Engineering and Master of Science in Shipping and Shipbuilding Management. The undergraduate requirements are the same as for Course XIII, except that 13.700–13.709 *Special Problems in Ocean Engineering* is omitted, the 9 units being allotted to additional professional subjects, and that concentration in Economics (Field 6) and Labor Relations (Field 8) of the humanities program is not permitted. The graduate program is described under Course XIII-B in the graduate section of this departmental description.

GRADUATE STUDY IN THE DEPARTMENT

The Department's graduate programs in Ocean Engineering and in Naval Architecture and Marine Engineering require a broad engineering science base. If the undergraduate background of an entering graduate student does not meet this requirement, he is expected to include one or more subjects in his program as a graduate student to assure that his total educational experience conforms to this principle.

Graduate study may be pursued in one or more of the following areas: Ocean Engineering, Marine Applied Mechanics, Naval Architecture, Marine Engineering, Naval Engineering (Course XIII-A), Shipping and Shipbuilding Management (Course XIII-B), and Marine Systems.

Except for subjects required to achieve broadness, a graduate program in the Department is largely under control of the student, with the assistance of his Program Advisor, and within the detailed departmental requirements which are available from the departmental Student Information and Records Office.

An acceptable graduate program of 72 units plus an acceptable thesis leads to the degree of Master of Science in Ocean Engineering, in Naval Architecture and Marine Engineering, or without specification of field. Such a program usually requires about one calendar year, if the undergraduate preparation is adequate. The degrees Ocean Engineer, Naval Architect, Marine Mechanical Engineer, or Naval Engineer require at least two years.

To obtain the degree of Doctor of Science or Doctor of Philosophy usually requires more than three years following a Bachelor of Science degree. Specialization in any aspect of ocean engineering, naval architecture, marine engineering or other marine-related fields is appropriate.

Subjects in this Department which are appropriate to the programs of civilian graduate students in various areas are suggested by the tabulation below, which lists some areas of interest together with a few subjects in each area. These subjects are given as examples only, selected from the large number available within and outside the Department.

ACOUSTICS AND VIBRATION (2.06[U], 13.80, 13.81j, 13.83, 13.85)
DESIGN (13.36, 13.40[U], 13.41, 13.42)
HYDRODYNAMICS (13.00[U], 13.02, 13.06, 13.07, 13.08)
INSTRUMENTATION (2.14[U], 6.14[U], 13.72)
MATERIALS AND FABRICATION (3.141[U], 13.151J, 13.161J, 13.39)
OCEAN ENVIRONMENT (12.21[U], 13.93[U], 19.83[U])
POWER AND PROPULSION (13.20[U], 13.21, 13.25J[U], 13.27)
PROBABILITY (6.28[U])

Engineering

DEPARTMENT OF OCEAN ENGINEERING

STRUCTURES AND STRUCTURAL MECHANICS (13.10[U], 13.12, 13.30[U], 13.31[U], 13.32)
MARINE SYSTEMS AND ECONOMICS (13.61, 13.62, 13.67)

Those subjects marked with the superscript U are intended primarily for undergraduates and may not necessarily result in the accumulation of degree credit, depending on the level of the subject and the nature of the graduate program of which they are a part.

Selected subjects from other departments are usually included, as appropriate to the various graduate programs. Subjects offered in connection with the Joint Program in Ocean Engineering with Woods Hole Oceanographic Institution also may be included.

In support of the broad view which it takes of its responsibilities, the Department offers a Master's degree program in marine systems. In order to complete this program in one year, the student must have background in economics and probabilistic systems in addition to the Department's usual requirements. Central to this curriculum are two departmental subjects which introduce the student to optimization techniques and network analysis and their application to marine problems, and two departmental subjects which introduce the student to the private and public economics of marine transportation and natural resource systems, and techniques for making operational and investment decisions with respect to these systems under the uncertainties that generally prevail. These subjects are supplemented by other offerings of the student's choice. Such a program usually leads to the Master of Science degree without specification of field.

The following tabulation indicates those graduate degrees implying specification which are available:

MASTER OF SCIENCE

Ocean Engineering	Course XIII
Naval Architecture and Marine Engineering	Course XIII
Shipping and Shipbuilding Management	Course XIII-B

ENGINEER DEGREES

Ocean Engineer	Course XIII. Also available in joint program with Woods Hole Oceanographic Institution, Course XIII-W.
Naval Architect	Course XIII
Marine Mechanical Engineer	Course XIII
Naval Engineer	Course XIII-A

THE DOCTORATES

{ Doctor of Science { Doctor of Philosophy	Course XIII. Also available in joint program with Woods Hole Oceanographic Institution, Course XIII-W.

The joint program with Woods Hole Oceanographic Institution is described in this section.

Entrance Requirements for Graduate Study

In addition to the general requirements for admission described in Section 8 of this Catalogue, the undergraduate preparation should be equal in quality, quantity, and breadth of coverage to the Department's undergraduate curricula. (See also the description of Course XIII-B, below.)

If undergraduate preparation has been significantly less intensive in any area, the deficiencies must be removed prior to the award of any of the degrees implying specification. This may be accomplished concurrently with graduate work if the deficiencies are not extensive. Undergraduate subjects so required are not acceptable to the Department in partial fulfillment of the advanced degree requirements. Somewhat less broad undergraduate work is appropriate for candidates for the degree of Master of Science without specification, if accompanied by correspondingly increased competence in areas pertinent to the proposed graduate program.

Departmental Requirements for Advanced Degrees

The program of studies for an advanced degree must meet the general requirements specified in Section 3 of this Catalogue and must be acceptable to the Departmental Committee on Graduate Students.

Unless special approval is given by this Committee, candidates for any graduate degree are expected to include in their programs at least one term of advanced mathematics beyond the requirements of the Department's undergraduate curricula. The program for an S.M. degree must include a minimum of 72 subject units plus a thesis acceptable to the Department. A minimum of 48 of the 72 units must be "A" subjects. The S.M. degree thesis should represent the equivalent of a half term of full-time work.

A program for an Engineer degree ordinarily includes two subjects in the area of economics, industrial management, or political science, and at least 12 units of comprehensive design, such

as DESIGN OF A WATERBORNE VEHICLE (13.42), or the equivalent. A single thesis will generally be acceptable for both the Master of Science and Engineer degrees, provided it is appropriate to the specifications of both degrees and demonstrates the educational maturity expected of candidates for the higher degree.

Additional departmental requirements applicable to each of the S.M. and Engineer degrees are available from the departmental Student Information and Records Office.

In addition to the Institute requirements for the doctoral program, the Department requires the successful completion of qualifying examinations before a student is admitted to a doctoral program. The programs of students must be acceptable to the Departmental Committee on Graduate Students, both as to depth in the major area and broadness in collateral areas. Details of the examination and other special departmental requirements, including those for the doctoral thesis, may be obtained from the departmental Student Information and Records Office.

The Department interprets its programs rather broadly. Thus a program for a degree with specification can include selected subjects in other departments, such as mathematics, aeronautics and astronautics, or civil or mechanical engineering. The thesis may be in another department if it is directly applicable to the respective graduate degree programs.

Assistantships and Graduate Scholarships

A limited number of teaching and research assistantships are available in the Department each year. These are awarded on the basis of both qualification and need. The duties associated with these assistantships contribute directly to the assistant's educational program. Maximum registration for an assistant is limited to 24 to 36 units per term depending upon the type of appointment. Additional registration may be allowed when directly connected with an assistant's assigned duties.

M.I.T. fellowships and scholarships, and National Science Foundation grants awarded on recommendation of the Department are available. In addition, some industrial fellowship aid is available, generally to students who are graduates of this Department or who have completed some graduate work in the Department. Fellowships are also awarded each year by the Society of Naval Architects and Marine Engineers. These latter are valid for study at any institution of the recipient's choice and are usually awarded to applicants who have previously evidenced strong interest in the fields of naval architecture, ocean engineering, and marine engineering or in the shipping industry, either through their education or their professional work. Prospective students are invited to communicate with the Head of the Department regarding any of these educational and financial opportunities. Applications for the Society of Naval Architects and Marine Engineers Graduate Fellowships are made directly to that Society. Inquiries for the fall term should be made late in the preceding fall term.

Naval Construction and Engineering (Course XIII-A)

This Course provides appropriate academic background for officers who would later actively participate in concept formulation, design, and construction of naval vessels. In addition to general engineering and science and a core program of naval architecture and marine engineering subjects, each student follows one of several specialized curricula in aspects of, or applicable to, naval construction and engineering.

In addition to full-time study at the Institute for six terms and two summer terms, the Course provides, during the summer preceding the final year, either appropriate non-resident work experience or an additional term of full-time resident academic study.

The Course leads to the degree of Naval Engineer or Master of Science in Naval Architecture and Marine Engineering. For programs leading to the Naval Engineer degree, a Master of Science degree normally is awarded simultaneously upon recommendation of the Department or of the Department represented by the student's specialty. For programs leading to the degree of Master of Science in Naval Architecture and Marine Engineering, a Master of Science degree may be awarded simultaneously in a second field of specialization upon recommendation of the Department represented by that field.

Admission to the Course requires that the Department's entrance requirements for graduate study be satisfied.

Shipping and Shipbuilding Management (Course XIII-B)

The educational objectives of the five-year program in Shipping and Shipbuilding Man-

agement, previously described, may also be achieved by post-baccalaureate study. In addition to satisfaction of departmental requirements for the undergraduate curriculum in Naval Architecture and Marine Engineering, students select areas of concentration in management or operations. They study undergraduate and graduate subjects in the Department of Economics, the Alfred P. Sloan School of Management, and the Department of Ocean Engineering. They may also broaden their experience by electing advanced subjects offered by other departments at the Institute.

Requirements for admission to the graduate program in shipping and shipbuilding management are the same as for other graduate study in the Department, as stated above, with the addition that scores in the Admissions Test for Graduate Schools of Business must be submitted.

Students entering the program at the graduate level should expect to devote two years to completing requirements for the degree of Master of Science in Shipping and Shipbuilding Management, in view of the prerequisites necessary. Students in the five-year program satisfy these prerequisites by using undergraduate elective time.

The graduate subjects required for the degree are established after consultation with and concurrence of the Alfred P. Sloan School of Management. All general requirements of the Department for the award of advanced degrees as specified above must be satisfied.

Center for Advanced Engineering Study

The M.I.T. Center for Advanced Engineering Study was established in order to provide ways for experienced professional engineers and scientists to attain and maintain the competence needed for continued leadership in an age of unparalleled technological change. The Center adds a new dimension to the activities of M.I.T. by offering educational programs which are designed to enable experienced engineers and scientists from industry, government, and educational institutions to acquire the understanding and skills needed to open technical frontiers.

Programs of the Center

The programs of the Center include the Practicing Engineer Advanced Study Program described below, the Systematic Policy Analysis Program, five- to ten-week programs in specialized areas of science and engineering, interdisciplinary projects concerned with the potential contributions of new and advanced technological developments to important and complex problems, and participation in continued education programs offered on the premises of industrial and government organizations.

The Practicing Engineer Advanced Study Program

The Practicing Engineer Advanced Study Program is planned to enable practicing engineers and scientists to work in depth in technological areas pertinent to their professions. The program of each participant is tailored to his needs. It is thus possible to accommodate the technical manager who wishes to understand those developments that bear directly on his problems, the man who seeks competence in depth at a technological frontier, and the man who desires to strengthen and expand his technological base.

Members of the Program are affiliated with the Center for one or more terms; a two-term sequence is recommended. Each member is associated with a faculty member who acts as his sponsor for the Program and helps arrange activities divided between formal classroom study, tutorial or research study, and other M.I.T. opportunities best suited to the member's needs and background.

The entire offering of M.I.T. undergraduate and graduate subjects, seminars, and colloquia are available. Subjects may be selected from those offered by the Schools of Engineering, Science, Architecture and Planning, Management, and Humanities and Social Science. Participation in ongoing research work may be carried out, and self-study programs with informal tutorial assistance can be arranged. The program of each participant can be largely tailored to his specifications provided it represents a serious intellectual commitment commensurate with his background and professional aims.

SEMINARS AND SPECIAL SUBJECTS

Members of the M.I.T. Faculty conduct weekly seminars in the Center for Advanced Engineering Study during the fall and spring terms; these seminars are planned especially for members of the Practicing Engineer Advanced Study Program. The following special subjects of broad interdisciplinary interest are also offered within the Center for members of the Program:

COMPUTER SYSTEMS (1.156)
PROBABILITY THEORY AND RANDOM PROCESSES (6.579)
INTRODUCTION TO OPERATIONS RESEARCH (6.538, 6.539)

Special sections of the following subjects are offered for participants in the Center's Systematic Policy Analysis Program. However, these subjects are also open to the Advanced Study Program participants.

PRINCIPLES OF SYSTEMATIC POLICY ANALYSIS (17.838)
SEMINAR IN SYSTEMATIC POLICY ANALYSIS (17.840)
INTRODUCTION TO MATHEMATICAL MODELS IN THE SOCIAL SCIENCES (17.955)
STATISTICS FOR THE SOCIAL SCIENCES (17.952)

Before the fall term starts, participants in the Practicing Engineer Advanced Study Program may attend CALCULUS REVISITED, an optional six-week review offered by the Center to provide an opportunity to strengthen mathematical skills before entering the mainstream of activities of the Center. This review is an intensive development of the first two years of a modern approach to calculus. The point of view adopted is that of the technical professional who intends to apply mathematics to his problems. The aim is to provide the real understanding that supplies the basis for more advanced work and for continued self-development as well as for proficiency.

Engineering

CENTER FOR ADVANCED ENGINEERING STUDY

DEGREES AND GRADES

A certificate will be awarded following satisfactory completion of the Program. Participants who fulfill the requirements of the Graduate School are eligible for advanced degrees. Grades will be recorded for those M.I.T. subjects which are taken for credit.

The Program fee, payable to M.I.T., is $1,800 for the fall or spring term, $3,600 for the two-term school year, $1,400 for the regular summer term, and $700 for CALCULUS REVISITED. The costs of the program are substantially greater than this fee. Initially, each man accepted as a participant will be awarded, from the grant to begin the Program provided by the Alfred P. Sloan Foundation, a scholarship which will supplement the Program fee in meeting M.I.T.'s costs.

The personal and family costs incident to living in Greater Boston for participation in the Program will vary among the men according to their personal circumstances. A personal budget for the year in Greater Boston should include (1) living costs; (2) the extra costs involved in moving; (3) the cost of books and other study materials.

ADMISSION REQUIREMENTS

The primary requisites for admission are evidence of serious intent, intellectual maturity, and the technical background needed for participation, with appropriate guidance, in regular M.I.T. subjects and other scholarly activities at the Institute. Participants will be selected by an M.I.T. committee drawn from faculty members working in areas in which the candidate proposes to study. Application forms are available from the Director of the Center. Applications for the fall term should be received before July 1, for the spring term before December 1, and for the summer term before May 1.

Joint Program with the Woods Hole Oceanographic Institution

The Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology offer joint programs of education and research in oceanography, biological oceanography, and ocean engineering. (See this Section under the School of Science for the programs in oceanography and biological oceanography.) These programs are administered by committees drawn from the faculty and staff of the two institutions and lead to degrees awarded jointly by the two institutions. Extensive resources for advanced study and research are available at both M.I.T. and the Woods Hole Oceanographic Institution.

Subjects are offered at both institutions, and bus service is provided to make it possible for a student to be resident at either Cambridge or Woods Hole. Most fundamental subjects are taught at M.I.T. Thesis research may be carried on at either institution.

The Woods Hole Oceanographic Institution operates a fleet of research ships, submarines, and aircraft, and has extensive laboratory facilities and an active research staff. A modest marine facility is maintained by M.I.T. at Boston harbor consisting of dock space and a small research vessel.

OCEAN ENGINEERING

The Department of Ocean Engineering offers a joint program in Ocean Engineering with the Woods Hole Oceanographic Institution leading to the degrees of Ocean Engineer, Doctor of Philosophy, or Doctor of Science awarded jointly by the two institutions. Students in this program choose to specialize in those areas of ocean engineering related to advancements in marine geophysics, marine geology, and oceanography.

Entrance Requirements for the Joint Program

Applicants to this program should have an undergraduate degree in one of the fields of engineering or applied mechanics appropriate to ocean engineering and have a sound foundation in engineering sciences and related mathematics.

The Graduate Program

The general requirements for the degrees are the same as for the corresponding M.I.T. degrees given in Section 3 of this catalogue and the requirements of the Department of Ocean Engineering as described in this section. A student will normally have to spend at least his first graduate year at M.I.T., and for the engineer's degree at least another year at Woods Hole. The candidates for the doctorate will have to spend more time at both institutions. Students are strongly encouraged to spend the summer preceding the first academic year at the Woods Hole Oceanographic Institution and normally are required to spend the following summer there. Subjects in ocean engineering and the related engineering sciences are offered by the Department of Ocean Engineering and at the Woods Hole Oceanographic Institution. These subjects are described in the Description of Subjects under Ocean Engineering (13). In addition, several other M.I.T. departments, especially Earth and Planetary Sciences, and Meterology, offer subjects in fields related to ocean engineering. The Departments of Earth and Planetary Sciences and of Meteorology also offer subjects given at Woods Hole in connection with the Joint Doctoral Program in Oceanography. These latter will be found in the Description of Subjects under Earth and Planetary Sciences (12.) and Meteorology (19.).

The Graduate Degrees

The Program leads to the degrees of Ocean Engineer or the degree of Doctor of Philosophy or Doctor of Science, all awarded jointly by the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution. This program is coordinated closely with the separate M.I.T. Ocean Engineering Degree Program described under the Department of Ocean Engineering.

Assistantships and Fellowships

A limited number of fellowships and graduate assistantships for the joint program is available on a competitive basis. Further information and applications may be obtained from the Head of the Department of Ocean Engineering

at M.I.T. and from the Dean of Graduate Studies of the Woods Hole Oceanographic Institution.

Application Procedure

Application for admission to the joint program or for financial aid should be made on the M.I.T. Graduate Application Form, copies of which may be obtained from the Director of Admissions at M.I.T. or from the Woods Hole Oceanographic Institution. Requests for further information relating to the joint program may be addressed to the Head of the Department of Ocean Engineering of M.I.T. or to the Dean of Graduate Studies of the Woods Hole Oceanographic Institution.

SCHOOL OF HUMANITIES AND SOCIAL SCIENCE

The Dean of the School of Humanities and Social Science describes its many activities in serving M.I.T. Courses and granting M.I.T. degrees.

The School of Humanities and Social Science consists of six departments, with a faculty of about 140 in the three professorial ranks. Three of these departments are in the social sciences — Economics, Political Science, and Psychology. Of the three humanistic departments, two are multidisciplinary in their scope. Thus the Department of Humanities embraces the fields of history, literature, and music, while the Department of Foreign Literatures and Linguistics is concerned with language skills, literature in foreign languages, and the more technical field of linguistics. The Department of Philosophy completes the roster.

The faculty of this School has three complementary missions. In the first place, it is responsible for much of the general education required of every undergraduate at M.I.T., regardless of his area of specialization. In this role, the Department of Humanities and the Department of Philosophy offer several sequences of interdisciplinary subjects for all freshmen; and the members of those Departments are then joined by social scientists in offering a limited number of rather broadly disciplinary subjects in the sophomore year. Some of these freshman and sophomore subjects are also available in sections taught exclusively in French. Later, all of the faculties of the School meet their share of juniors and seniors, since these upperclassmen are required to elect four additional terms in the humanities or social sciences, including typically a sequence of three terms in a single field chosen from ten available areas. The curriculum for the first two years and the ten fields for subsequent study are described in Section 2 of this Catalogue.

A second mission of the School involves curricula leading to the degree of Bachelor of Science. There are currently such programs in the Department of Economics, the Department of Political Science, the Department of Philosophy, and the Department of Humanities. Those in Humanities involve for some students, essentially a second major in some branch of either science or engineering, while those in Economics, Political Science, and Philosophy are specified as single majors. There is always, however, ample opportunity for each student through the use of free electives to combine a considerable amount of science or engineering with his chosen field of social science if he is so inclined. Even when the student uses his free electives otherwise, there remains of necessity a substantial amount of mathematics and science in his program, as a highly desirable complement to his social science major. In this respect, all of the School's undergraduate degree programs differ substantially from curricula in similar fields at most other institutions.

There are other differences of perhaps greater import. The view is over-

whelmingly accepted at M.I.T. that science and engineering are important not only for their own sake but also as vital components of modern life and culture. For our own students no less than for all others at the Institute, these disciplines are to be embraced and mastered rather than feared. In other words, no matter what the extent of our students' involvement with science and engineering subjects, the same rigor is expected of them as of their fellow students who are majoring in a field of science or engineering. This is so both for those technical fields that are professionally complementary to study within our own School and also for those aspects of science or engineering that serve only to fill out our own students' general education. Far from regarding scientific study as antithetical to the humanistic or social-scientific, we feel that the essential unity of serious study in any area should be recognized. Accordingly, we hope that our programs are particularly well fitted to prepare the right kind of young man or woman for living in the modern world.

The student whose formal education is completed with his four-year degree should find that the preparation for modern life afforded by our Courses in humanities or social science is unique and effective. Alternatively, he should also find himself well prepared for further study in a law school, medical school, or graduate school of business, as well as in a graduate department in the area of his own major in the humanities or social science. And finally, if he has planned his program suitably, he should also find it possible to continue in graduate work in his selected field of science or engineering. Thus our curriculum is an unusually flexible and open-ended one.

The School of Humanities and Social Science accepts with enthusiasm as the third part of its mission a responsibility to contribute to an expansion of the frontiers of knowledge. It does so both through the research and creative scholarship of its faculty and, in a growing number of fields, through programs of graduate study leading to the doctorate. These activities are prized not only for their own sake but also as contributing to the quality of undergraduate instruction. Few members of the faculty of this School are not engaged in research and publication, ranging from individual efforts to the large group engagement of the Center for International Studies, which is also a part of the School. Doctorates can be earned through research and study in fields of economics, political science, psychology, linguistics, and philosophy.

The extent of the graduate work and research is perhaps the feature which most distinguishes the School of Humanities and Social Science at M.I.T. from those to be found in other technological institutions. The extent to which the members of this faculty are in close contact with the faculties of science and engineering is perhaps what most distinguishes it from those of non-technological institutions. We believe this to be a happy pair of circumstances, which make every part of our student offering richer.

THE UNDERGRADUATE CURRICULA IN THE SCHOOL OF HUMANITIES AND SOCIAL SCIENCE

The S.B. curricula in the School of Humanities and Social Science consist of a program of general education, emphasizing science, mathematics, and the humanities and social sciences (the General Institute Requirements), and a concentration in one of the humanities or social science disciplines, sometimes combined with a group of subjects in science or engineering (the Departmental Programs). The Departmental Programs are given by each department on the following pages.

Each student arranges his program of studies with the advice and consent of a Faculty Counselor. Typical Course Schedules are issued each term by the Registrar with the Class Schedules. R.O.T.C. subjects may be used according to the specifications in Section 2.

Department of Economics

Economics is the scientific study of economic institutions and systems. It is a useful study in an intellectual sense because it trains students to think carefully and logically about complex social phenomena. By such knowledge it is possible to understand the impact on economic systems and institutions of broad social and economic developments or of new economic policies and the response of these units to them. The growing awareness of these interactions on the part of scientists and engineers makes the study of economics especially relevant at M.I.T.

THE UNDERGRADUATE CURRICULUM

Economics (Course XIV)

The Course leading to the degree of Bachelor of Science in Economics combines a rigorous and complete training in technical economics with opportunities for a broad and balanced undergraduate education. Students may select programs that emphasize the relation of economic ideas to technology by concentrating their free time in science and engineering; they may choose programs that focus on economics and other social sciences; or they may undertake to relate economics to history, philosophy, or literature. The successful completion of the degree prepares students for graduate study in economics, industrial relations, business administration, law, and related fields, or for careers in teaching, government, research, unions, and business.

The aims of the degree program are: (1) to give the student a firm grounding in modern economic theory, (2) to provide a basic descriptive knowledge of the U.S. and world economy, (3) to develop in the student a capability for quantitative research and independent thought. These aims roughly correspond to the requirements of theory, electives, and statistics and research. The choice of electives also provides an opportunity for students to go into a single field or problem in depth.

The requirements allow substantial freedom for the student, both in designing his program within economics and in balancing it with subjects in other disciplines. The large amount of unrestricted elective time exists to encourage students to shape a program close to their own needs and interests.

Students who have taken 14.01 and 14.02 by the end of their second year can follow a program which permits considerable depth in electives in the third and fourth years. The most satisfactory plan is to take intermediate economic theory (14.04 and 14.06) in successive terms of the third year, and to complete introductory statistics before the end of the third year. This satisfies prerequisites for all subjects, including the required economic research seminar (14.39), which prepares the student for thesis research.

The Department specifies one science distribution subject and strongly recommends that all students take some subject in computer techniques and, especially if professionally interested in economics, further work in mathematics.

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.[2]				**132**[1]
	The Science Distribution Requirement will be satisfied by 14.30, which is required in the Departmental Program, plus appropriate subjects totaling				**24**
	Laboratory Requirement				**12**
DEPARTMENTAL PROGRAM					
	Required Subjects				
14.01	ECONOMIC PRINCIPLES I	3	0	6	
14.02	ECONOMIC PRINCIPLES II	3	0	6	
14.04	INTERMEDIATE MICROECONOMIC THEORY	4	0	8	
14.06	INTERMEDIATE MACROECONOMIC THEORY	4	0	8	
14.30	INTRODUCTION TO STATISTICAL METHOD IN ECONOMICS	4	0	8	
14.39	ECONOMIC RESEARCH SEMINAR	2	0	10	
	THESIS			9	
					75
	Restricted Electives				
	Elective subjects in economics			39	
	A coherent program in a field related to economics but outside the Department as agreed on between the student and the Faculty Counselor. Subjects which also satisfy the General Institute Requirement may be used with a corresponding increase in unrestricted electives.			24	**63**
	Unrestricted Electives				**54**
Total units required for the S.B. degree					**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] Subjects in Field Six (Economics) and Field Eight (Labor Relations) may not be used for the humanities and social science requirement.

GRADUATE STUDY IN ECONOMICS

The Department of Economics offers work leading to the degrees of Master of Science in Economics and Doctor of Philosophy.

Entrance Requirements for Graduate Study

In place of the general requirements for admission given in Section 8 of this Catalogue, the Department specifies the following prerequisites for graduate study in economics. A student whose deficiencies are of minor extent will be permitted graduate registration while taking appropriate subjects to remove them.

Mathematics. One full year of college mathematics, including at least one term of calculus. Students may remove a deficiency in mathematics by completing a special one-term subject, MATHEMATICS FOR ECONOMISTS (14.101).

Science. One full year of college work in science. A deficiency in science may be removed by completing any suitable one-term subject in science at the Institute.

Humanities and Social Science. At least six semester subjects in English, history, and other humanities or social science subjects equivalent in scope to those included in the undergraduate curriculum of the Institute. These subjects should be in other than the candidate's own professional field.

Professional Subjects. An undergraduate major in economics is considered desirable for graduate study in economics. Qualified students who have majored in other fields may be admitted, however, if their programs have included an appreciable amount of economics.

Master of Science in Economics

Most graduate students in the Department are Ph.D. candidates. Under special circumstances, however, admission may be granted to candidates for the S.M. degree. The general requirements for the Master's degree are given in Section 3.

Doctor of Philosophy

A candidate for the doctorate must prepare himself in five fields, three of which are covered by the General Examination. Two fields may be satisfied by one year of course work. Economic theory, including both micro- and macroeconomics, is required as a field in the General Examination for all students. Among the four elective fields are advanced economic theory, monetary economics, fiscal economics, industrial organization, international economics, economic development, Soviet economics and comparative economic systems, urban economics, labor economics, economic history, and statistical theory and econometrics. If econometrics and economic history are not among the candidate's five fields of concentration, he must also take one graduate subject in each of these areas.

No stated number of graduate subjects in the Department of Economics is required, but ordinarily the candidate will need two full academic years of work to prepare himself adequately for his General Examination and to meet the other pre-thesis requirements.

The doctoral thesis must be written in residence. As a rule it represents at least one year's research.

The Department has no general foreign language requirements. When a foreign language is essential for full access to the literature in the field of the student's major interest (for example, European Economic History, Communist Economies) or to his thesis research, a language requirement will be imposed by the Department upon the recommendation of the Thesis Supervisor or the Graduate Registration Officer. Such a requirement will be administered by the Department of Foreign Literatures and Linguistics, and can be met by satisfactory course work at other schools, at M.I.T., or by examination.

Students interested in developing professional competence in the economics and planning problems of the city may combine study in the Department of Economics with study in the Department of Urban Studies and Planning. Depending on background, candidates can expect to take two and a half academic years of work to prepare for the General Examination.

Department of Foreign Literatures and Linguistics

The Department of Foreign Literatures and Linguistics offers subjects for undergraduate and graduate students in several foreign languages and literatures and in linguistics. It also provides a program leading to the degree of Doctor of Philosophy.

UNDERGRADUATE SUBJECTS

The Department provides instruction on several levels in German, French, and Russian. Introductory subjects aim first at familiarity with the spoken language, emphasizing pronunciation, and second at minimum essentials for a reading knowledge. The intermediate level provides for a continuation of speaking and the development of a broad reading vocabulary. The texts cover fiction, drama, and historical or descriptive works to introduce students to the genius, institutions, and social organization of the countries in question. Advanced subjects are conducted largely in the foreign language and stress analysis of the form and content of the literature of each country. A specially equipped language laboratory provides facilities for hearing and speaking languages at all levels.

Undergraduate subjects in linguistics are offered to explore the structural and semantic relationships of language and to examine problems in linguistics and search for possible solutions. There is an active program of research, in which tools and concepts of science and engineering are applied to the study of language.

Special freshman and sophomore humanities subjects provide reading and lectures in French allowing students to use and improve their knowledge of the language while simultaneously satisfying the humanities requirement. These subjects are open to graduates of American secondary schools with three or more years of unusually good achievement in French.

A two-term sequence on Dante provides both language study and literary analysis. Four advanced subjects in Spanish literature are offered for undergraduates with an adequate background in Spanish.

The Department's subjects are open as electives to all qualified students throughout the Institute and are acceptable as freshman electives. There is, however, no undergraduate degree program in foreign literatures or linguistics at M.I.T.

In choosing language subjects, students should bear in mind that credit towards graduation will not be given for repeating work offered for admission.

GRADUATE SUBJECTS

For departments which have a foreign language requirement, two-term subjects in French, German, Russian, and Spanish, *open to graduate students only*, are designed to help develop intermediate competence in the reading of both technical and general materials. There are parallel two-term subjects in the same languages, *also open to graduate students only*, which aim to develop intermediate competence in the listening, speaking, and reading skills. Here again, the materials studied are both technical and general. These subjects carry no credit.

The Doctoral Program in Linguistics (Course XXIII)

The program of studies leading to the degree of Doctor of Philosophy aims to give a comprehensive knowledge of modern linguistics, with particular emphasis on its experimental, quantitative, and theoretical aspects. To enter the program, each student must satisfy the Institute requirements for admission to the Graduate School and have done well in his previous academic work. He must be formally accepted by the Department of Foreign Literatures and Linguistics as a candidate for the degree.

DOCTOR OF PHILOSOPHY

In place of the general requirements for admission given in Section 8 of this Catalogue, the Department specifies the following prerequisites:

Mathematics. One full year of college mathematics.

Science. One full year of college work in science.

Languages. Competence in two languages in addition to English is required, competence being defined as at least three years of formal study or the equivalent.

Humanities. At least six term subjects in literature, history, philosophy, or other humanities subjects equivalent in scope to those included in the undergraduate humanities curricula of the Institute.

A student with high academic rating who is deficient to a minor extent in one or more of the above requirements may be permitted graduate registration while fulfilling them at the Institute by taking appropriate subjects.

Subjects required of all doctoral candidates are as follows:

LINGUISTIC STRUCTURE (23.755)
INTRODUCTION TO LINGUISTICS II: PHONOLOGY (23.761)
ADVANCED PHONOLOGY (23.762)
SURVEY OF GENERAL LINGUISTICS I (23.792)

Before the student may start his doctoral research he is required to pass a comprehensive General Examination demonstrating competence in general linguistics, linguistic theories and methods, practical linguistic analysis, and the relation between linguistics and some adjacent field such as electrical engineering, mathematics, philosophy, physics, or psychology.

A Minor in one of the above related fields is recommended, though many other fields may also be suitable. The general requirements for the Ph.D. degree are indicated in Section 3 of this Catalogue.

Humanities

DEPARTMENT OF HUMANITIES

Department of Humanities

In its efforts to achieve a balanced curriculum for all undergraduates, M.I.T. provides both a required and an elective program in history, literature, philosophy, history and philosophy of science, anthropology, music, and drama in the Department of Humanities.

In addition, the Department of Humanities offers three undergraduate programs which combine the basic subjects in science and engineering with a concentrated program in the humanities; these programs are Humanities and Engineering (Course XXI-A) and Humanities and Science (Course XXI-B, Programs 1 and 2).

THE UNDERGRADUATE CURRICULA

Humanities and Engineering (Course XXI-A)
Humanities and Science (Course XXI-B, Program 1)

These two undergraduate Programs in Humanities and Engineering and in Humanities and Science offer a kind of education from which students may go on to graduate study in science, engineering, and humanities; or into teaching, law, linguistics, medicine, business, and a variety of other fields.

Because of their flexibility, these programs provide for choice of electives, especially in the third and fourth years. A student may devote more than half of his studies to humanities and the remainder to science or engineering, developing special interests in any combination of the two subject areas. Both Programs lead to a Bachelor's degree at the end of senior year; a student may continue for a fifth year to earn a second Bachelor's degree in the particular field of science or engineering which he studied as an undergraduate. In some cases the fifth year may lead to a Master's degree.

Built on the base provided by the Institute's general requirements in mathematics, physics, chemistry, and humanities, each of these Programs provides a curriculum of unusual scope and balance. One part is the undergraduate curriculum of one of the science or engineering departments, shortened through the omission of certain of the more specialized or technical subjects. The other part consists of study in the humanities, chosen by each student with the advice of his Faculty Counselor from the various disciplines of the Department of Humanities and the Department of Foreign Literatures and Linguistics. The student chooses one field for concentration: literature (English, American, French, German, Russian, and comparative literature); history and history of science; anthropology, philosophy; or music. Study combining psychology and humanities is also available.

An experimental program in Social Inquiry, consisting of seminars and subjects in different disciplines, provides an option in which students in Course XXI-A and Course XXI-B, Program 1 can combine a field of Engineering or Science with the study of social, political and cultural issues in contemporary society. The option is also available to students in Course XXI-B, Program 2 to satisfy the minor field requirement.

In the fourth year members of Course XXI-A and Course XXI-B, Program 1, participate in a Humanities Seminar, interdisciplinary in character, which examines a single topic from the several perspectives of the students' previous study under the guidance of the Humanities department faculty and visiting professors. Each student also receives instruction in the writing of a thesis.

Humanities and Science
(Course XXI-B, Program 2)

This new program, first offered to the class of 1969, provides a concentration or a major in history, literature, philosophy (available only to students in the Classes of '72, '73, and '74), anthropology, or music. Like the other branches of Course XXI, it is based on the regular Institute requirements in science and in humanities, but provides a study of the humanities in greater range and depth. The required curriculum consists mainly of eight or nine subjects in a chosen field plus four subjects from related fields of humanities, social science, foreign literatures, linguistics, or visual arts. Depending upon the field of specialization, a seminar devoted to advanced study is required in the junior or senior year and a thesis in the fourth year. Students whose accomplishment is high should be able to qualify for graduate study in their fields in major universities; the Program could also be elected by students who wish to

pursue a humanities discipline in greater depth than is ordinarily provided in Courses XXI-A and XXI-B, Program 1. A generous number of electives makes it possible to continue work in science, engineering, humanities, or other fields taught in the Institute, allowing the student to increase the concentration in the discipline chosen or to broaden intellectual interests by studies in fields outside of his concentration. Faculty Counselors in each of the disciplines will help students to arrange suitable programs following both their main lines of interest and future professional objectives.

Course XXI-A leads to the degree of Bachelor of Science in Humanities and Engineering, and both Programs of XXI-B lead to the degree of Bachelor of Science in Humanities and Science. The curriculum for the first year is shown in Section 2; the curriculum requirements for the degrees in both Courses are summarized below.

HUMANITIES AND ENGINEERING (COURSE XXI-A)

				Total units
GENERAL INSTITUTE REQUIREMENTS				
	Specific science and humanities and social science subjects.			**132**[1]
	Science Distribution Requirement.			**36**
	Laboratory Requirement.			**12**
DEPARTMENTAL PROGRAM				
	Required Subjects			
21.08	HUMANITIES SEMINAR	3	0 9	
	THESIS		14	
				26
	Restricted Electives			
	Elective subjects restricted to one of the Humanities disciplines, e.g., history, literature, philosophy, music; social inquiry.		54	
	Elective subjects restricted to one of the engineering curricula		48	
				102
	Unrestricted Electives			**52**
Total units required for the S.B. degree				**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

HUMANITIES AND SCIENCE (COURSE XXI-B)
CURRICULUM OF PROGRAM 1

				Total units
GENERAL INSTITUTE REQUIREMENTS				
	Specific science and humanities and social science subjects.			**132**[1]
	Science Distribution Requirement.			**36**
	Laboratory Requirement.			**12**
DEPARTMENTAL PROGRAM				
	Required Subjects			
21.08	HUMANITIES SEMINAR	3	0 9	
	THESIS		14	
				26
	Restricted Electives			
	Elective subjects restricted to one of the humanities disciplines, e.g., history, literature, philosophy, music; anthropology, social inquiry.		54	
	Elective subjects restricted to one of the science curricula or to psychology		48	
				102
	Unrestricted Electives			**52**
Total units required for the S.B. degree				**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

CURRICULUM OF PROGRAM 2

				Total units
GENERAL INSTITUTE REQUIREMENTS				
	Specific science and humanities and social science subjects.			**132**[1]
	Science Distribution Requirement.			**36**
	Laboratory Requirement.			**12**
DEPARTMENTAL PROGRAM				
	Restricted Electives			
	One of the following:			**117 to 135**
	(a) *History*			
21.081	HISTORY SEMINAR	2	0 8	
	THESIS		14	
	Elective subjects in History		72	
	Elective subjects in a second discipline of humanities, social science, visual arts, foreign literatures, or linguistics; anthropology, social inquiry.		36	
			132	
	(b) *Literature*			
	Elective subjects in Literature		90	
	Elective subjects in a second discipline of humanities, social science, visual arts, foreign literatures, or linguistics; anthropology, social inquiry.		36	
			126	
	(c) *Philosophy*[2]			
24.291	PHILOSOPHY SEMINAR	2	0 7	
	Elective subjects in Philosophy		72	
	Elective subjects in a second discipline of humanities, social science, visual arts, foreign literatures, or linguistics; anthropology, social inquiry.		36	
			117	
	(d) *Music*			
	THESIS		18	
	Elective subjects in Music		81	
	Elective subjects in a second discipline of humanities, social science, visual arts, foreign literatures, or linguistics; anthropology, social inquiry.		36	
			135	
	(e) *Anthropology*[3]			
	Unrestricted Electives			**63 to 45**
Total units required for the S.B. degree				**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Available only to students in the Classes '72, '73, and '74.
[3] The Anthropology Program in Course XXI-B, Program 2 will be available on registration day.

Department of Philosophy

Philosophy aims at analysis and criticism of the concepts and principles fundamental to the sciences, to our common sense view of the world, and to our modes of valuation. The study of philosophy is thus appropriate for those who enjoy thinking carefully and logically about basic issues, for those who seek perspective on a scientific education, and for those who wish breadth of educational experience prior to entering professional programs such as law or medicine.

Although philosophy is a discipline in its own right, and one that places severe and somewhat unusual demands on its practitioners, it is also a discipline that requires acquaintance with other areas of inquiry. Students who concentrate in philosophy are therefore advised to acquire as thorough a knowledge as time permits of one or two other disciplines. Many such are relevant to philosophy, among the more prominent of these being mathematics, physics, psychology, and linguistics.

THE UNDERGRADUATE CURRICULUM

Philosophy (Course XXIV)

The Course leading to the degree of Bachelor of Science in Philosophy is designed to provide: (1) familiarity with the history and current status of the main problems in epistemology, metaphysics, and ethics; (2) mastery of some of the technical skills requisite for advanced work in philosophy; (3) facility at independent philosophical study; (4) work at an advanced level in an allied field. A relatively large amount of unrestricted elective time is left available, so that students can devise programs suited to their individual needs and interests.

GENERAL INSTITUTE REQUIREMENTS				*Total units*
Specific science and humanities and social science subjects				132[1]
Science Distribution Requirement				36
Laboratory Requirement				12
DEPARTMENTAL PROGRAM				
Required Subjects				
24.201	HISTORY OF PHILOSOPHY I	3	0 6	
24.202	HISTORY OF PHILOSOPHY II	3	0 6	
24.211	THEORY OF KNOWLEDGE	3	0 6	
24.231	ETHICS	3	0 6	
24.241	SYMBOLIC LOGIC	3	0 6	
24.291	PHILOSOPHY SEMINAR	2	0 7	
				54
Restricted Electives				
A coherent program of 54 units of which 18 must be in philosophy and 36 in advanced subjects in some other discipline.				54
Unrestricted Electives				72
Total units required for the S.B. degree				360

[1] The requirement for Class of '72 is 128 units, the unrestricted elective units being increased by 4.

THE DOCTORAL PROGRAM IN PHILOSOPHY

The program of studies leading to the degree of Doctor of Philosophy is designed to provide comprehensive training in modern philosophy, emphasizing particularly its analytical and scientific aspects. An arrangement is also available whereby selected students may pursue a program in the philosophy of a special science — linguistics, mathematics, physics, psychology — while taking graduate work in that science. To enter the program, the student must satisfy the Institute requirements for admission to the Graduate School and have done well in his previous academic work. He must be formally accepted as a candidate for the degree by the Department of Philosophy.

DOCTOR OF PHILOSOPHY

Students planning to avail themselves of the arrangement to work on the philosophy of a special science must meet the requirements for admission to graduate study in that science. For all other students, the Department specifies the following prerequisites in place of the general requirements for admission.

Mathematics. One full year of college mathematics.

Science. One full year of college work in science.

Humanities. At least six term subjects in literature, history, or other humanities subjects equivalent in scope to those included in the undergraduate humanities curriculum of the Institute.

A student with high academic rating who is deficient to a minor extent in one or more of the above requirements may be permitted graduate registration while fulfilling them at the Institute.

Before beginning dissertation research, students are required to pass general examinations demonstrating competence in three of the following four areas: (1) metaphysics and epistemology, (2) value theory, (3) philosophy of

logic, of language, of science, and of mathematics, and (4) the history of philosophy.

Candidates for the doctorate are encouraged to take a Minor in a field other than philosophy. Possibilities include linguistics, mathematics, physics, psychology, and other humanities or social sciences. There is no general language requirement for the doctorate, save in those cases where competence in one or another foreign language is needed to carry on research for the dissertation.

Department of Political Science

Political science is the systematic study of conflict and interdependence among people as members of society. As such, it explores the roles of man in political conflict situations, the distribution and use of power, and political relations and behavior in groups and institutions. Instruction in the Department aims at providing the professional competence that enables students to analyze, understand, and propose operative solutions to political conflicts of consequence to the national society and international community. Undergraduate and graduate subjects seek to equip each student with skills now available to assemble and structure empirical observations about politics — including opinion surveys, political gaming, and computer simulation. Instruction focuses also on contemporary political conditions, born of sustained technological advance, rapid population increase, and changing economic circumstance as reflected in substantive areas of political science. Finally, within a rapidly expanding and increasingly rigorous discipline, emphasis falls on encouraging the general intellectual attributes of the scholar. Hence the stress is upon empirical and interdisciplinary research to ensure the widest possible grounding in knowledge relating to political behavior.

THE UNDERGRADUATE CURRICULUM

Political Science (Course XVII)

Students concentrating in political science acquire knowledge and skills necessary for understanding political behavior with special emphasis on the increasing range of problems that involve the activities of governmental agencies and political groups in matters of direct concern to science and technology.

The Political Science curriculum for undergraduate majors combines a core curriculum, which introduces the student to the normative and empirical theories and methodologies of the discipline. Additional subjects may be chosen from a wide variety of key specialized fields: these include offerings solely for undergraduates (numbered 17.01-17.69), as well as a large number of graduate subjects in which undergraduates may normally enroll. Each student's program is worked out with the aid of his Faculty Counselor.

The Department believes that every political science major should have the experience of conducting and writing up at least one substantial research project. This requirement is fulfilled by the senior thesis. For this purpose, each undergraduate student is assigned a faculty thesis advisor. After deciding on his thesis topic during his junior year, the student must register for the Pre-Thesis Reading Seminar (17.69, 9 units) in the fall semester and for Thesis (9 units) in the spring semester of his senior year. In the Pre-Thesis Seminar, he will be required to write a paper which will be in effect a major part of his thesis. This paper will be read at the end of the fall semester, as will his final product at the end of the spring semester, by one other faculty member besides his advisor. The Pre-Thesis Seminar (17.69) will be on a pass-fail basis.

The Course leads to the degree of Bachelor of Science in Political Science; the curriculum requirements are given below.

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects[2].				**132**[1]
	Science Distribution Requirement[3].				**36**
	Laboratory Requirement.				**12**
	The subject 17.01 which is among the Restricted Electives appears on the list of Laboratory Subjects and can be used to satisfy the Laboratory Requirement.				
DEPARTMENTAL PROGRAM					
	Required Subjects				
17.69	PRE-THESIS READING SEMINAR	3	0	6	
	THESIS			9	
					18
	Restricted Electives				**81** or **84**
	At least one subject from three of the following five groups:				
	Group 1				
17.21	INTRODUCTION TO THE AMERICAN POLITICAL PROCESS	3	0	6	
17.31	URBAN POLITICS	3	0	6	
17.41	GOVERNMENT, POLITICS, AND TECHNOLOGY	4	0	8	
	Group 2				
17.51	INTRODUCTION TO POLITICAL DEVELOPMENT	3	0	6	
17.52	COMPARATIVE POLITICAL SYSTEMS	3	0	6	

	Group 3			
17.56	INTERNATIONAL RELATIONS	3	0	6
17.57	PRINCIPLES AND PROBLEMS OF AMERICAN FOREIGN POLICY	3	0	6
	Group 4			
	One of the following alternatives:			
17.11	INTRODUCTION TO NORMATIVE POLITICAL THEORY (Coursette)	1	0	3
17.950	LOGIC OF SOCIAL RESEARCH (Coursette)	1	0	3
	or			
17.14	REVOLUTION AND THE THEORY OF POLITICS	3	0	9
	or			
17.11	INTRODUCTION TO NORMATIVE POLITICAL THEORY (Coursette)	1	0	3
	and one of the following:			
17.12	POLITICAL IDEAS AND INDUSTRIAL SOCIETY	3	0	6
17.13	CRITIQUES OF TECHNOLOGICAL SOCIETY	3	0	6
17.825	RADICAL AND REVOLUTIONARY IDEOLOGIES	3	0	6
21.655	LIBERTY AND EQUALITY	3	0	6
	Group 5			
17.01	POLITICAL SCIENCE LABORATORY	2	6	4
17.838	PRINCIPLES OF SYSTEMATIC POLICY ANALYSIS	3	0	6
	Unrestricted elective subjects chosen by the student in consultation with his advisor which may include the following: up to 27 units[5] of 17.68 COOPERATIVE WORK-STUDY PROGRAM; political science subjects, in addition to those taken to fulfill the requirement in Groups 1–5; and not more than two subjects outside the Department taken from the following list.			
14.41	DISTRIBUTION OF INCOME AND EMPLOYMENT OPPORTUNITIES	3	0	6
15.612J	LEGAL ASPECTS OF NEW TECHNOLOGY	3	0	6
21.091	PHILOSOPHY AND SCIENTIFIC METHOD	2	0	4
21.271	UTOPIAN LITERATURE	3	0	6
21.482	SOCIAL CRITICISM AND SOCIAL SCIENCE IN AMERICA	3	0	6
21.485J	THE BLACK GHETTO	3	0	6
21.515	INTELLECTUAL HISTORY OF MODERN EUROPE	3	0	6
21.545	WAR AND THE MILITARY INSTITUTIONS OF THE MODERN STATE	3	0	6
21.618	MODERN SOCIAL THEORY	3	0	6
21.963	TECHNOLOGY, VALUES, AND SOCIAL CHOICE	3	2	5
21.995	INTELLECTUALS AND SOCIAL CHANGE	3	0	6
	Unrestricted Electives[1]			**81 or 78**
Total Units required for the S.B. degree				**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Subjects in Field Seven (Political Science) may not be used for the humanities and social science requirement.
[3] 1.00 INFORMATION SYSTEMS (3–3–6) and 18.303 APPLICATIONS OF PROBABILITY AND RANDOM VARIABLES (3–0–9) are suggested.
[4] Students electing 17.01 may use it to satisfy the General Institute Laboratory Requirement, thus making available 12 additional units of Unrestricted Elective.
[5] Up to 18 additional units of 17.68 may be taken as Unrestricted Elective.

COOPERATIVE PROGRAM

In recognition of the Department's belief that much degree-relevant learning in political science can take place outside the university, regular academic credit in political science may be obtained for related "work experience" in a cooperative program. This work may be done in local, state, or national government, in public or private social and welfare agencies, in private research-oriented organizations, or in law firms. The Department encourages this work to be done either during the summer or in the second semester of the junior year. Application for a proposed cooperative program must be made at least three months before the program would begin, to the Department's Advisor on the Cooperative Program. It will be governed by the following regulations:

1) The Committee will require supplementary academic output, normally a paper, on the student's part in addition to the work experience itself; the paper must be submitted by the end of the semester following the semester of the work experience.
2) An approved summer program will generally carry nine (9) units credit. No more than 18 units may be taken during any single summer.
3) Term-time work approved for credit will be only for one semester, and will be judged by more stringent standards of academic relevancy than a summer program. This work will normally carry no more than 27 units. In no event shall term-time work carry more than 45 units.
4) No more than a total of 45 units of work experience may be applied toward the Bachelor's Degree. Of those 45, no more than 27 may be applied to the political science restricted elective requirement, and up to 18 units may be taken as unrestricted elective.

GRADUATE STUDY IN POLITICAL SCIENCE

The Department of Political Science offers work leading to the degrees of Master of Science in Political Science and Doctor of Philosophy.

Entrance Requirements for Graduate Study

In place of the general requirements for admission given in Section 8 of this Catalogue, the Department specifies the following prerequisites for graduate study in political science:

Mathematics. One full year of college mathematics, including at least one term of calculus.

Science. One full year of college work in science.

Humanities and Social Science. At least six term subjects in English, history and other humanities or social science subjects equivalent in scope to those included in the undergraduate curriculum of the Institute. These subjects should be in other than the candidate's own professional field.

Students may remove a deficiency in mathematics by completing a special one-term subject, INTRODUCTION TO MATHEMATICAL MODELS IN THE SOCIAL SCIENCES (17.955), and one other term of mathematics in a subject such as STATISTICS FOR THE SOCIAL SCIENCES (17.952). A deficiency in science may be removed by completing any suitable one-term subject in science at the Institute. A student whose deficiencies are of minor extent will be permitted graduate registration while taking appropriate subjects to remove them.

MASTER OF SCIENCE IN POLITICAL SCIENCE

Most graduate students in the Department are Ph.D. candidates. Under special circumstances, however, admission may be granted to candidates for the S.M. degree.

The general requirements for the Master's degree are given in Section 3. Subjects are wholly elective and are not restricted to those given by the Department. The program of study must be well balanced, however, and meet with the approval of the student's Advisory Board.

ACCELERATED S.M. PROGRAM

The Department offers a five-year program leading to the S.B. and S.M. degrees, awarded simultaneously. This program is open to M.I.T. undergraduates only. Applications for the program may be made in the spring term of the junior year or before November 1 of the senior year. Notification about admission will be sent in December of the senior year. This allows the student to plan for a combined S.B.–S.M. thesis written during the last three terms at the Institute. A separate S.B. thesis is not required. Undergraduate Institute requirements may be completed during the fifth year of the program.

DOCTOR OF PHILOSOPHY

A candidate for the doctorate must prepare himself in four approved fields of study. Two of these fields (viz., political analysis and one other) are normally satisfied by completing stipulated subjects. The remaining two fields are the focus of the student's General Examination, written and oral. The student is also required to present and defend an advanced research paper (Second Year Paper) prior to the General Examination. Established fields include: political analysis, political communication and behavior, American government, comparative politics, communist studies, defense policy, science and public policy, international politics and foreign policy, political and economic development, concepts and methods, and urban politics.

Approved combinations of some of these fields together with economics, industrial management, sociology, social psychology, or science and engineering fields may be acceptable. A program in Urban Politics and Planning is offered jointly with the Department of Urban Studies and Planning. There are also a variety of joint M.I.T.-Harvard teaching programs in subjects such as analysis of complex systems, West European studies, and International Relations.

Programs of study logically combining advanced work in some scientific or engineering fields with political science will be welcomed. A candidate's qualifications must indicate promise of ability to develop fruitful new lines of inquiry on problems touching the relationship of government, human behavior, science, technology, and the political process. Guided field research and close working ties with faculty members engaged in major research activities are stressed.

General Requirements for Doctoral Candidates

No stated number of graduate subjects in the Department of Political Science are required, but ordinarily the candidate will need two full academic years of work to prepare himself adequately for his General Examination and to meet the other pre-thesis requirements. The doctoral dissertation as a rule requires at least one additional year of original research and analysis, with the collection of data often conducted in the field.

Candidates are required to fulfill the language requirement as described in Section 3. The language or languages will ordinarily be chosen from German, French, or Russian; however, other languages may be substituted when they have sufficient professional significance for the individual candidate.

Department of Psychology

Psychology, the study of behavior, has grown in recent years with unforeseen rapidity. New avenues of approach have been opened by convergent developments of methods in the natural and social sciences and in mathematics, raising the hope that man, who has achieved considerable mastery over the world around him, might also come closer to an understanding of himself.

Psychology at M.I.T. stresses its connections with basic science and concentrates its efforts on the search for new knowledge in three distinct but interrelated areas: the study of relationships between brain and behavior (physiological psychology), the study of perception and learning (general experimental psychology), and the study of origins of individual behavior (developmental psychology and psycholinguistics). Accordingly, instruction in psychology on all levels (undergraduate, graduate, and postdoctoral) is organized to fall into these three areas which border on such diverse fields as anatomy, computer science, biophysics, neurology, neurophysiology, sociology and, philosophy, as well as linguistics and other communication sciences.

Programs of research on these three principal themes (those of brain and behavior, perception and learning, and early development and psycholinguistics) proceed in the Institute's Psychology Laboratories in close contact with the teaching program. The M.I.T. Psychology Building contains machine shops and electronic shops, a specialized research library, and facilities for brain research (electrophysiology, experimental surgery, and neurochemistry), for comparative studies of animal behavior, for observations on perception and memory in man in normal and abnormal states, and for the study of early stages in the acquisition, by children, of language, logic and social values.

UNDERGRADUATE SUBJECTS

Psychology subjects at the undergraduate level begin with INTRODUCTION TO PSYCHOLOGY AND BRAIN SCIENCE (9.00), which is the prerequisite for all of the subsequent undergraduate subjects. The remaining subjects fall into the three areas covered by the Department: physiological psychology, experimental psychology, and developmental psychology. There is at present no undergraduate major in psychology at M.I.T., but undergraduate psychology subjects are open to all undergraduates as electives and can serve in fulfilling the undergraduate requirements for electives in the humanities and social sciences.

GRADUATE STUDY IN PSYCHOLOGY (COURSE IX)

The program of studies leading to a graduate degree is designed to prepare graduate students for careers in teaching and research. The program permits concentration in any one of the three areas already described: physiological psychology, experimental psychology, and psycholinguistics. Throughout his graduate career, a student will be involved in research projects occupying at least one-half of his time, and aptitude will be assessed as much in the light of his demonstrated research abilities as in his performance in seminars or tutorials.

Approximately one-half of the incoming graduate students have majored in psychology or related fields; the balance are promising candidates with other backgrounds. In place of the general requirements for admission given in Section 8 of this Catalogue, a student is expected to have the equivalent of one year of college-level work in three of the following four areas: physics, chemistry, biology, and mathematics. Minor deficiencies in this undergraduate preparation can be removed, with the permission of the Department, by taking the appropriate subjects at the Institute.

DOCTOR OF PHILOSOPHY

The Doctoral program begins with the PROSEMINAR IN PSYCHOLOGY (9.001), which is taken during the first graduate year and serves to equalize the diverse backgrounds of the incoming graduate class. Following the PROSEMINAR, the candidate will choose appropriate graduate subjects to prepare himself adequately for his general examinations and to meet other pre-thesis requirements. Because the number of required graduate subjects other than PROSEMINAR is minimal, the candidate has great flexibility in choosing subjects that will best supplement his research activities.

Humanities

DEPARTMENT OF PSYCHOLOGY

The doctoral thesis represents an outgrowth of two preceding research reports, each written in the first two years of graduate study. As a rule, the thesis itself represents one year's research and must be written in residence.

Candidates are required to fulfill the departmental minor and language requirements. The language or languages will ordinarily be chosen from German, French, or Russian; however, substitutions may be made when they have sufficient professional significance.

MASTER'S PROGRAM IN PSYCHOLOGY AND BRAIN SCIENCE

In order to provide better preparation for students desiring graduate study in medicine, biology, psychology, and neurophysiology, the Department of Psychology offers a five-year program in Psychology and the Brain Sciences. This program allows a limited number of undergraduate students to spend a fifth year at M.I.T., following which they are awarded two degrees: a Bachelor of Science degree (awarded by a department outside of Course IX) and a Master of Science degree, awarded by the Department of Psychology. In order to enter this program, the undergraduate must be accepted to Graduate School by the Department of Psychology, and, following acceptance, must obtain approval by another department to delay the awarding of the Bachelor's Degree to the end of the fifth year.

Students enrolled in the five-year program are already provided with a firm foundation in the physical sciences during the first two years, and in the latter half of their junior year should begin laboratory work (9.015 or 9.50) in one of the following three areas: Neurosciences, Perceptual Mechanisms, or Cognitive Systems. Because only a very limited number of master's candidates can be accommodated in the Department, it is imperative that a student wishing to enter the five-year program begin his research experience in Psychology as early as possible and no later than the second half of his junior year. In this way, a good portion of his senior year, and almost the entire fifth year may be devoted to research and thesis.

In order to aid students in planning a flexible undergraduate curriculum that could lead into the five-year program, a list of recommended, basic subjects is given below. Many of these subjects can be incorporated into the undergraduate curriculum. Following this list are guidelines that suggest three possible distributions of graduate electives, each group forming a cohesive unit in one of three areas: neurosciences, perceptual mechanisms, or cognitive systems. Substitutions appropriate to individual objectives are encouraged, and these substitutions should be proposed when applying at the end of the Junior Year to the Graduate School for admission to the five-year program.

GENERAL INSTITUTE REQUIREMENTS					*Total Units*
	Specific science and humanities and social science subjects.				**132**
	The Science Distribution Requirement will be satisfied by 5.41, 7.01, and 18.03 which are required in the Department program (see below).				**36**
	The Laboratory Requirement will normally be satisfied by 9.50 or the sequence 9.014-9.015. (minimum)				**12**
					180

DEPARTMENTAL PROGRAM					*Additional Units*
	Basic Subjects†				
5.41	INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM (1-1) *	4	0	8	
7.01	GENERAL BIOLOGY (3-1)	4	0	8	
9.00	INTRODUCTION TO PSYCHOLOGY (1-2)	3	0	6	
9.01	PHYSIOLOGICAL PSYCHOLOGY (2-1)	3	0	6	
9.35	SENSATION AND PERCEPTION (2-2)	3	0	6	
9.921	RESEARCH IN PSYCHOLOGY (4-1, 2)	0	24	0	
18.03	DIFFERENTIAL EQUATIONS (2-1)	4	0	8	
	THESIS (5-1, 2)	0	36	0	
					60
	Subjects specified by the undergraduate department				**120**

Suggestions for specialization (elect one of the following three areas):†

					Additional Units
	Area I: Neurosciences				
6.14	INTRODUCTION TO ELECTRONICS	4	2	6	
7.05	GENERAL BIOCHEMISTRY	4	0	8	
9.021	BRAIN AND BEHAVIOR	3	0	6	
9.013	OUTLINE OF MAMMALIAN NEUROANATOMY	3	0	6	
9.022	LIGHT AND ELECTRON MICROSCOPE TECHNIQUES IN NEUROBIOLOGY	2	6	2	
9.361	ELECTROPHYSIOLOGY OF THE VISUAL SYSTEM	3	0	6	
20.80	NEUROENDOCRINE REGULATION AND COMMUNICATIONS	4	0	8	
					73
	Area II: Perceptual Mechanisms				
6.001	ELEMENTS, SYSTEMS AND COMPUTATION I	4	0	8	
6.258	ARTIFICIAL INTELLIGENCE	3	0	9	
7.36	ADVANCED NEUROPHYSIOLOGY	2	0	4	
9.37	COLOR SCIENCE AND COLOR VISION	3	1	5	

9.331	DEVELOPMENT OF VISION	3	0	6	
9.361	ELECTROPHYSIOLOGY OF THE VISUAL SYSTEM	3	0	6	
23.768J	SPEECH COMMUNICATION	3	0	6	
					66

Area III: Cognitive Systems

1.00	INFORMATION SYSTEMS	3	3	6	
6.14	INTRODUCTION TO ELECTRONICS	4	2	6	
6.258	ARTIFICIAL INTELLIGENCE	3	0	9	
9.591	SEMINAR IN PSYCHOLOGY OF LANGUAGE AND COMMUNICATION	3	0	6	
9.88	SEMINAR IN THE ORIGINS OF BEHAVIOR	3	0	6	
23.768J	SPEECH COMMUNICATION	3	0	9	
					66
Total Units required for the S.M. Degree					426

*Recommended year and term.
†Substitutions should be proposed when applying for admission to the five-year program.

ALFRED P. SLOAN SCHOOL OF MANAGEMENT

The Dean of M.I.T.'s Alfred P. Sloan School of Management describes its origins and present objectives.

The Alfred P. Sloan School of Management, founded at M.I.T. in 1952 as the School of Industrial Management, is the outgrowth of a pioneering curriculum combining management and engineering education which was first organized at the Institute in 1914. From that time, Course XV became the regular vehicle for providing this unique pattern of education to M.I.T.'s undergraduates. During this period many of M.I.T.'s most distinguished sons made their reputations as managers and business leaders. The gift of Alfred P. Sloan, Jr., in 1952, however, was the landmark in establishing a new level and a new scope in management education at M.I.T., and much of the story of management education at the Institute has been written since then. The Sloan School now offers an undergraduate Course leading to the degree of Bachelor of Science in Management; a two-year Master's Program leading to the degree of Master of Science in Management; a Doctoral Program leading to the degree of Doctor of Philosophy; a one-year Alfred P. Sloan Program in executive development leading to the degree of Master of Science in Management; a Program for Senior Executives (a nine-week Executive Development Program for senior members of management); and a four-week Urban Management Program for those who manage cities, counties, and state governments. Over the past several years the School has developed an extensive program of summer courses designed primarily to meet the needs of practicing professionals in the various areas of the School's program.

In all its efforts, this School is committed to educating enterprise managers — men who have the will to manage and to risk, who can deal with complex systems, who have insight into themselves as well as others, who understand the total environment in which they live, and who continue to learn.

We seek to provide these men with a solid grounding in the academic disciplines relevant to management — economics, mathematics, and the behavioral sciences — and to develop their awareness of the multiple facets which characterize important management problems, from technical data to human factors. We want them to be able to reach decisions. At his best, our young graduate has the ability to move decisively and responsibly in an increasingly complex world. The opportunities for such men in a society full of challenge, both social and technical, are substantial and growing in fields which include industrial management, the management of health services, the management of education and the management of public and urban affairs.

The education of men for management is our first purpose. But we are equally committed to the conduct of research to produce new understanding and better solutions to management problems, and we are engaged in communicating these results to an increasingly broader audience. Together, our research and education, goals are mutually reinforcing, and we are confident of their continued impact on the fields of management and management education.

Alfred P. Sloan School of Management

THE UNDERGRADUATE CURRICULA

Management (Course XV)

The Alfred P. Sloan School of Management offers five undergraduate programs that provide bases for widely varying alternative management-related careers. The five curricula range from an opportunity for student initiative in the design of special management programs, to those providing skills in the understanding and managerial use of behavioral science and management science, to one that develops the broad outlook needed for general management practice. In most of the programs, it is possible for a student who is admitted to graduate work to schedule his electives to permit receipt of the Bachelor of Science in Management degree at the end of four years of study and the Master of Science in Management degree at the conclusion of the fifth year.

Common to all of the curricula is the principle that each of the School's undergraduate students should gain an education in depth in an area of relevance and importance to the future manager. This education includes exposure to the underlying disciplines of management and to the general environment in which management operates. A sequence of five core subjects enables a common foundation to be built around an understanding of the organizational problems of the manager in coping with situations arising inside and outside of the firm, and develops a knowledge of the psychological and economic fundamentals of management. Beyond this management core each student has a number of alternative paths by which he is encouraged to learn something about management reasonably well, in contrast with being exposed to a large number of things but only superficially.

In addition to the flexibility inherent in the five curricula, and especially in the option for student initiative in Program 1, each program provides the further freedom of a number of unrestricted elective subjects. By different approaches to elective choice a variety of educational objectives might be served. Selection of subjects treating the functional areas of management should permit completion of both the Bachelor and Master of Science degrees in five years, as mentioned above. In-depth exposure to an area of physical science or engineering, in addition to an education in management, can be achieved by a technically oriented elective program. Appropriate selection of electives should permit a student to meet admission requirements of medical, law, or other graduate schools.

Each student arranges his program of studies with the advice and consent of a Faculty Counselor. To assist freshmen and sophomores further in choosing among the several alternative career paths, a senior faculty member of the Sloan School, designated the Undergraduate Planning Counselor, is available for discussions.

The curricula requirements are given below.

THE SPECIAL PROGRAM IN MANAGEMENT (PROGRAM 1)

The Special Program in Management has been designed to encourage student initiative in management education. Specific requirements are limited to General Institute Requirements and the five management core subjects. Beyond these any student (or group of students) may propose a coordinated program that he regards as meaningful to his own management-related career objectives. Each student-initiated professional program needs the approval of three faculty members (including at least two from the Sloan School of Management).

A proposed program should contain a specified series of subjects, planned and designated in advance of proposal submission, totaling between 54 and 82 Institute credit units. No more than one-third of these credits may be in Special Studies subjects. Not all of the individual subjects need be offered by the Sloan School of Management, but the program as a whole will be judged for its relevance and importance to management.

Programs 2, 3, 4, and 5 have been planned to meet the anticipated needs of most undergraduates interested in management. Program 1 is intended to cope with unanticipated student interests, as well as with the special requirements of the highly motivated student. A senior faculty member of the Sloan School of Management has been designated Undergraduate Plan-

ning Counselor. He is available to freshmen and sophomores to discuss the appropriateness of Programs 2, 3, 4, and 5 to each student's career plans, and/or to assist students in designing new professional programs within the over-all framework of Program 1.

BEHAVIORAL SCIENCE IN MANAGEMENT PROGRAM (PROGRAM 2)

This program is designed to provide its graduate with the proper tools for the utilization of behavioral science theory and research knowledge in the managerial context.

The curriculum will pursue a spiral course exposing the student to the same basic behavioral science principles at several levels of complexity, and each time, from a somewhat different vantage. In following such a course, the student will develop the structure necessary for the accomplishment of a major learning experience, the research practicum, in his senior year. In other words, following an introductory survey in the MANAGERIAL PSYCHOLOGY "core" subject (15.301), each student will go through a second cycle of the spiral process as he studies behavioral science concepts and their interrelations in depth in two subjects, SOCIAL PSYCHOLOGY (15.302) and COMPLEX ORGANIZATIONS (15.304). In his senior year the student encounters the third cycle, that of an actual experience in searching for new knowledge and interpreting his findings.

This combination of theory, research and practical experience in behavioral science will enable an individual to pursue any one of a number of endeavors upon completion of the program.

MANAGEMENT SCIENCE PROGRAM (PROGRAM 3)

The Management Science Program caters to the mathematically and scientifically oriented undergraduate who would like to participate in solving some of the technical problems central to the successful management of a complex society. The program is difficult and challenges even the superior student.

In recent years the rise of the computer, along with the development of mathematical models of systems and the collection of large quantities of data, has stimulated the growth of a technology of management. This is the domain of operations research and management science, two names commonly used to describe the field. The knowledge and methods being developed are applicable to problem solving in business, government, and other public and private organizations. The elements of the technology are the interrelated techniques of systems analysis, mathematical models, statistics, and computer science. In systems analysis, problem solving is approached by identifying the system, establishing its objectives, and setting down measures of its performance. Then the variables or actions under managerial control are determined and a model is constructed to relate the controllable variables to the measures of system performance. Thereafter the variables can be set to optimize performance.

The Management Science Program develops an underlying competence in mathematical models, optimization techniques, statistics, and computers. This provides wide flexibility in career choice. It prepares the student for immediate participation in systems analysis or operations research activities in industry or government. Alternatively, it provides a basic groundwork for pursuing graduate work in several directions, either more broadly toward management and social science or more technically toward a research career in operations research, computer science, or applied mathematics.

GENERAL MANAGEMENT PROGRAM (PROGRAM 4)

Program 4 is designed to meet the educational needs of the undergraduate who wants a broader background in the decision making, policy formulation and operating problems of the manager. The program builds upon the five required management core subjects with specified subjects that integrate psychological, economic, and environmental considerations in management. Further depth in any of these areas may be attained through appropriate elective choice.

The General Management Program will prepare the student for line management responsibilities in the generalist tradition. Administrative positions in the functional and staff fields would be the normal beginnings of career development through this program with the special advantage of a wide choice of areas. For the graduate of this program, the typical company will provide effective orientation activities as a valuable complement to his educational experience. Research administration, engineering and office management, and varied executive responsibilities in production, marketing and finance are examples of employment possibilities.

DYNAMICS OF MANAGEMENT SYSTEMS PROGRAM (PROGRAM 5)

The Dynamics of Management Systems Program focuses on the feedback structure of organizations. The unifying concepts of feedback processes are stressed to show how the same principles are encountered in management, economics, engineering, life processes, and the humanities.

The systems of interest to the manager are multi-loop, contain both positive and negative feedback, and are of high order and non-linear. To understand such systems they must be seen from as many perspectives as possible — as organized according to principles of structure; as laboratory observation using physical feedback processes; as descriptive subjects dealing with the structure and dynamics of social systems; as a mathematical interpretation relating structure and policy to growth and stability; as computer simulation of system models; and as field projects relating theory to practice.

This program uses feedback structure and dynamics to unify and interrelate the functional areas of management. The program is suitable for either the line manager or the systems analyst. It should serve as a foundation for graduate study or practice in a wide variety of fields.

1. SPECIAL PROGRAM IN MANAGEMENT CURRICULUM

				Total units
GENERAL INSTITUTE REQUIREMENTS				
	Specific science and humanities and social science subjects.[2]			132[1]
	Science Distribution Requirements[3].			36
	Laboratory Requirement[3].			12
DEPARTMENTAL PROGRAM				
	Required Subjects			
15.001	MANAGERIAL ECONOMICS	4	0	8
15.251	MANAGERIAL ENVIRONMENT	4	0	8
15.301	MANAGERIAL PSYCHOLOGY	3	0	6
15.501	INFORMATION AND DECISION SYSTEMS I	4	0	8
15.905	INFORMATION AND DECISION SYSTEMS II	4	0	8
				57
	Restricted Electives[4]			
	A coordinated program of professional electives relevant to management should be developed by the student, subject to faculty approval.			54 to 82
	Unrestricted Electives[4]			69 to 41
Total units required for the S.B. degree				360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] The upperclass program in the humanities and social sciences is to be chosen in consultation with the student's Faculty Counselor.
[3] One or two science distribution or laboratory subjects may be required as part of an approved professional program. See, for example, the specified curricula of the Behavioral Science, Management Science, General Management, and Dynamics of Management Programs.
[4] The student has the option of designing his own professional program of electives (subject to faculty approval) or of selecting one of the previously designated professional programs in Course XV. For examples of the latter option see the curricula of the Behavioral Science Program, the Management Science Program, the General Management Program, and the Dynamics of Management Program.

2. BEHAVIORAL SCIENCE IN MANAGEMENT PROGRAM CURRICULUM

				Total units
GENERAL INSTITUTE REQUIREMENTS				
	Specific science and humanities and social science subjects.[2]			132[1]
	The Science Distribution Requirement will be satisfied by 1.00 and 18.303, which are required in the Departmental Program, plus appropriate subjects totaling			12
	The subject 15.307, which is required in the Departmental Program, appears on the list of Laboratory Subjects and can be used to satisfy the Laboratory Requirement.			
DEPARTMENTAL PROGRAM				
	Required Subjects			
1.00	INFORMATION SYSTEMS	3	3	6
15.001	MANAGERIAL ECONOMICS	4	0	8
15.251	MANAGERIAL ENVIRONMENT	4	0	8
15.301	MANAGERIAL PSYCHOLOGY	3	0	6
15.302	SOCIAL PSYCHOLOGY	3	0	6
15.304	COMPLEX ORGANIZATIONS	3	0	6
15.305	STATISTICS FOR BEHAVIORAL SCIENCE	3	0	6
15.306	BEHAVIORAL SCIENCE RESEARCH METHODS	3	0	9
15.307	BEHAVIOR SCIENCE RESEARCH PRACTICUM	2	8	8
15.501	INFORMATION AND DECISION SYSTEMS I	4	0	8
15.905	INFORMATION AND DECISION SYSTEMS II	4	0	8
18.303	APPLICATIONS OF PROBABILITY AND RANDOM VARIABLES	3	0	9
				138
	Restricted Electives			
	A minimum of 24 units of additional engineering or science electives			24
	Unrestricted Electives[3]			54
	Total units required for the S.B. degree			360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] The upperclass program in the humanities and social sciences is to be chosen in consultation with the student's Faculty Counselor.
[3] Schedules of students in Course XV, Program 2, may always be arranged to leave available 12 units of unrestricted elective in the second year.

3. MANAGEMENT SCIENCE PROGRAM CURRICULUM

		Total units
GENERAL INSTITUTE REQUIREMENTS		
	Specific science and humanities and social science subjects.[2]	132[1]
	The subjects 6.28, 15.053, and 18.03, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.	
	Laboratory Requirement.	12

Management

SLOAN SCHOOL OF MANAGEMENT

DEPARTMENTAL PROGRAM

	Required Subjects				
6.28	PROBABILISTIC SYSTEMS ANALYSIS	4	0	8	
15.001	MANAGERIAL ECONOMICS	4	0	8	
15.053	QUANTITATIVE METHODS FOR MANAGEMENT	4	0	8	
15.054	STATISTICAL DECISION THEORY I	3	0	6	
15.251	MANAGERIAL ENVIRONMENT	4	0	8	
15.301	MANAGERIAL PSYCHOLOGY	3	0	6	
15.501	INFORMATION AND DECISION SYSTEMS I	4	0	8	
15.554	[3]MANAGEMENT INFORMATION TECHNOLOGY	3	0	6	
15.751	MANAGEMENT SCIENCE FIELD STUDY	4	0	8	
15.905	INFORMATION AND DECISION SYSTEMS II	4	0	8	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
					123
	Restricted Electives				
	A minimum of 9 units are to be selected from the following list of electives:				
6.251	DIGITAL COMPUTER PROGRAMMING SYSTEMS	3	2	7	
6.253	THEORETICAL MODELS FOR COMPUTATION	3	0	9	
6.536	PROBABILISTIC MODELS IN SYSTEMS ENGINEERING AND OPERATIONS RESEARCH	3	0	9	
6.544J	HEURISTIC PROGRAMMING AND ARTIFICIAL INTELLIGENCE	3	0	9	
14.372	STATISTICS	3	0	9	
15.073	STOCHASTIC SYSTEMS	3	0	6	
15.081	MATHEMATICAL PROGRAMMING	3	0	6	
15.854	DESIGN OF INFORMATION AND CONTROL SYSTEMS FOR RESOURCE MANAGEMENT	3	0	6	
					9
	Unrestricted Electives[4]				**84**
Total units required for the S.B. degree					**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] The upperclass program in the humanities and social sciences is to be chosen in consultation with the student's Faculty Counselor.
[3] 1.00 is an acceptable substitute for 15.554.
[4] Schedules of students in Course XV, Program 3, may always be arranged to leave available 12 units of unrestricted elective in the second year.

4. GENERAL MANAGEMENT PROGRAM CURRICULUM

GENERAL INSTITUTE REQUIREMENTS	*Total units*
Specific science and humanities and social science subjects.[2]	**132**[1]
The subjects 1.00, 15.053, and 18.303, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.	
Laboratory Requirement.	**12**

DEPARTMENTAL PROGRAM

	Required Subjects				
1.00	INFORMATION SYSTEMS	3	3	6	
15.001	MANAGERIAL ECONOMICS	4	0	8	
15.053	QUANTITATIVE METHODS FOR MANAGEMENT	4	0	8	
15.251	MANAGERIAL ENVIRONMENT	4	0	8	
15.301	MANAGERIAL PSYCHOLOGY	3	0	6	
15.309	ADMINISTRATIVE THEORY AND PRACTICE	3	0	6	
15.501	INFORMATION AND DECISION SYSTEMS I	4	0	8	
15.703	MANAGEMENT LABORATORY	3	3	3	
15.905	INFORMATION AND DECISION SYSTEMS II	4	0	8	
18.303	APPLICATIONS OF PROBABILITY AND RANDOM VARIABLES	3	0	9	
					111
	Restricted Electives				
	A minimum of 24 units of additional engineering or science electives.				**24**
	Unrestricted Electives[3]				**81**
Total units required for the S.B. degree					**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] The upperclass program in the humanities and social sciences is to be chosen in consultation with the student's Faculty Counselor.
[3] Schedules of students in Course XV, Program 4, may always be arranged to leave available 12 units of unrestricted elective in the second year.

5. DYNAMICS OF MANAGEMENT SYSTEMS CURRICULUM

GENERAL INSTITUTE REQUIREMENTS	*Total units*
Specific science and humanities and social science subjects.[2]	**132**[1]
The Science Distribution Requirement will be satisfied by 18.03, which is required in the Departmental Program, and 2.02 or 6.01, which appear on the list of restricted electives, plus appropriate subjects totaling	**12**
Laboratory Requirement	**12**

DEPARTMENTAL PROGRAM

	Required Subjects				
15.001	MANAGERIAL ECONOMICS	4	0	8	
15.251	MANAGERIAL ENVIRONMENT	4	0	8	
15.301	MANAGERIAL PSYCHOLOGY	3	0	6	
15.501	INFORMATION AND DECISION SYSTEMS I	4	0	8	
15.852	PRINCIPLES OF DYNAMIC SYSTEMS I	3	0	9	
15.853	PRINCIPLES OF DYNAMIC SYSTEMS II	3	0	9	
15.905	INFORMATION AND DECISION SYSTEMS II	4	0	8	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
					93
	Restricted Electives				
2.02	INTRODUCTION TO SYSTEM DYNAMICS	3	1	8	
	or				
6.01	INTRODUCTORY NETWORK THEORY	4	0	8	
	and				
2.14	CONTROL SYSTEM PRINCIPLES	3	1	8	
	or				
6.05	CIRCUITS, SIGNALS, AND SYSTEMS	4	0	8	
					24
	A minimum of 27 units to be selected from the following list of electives:				
15.854	DESIGN OF INFORMATION AND CONTROL SYSTEMS FOR RESOURCE MANAGEMENT	3	0	6	
15.855	APPLICATIONS AND IMPLEMENTATION OF INDUSTRIAL DYNAMICS	3	0	6	
15.858	RESEARCH SEMINAR IN DYNAMICS OF MANAGEMENT SYSTEMS I	3	0	6	
15.859	RESEARCH SEMINAR IN DYNAMICS OF MANAGEMENT SYSTEMS II	3	0	6	
15.876	GROWTH DYNAMICS	3	0	6	
					27
					51

Unrestricted Electives	60
Total units required for the S.B. degree	360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] The upperclass program in the humanities and social sciences is to be chosen in consultation with the student's Faculty Counselor.

GRADUATE STUDY IN MANAGEMENT

The Alfred P. Sloan School of Management offers graduate study leading to the degrees of Master of Science in Management and Doctor of Philosophy.

MASTER OF SCIENCE

The two-year program leading to the Master's degree is designed to prepare young men and women for careers as professional managers in private and public organizations. The program emphasizes the fundamental disciplines underlying managerial decision making and the breadth of perspective required by those who are to assume general management responsibilities. The program reflects the School's concern with organizational relationships, measurement and quantitative analysis, and application of theory to practical problems.

Systems analysis is a fundamental integrating discipline on which the Master's program is based. Candidates gain experience in using this process to examine the implications of alternative managerial approaches to industrial, market, and social systems. Course projects provide opportunities for the Master's candidate to work with faculty members and experienced managers to structure and solve significant managerial problems.

The typical Master's candidate completes the 18 term subjects plus thesis required for a degree in two years. However, the program is unusually flexible. Through waiver examinations or credit for subjects taken elsewhere, it is possible for some students to meet the requirements for the degree in three terms or occasionally in one year.

The first year of the program is devoted primarily to the following core subjects required of all students:

ECONOMICS FOR MANAGEMENT I AND II (15.012, 15.014)
MATHEMATICS FOR MANAGEMENT I AND II (15.061, 15.062)
INFORMATION AND DECISION SYSTEMS I AND II (15.515, 15.915)
HUMAN FACTORS IN MANAGEMENT (15.311)
LABOR MANAGEMENT RELATIONS (15.663)

During the first year each student is also expected to take one elective and a subject giving him exposure to the broader problems of the manager's relationship with society. In addition, every student must satisfy a basic computer requirement within the framework of one of the core subjects.

Since the required core is limited to nine term subjects each student has the opportunity to select at least nine additional subjects plus a Master's thesis. When choosing electives the student is expected to establish a concentration option. To satisfy the concentration requirement the student will normally (a) take three or more subjects in at least one of several concentration areas, and (b) do thesis research relevant to his chosen area (or areas) of subject concentration.

The nine electives available in a "normal" program make possible as many as three such concentrations. However, it is strongly recommended: (a) that concentrations be limited to a maximum of two, (b) that the primary concentration consist of more than three subjects, and (c) that some electives be employed deliberately to broaden the individual's range of interest.

The student devotes the equivalent of about one-half term in his second year to his Master's thesis. The thesis is normally a study and report on a specific management problem selected by the student. Thesis research is conducted under the supervision of the committee and faculty members who share the student's interest in the selected topic. The extensive facilities of the Institute's Information Processing Center are available for use in thesis and research work.

Concentration options are most often in the areas indicated below. However, the student may offer for consideration a "package" of logically interrelated subjects differing from any of those described. The package will be accepted in satisfaction of the concentration requirement on written approval of a faculty member in a concentration area related to the student's proposed program. Subjects listed under the following headings are illustrative of those covered by typical options in the indicated fields. A concentration option normally consists of three or four subjects agreed upon by the student and a faculty member in the area of concentration.

Finance

15.412 FINANCIAL MANAGEMENT
15.416 FINANCIAL ADMINISTRATION OF INDUSTRY
15.418 TAXATION AND BUSINESS MANAGEMENT
15.422 INVESTMENTS
15.423 THE MANAGEMENT OF FINANCIAL INTERMEDIARIES
15.432 CAPITAL MARKETS AND FINANCIAL INSTITUTIONS

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Industrial Dynamics
15.872 PRINCIPLES OF DYNAMIC SYSTEMS I
15.874 DESIGN OF INFORMATION AND CONTROL SYSTEMS FOR RESOURCE MANAGEMENT
15.875 APPLICATIONS AND IMPLEMENTATION OF INDUSTRIAL DYNAMICS
15.876 GROWTH DYNAMICS

Industrial Relations
15.671J LABOR ECONOMICS
15.672J PUBLIC POLICY ON LABOR RELATIONS
14.41 DISTRIBUTION OF INCOME AND EMPLOYMENT OPPORTUNITY
15.664 MANAGEMENT OF HUMAN RESOURCES
15.674J COMPARATIVE SYSTEMS OF INDUSTRIAL RELATIONS AND HUMAN RESOURCE DEVELOPMENT

International Management
15.221 INTERNATIONAL BUSINESS MANAGEMENT I
15.222 INTERNATIONAL BUSINESS MANAGEMENT II
15.223 INTERNATIONAL BUSINESS ENVIRONMENTS
15.674J COMPARATIVE SYSTEMS OF INDUSTRIAL RELATIONS AND HUMAN RESOURCE DEVELOPMENT

Managerial Information and Control
15.416 FINANCIAL ADMINISTRATION OF INDUSTRY
15.521 MANAGERIAL INFORMATION AND CONTROLS
15.532 ADVANCED CONCEPTS IN MANAGERIAL INFORMATION FOR PLANNING AND CONTROL
15.545 CONTROL PROCESSES AND SYSTEMS
15.568 MANAGEMENT INFORMATION SYSTEMS

Management Information Systems
15.564 MANAGEMENT INFORMATION TECHNOLOGY I
15.565 MANAGEMENT INFORMATION TECHNOLOGY II
15.568 MANAGEMENT INFORMATION SYSTEMS
15.569 MANAGEMENT DECISION SYSTEMS

Marketing
15.812 MANAGEMENT SCIENCE IN MARKETING
15.823 BUSINESS GAME
15.824 INFLUENCE PROCESSES AND MASS COMMUNICATIONS
15.825 MARKETING MODELS
15.826 MARKETING ISSUES IN PUBLIC SYSTEMS
15.832 MEASUREMENT FOR MANAGEMENT

Operations Management
15.761 OPERATIONS MANAGEMENT
15.781 CAPACITY PLANNING: PRODUCTION AND DISTRIBUTION SYSTEMS
15.791 OPERATIONS PLANNING AND CONTROL SYSTEMS
15.792 MANUFACTURING DECISIONS SEMINAR
15.793 STUDIES IN PUBLIC OPERATIONS MANAGEMENT

Organization Studies
15.317 COMPARATIVE ANALYSIS OF ORGANIZATIONS
15.318 ORGANIZATION
15.319 SEMINAR ON ORGANIZATION CHANGE
15.332 ADMINISTRATIVE THEORY AND PRACTICE
15.334 PRACTICUM IN ORGANIZATION DEVELOPMENT
15.336 RESEARCH MANAGEMENT

Operations Research/Mathematical Models
15.063 STATISTICS FOR MODEL BUILDING
15.065 STATISTICAL DECISION THEORY
15.073 STOCHASTIC SYSTEMS
15.075 MATHEMATICAL STATISTICS
15.081 MATHEMATICAL PROGRAMMING
15.083 COMBINATORIAL OPTIMIZATION
15.761 OPERATIONS MANAGEMENT
15.812 MANAGEMENT SCIENCE IN MARKETING

DOCTOR OF PHILOSOPHY

The doctoral program in management is designed for students interested in teaching, consulting and other professional management careers. The goals of the program are to prepare intellectual leaders in management training with a mastery over a wide range of management research techniques, and to furnish the background required for adding to knowledge in some branch of management. The ultimate goal is that the successful Ph.D. will add to the research in his specialty both at M.I.T. and later during his professional career. For the candidate entering with a Bachelor's degree, it is possible to complete the program in three years. For the candidate entering with an advanced degree, it will be possible to finish in less time, depending upon previous experience in research. For descriptive purposes, the program divides easily into three parts.

Part I

The first part of the Ph.D. program is devoted to work in the basic disciplines of management as well as some preliminary work in one of the major fields of management. Doctoral students are expected to be able to work with facility in the advanced literature in Economics, Behavioral Science, and Quantitative Methods, because the literature in these fields has direct application to the functional fields of management. The candidate is required to demonstrate this ability in three qualifying examinations offered normally at the end of the first year in residence, but available upon entrance into the program for those who have already done advanced work. There are no subject requirements in the disciplines, although entering doctoral candidates are offered three special year-long subject sequences in the basic disciplines in preparation for the qualifying examinations. In addition to preparing for the qualifying examinations, the student will take subjects and do individual reading in the major field of his choice. In order to gain preliminary experience in research techniques, he also works with his faculty adviser in a research apprenticeship which is planned and initiated during the fall term.

Part II

The second year is devoted primarily to preparation in the candidate's major and minor fields, during which time he masters the subject materials in the functional field designated as his "major field;" gains mastery over the materials in the underlying theoretical discipline designated as his "minor field," and demonstrates the ability to formulate, conduct, and present a research study. The candidate and his adviser will design an appropriate program

of subjects and individual research to prepare the candidate for General Examinations in his major and minor fields at the end of the second year. In recent years, candidates have taken major field examinations in Finance, Industrial Dynamics, Industrial Relations, International Management, Managerial Information for Planning and Control, Management Information Systems, Marketing, Operations Management, and Organization Studies. Candidates have offered Economics and Behavioral Science as minor fields. Also, in the general area of Quantitative Studies, there have been minor field offerings in Operations Research, Statistics, Mathematical Programming, and Information Technology. General Examinations differ in form (written, oral, detailed and lengthy research papers) from area to area and are prepared by the faculty members in each field.

In addition, each student in Part II is required to write a paper of article length and quality for inclusion in the Sloan School Working Paper Series. The paper will be evaluated by members of the faculty in terms of the general standards for Sloan School Working Papers. The work in the major field, the minor field, and the student's performance on the research paper will be used to evaluate his position at the end of the second year.

Part III

This part of the Ph.D. program centers on the doctoral dissertation, which consists of significant scholarly research in some area of management. Close working relationships with senior faculty are to be established early in Part III, so that the thesis is defined as a manageable project as early as possible. The candidate has the opportunity of completing his dissertation within a year of entering Part III of the program, and he should complete the dissertation within two years of entrance into Part III. Because the Ph.D. candidate is likely to be involved in some form of teaching, whether in a university, or a less formal "classroom" in industry, each doctoral student will be partially responsible for conducting a Sloan School subject in the fall term of his first year in Part III. In the conduct of that subject he will be teaching in close cooperation with a faculty member. The student may conduct the subject jointly with the senior faculty member, or he may be a discussion or section leader.

Entrance Requirements for Graduate Study

The general admission requirements are those set forth in Section 8 of this Catalogue, with the following additions and exceptions.

Undergraduate preparation for this program should include: mathematics through college algebra and differential calculus; at least one year of an experimental science at the college level; and a subject in principles of economics. The Graduate Committee is willing to consider the particular needs of any applicant who is strongly motivated to study in the School and who has demonstrated high intellectual capacity.

Admission Test for Graduate Study in Business

All candidates for admission to graduate study in the Alfred P. Sloan School of Management, other than applicants for the Executive Development Programs (see below), are required to take the Admission Test for Graduate Study in Business. This test is administered by the Educational Testing Service, Princeton, New Jersey; information about dates and locations at which the test will be administered may be obtained from that agency.

EXECUTIVE DEVELOPMENT PROGRAMS IN MANAGEMENT

The Alfred P. Sloan School of Management provides two programs for business executives who wish to extend their knowledge of the fundamentals underlying effective management. Applicants for these programs are nominated by their companies and selected by M.I.T.

The *Alfred P. Sloan Program* enrolls exceptionally able young executives (32 to 38 years of age) who have demonstrated potential for filling positions of senior responsibility in the future. These young executives are sponsored by industry, government, and other organizations (or they may apply independently); a limited number of men are selected from abroad. The 12-month Program provides for regular classroom work plus intimate contact with business and government leaders here and abroad. It is taken in conjunction with the regular graduate program and may lead to the degree of Master of Science in Management. Approximately 45 Fellows are admitted each year, and they are divided into two groups for most of their Course work.

The *Program for Senior Executives* is an intensive nine-week course of study designed for the mature executive already in or preparing for a position of major managerial responsibility. Enrollment is limited to 25 qualified executives in each of the two nine-week sessions held in the spring and fall each year.

Management

SLOAN SCHOOL OF MANAGEMENT

Participants reside at Endicott House in Dedham, where they enjoy the quiet and graceful environment of a private estate furnished tastefully and comfortably. The regular classroom work is conducted at the Sloan Building, 50 Memorial Drive.

The *M.I.T. Program for Urban Executives* is a four-week program available for those men and women who manage cities and deal with the complex issues facing municipal, non-elected administrators.

Information about these programs may be obtained by writing to the Associate Dean for Teaching Programs.

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SCHOOL OF SCIENCE

The role of science at M.I.T. is described by the Dean of the School.

Science is concerned with the understanding of the physical world, and the range of this search for understanding extends from the innermost events in the atomic nucleus to the farthest detectable reaches of the universe. Modern science has proved useful in many important ways, but the search for understanding is also carried out because man is curious about the world around him.

Science has of course contributed in the most fundamental way to the advancement of technology, and technology has contributed importantly to the advancement of science. At M.I.T., the relationships between science and technology are especially close and mutually reinforcing.

Training in science provides the basis for many types of careers. People with scientific training are needed for teaching and research, but scientific training provides an opportunity to enter other professions as well.

The sciences may be broadly classified as earth and planetary sciences, life sciences, mathematics, and physical sciences. At M.I.T., instruction is provided in all of these fields at the undergraduate and graduate levels. The various programs are described on the following pages.

The science programs at M.I.T. profit from the availability of laboratories of an interdepartmental nature which facilitate work in fields which cross the lines of traditional disciplines. Some of these facilities include the Cambridge Electron Accelerator (operated jointly by Harvard University and M.I.T.), Center for Materials Science and Engineering, Center for Space Research, Information Processing Center, Laboratory for Nuclear Science, Lincoln Laboratory, Bitter National Magnet Laboratory, and Research Laboratory of Electronics. Through these laboratories and through personal contacts by members of the science departments within the Institute and outside, the sciences are brought to bear on problems of importance to the surrounding academic community, industry, and government. The School of Science provides the possibility of study and research in the most basic scientific and mathematical areas and also for the use of these ideas in a wide variety of applications.

Science

SCHOOL OF SCIENCE

THE UNDERGRADUATE CURRICULA IN THE SCHOOL OF SCIENCE

The School of Science provides S.B. degree programs in Biology, Chemistry, Earth and Planetary Sciences, Mathematics, and Physics. In addition, a program in the physical sciences leading to the degree of S.B. without designation of field is offered under the direction of the Department of Earth and Planetary Sciences. The Departmental Programs are described by each department on the following pages.

THE GRADUATE CURRICULA IN THE SCHOOL OF SCIENCE

The School of Science provides Ph.D. and Sc.D. programs in Biology, Chemistry, Earth and Planetary Sciences, Mathematics, Meteorology, Nutrition and Food Science, and Physics. The Departmental Programs are described by each department on the following pages. In addition the School of Science participates in a joint doctoral program with the Woods Hole Oceanographic Institution.

Department of Biology

The Biology Department offers undergraduate, graduate, and postdoctoral training in basic biology and in a variety of biological fields of specialization. The quantitative aspects of biology, including molecular biology, biochemistry, biophysics, genetics, and cell biology represent the core of the program. Students are encouraged to acquire a solid background in the physical sciences, not only in order to master applications of mathematics, physics, and chemistry to biology but also to develop an integrated scientific perspective. The undergraduate training emphasizes practical experimentation, with a minimum of formal laboratory exercises and with ample opportunities for research work, both in project-type laboratory subjects and in the research laboratories of the Department. The students are encouraged to acquire familiarity with advanced and sophisticated research techniques and to participate in seminar activities.

NUTRITION AND FOOD SCIENCE

The undergraduate curricula in Life Sciences also prepare students for careers in nutrition and food science and for graduate study in these fields. Students choosing specialization in this area should elect Program 2 and consult with the Department of Nutrition and Food Science before registration.

THE UNDERGRADUATE CURRICULA

Two programs are offered in Life Sciences, Course VII, leading to the degree of Bachelor of Science in Life Sciences. The curriculum of Program 1, Life Sciences, is designed to prepare students for a professional career in the area of the biological sciences. Graduates of this program will be well prepared for positions in industrial or research institutes. However, experience has shown that most graduates will probably choose to continue their education at graduate schools in order to obtain a Ph.D. degree in one of the biological fields such as biochemistry, microbiology, genetics, biophysics, cell biology or physiology and to do research or teaching in one of these areas. The undergraduate curriculum is also an excellent preparation for students who wish to continue their education toward an M.D. degree with the plan of spending their professional careers in laboratory investigations bearing on human disease. The curriculum of Program 2 offers specialization in nutrition and food science. Course VII-A, Life Sciences, is designed for students whose plans do not include careers of teaching or research in biology, but who wish to obtain a background in the Life Sciences as a preparation for a variety of careers, such as medicine without laboratory research, the graduate study of psychology, or management, and leads to the degree of Bachelor of Science. This program allows more time for electives in which the student can pursue his interests outside the area of Life Sciences.

PROGRAMS FOR THE DEGREE: BACHELOR OF SCIENCE IN LIFE SCIENCES

Life Sciences (Course VII)

PROGRAM 1. LIFE SCIENCES CURRICULUM — *Total units*

GENERAL INSTITUTE REQUIREMENTS

Specific science and humanities and social science subjects. **132**[1]

The subjects 8.03, 18.03, and either 5.41 or 5.60, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.

The subjects 7.031 or 7.041 or 7.051 or 7.061, which are among the restricted electives appear on the list of Laboratory Subjects and can be used to satisfy the Laboratory Requirement.

DEPARTMENTAL PROGRAM

Required Subjects

5.41	[3]INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM	4	0	8	
5.60	[3]CHEMICAL EQUILIBRIUM	4	0	8	
7.011	INTRODUCTION TO EXPERIMENTAL BIOLOGY	1	8	3	
7.05	GENERAL BIOCHEMISTRY	5	0	7	
8.03	PHYSICS III	5	0	7	
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
					72

Restricted Electives

One of the following subjects:

5.42	ORGANIC CHEMISTRY	4	0	8	
5.62	PHYSICAL CHEMISTRY	4	0	8	
7.07J	BIOPHYSICAL CHEMISTRY	3	0	9	

Three of the following subjects:

7.01	[3]GENERAL BIOLOGY	4	0	8	
7.03	GENETICS	3	0	9	
7.04	DEVELOPMENTAL BIOLOGY	3	0	6	
7.06	GENERAL AND CELL PHYSIOLOGY	3	0	9	
7.21	GENERAL MICROBIOLOGY	3	0	9	

Science

DEPARTMENT OF BIOLOGY

	One of the following subjects:			
7.031	EXPERIMENTAL GENETICS AND MICROBIOLOGY	2	16	6
7.041	EXPERIMENTAL CELL BIOLOGY	2	16	6
7.051	EXPERIMENTAL BIOCHEMISTRY	2	16	6
7.061	EXPERIMENTAL PHYSIOLOGY	2	16	6
				72 or **69**
	Unrestricted Electives[1]			**84** or **87**
	Total units required for the S.B. degree			**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Students in the Class of '73 and later classes who take 5.41 or 5.60 to fulfill the General Institute Requirement in Chemistry/Biology must take 12 additional units of Unrestricted Elective; if 7.01 is taken to fulfill the General Institute Requirement in Chemistry/Biology it may not be taken to fulfill part of the Restricted Elective program.
[3] Schedules of students in Course VII, Program 1, may always be arranged to leave available 24 units of Unrestricted Elective in the second year. A thesis is recommended but not required.

Although 5.31 Introduction to Chemical Experimentation is not a Departmental requirement, this subject is particularly useful for students whose interest is in biochemistry, and it may be required for admission to Medical School.

Although 7.01 General Biology is not specifically required, most students will find it an important basis for the study of other biology subjects.

Only those students with exceptionally good high school preparation in modern biology should elect *not* to take 7.01.

As part of their elective program, students are encouraged to enroll in the more advanced subjects offered by the department.

PROGRAM 2. NUTRITION AND FOOD SCIENCE CURRICULUM (See DEPARTMENT OF NUTRITION AND FOOD SCIENCE.)

PROGRAM FOR THE DEGREE: BACHELOR OF SCIENCE

Life Sciences (Course VII-A)

		Total units
GENERAL INSTITUTE REQUIREMENTS		
	Specific science and humanities and social science subjects	**132**[1]
	The Science Distribution Requirement will be satisfied by 7.01[3] and 5.41[3] and 5.60[3], which are required in the Departmental Program, plus appropriate subjects totaling	**12**
	Laboratory Requirement[2].	**12**

DEPARTMENTAL PROGRAM

	Required Subjects			
5.41	[3]INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM	4	0	8
5.60	[3]CHEMICAL EQUILIBRIUM	4	0	8
7.01	[3]GENERAL BIOLOGY	4	0	8
7.011	INTRODUCTION TO EXPERIMENTAL BIOLOGY	1	8	3
7.05	GENERAL BIOCHEMISTRY	5	0	7
				60
	Restricted Electives			
	Two of the following subjects:			
7.03	GENETICS	3	0	9
7.04	DEVELOPMENTAL BIOLOGY	3	0	6
7.06	GENERAL AND CELL PHYSIOLOGY	3	0	9
7.07J	BIOPHYSICAL CHEMISTRY	3	0	9
7.21	GENERAL MICROBIOLOGY	3	0	9
				24 or **21**
	Unrestricted Electives			**120** or **123**
	Total units required for the S.B. degree			**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Students interested in admission to Medical School are advised to consult the premedical advisory office for advice about choosing an appropriate laboratory subject that will meet the Institute Laboratory Requirement.
[3] Students in the Class of '73 and later classes who take 5.41 or 5.60 or 7.01 to fulfill the General Institute Requirement in Chemistry/Biology must take 12 additional units of Science Distribution Subjects.

GRADUATE STUDY IN BIOLOGY

The Department of Biology offers graduate work leading to the degrees of Master of Science in Biology, Biochemistry, or Biophysics, and Doctor of Philosophy or Doctor of Science. Study may be pursued in the following fields of specialization; cell biology, physiology, microbiology, biochemistry, and biophysics.

The Master's degree is not a prerequisite for a program of study leading to the doctorate. Master's candidates may, by permission, change to a doctoral program without loss of credit.

Research facilities are available for a wide variety of fields in analytical biology, biochemistry, biophysics, and microbiology.

CELL BIOLOGY AND PHYSIOLOGY

The laboratories of biology apply chemical and physical methods to modern problems of biology. Major areas of research include molecular biology; analytical cytology; physiological genetics; cellular, sensory, and neuro-physiology; and growth and differentiation.

BIOCHEMISTRY

The laboratories of biochemistry are equipped with the most modern tools for teaching and research. Special equipment for the isolation and characterization of proteins are in current use in these laboratories for the solution of problems in enzymology, biosynthesis of proteins, nucleic acids and co-enzymes, intermediary metabolism, and biochemical control mechanisms.

BIOPHYSICS

The physical aspects of biological problems are approached in the biophysical laboratories through the use of techniques such as X-ray

diffractions, electron microscopy, ultracentrifugation, electrophoresis, and spectroscopy, as well as through the development of new instruments. Current research problems lie in the area of the structures of proteins, polysaccharides, and nucleic acids; the physical chemistry of proteins and their interactions; molecular genetics; and communications biophysics.

The cooperative arrangement with Harvard University is described in Section 3 of this Catalogue.

MICROBIOLOGY

The general properties of microorganisms are stressed, with special emphasis on microbial genetics and metabolism. Bacterial and mammalian viruses are considered, with special emphasis on problems of reproduction. Microorganisms are compared with mammalian cells in tissue culture.

BIOLOGICAL OCEANOGRAPHY

M.I.T. and the Woods Hole Oceanographic Institution have established a joint program in biological oceanography which leads to jointly awarded degree of Doctor of Philosophy. For details of this program, see Joint Programs with the Woods Hole Oceanographic Institution.

Entrance Requirements for Graduate Study

The Department modifies the general Institute requirements for graduate study as follows:

Mathematics. CALCULUS (18.01, 18.02).

Physics. One year of college physics.

Chemistry. INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM (5.41).

Professional Subjects. GENERAL BIOCHEMISTRY or MICROBIOLOGY.

Deficiencies in the subjects listed above may be removed, if not too extensive, while pursuing a graduate program.

Requirements for Advanced Degrees

There are no specified programs for degree work, since the subjects required vary with the field of specialization. Each student selects his own program, according to certain broad principles, after consultation with the Graduate Committee of the Department.

Assistantships and Fellowships

A number of qualified students are appointed each year as teaching or research assistants. A research assistant may be permitted to use the results of his assigned research work in a graduate thesis, with possible acceleration of his program. In addition, a number of predoctoral and postdoctoral fellowships are available in cell biology, microbiology, physiology, biochemistry, and biophysics. Information is available from the Head of the Department.

Department of Chemistry

The Department of Chemistry offers an undergraduate program sufficiently flexible in its electives to provide excellent preparation for careers in many different areas of chemistry. The Department offers graduate programs leading to the degrees of Master of Science, Doctor of Philosophy, and Doctor of Science. There is a wide variety of opportunities for study and research in analytical, biophysical, geological, inorganic, organic, and physical chemistry and in chemical physics.

THE UNDERGRADUATE CURRICULUM

Chemistry (Course V)

The Course is designed to provide an education based on science for those who intend to go on to graduate study and a professional career in chemistry or in some allied field in which a sound knowledge of chemistry is important. Students receive thorough instruction in the principles of chemistry, supplemented by instruction in mathematics and physics and in the humanities and other subjects.

Unrestricted elective time allows each student to extend his knowledge in areas of special interest. Those intending to do graduate work may elect subjects in the department or in other departments which will give them more detailed knowledge in the areas in which they intend to specialize. Students who intend to enter industry may elect subjects which offer the fundamentals in a selected field of science, engineering or the humanities and social sciences. They may also enhance their education by arranging a five-year program of study leading to simultaneous Bachelor degrees in two fields of specialization, as mentioned above, and including economics and business administration.

The Course aims to stimulate and develop the research attitude and the curriculum may include a thesis in the fourth year or a special problem in chemistry (5.89) to give the student an opportunity to demonstrate his aptitude for creative effort.

The Course leads to the degree of Bachelor of Science in Chemistry. The curriculum requirements for the degree are given below.

GENERAL INSTITUTE REQUIREMENTS					*Total units*
	Specific science and humanities and social science subjects.				132[1]
	The Science Distribution Requirement will be satisfied by 5.41 or 5.60, which are required in the Departmental Program, plus appropriate subjects totaling				24
	The subject 5.31, which is required in the Departmental Program, appears on the list of Laboratory Subjects and can be used to satisfy the Laboratory Requirement.				
DEPARTMENTAL PROGRAM					
	Required Subjects				
5.41	[2]INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM	4	0	8	
5.31	INTRODUCTION TO CHEMICAL EXPERIMENTATION	2	8	2	
5.42	ORGANIC CHEMISTRY	4	0	8	
5.32	INTERMEDIATE CHEMICAL EXPERIMENTATION	2	8	2	
5.60	[2]CHEMICAL EQUILIBRIUM	4	0	8	
5.33	ADVANCED CHEMICAL EXPERIMENTATION	2	12	4	
5.61	PHYSICAL CHEMISTRY	4	0	8	
5.03	PRINCIPLES OF INORGANIC CHEMISTRY I	3	0	9	
					102
	Restricted Electives				
	At least one of the following subjects:				
5.43	ORGANIC CHEMISTRY	3	0	6	
5.62	PHYSICAL CHEMISTRY	4	0	8	
5.64J	BIOPHYSICAL CHEMISTRY	3	0	9	
					9 or 12
	Unrestricted Electives[3]				93 or 90
Total units required for the S.B. degree					360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] Students in Class '73 and later classes who take either 5.41 or 5.60 to fulfill the General Institute Requirement in Chemistry/Biology must take 12 Additional Units of Unrestricted Elective.

[3] The student's Faculty Counselor can offer suggestions for elective subjects, which are offered by this Department and by other departments, that will be of value in preparation for specialization in the various broad areas of chemistry. The proper choice of electives is particularly important for students planning to continue their education in a graduate school.

Students planning to take 5.89, particularly if they expect to prepare an undergraduate thesis during their fourth year, should indicate this interest to their Faculty Counselor as early as possible and not later than the beginning of their third year in order to arrange their subjects properly so as to have an adequate background in their area of specialization.

GRADUATE STUDY IN CHEMISTRY

The subjects offered in the graduate program aim to develop a sound knowledge of fundamentals and a familiarity with current progress

in the most active and important areas of chemistry. In addition to studying formal subjects, each student undertakes a research problem which forms the core of his graduate work. Through the experience of conducting an investigation leading to a doctoral or Master's thesis, the student learns general research attitudes and methods of approach, and acquires training in some of the specialized techniques of research.

Attainment of the Master's degree is not prerequisite to a program of study leading to a doctorate. Indeed, new graduate students should register as doctoral candidates from the beginning of their graduate work. Applications for admission as a S.M. candidate are not accepted unless there is some special reason to seek a Master's degree as a terminal degree.

All graduate students are encouraged to select a research supervisor during the first term of residence. The research supervisor will serve as the student's advisor during the balance of his graduate career. In particular, the final program of graduate subjects will be established by the student and his research supervisor. In planning this program and in establishing a thesis problem, careful consideration will be given to the candidate's previous academic record and professional experience as well as his long-range aims and objectives.

The areas of research in the Department are organic, inorganic, physical, analytical, geological, and biophysical chemistry, and chemical physics. A student's thesis research frequently will involve more than one of these fields.

Some of the research activities of the Department are carried out in association with the work of various interdisciplinary laboratories, such as the Center for Materials Science and Engineering, the Research Laboratory of Electronics, and the Spectroscopy Laboratory. These interdepartmental research laboratories provide a stimulating interaction among the research programs of several M.I.T. departments and give students the opportunity to become familiar with research work in disciplines other than chemistry. There is also an opportunity for research in cooperation with other departments, such as Biology, Earth and Planetary Sciences, and Physics.

Detailed information on the research activities of the faculty can be found in the *Directory of Graduate Research* published by the American Chemical Society.

Entrance Requirements for Graduate Study

The general requirements for admission to the Graduate School are set forth in Section 8 of this Catalogue. In particular, a student intending to pursue graduate work in chemistry should have as a background the equivalent of a good undergraduate program in chemistry. The Department is flexible in its attitude toward the specific mathematics and physics preparation; the essential requirement is demonstration of ability to progress with advanced study and research in some area of special interest. Mathematics and physics are important prerequisites for graduate work in physical chemistry or chemical physics. On the other hand, less preparation in mathematics and physics would be required for work in organic chemistry.

Graduate Record Examinations. Applicants for graduate admission to this Department are not required to submit G.R.E. scores. However, it is requested that scores be submitted by those persons who are taking the Graduate Record Examination.

The Graduate Degrees

The general requirements for graduate degrees are set forth in Section 3 of this Catalogue. Additional details relevant to Chemistry are given below.

MASTER OF SCIENCE IN CHEMISTRY

Candidates for the S.M. degree in Chemistry must demonstrate to the Department of Foreign Literatures and Linguistics an ability to read scientific literature in German, French, or Russian.

DOCTOR OF PHILOSOPHY AND DOCTOR OF SCIENCE

The Department does not have any formal subject requirements for the doctoral degree. Each student, with the advice of his research supervisor, will pursue an individual program of study which is pertinent to his long-range research interests. For some students this will include the acquisition of proficiency in reading scientific German.

Major examinations. Written major examinations are cumulative, and a series of examinations is given each term. Separate examinations in physical, organic and inorganic chemistry are offered each time, and additional examinations in analytical, biophysical chemistry or other specialized areas are also offered several

times during the year. The level of these examinations will correspond to introductory graduate subjects, but they are not based specifically on such subjects. Considerable emphasis is placed on seminars and current literature. Six of these cumulative examinations must be passed to complete the written major examination. No fixed time limit is set for completion of this requirement, but progress will be reviewed periodically.

No other general written examinations are required. In particular, no qualifying (or "entrance") examinations are given. An assessment of each new student's background and a decision on the proper level of first-term graduate work is made on the basis of individual interviews.

A comprehensive oral examination in the candidate's major field of advanced study is held near the end of the third term of residence. Progress in research is examined at that time.

A final oral presentation of the subject of the doctoral research is scheduled after the thesis has been submitted and tentatively evaluated by a committee of examiners.

Assistantships

The Department appoints a number of degree candidates as teaching assistants who are usually assigned to laboratory subjects in the Department or to discussion sections of lecture subjects. Financial support for students who maintain a satisfactory record is provided subject to the availability of funds. Many students receive appointments to research assistantships after their first year, although departmental fellowships and reappointments to teaching assistantships are also available.

Inquiries about the graduate program or concerning appointments should be addressed to the Chairman of the Department Committee on Graduate Students, Chemistry Graduate Office, Room 18-392.

Department of Earth and Planetary Sciences

Study of earth and planetary sciences at M.I.T. includes the broad field of the evolution of the main features of the planetary system; origin and the composition, structure, and state of the atmospheres, oceans, surfaces, and interiors of planets; the dynamics of planet and satellite motions; and the nature of the interplanetary medium. These problems are attacked by *in situ* physical measurements where possible, by laboratory studies on samples or models, and by theoretical-numerical studies influenced by the available data. No single department can fully cover all aspects of this broad subject. Chosen for special emphasis at M.I.T. are the fields of mineralogy-crystallography, experimental petrology, rock mechanics, regional geology and geophysics, geochemistry, seismology, planetary magnetism and electricity, heat flow, high pressure geophysics, geophysical fluid dynamics, optical, radio, and radar astronomy, dynamical astronomy, planetary atmospheres and surfaces, meteoritics, particles in planetary fields, physical and chemical oceanography, and marine geology and geophysics. Experimental facilities are available for training and research in these fields in the Department, in M.I.T. laboratories such as the Center for Space Research, Lincoln Laboratory, Haystack radar and radio observatory, Wallace Observatory (optical telescopes), and the Charles Stark Draper Laboratory, and in cooperating institutions such as the Woods Hole Oceanographic Institution. To summarize in more conventional terms, the Department is concerned with a program of education and research in modern aspects of geology and geochemistry, solid earth geophysics, space physics, astronomy and oceanography. The latter three fields are also covered by other M.I.T. departments, and joint programs not only are possible but are encouraged.

Graduates in the earth sciences typically pursue careers in universities, government agencies, and industrial firms where they are concerned with teaching, research, or management.

Science and engineering students transferring into the Department are generally able to get full credit for subjects they have taken.

THE UNDERGRADUATE CURRICULA

Earth and Planetary Sciences (Course XII)

The undergraduate programs in Course XII provide students with an opportunity to acquire competence in some aspect of the earth and planetary sciences as described above. They are designed to prepare the student for work in the leading graduate departments in these areas.

Two programs are offered. Program 1, for geologists and geochemists, is built around a core of prescribed professional subjects and basic subjects in physics and chemistry; electives allow for additional work in the basic and applied sciences and in the earth sciences. Program 2, which encompasses solid earth and planetary physics, emphasizes physics and mathematics in the required core; electives are used to meet the departmental requirement for the senior-year subjects in earth and planetary sciences and for further work in related fields. While both programs are normally begun in the sophomore year, some students may enter at the beginning of the third year. Both programs lead to the degree of Bachelor of Science in Earth and Planetary Sciences.

1. GEOLOGY, GEOCHEMISTRY AND GEOLOGICAL OCEANOGRAPHY PROGRAM CURRICULUM

		Total units
GENERAL INSTITUTE REQUIREMENTS		
	Specific science and humanities and social science subjects.	132[1]
	The subjects 8.03, 12.01, and 18.03, which are required in the Departmental Program, appear on the list of Science Distribution Subjects and can be used to satisfy the Science Distribution Requirement.	
	Laboratory Requirement.	12
DEPARTMENTAL PROGRAM		
	Required Subjects	
5.60	[2]CHEMICAL EQUILIBRIUM 4 0 8	
8.03	PHYSICS III 5 0 7	
18.03	DIFFERENTIAL EQUATIONS 4 0 8	
12.01	EARTH SURFACE PROCESSES 3 4 5	
12.02	PHYSICS AND CHEMISTRY OF GEOLOGICAL MATERIALS 3 4 5	60
	Restricted Electives	
	An approved sequence of subjects concentrating in some field. Copies of recommended programs in the fields of geochemistry, hard-rock geology, soft-rock geology, and geological oceanography may be obtained from departmental headquarters. Students who wish to take some other program must submit it for approval to the departmental committee on undergraduates.	108
	Students concentrating in geology are required, and those primarily interested in geochemistry are	

strongly urged, to attend a summer field camp in geology. This requirement is ordinarily met by attendance at an eight-week field course in geology in Montana conducted by the Department of Geology of Indiana University. Students completing this course of study satisfactorily may receive academic credit of 24 units.

Unrestricted Electives[3]	**48**
Total units required for the S.B. degree	**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] Students in Class '73 and later classes who take 5.60 to fulfill the General Institute Requirement in Chemistry/Biology, must take 12 additional units of Unrestricted Elective.

[3] Schedules of students in Course XII, Program 1, may always be arranged to leave available 12 units of unrestricted elective in the second year.

2. GEOPHYSICS, PLANETARY PHYSICS, AND OCEANOGRAPHY PROGRAMS

A student in this department chooses courses from physics, mathematics, geophysics, planetary physics, astronomy, and oceanography. The exact program depends on his interests and is arranged in consultation with his advisor.

				Total units
GENERAL INSTITUTE REQUIREMENTS				
	Specific science and humanities and social science subjects.			**132**[1]
	The Science Distribution Requirement will be satisfied by 8.03 and 18.03 which are required in the Departmental Program, plus appropriate subjects totaling			**12**
	Laboratory Requirement.			**12**
DEPARTMENTAL PROGRAM				
	Required Subjects			
8.03	PHYSICS III	5 0 7		
18.03	DIFFERENTIAL EQUATIONS	4 0 8		
				24
	Restricted Electives			
	Three physics subjects beyond 8.03		36	
	Other subjects in physics, mathematics, geology, geophysics, planetary physics, astronomy, and oceanography, including laboratory and/or field work; with advisor's approval		60	
				96
	Unrestricted Electives			**84**
Total units required for the S.B. degree				**360**

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

Earth and Planetary Sciences (Five-Year Course) (Course XII-A)

The problems that geologists, geochemists, geophysicists, and other earth scientists now have to consider require more basic science and more geological training than ever before, and this situation will certainly be intensified in the future. For this reason, students no longer receive training adequate for certain kinds of professional careers in the earth and planetary sciences in the normal four-year program. The primary educational objective of Course XII-A is to train earth and planetary scientists; the five-year plan has been organized with this purpose in view. This plan gives the qualified student maximum opportunity for a broad and thorough training in the basic sciences and a comprehensive training in the different fields of earth science — geology, geochemistry, geophysics, planetary physics, and others. Upon completion of the program he should be able to work in widely diversified fields and on many different kinds of problems in the areas mentioned in the description of the four-year curriculum.

Inasmuch as all requirements, except number of hours of thesis and of unrestricted electives, are the same for both Course XII and Course XII-A, candidates for the five-year plan will generally apply for it by the end of the first term of the senior year; at that time their qualifications will be examined and their preparation for graduate work determined. Since Course XII-A leads to the Master's degree, acceptance of a student for the graduate year will depend partly on his scholastic record and partly on the professional promise he has demonstrated in the field, the laboratory, or professional summer work with some organization.

Course XII-A leads to the degrees of Bachelor of Science in Earth and Planetary Sciences and Master of Science in Earth and Planetary Sciences awarded simultaneously at the end of the graduate year.

THE CURRICULUM

The undergraduate curriculum requirements are the same as for Course XII.

The graduate requirement is 66 units of graduate study and an acceptable thesis.

Physical Sciences (Course XII-B)

The School of Science offers a program in the physical sciences leading to the degree of Bachelor of Science without designation of field. The program is directed by the Department of Earth and Planetary Sciences but this implies no commitment for the student to follow a program in the earth sciences. The purpose of the program is to enable qualified students to delve more deeply into a range of physical science subjects, or to obtain a more comprehensive background in the physical sciences than would be possible within other more specialized

curricula. The XII-B curriculum must contain a coherent set of physical science and engineering subjects beyond the introductory level, in addition to the general Institute requirements. The curriculum is individually arranged in consultation with an advisor to meet the specific needs of the student. Advisors are drawn from the faculty of the Department of Earth and Planetary Sciences, and from other School of Science Departments. The program aims to provide a broad, interdisciplinary and coherent education in science. It is anticipated that students in this curriculum will be qualified for admission to graduate studies in one of the physical, environmental or applied sciences.

Admission to the program will be by the approval of the advisory team only, during an experimental period in which the program will be evaluated.

The curriculum requirements for this degree are given below.

	Total units
GENERAL INSTITUTE REQUIREMENTS	
Specific science and humanities and social science subjects.	132[1]
Science Distribution Requirement.	36
Laboratory Requirement.	12
Restricted Electives	
Science, and in special cases, engineering subjects chosen with advisor's approval	84
Unrestricted Electives	96
Total units required for the S.B. degree	360

[1]The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

GRADUATE STUDY

Earth and Planetary Sciences

The Department of Earth and Planetary Sciences offers a wide choice of graduate study and research for specialization in geology, geochemistry, and solid earth and planetary physics. In the borderland between geology, geophysics, geochemistry, and another science, the student may arrange a program of study and research under supervision of a special interdepartmental committee. Advanced work in the fields mentioned leads to one of the following degrees: Master of Science in Earth and Planetary Sciences, or Doctor of Philosophy or Doctor of Science with a thesis in the field of specialization.

The Department offers graduate students an unusual opportunity to pursue study and research in both theoretical and experimental aspects of the subjects. Modern laboratory facilities, electronic computers, research instruments, and extensive collections of specimens and materials are available to qualified graduate students. Field studies are included as an essential part of the graduate curriculum in geology, geophysics, and geochemistry, and special arrangements may be made for summer employment and field research on departmental projects and with industrial organizations and government agencies.

Oceanography

M.I.T. and the Woods Hole Oceanographic Institution have established a joint program in oceanography which leads to jointly awarded degrees of Doctor of Philosophy or Doctor of Science. For details of this program, see Joint Programs with the Woods Hole Oceanographic Institution.

Entrance Requirements for Graduate Study

The general admission requirements are those given in Section 8 of this Catalogue.

In addition, the Department requires preparation essentially equivalent to the program of subjects leading to the degree of Bachelor of Science in Earth and Planetary Sciences at the Institute. If the student is not fully prepared in certain of the required subjects, he usually will be asked to extend his preparation in these while he pursues his advanced work. The subjects to be taken for this purpose will be selected by the student after his preparation and proposed program of study have been considered by an advisory committee. The actual program of advanced subjects and research leading to a graduate degree is arranged by the student and his faculty advisors, to whom he is assigned at the time he first registers and who will generally direct the major part of his program.

The Graduate Degrees

MASTER OF SCIENCE IN EARTH AND PLANETARY SCIENCES OR MASTER OF SCIENCE IN OCEANOGRAPHY

In addition to the general and departmental requirements stated in the preceding paragraphs, the candidate for the degree of Master of Science in Earth and Planetary Sciences or in Oceanography is required to pursue a program of advanced study and research in an area approved by his faculty advisors. Possible fields of specialization are specified above.

THE DOCTORATES

The general requirements for the degrees of Doctor of Philosophy or Doctor of Science are given in Section 3. Possible fields of specializa-

tion are indicated above. Departmental requirements for graduate work leading to these degrees are given in the following paragraphs.

The preparation and research ability of any candidate for the doctorate must be such as to satisfy the Department Committee on Graduate Students that he is qualified to undertake advanced study and research. The thesis is expected to be a publishable contribution in the field of the candidate's specialization.

A student registered in the Department as a doctoral candidate will be required to take a qualifying examination, which may be partly oral and partly written; this examination is intended to survey his training and attainments and to serve as a basis for certifying him for a Doctor's program.

The program of graduate work may, with the approval of an appropriate Departmental Committee on Graduate Students, include subjects in other departments for which the student has adequate preparation. Candidates for the doctorate in oceanography will work under the guidance of an interdepartmental committee.

A reading knowledge of one or more foreign languages is strongly recommended, but not required of doctoral candidates.

In general, students are required to take at least 24 units of approved study in another department.

Teaching and Research Assistants

The Department regularly appoints 45 to 50 assistants who are candidates for a graduate degree. Teaching assistants conduct regularly scheduled laboratory sections and examinations, grade papers, and prepare teaching materials. Research assistants do assigned work on one of the Department's projects and may be able to use some of the work done toward a thesis. Information about these appointments may be obtained by writing to the Head of the Department.

Department of Mathematics

This Department offers a variety of programs to those interested in mathematics primarily as a pure science or for the additional purpose of applying it to other sciences, to fields of engineering, or to business.

THE UNDERGRADUATE CURRICULUM

Mathematics (Course XVIII)

Each undergraduate's program is arranged through continuous collaboration between the individual student and his Faculty Counselor, subject only to a minimum set of Course requirements. In most cases, the undergraduate curriculum in mathematics is preparatory to further professional training at the graduate level. For this purpose each student is encouraged both to obtain a substantial grounding in each of the fundamental branches of mathematics and also to explore certain fields of application, in order to establish a basis for the selection of an appropriate field of graduate specialization.

Whatever the ultimate objective — preparation for teaching, participation in the research programs of an industrial or government-sponsored organization, or a position as consultant in a business or in a modern high-speed computation center — the immediate educational aims are to provide an understanding of a substantial part of the existing body of mathematical knowledge and an ability to impart this knowledge to others. But most important, the Department hopes to inspire a deep interest in the discovery or invention of new mathematics or in the application of mathematics to a new field.

Students wishing to work with a small group of students under the supervision of a faculty member or to do individual work with a member of the Department may elect either to participate in a mathematics seminar or to write a thesis. These possibilities furnish excellent opportunities for students to develop initiative. The experience gained from active participation in a seminar conducted by a research mathematician may be particularly valuable for a student planning to pursue graduate work in any branch of mathematics.

The undergraduate Course leads to the degree of Bachelor of Science in Mathematics. The curriculum requirements for the degree are given below.

				Total units
GENERAL INSTITUTE REQUIREMENTS				
Specific science and humanities and social science subjects				132[1]
The Science Distribution Requirement will be satisfied by 18.03 or 18.031, which are among the Restricted Electives, plus appropriate subjects totaling				24
Laboratory Requirement.				12
DEPARTMENTAL PROGRAM				
Restricted Electives				
One of the following subjects:				
18.03 DIFFERENTIAL EQUATIONS	4	0	8	
18.031 INTRODUCTION TO LINEAR ALGEBRA AND APPLICATIONS	3	0	9	
Course XVIII subjects with the first decimal digit one or higher, including also 18.041-18.042, but excluding 18.999 totaling[2]		12 72		84
Unrestricted Electives				108
Total units required for S.B. degree				360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.
[2] Advanced standing credit will not fulfill any part of this requirement, but will be accepted as Unrestricted Elective.

Students intending to pursue a career in pure mathematics should plan to take advanced subjects in mathematics beyond the minimum requirement of six. These should normally include subjects in at least three of the five divisions in the list of descriptions of Course XVIII subjects, although students with exceptional interest and ability in one particular area may concentrate their efforts there. The following subjects form an integrated program in pure mathematics, which may serve as a basis for further study:

18.100 ANALYSIS
18.101 ANALYSIS
18.701 ALGEBRA I
18.702 ALGEBRA I
18.901 INTRODUCTION TO TOPOLOGY
18.951 RIEMANNIAN GEOMETRY

Students are strongly urged to plan a basic program with their Faculty Counselor, to be completed by the end of the third year, which should include at least four of these six subjects. It is

also recommended that the total program include at least two subjects at the graduate level, chosen from one of the five areas.

Applied Mathematics is the mathematical study of general scientific concepts, principles and phenomena which, because of their widespread occurrence and application, relate or unify various disciplines. The core of the program at M.I.T. concerns the following principles and their mathematical formulations: propagation, equilibrium, stability, optimization, cybercomparable university), is:

The recommended sequence of subjects, which is a minimal prerequisite for graduate work in Applied Mathematics at M.I.T. (or a comparable university), is:

18.041 PRINCIPLES OF APPLIED MATHEMATICS
18.042 PRINCIPLES OF APPLIED MATHEMATICS
18.301 INTRODUCTION TO PHYSICAL MATHEMATICS I
18.303 PROBABILITY AND RANDOM VARIABLES
18.401 CONTROL THEORY
18.420 MATHEMATICAL THEORY OF COMPUTATION

Freshmen interested in applied mathematics should take 18.001 and 18.002. This plan provides an introduction to all basic concepts and for the study of several in greater depth. Subjects of equivalent content may be substituted for those listed above, and in this respect or for continued study the following subjects should also be considered:

18.302 INTRODUCTION TO PHYSCIAL MATHEMATICS II
18.304 PROBABILITY AND STATISTICS
18.330 ELASTICITY
18.350 FLUID DYNAMICS
18.370 ASTRONOMY AND ASTROPHYSICS
18.403 APPLIED COMBINATORIAL ANALYSIS
18.404 SEMINAR IN APPLIED MATHEMATICS

Students should consult with their Faculty Counselor in Applied Mathematics to plan more personal and specialized curricula including advanced subjects.

GRADUATE STUDY IN MATHEMATICS

On the graduate level, the Department offers programs leading to the degrees of Master of Science, Doctor of Philosophy, or Doctor of Science.

Students may select their programs from a broad range of subjects, descriptions of which appear elsewhere in this Catalogue. Numerous informal seminars supplement the basic program. There are also a weekly Mathematics Colloquium sponsored by M.I.T., Brandeis University, and Harvard University and a weekly Colloquium on Applied Mathematics, each of which brings guest lecturers from other institutions.

Candidates whose primary interest is in the field of pure mathematics will ordinarily take most of their subjects in the Department of Mathematics. In addition to their advanced specialization, they will be encouraged to acquire breadth by taking basic subjects in analysis, algebra, geometry, and topology.

Candidates whose primary interest is in the field of applied mathematics will be encouraged to study important aspects of one or more engineering or scientific fields closely related to research in applied mathematics, in addition to their studies in mathematics.

Candidates primarily interested in pure mathematics which is basically motivated by applications and developments in theoretical physics or other disciplines will take special programs involving substantial breadth in both pure mathematics and the relevant cognate discipline.

Assistance or even collaboration in problems in pure or applied mathematics which are being investigated by members of the staff may constitute part of a graduate student's program.

Entrance Requirements for Graduate Study

The admission requirements are those set forth in Section 8 of this Catalogue, with the following additions and exceptions:

Science. Students are expected to have one year of college-level natural science.

Mathematics. Students will normally be expected to present an undergraduate mathematics program approximating that required of undergraduate mathematics majors at M.I.T. Students may enter the applied mathematics program from any undergraduate field of concentration and special consideration will be given to students with a strong scientific background.

The Graduate Degrees

MASTER OF SCIENCE IN MATHEMATICS

For the Master's degree, a student must take not less than 72 units including at least four 12-unit graduate ("A") subjects offered by the Department as well as submitting an acceptable thesis. With the approval of the registration officer two subjects may be taken from among the advanced undergraduate subjects offered by the Department. Where deemed appropriate, subjects from other Departments may be allowed.

DOCTOR OF PHILOSOPHY AND DOCTOR OF SCIENCE

The general requirements for the Doctor of Philosophy and Doctor of Science degrees are those set forth in Section 3. As soon as possible after beginning graduate work, each student who plans to take a doctorate should elect one of the following two plans of study:

Plan A. Under Plan A, there is a three-hour written qualifying examination on basic undergraduate mathematics, which is required of those who do not present satisfactory evidence of having learned the material. The examination will be waived for students presenting to the Departmental Graduate Committee satisfactory evidence of having learned the material; for example, by having achieved sufficiently high standing in classes in these subjects at M.I.T. or elsewhere.

A general oral examination is required of each candidate. The plan of this examination is made in consultation with three faculty members and is reviewed by the Graduate Committee.

Plan B. All students electing Applied Mathematics as their field of study should normally follow this program. Its basic objective is a proper balance of specialization and diversity. To secure maximum flexibility, each student's program is considered individually. The degree candidate, in consultation with a faculty advisor, submits a "Plan of Study" in his second term for approval by the Applied Mathematics Committee. In addition to a listing of subjects related to the major field, the plan must include a distinct minor, or its equivalent, to assure familiarity with the basic concepts of Applied Mathematics, i.e., propagation, equilibrium, stability, optimization, cybernetics and random processes. This plan forms the basis for the oral general examination which is arranged by the prospective thesis advisor and takes place in the second year of full-time graduate work. (The oral examination proposal is submitted to the Graduate Committee of the Department.) The student may officially begin his thesis research after passing this examination.

Students in both Plan A and Plan B will take additional subjects, chosen in consultation with an advisor. Unless otherwise specified by the advisor, 132 hours of graduate (A) credits with grade A or B are required Where deemed advisable, subjects from other departments may be allowed.

In special circumstances a student may receive permission to work under another plan (Plan N), in which regular Course requirements and written examinations in mathematics subjects are omitted. Students admitted to this program are given oral examinations on their general mathematical progress.

Doctoral candidates are required to demonstrate to the Department of Mathematics a mathematical reading knowledge in at least one foreign language. French, German, and Russian are acceptable languages.

Thesis work is done under the supervision of an advisor. The thesis is expected to represent original research and to meet the standards ordinarily required for publication in one of the standard journals devoted to research in mathematics or in a closely allied field. The thesis examination committee consists of three members, including the advisor.

Fellowships and Assistantships

Fellowships and teaching and research assistantships are available to graduate students in mathematics. Detailed information about these opportunities may be obtained from the Department.

Department of Meteorology

Meteorology is the science of the atmosphere. It is one of the earth sciences, all of which deal with the physical properties of the earth. Many of man's unsolved problems depend for their solution on increased knowledge of our physical environment. The Department's educational aim is to provide its students with a broad background in meteorology and related sciences, one which will prepare them to cope with these challenging problems of the atmosphere and the physical environment.

UNDERGRADUATE PREPARATION FOR METEOROLOGY AND OCEANOGRAPHY

The most essential element is a sound preparation in physics and mathematics, supplemented if possible by some chemistry. Exposure to courses in earth sciences is helpful but not required.

Undergraduate students at M.I.T. who wish to prepare for graduate work in meteorology or physical oceanography are advised to register in the Interdisciplinary Science program offered by the School of Science (formerly Course XII-B). Adequate preparation is also provided by other M.I.T. undergraduate curricula, particularly in the Departments of Physics and Mathematics.

Students who are taking their undergraduate work at other institutions are advised to include in their programs the equivalent of the mathematics and physics contained in the M.I.T. curricula referred to above. Students with baccalaureate degrees in meteorology or oceanography may be required to supplement their physics and mathematics during the first year of graduate residence, in lieu of some of the introductory meteorology courses given by the Department.

GRADUATE STUDY (*Course XIX*)

Emphasis in graduate training is placed on the theoretical and quantitative approach, supplemented by empirical and experimental methods. This approach is based on the conviction that the progress of meteorology and oceanography depends on the quantitative application of the laws of physics. However, the Department recognizes that there is equal demand for individuals who are more concerned with applications and experimental studies. Such students need to understand the implications of the theoretical developments, while the theory-oriented students need an appreciation of the observational material.

METEOROLOGY

Formal subjects of instruction are offered in all of the principal areas of meteorology. Subjects commonly taken by graduate students include:

19.15	LONG-RANGE FORECASTING
19.22	AIR AND SEA INSTRUMENTS
19.24	FLUID DYNAMICS LABORATORY
19.35	STATISTICAL PROBLEMS IN METEOROLOGY
19.45	SYNOPTIC METEOROLOGY II
19.46	NUMERICAL WEATHER PREDICTION
19.53	SYNOPTIC LABORATORY
19.61	INTRODUCTION TO DYNAMICAL METEOROLOGY
19.62	DYNAMIC METEOROLOGY
19.64	DYNAMIC METEOROLOGY II
19.65	TURBULENCE AND RANDOM PHENOMENA IN FLUID MECHANICS
19.67	PLANETARY FLUID DYNAMICS
19.71	ATMOSPHERIC PRECIPITATION PROCESSES
19.72	PHYSICAL METEOROLOGY
19.74	PHYSICS OF THE UPPER ATMOSPHERE

As this list suggests, facilities for instruction and research are available in all of the principal areas of meteorology. There are several radar systems and associated equipment together with a large and comprehensive file of radar data. Current weather data covering North America, Western Europe, and the adjacent oceans are available on teletypewriter circuits and by facsimile. Extensive files of weather data are available for most areas of the world; much of this is already in form for use on modern computing machines, and students have access to desk computers, IBM card equipment, and the high-speed computing facilities of the Information Processing Center.

The Meteorological Instrumentation Laboratory contains standard and specialized instrumentation and special test equipment. Laboratory facilities are available for research in physical meteorology, especially in the fields of cloud and precipitation physics. The Fluid Dynamics Laboratory contains apparatus that models atmospheric and oceanic circulations.

The Department conducts an extensive program of sponsored research. Graduate students are often able to participate in this program as

research assistants. Such active participation is considered a valuable supplement to the formal academic program and also provides some financial assistance.

The area surrounding Cambridge contains a number of institutions engaged in research in meteorology and related fields, such as the Air Force Cambridge Research Laboratories, the Woods Hole Oceanographic Institution, Harvard University, and the Boston offices of the United States Weather Bureau. Close contact with the scientific personnel of these institutions is maintained through joint seminars and symposia as well as by more informal means.

OCEANOGRAPHY

The Department of Meteorology is an active participant in the joint M.I.T.-Woods Hole Oceanographic Institution graduate program in oceanography. Except in special circumstances, all students in the Department pursuing a doctorate in oceanography will be entered in this joint program. At the present time the degree of Master of Science in Oceanography is offered only by the Department of Meteorology and the Department of Earth and Planetary Sciences. Students pursuing this degree do have access to the facilities of the joint program, however. The Master of Science degree is not a prerequisite to the doctorate, but many students find it desirable to earn a Master of Science on the way to the doctorate. The Department of Meteorology is active in physical oceanography including theoretical studies of the oceanic circulation, observational studies at sea, laboratory models and field and laboratory investigations of the interactions between the atmosphere and the ocean. The programs of graduate students in oceanography also include subjects in oceanography and related areas offered by the Department of Earth and Planetary Sciences, several other M.I.T. departments and the Woods Hole Oceanographic Institution.

Further information on the joint program with the Woods Hole Oceanographic Institution may be found in this section of the Catalogue.

The Graduate Degrees

The advanced subjects offered by the Department lead to the degrees of Master of Science in Meteorology, Master of Science in Oceanography, Doctor of Philosophy and Doctor of Science.

MASTER OF SCIENCE IN METEOROLOGY OR IN OCEANOGRAPHY

The graduate ("A") subjects required for the Master of Science degree may be selected from those offered in meteorology or in oceanography and those in related fields offered by other departments. Undue specialization in one branch of the field is discouraged. There are no foreign language requirements for the degree.

DOCTOR OF PHILOSOPHY AND DOCTOR OF SCIENCE

The general requirements for the degrees of Doctor of Philosophy and Doctor of Science are given in Section 3. The Department does not require candidates for the doctorate to present evidence of competence in a foreign language or languages. Because of the importance of communication with foreign scientists, it is strongly urged that candidates for the doctorate acquire intermediate competence in one or more foreign languages. It is preferable that this competence in foreign languages be acquired prior to enrollment as a graduate student, but the study of language may be undertaken while in residence at M.I.T. Russian and German are recommended, but French and Spanish are also appropriate.

Assistantships and Fellowships

The Department offers a limited number of research and teaching assistantships each year. Research assistants are assigned to work on one of the many research projects in the Department. Teaching assistants may be assigned to assist in laboratory instruction or in the preparation of teaching materials and the grading of papers. Information concerning these appointments may be obtained from the Head of the Department. The Department offers a few predoctoral fellowships in the atmospheric sciences and oceanography. Announcements and application forms are available in early October and may be obtained from the Head of the Department.

Department of Nutrition and Food Science

The Department of Nutrition and Food Science, by virtue of the diverse backgrounds and interests of its faculty, integrates knowledge from biology, chemistry, physics, microbiology, food science, medicine, and engineering in its research and teaching programs. Complex problems dealing with interactions occurring between man and various factors in the environment require systematic and quantitative analysis for their eventual solution. Examples of the kinds of broad problems to which departmental programs are related are the prevalence of malnutrition in developing countries and of degenerative diseases in technologically advanced countries; the need for improved understanding of the origin and nature of diseases and disability; the safety of new, and re-examination of old, chemical substances added intentionally or accidentally finding their way into the environment; the development of information necessary for the derivation of environmental control systems; the need for new and improved methods of food processing and for storage and distribution of foodstuffs. In response to challenges presented by such problems, the Department of Nutrition and Food Science has developed in such a way that integrated programs involving a broad range of scientific disciplines can be brought to bear on them. Programs involve not only research activities that provide scientific information, but also educational opportunities for students to acquire professional expertise and breadth of perspective necessary for them to make meaningful contributions to the solution of these problems.

UNDERGRADUATE SPECIALIZATION IN NUTRITION AND FOOD SCIENCE

The Department offers an undergraduate curriculum as part of the Life Sciences Curriculum Program 2. This curriculum (described below) emphasizes fundamental subjects in the physical and biological sciences.

Either of two fields of specialization may be elected. For those interested in nutritional biochemistry and metabolism, introductory subjects are taken in biochemistry, mammalian physiology, and nutrition; a series of electives may be chosen from areas which include mammalian biochemistry and metabolism, human nutrition, endocrinology, neuroendocrinology, and psychology. Specialization in food science and technology, involves a series of planned electives selected from subjects such as food engineering, analytical chemistry, physiology, microbiology, and toxicology.

For those who wish to go further in either degree area, most of the specialized training must be obtained at the graduate level. The undergraduate student may take courses in these fields while acquiring knowledge that will serve him well in a broad range of careers in the life sciences.

Life Sciences (Course VII)

PROGRAM 2. NUTRITION AND FOOD SCIENCE CURRICULUM

		Total units
GENERAL INSTITUTE REQUIREMENTS		
	Specific science and humanities and social science subjects	**132**[1]
	The Science Distribution Requirement will be satisfied by 5.41[2] and 5.60[2], which are required in the Departmental Program, plus appropriate subjects totaling	**12**
	The subjects 7.011 or 20.02, which are restricted electives appear on the list of Laboratory Subjects and can be used to satisfy the Laboratory Requirement.	

DEPARTMENTAL PROGRAM

	Required Subjects				
5.41	[2]INTRODUCTION TO STRUCTURE, BONDING AND MECHANISM	4	0	8	
5.60	[2]CHEMICAL EQUILIBRIUM	4	0	8	
7.05	GENERAL BIOCHEMISTRY	5	0	7	
					36
	Restricted Electives				
	One of the following subjects:				
7.011	INTRODUCTION TO EXPERIMENTAL BIOLOGY	1	8	3	
20.02	NUTRITION AND FOOD SCIENCE PROJECTS LABORATORY	1	8	3	
				12	
	Any two of the following subjects:				
7.01	[2]GENERAL BIOLOGY	4	0	8	
7.03	GENETICS	3	0	9	
7.04	DEVELOPMENTAL BIOLOGY	3	0	6	
7.06	GENERAL AND CELL PHYSIOLOGY	3	0	9	
7.21	GENERAL MICROBIOLOGY	3	0	9	
				24 or 21	

A coherent selection of subjects aimed at a well defined educational goal. The planned electives are to be agreed upon between the student and a designated faculty counselor of the Department of Nutrition and

Food Science, and will be distributed in the following manner:

1. Additional subjects in physics, mathematics or equivalent subjects; for example, 1.00, 6.01, 8.03, 18.03.	at least	24
2. Additional subjects in chemistry; for example, 5.42, 5.62, 7.07J.	at least	12
3. Laboratory subjects in life sciences; for example, 7.031, 7.041, 7.051, 7.061, 20.41.	at least	12
4. Additional subjects in the Department of Nutrition and Food Science or other related subjects approved by the advisor; for example, 20.30, 20.38, 20.63, 20.80, 20.84.	at least	30 or 33
		114
Unrestricted Electives[3]		66
Total units required for S.B. degree		360

[1] The requirement for Class of '72 is 128, the Unrestricted Elective units being increased by 4.
[2] Students in the class of '73 and later classes who take 5.41 or 5.60 to fulfill the General Institute Requirement in Chemistry/Biology must take 12 additional units of Science Distribution Subjects. 7.01 may be taken as partially fulfilling the Restricted Elective requirement and partially fulfilling the Science Distribution Requirement, provided it has not been taken to fulfill the General Institute Requirement in Chemistry/Biology, thereby providing 12 additional units of Unrestricted Elective.
[3] Schedules of students in Course VII, Program 2, may always be arranged to leave available 12 units of unrestricted elective in the second year.

GRADUATE STUDY (COURSE XX)

The Department offers programs leading to the degrees of Master of Science, Doctor of Philosophy, and Doctor of Science in three areas: Nutritional Biochemistry and Metabolism; Food Science and Technology; and Biochemical Engineering. A number of special training programs are offered. These include experimental toxicology, clinical nutrition and metabolism, oral science, experimental medicine, and neuroendocrine regulation. Detailed information about these programs may be obtained from the Department.

A wide choice of graduate study and research opportunities are offered for specialization in: mammalian biochemistry and metabolism, basic nutrition; clinical nutrition; experimental toxicology; food chemistry; food microbiology; food processing; food engineering; and biochemical engineering. Excellent facilities are available for research, including well-equipped laboratories for chemical, biochemical, physical, and microbiological research. A clinical research center is available for metabolic studies on human subjects, and modern animal facilities are available for most experimental animal species. Laboratories also exist for research on the effects of various types of food processing (e.g., heat, dehydration, radiation, refrigeration, and freezing), and a modern pilot plant includes equipment for large-scale fermentations and other similar processes. Detailed summaries of research activities of the members of the departmental faculty are available in the departmental headquarters.

NUTRITIONAL BIOCHEMISTRY AND METABOLISM

Research in nutritional biochemistry and metabolism is concerned with nutritional, genetic, environmental, and endocrine variations in the metabolic processes of man and various laboratory animals and their alterations in disease states.

A program of training in mammalian biochemistry is offered to graduate students who want to acquire knowledge and research experience in physiological chemistry and biochemistry as it applies to nutritional problems. To this end, several advanced subjects in nutritional biochemistry have been instituted. The staff of the Department also carry out research into effects of the environment, and especially the nutritional environment, on the functioning of the mammalian organism. Current research projects include: biochemical, morphological, and physiological effects of malnutrition; the biochemical defects underlying inherited disorders of the endocrine system; endocrine control mechanisms; effects on infection and physical and mental stress on nutrient requirements and nutritional status; dietary and hormonal factors influencing protein synthesis; environmental factors influencing endocrine rhythms; enzyme synthesis and turnover in tissues; utilization in metabolism of synthetic compounds as energy sources; functions of vitamin A in the metabolism of amino acids and related compounds; protein and nucleic acid synthesis and turnover and their control; biological activities of fatty acids; effects of nutritional and endocrine variations on the activities of tissue enzymes; congenital defects due to vitamin deficiencies. Effects of protein malnutrition on brain chemistry; effects of drugs and amino acids on neurotransmitters; effects of environmental lighting on neuroendocrine functions are also being studied.

Science

DEPARTMENT OF NUTRITION AND FOOD SCIENCE

FOOD SCIENCE AND TECHNOLOGY

A program of training is offered in the fields of food chemistry, food engineering, and food microbiology. Research in food toxicology, food chemistry, and food biochemistry is concerned with the formation, occurrence, and analysis of trace toxic substances in foods, changes in food composition and loss of nutrient value due to chemical reactions, processing and storage components contributing to the organoleptic properties (flavor) of foods, and enzymatic food processes. Food microbiology, food processing, and food engineering deal with the establishment of scientific principles and engineering practices for the processing, storage, distribution and use of foods and with procedures for maintaining or improving their acceptability and nutritive value.

BIOCHEMICAL ENGINEERING

A program in biochemical engineering is offered leading to the Master of Science and doctoral degrees. In this program integration of studies in biological sciences with engineering is emphasized. Particular attention is directed toward industrial microbiology and fermentation processes. Research projects in biochemical engineering include: continuous culture of microorganisms; dynamics of microbial growth; microbiology of mixed cultures and multiple substrate utilization; recovery of metabolites from fermentation broths; ultrafiltration and reverse osmosis for recovery of biological substances; mass transfer in fermentation vessels; microbiology and fermentation technology in single-cell protein production; and biosynthesis of secondary metabolites.

Entrance Requirements for Graduate Study

Requirements for graduate study are those described for admission to the Graduate School in Section 8 of this Catalogue, modified to include one year each of calculus and physics.

To qualify for graduate study in this department, applicants should possess a Bachelor's degree with a major in one of the following areas: life sciences, chemistry, nutrition, food science, or chemical engineering, or professional degrees such as the M.D., D.D.S., or D.V.M. degrees.

The Graduate Degrees

The general Institute requirements for graduate study are set forth in Section 3. Additional details concerning the programs of this Department are summarized below.

MASTER OF SCIENCE

Students who do not already possess Master's or professional degrees are normally registered as S.M. candidates during their first year of graduate study. However, the S.M. degree is not a prerequisite for doctoral candidacy, and most students change to a doctoral program, by permission, based on academic performance during the first year.

S.M. degree programs are available in Nutritional Biochemistry and Metabolism; Food Science and Technology; and Biochemical Engineering. Each curriculum consists of a limited number of recommended graduate subjects supplemented by sufficient elective units selected by the student in consultation with his adviser to fulfill the Institute requirement. A thesis conducted under the direction of a departmental faculty member, or as part of an interdepartmental program, is required of all S.M. candidates.

DOCTOR OF PHILOSOPHY AND DOCTOR OF SCIENCE

Departmental programs lead to Ph.D. or Sc.D. degrees in nutritional biochemistry and metabolism, food science and technology; or in biochemical engineering. These programs consist of major and minor programs of study, together with an original thesis.

Major and minor programs comprise a total of 54 units of subjects consisting of a limited number of required subjects supplemented by electives. Programs for individual students are arranged, in consultation with faculty advisers, to meet the needs of individual research areas. Programs of study in biochemical engineering must be approved by an interdepartmental committee consisting of faculty members in the Departments of Nutrition and Food Science, Biology, and Chemical Engineering.

Written general examinations are taken during the fourth or fifth term of graduate study. Written examinations establish competence with reference to basic scientific background as well as in specialized areas of knowledge related to the specific degree programs. Completion of the written examinations is followed by oral presentation and defense of a research proposal upon which the thesis research will be based.

Thesis research is done under the supervision of faculty members in the various areas of specialization described above. Research progress is evaluated periodically by the thesis

advisory committee, which also conducts an oral defense of the completed thesis.

Assistantships and Fellowships

Financial assistance is available to qualified applicants in the form of research assistantships, traineeships, and a limited number of fellowships, subject to availability of funds. Research assistantships are provided from grants obtained by members of the faculty for work on specific research projects. Traineeships are provided from training grants in several fields. Further information may be obtained from the Head of the Department.

Department of Physics

The Physics Department offers programs of formal study and research in most areas of physics. The emphasis is on fundamental principles, but with a recognition of the constantly increasing connections of physics with other scientific fields. Besides its undergraduate degree, the Department offers graduate programs leading to the degrees of Master of Science, Doctor of Philosophy, and Doctor of Science.

The Department is organized in four main research divisions: atomic and solid state physics; experimental nuclear and particle physics; theoretical physics; space physics and astrophysics.

The large and active program in atomic, molecular, plasma, and solid-state physics provides a student with unique opportunities for studies in these fields. Equipment is available for spectroscopic studies at radio, microwave, infrared and optical frequencies. Currently available are facilities for the production of low temperatures, high pressures, and magnetic fields up to 100,000 gauss. A magnet capable of producing a steady magnetic field of 250,000 gauss is available as one of the facilities of the Francis Bitter National Magnet Laboratory. Facilities for the study of matter using X-ray and neutron diffraction techniques are at hand. The 5,000 kw M.I.T. Reactor is used for neutron diffraction studies.

The extensive facilities of the Information Processing Center and of the Multiple Access Computer (Project MAC) are available for research that involves the use of high-speed computation.

Experimental research in nuclear and particle physics is based on the Cambridge Electron Accelerator (operated jointly by Harvard and M.I.T.), on a new 400 Mev electron linear accelerator, and on use of accelerators at Brookhaven, Stanford University, Hamburg (Germany) and other institutions.

The research in astrophysics, radio astronomy, and space physics is a rapidly growing field at M.I.T. Investigations in this subject have made use of earth satellites and deep space probes. Because of the strongly interdisciplinary and interdepartmental character of work in this area, a fuller description of it will be found in a separate section entitled "Astronomy and Astrophysics" at the end of this section.

Closely integrated with the experimental work, using the equipment mentioned, there are active groups studying nuclear, elementary particle, atomic, molecular, and solid-state theory.

Much of the research described above is carried out as part of the work of various interdepartmental laboratories, including the Laboratory for Nuclear Science, Research Laboratory of Electronics, Spectroscopy Laboratory, Center for Materials Science and Engineering, Center for Space Research, the Center for Theoretical Physics, and the Education Research Center. These facilities provide close relationships among the research activities of a number of M.I.T. departments and give students the opportunity for contact with research carried out in disciplines other than physics.

Center for Theoretical Physics

In developing a Center for Theoretical Physics at M.I.T., it has been our intention to create an atmosphere in which theoretical physics research and teaching can flourish. Toward this end, a fairly large group of theorists has been brought together and a "home" has been established for them which maximizes the opportunities for communication and collaboration. In addition to the professorial staff, the Center consists of a number of postdoctoral fellows as well as senior visitors. M.I.T. graduate students engaged in research in theory also are housed at the Center. At the present time the major areas of research represented are elementary particles, nuclear physics, and astrophysics. The lively interaction among the specialists in each of these fields is unique to the M.I.T. group and is one of the major sources of its strength.

THE UNDERGRADUATE CURRICULUM

Physics (Course VIII)

The undergraduate curriculum in physics offers students the opportunity of acquiring basic competence in the fundamentals of both experimental and theoretical physics. The offerings are of sufficient depth and breadth so that the

Course VIII graduate is well equipped either to build a career in the field of applied physics in industry or to enter a graduate program in preparation for more advanced professional work. The central core of requirements for the Bachelor's degree, as listed in the subsequent tabulation of departmentally prescribed subjects and elective subjects, is designed not only to accomplish the foregoing objective but also to allow each student to select a considerable variety of subjects and to proceed at the pace best suited to his individual desires and capabilities.

The curriculum for the first year is described in Section 2.

It is suggested that the student in the second year should take INTRODUCTORY NETWORK THEORY (6.01) or INTRODUCTION TO ELECTRONICS (6.14) in the second term in order to acquire a familiarity with and a knowledge of some topics in electrical engineering. Adequate elective time is made available in the second year and students may wish to take a mathematics subject beyond 18.03 at this time. During the second year the prospective physics major should also take a project laboratory (preferably but not necessarily the project laboratory administered by the department) or some departmentally approved substitute (e.g. research participation).

The departmentally prescribed subjects 8.05, 8.13, and 8.14 are normally taken in the third year and this is an appropriate time to take some of the restricted elective subjects. It is usual to start the theoretical physics sequence with 8.06 in the second term of the third year. Each student is urged to explore with his Faculty Counselor various possibilities of electing those subjects which are best suited to his individual needs at this stage of his studies.

In the fourth year, the theoretical sequence is then continued with 8.07 and completed with 8.08. A relatively large amount of elective time thus becomes available in this year and can be used effectively in a wide variety of ways. EXPERIMENTAL PHYSICS (8.15) is designed to enable the student to come face to face with the challenge of exploring a problem in experimental physics in the same spirit in which research is done by the professional physicist.

In the specific choice of a curriculum for Course VIII, each student should keep in mind the following essential pattern of subjects falling into two major categories:

1. An orderly sequence of laboratory subjects culminating in 8.15 to enable him to obtain the competence in experimental work which he needs to embark successfully on his future professional career.

2. A corresponding sequence of lecture (and recitation) subjects. In this sequence the theoretical subjects 8.06, 8.07 and 8.08 are designed to recapitulate and organize the essentials of theoretical physics and also to provide a solid springboard for much of the student's future education in physics.

The Course leads to the degree of Bachelor of Science in Physics. The curriculum requirements for the degree are given below.

					Total units
GENERAL INSTITUTE REQUIREMENTS					
	Specific science and humanities and social science subjects.				132[1]
	The Science Distribution Requirement will be satisfied by 8.03 and 18.03, which are required in the Departmental Program, plus appropriate subjects[2] totaling				12
	The Institute laboratory requirement may be satisfied through the Department's project laboratory (8.11 or 8.12.)				
DEPARTMENTAL PROGRAM					
	Required Subjects				
18.03	DIFFERENTIAL EQUATIONS	4	0	8	
8.03	PHYSICS III	5	0	7	
8.04	PRINCIPLES OF QUANTUM PHYSICS	5	0	7	
8.05	PHYSICS OF ATOMS AND MOLECULES	4	0	8	
8.13	EXPERIMENTAL ATOMIC PHYSICS I	1	6	5	
8.14	EXPERIMENTAL ATOMIC PHYSICS II	1	6	5	
8.15	EXPERIMENTAL PHYSICS	2	0	2	
	[3]THESIS		12		
					88
	Restricted Electives				
	Two subjects given by the Department of Mathematics beyond 18.03		24		
	Two subjects given by the Department of Physics in addition to those listed above[4]		24		
					48
	Unrestricted Electives[5]				80
Total units required for the S.B. degree					360

[1] The requirement for Class of '72 is 128 units, the Unrestricted Elective units being increased by 4.

[2] Students may find it advantageous to elect 6.01 INTRODUCTORY NETWORK THEORY (4–0–8) or 6.14 INTRODUCTION TO ELECTRONICS (4–2–6) in the second term of the second year. This would complete the Science Distribution Requirement.

[3] A thesis of 12 units is required. Not more than 30 units of thesis credit may be included in the minimum of 360 units required for the S.B. degree.

[4] Students planning to do graduate work in physics would normally take the theoretical sequence 8.06, 8.07 and 8.08.

[5] Schedules of students in Course VIII may always be arranged to leave available 12 units of unrestricted elective in the second year.

Science

DEPARTMENT OF PHYSICS

GRADUATE STUDY IN PHYSICS

The Department of Physics offers graduate work leading to the degrees of Master of Science in Physics, Doctor of Philosophy, and Doctor of Science. No stated curriculum of subjects of instruction is required for any of these degrees; instead, individual curricula are chosen in consultation with the Registration Officer, in accordance with certain broad principles.

Subjects of study include work in almost all of the experimental fields described in the paragraphs above, and in the various branches of theoretical physics as well. Graduate students are expected to gain familiarity with several of the branches of physics, not merely with one specialty. They will be well prepared for either academic work or industrial research, since the training includes a broad and thorough understanding of both the fundamentals of physics and its advanced applications.

A number of assistantships are available each year for graduate students. The duties of these assistants involve both the teaching and research activities of the Department. Application forms and further information may be obtained from the Graduate Registration Officer, Department of Physics.

Entrance Requirements for Graduate Study

The general requirements are those given in Section 8 of this Catalogue. Specifically, a student intending to pursue graduate work in physics should have as a background the equivalent of the S.B. requirements for Course VIII, but some deficiencies may be removed while the student is engaged in graduate work.

The Graduate Degrees

The general requirements for graduate degrees are set forth in Section 3.

MASTER OF SCIENCE IN PHYSICS

For the Master of Science degree in Physics the requirements are the General Institute Requirements for this degree. The Department of Physics has no language requirement for this degree.

DOCTOR OF PHILOSOPHY AND DOCTOR OF SCIENCE

A student for the degree of Doctor of Philosophy or of Doctor of Science is expected to take graduate subjects to prepare himself for the General Examination, but there are no stated required subjects. A reading knowledge of French, German, or Russian, or such other language as the Department may approve, must be demonstrated.

Joint Programs with the Woods Hole Oceanographic Institution

The Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology offer joint programs of education and research in oceanography, biological oceanography, and ocean engineering. These programs are administered by committees drawn from the Faculty and Staff of the two institutions and lead to degrees awarded jointly by the two institutions. Extensive resources for advanced study and research are available at both M.I.T. and the Woods Hole Oceanographic Institution.

Subjects are offered at both institutions, and bus service is provided to make it possible for a student to be resident at either Cambridge or Woods Hole. Most fundamental subjects are taught at M.I.T. Thesis research may be carried on at either institution.

The Woods Hole Oceanographic Institution operates a fleet of research ships, submarines, and aircraft, and has extensive laboratory facilities and an active research staff. A modest marine facility is maintained by M.I.T. at Boston harbor consisting of dock space and a small research vessel.

OCEANOGRAPHY

The Department of Earth and Planetary Sciences and the Department of Meteorology offer joint programs in oceanography with the Woods Hole Oceanographic Institution leading to the degree of Doctor of Philosophy or Doctor of Science awarded jointly by the two institutions. Students in this program may choose to specialize in marine geophysics, marine geology, marine chemistry, or physical oceanography.

Entrance Requirements for the Joint Program

Oceanography is not a separate scientific discipline but is a field in which the basic sciences and the methods of other earth sciences are used to explore the scientific problems of the waters and the floors of the ocean basins. All applicants should have sound preparation in basic physics and mathematics. Students specializing in marine geology or marine chemistry should have undergraduate preparation in geology or chemistry. Physical oceanography is the study of the fluid dynamics and physics of the ocean; therefore, adequate preparation for this field is an undergraduate major in physics, mathematics, or other basic science. No previous experience in oceanography is required.

THE GRADUATE PROGRAM

The general requirements for the degrees in the joint program are the same as those for the M.I.T. doctorates, given in Section 3 of this Catalogue. The first year of residence at M.I.T. or Woods Hole will be determined by the student's background.

Subjects in oceanography are offered by the Departments of Meteorology and of Earth and Planetary Sciences and by the Woods Hole Oceanographic Institution. These subjects are described in the Description of Subjects under Earth and Planetary Sciences (12.), and Meteorology (19.). In addition, several other M.I.T. departments offer subjects in the marine sciences or in areas basic to oceanography. Each student in the program will have advisors who will help him to plan an academic program that is adapted to his interests. The program of academic subjects occupies the first two years of graduate study and serves to prepare the student for the General Examination. Oceanographers use knowledge, techniques, and methods from many areas of science and engineering. Hence the curricula followed by students are very varied. Among the subjects commonly taken by oceanography students are:

12.73 MARINE GEOLOGY
12.75 CHEMICAL OCEANOGRAPHY
12.81 WAVES AND TIDES
18.307 METHODS OF APPLIED MATHEMATICS III
18.350 INTRODUCTION TO FLUID MECHANICS
19.81 INTRODUCTION TO OCEANIC MODELS
19.82 INTRODUCTION TO OCEANIC MODELS
19.84 DYNAMIC OCEANOGRAPHY

The Graduate Degrees

The joint program leads to the degree of Doctor of Philosophy or Doctor of Science.

Financial Aid and Application Procedures

A limited number of fellowships and graduate assistantships is available on a competitive basis. Application for admission to the joint program and for financial aid should be made on the M.I.T. Graduate Application Form. Copies may be obtained from the Director of Admissions at M.I.T. or from the Dean of Graduate

Studies of the Woods Hole Oceanographic Institution. Requests for further information on the joint program may be addressed to The Joint Program in Oceanography at either Room 54-912, M.I.T., Cambridge, Massachusetts 02139, or Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543.

BIOLOGICAL OCEANOGRAPHY

The Department of Biology offers a joint program in Biological Oceanography with the Woods Hole Oceanographic Institution leading to the degree of Doctor of Philosophy, awarded jointly by the two institutions. Students in this program specialize in areas of biology related to oceanography. The Woods Hole Oceanographic Institution has a large staff active in various areas of biological sciences, including marine biology, microbiology, ecology, photosynthesis and electron microscopy.

Entrance Requirements for the Joint Program

Applicants to this program should have an undergraduate degree with a substantial preparation in mathematics and the basic sciences. The requirements for admission are similar to those for admission to the doctoral program in Biology. Applicants must take the Graduate Record Examinations and submit scores, specifically verbal and quantitative.

THE GRADUATE PROGRAM

The general requirements for the Ph.D. degree in the joint program are similar to those for the M.I.T. degree in Biology. A student will normally spend part or all of his first graduate year at M.I.T. and carry out his graduate and thesis research at Woods Hole. Students are encouraged to spend at the Woods Hole Oceanographic Institution the summer immediately preceding the first year of graduate work. Subjects in biology and biological oceanography are offered by the Department of Biology and at the Woods Hole Oceanographic Institution. These subjects are described in the Description of Subjects, under Biology (Subjects in the 7.4 sequence). Several other M.I.T. departments offer subjects in fields related to biological oceanography, including specialized subjects in oceanography described in the Description of Subjects, under Earth and Planetary Sciences (12.), and Meteorology (19.).

The Graduate Degree

The Program leads to the degree Doctor of Philosophy awarded jointly by the Massachusetts Institute of Technology and the Woods Hole Oceanographic Institution.

Assistantships and Fellowships

A limited number of fellowships and graduate assistantships for the joint program is available on a competitive basis. Further information and applications may be obtained from the Head of the Department of Biology at M.I.T. or from the Dean of Graduate Studies of the Woods Hole Oceanographic Institution.

Application Procedure

Application for admission to the joint program or for financial aid should be made on the M.I.T. Graduate application form, copies of which may be obtained from the Director of Admissions at M.I.T. or from the Woods Hole Oceanographic Institution. Requests for further information relating to the joint program may be addressed to the Head of the Department of Biology of M.I.T. or to the Dean of Graduate Studies of the Woods Hole Oceanographic Institution.



INTERDISCIPLINARY PROGRAMS AND RESEARCH FACILITIES 5.

Advances in knowledge and concern with the functioning of industrial societies have led researchers to become interested in complex problems that can no longer be adequately dealt with from the vantage point of a single scientific or engineering discipline. There is thus an increasing tendency at M.I.T. for faculty and students from different fields to work together in a variety of groups, laboratories, centers, and programs that cut across disciplinary lines. Out of these common research undertakings there are also emerging several educational programs ranging from those which can be accommodated within certain departments to others which involve faculty from several schools. The most important of these interdisciplinary programs and research facilities are described in this section.

PROGRAMS

Astronomy and Astrophysics

Teaching and research in astronomy at M.I.T. are truly interdepartmental, involving more than 20 faculty members of the Departments of Physics, Earth and Planetary Sciences, Mathematics, Electrical Engineering, and Chemistry. The subjects offered and the opportunities for thesis research cover a correspondingly broad spectrum.

The observational astronomy program emphasizes the application of modern technology: objects as diverse as pulsars, supernova ejecta, and the planets are being investigated with X-ray, optical, and radio telescopes. Quasars, the cosmic microwave background, stars in the process of formation, and molecules in space are being studied with radio telescopes, often involving very long baseline interferometers; the properties of the interplanetary medium are being explored with particle detectors on spacecraft; planets are being viewed with radar and by optical telescope both in the visible and the infrared. The moon is being examined not only from afar, but also on site with seismographs, and lunar material is being analyzed in several of our laboratories.

Some of the theoretical astronomy relates directly to these observations, as in testing general relativity in the solar system or in trying to understand the complex interactions of the solar wind with our own planet. Probably the bulk of our theoretical effort lies in intensive studies of the structure and evolution of stars, the dynamics of spiral galaxies and the solar system, and relativistic astrophysics.

Opportunities for student research include the use of the Haystack radio telescope and of the unique electronic instrumentation at the nearby 24-inch and 16-inch optical telescopes of the new Wallace Observatory. Active experimental programs with student participation also involve instruments launched in balloons, rockets, satellites, and interplanetary spacecraft. In addition, M.I.T. students and staff observe at other installations such as the National Radio Astronomy Observatory in West Virginia and the telescopes of both the Kitt Peak National Observatory and the Cerro-Tololo Interamerican Observatory in Chile.

The astronomy subjects offered by various departments are listed below and are described in more detail at the back of this Catalogue. The asterisks mark subjects that will be offered in 1971/72.

UNDERGRADUATE

*12.111	ASTRONOMY I
*12.112	ASTRONOMY II
*12.113	WORKSHOP IN ASTRONOMY
12.	EXPERIMENTAL ASTRONOMY
*12.002	THE EARTH AND THE PLANETS
*8.285	INTRODUCTION TO ASTROPHYSICS
18.370	DYNAMICAL PROBS. OF ASTRONOMY
*12.131J	PLANETARY PHYSICS AND CHEMISTRY I
*12.132J	PLANETARY PHYSICS AND CHEMISTRY II
12.121	EXPLORATION OF THE SOLAR SYSTEM I
12.122	EXPLORATION OF THE SOLAR SYSTEM II

GRADUATE

*8.921	PHYSICS OF THE STARS
8.932	PHYSICS OF THE GALAXY
*12.115J	DYNAMICAL ASTRONOMY
*18.376	GALAXIES, AND THEIR DYNAMICS
*6.624	DETECTION AND MEASUREMENT OF RADIO ASTRON. SIGNALS
8.942	COSMOLOGY
8.911	CHARGED PARTICLES IN SPACE
8.	SOLAR PHYSICS
*12.631J	PLANETARY ATMOSPHERES
12.623	PLANETARY SURFACES
12.501	PLANETARY INTERIORS
12.	THE EARTH FROM SPACE
8.922	STELLAR EVOLUTION
18.375	STELLAR DYNAMICS AND GALACTIC STRUCTURE
8.962	GENERAL RELATIVITY
*12.614J	DYNAMICAL PROBS. OF THE SOLAR SYSTEM
18.397	GENERAL RELATIVITY
5.129J	CURRENT RESEARCH IN METEORITICS
8.	SEMINAR IN THEORETICAL ASTROPHYS.
8.951J	FUNDAMENTALS OF RADIO ASTRONOMY

Interdisciplinary Programs and Research Facilities

PROGRAMS

Biomedical Engineering

Students and faculty in many departments at M.I.T. are conducting research in Biomedical Engineering. These research interests, spanning biology, engineering, and the physical and social sciences, have led to new programs of graduate study for students wishing to pursue careers in these rapidly evolving fields. The spectrum of academic and research programs is extremely broad — ranging from basic physiological studies to the development of new medical and biological techniques with related engineering analysis and design to problems in the design of new systems for the delivery of health services. Each of these programs, although strongly interdisciplinary in nature, has evolved out of the interests and professional specialties of the participating faculty. Many are based primarily in the School of Engineering departments and, therefore, are available to students as regular departmental activities. In addition, graduate students from any department may apply for admission to a new interdepartmental program in biomedical engineering described below.

The undergraduate wishing to explore this developing area will have ample opportunity within his regular departmental major through elective subjects, special laboratory projects, and the senior thesis. These studies should be of special interest to students who are enrolled in a premedical curriculum.

There are active programs of research in the biological and medical sciences within the School of Engineering departments listed in the accompanying table. In addition, there is a broad range of activities closely related to biomedical engineering in the Schools of Architecture, Management, and Science. Virtually all of the engineering studies are collaborative with life scientists, many of whom are faculty of the medical schools and affiliated teaching hospitals in the Boston area. A background in mathematics and the physical sciences is a necessary prerequisite for graduate study in biomedical engineering; preparation in the biological sciences, though desirable, is not required.

With the establishment in 1970 of the joint Harvard-M.I.T. Program in Health Sciences and Technology, new programs of study and research and many new courses of instruction have become available to students in biomedical engineering and the related life and health sciences. (A description of the program is included in this section.) Starting in 1971, interdepartmental graduate study in biomedical engineering will be offered under the administration of the Committee on Biomedical Engineering. This program is designed for the graduate student enrolled in a department who desires training in depth in both the biomedical and the engineering sciences. Students desiring to enter the program in biomedical engineering should normally apply for admission to the department most closely related to the field of their undergraduate major. A brochure entitled "A Guide to Graduate Study in Biomedical Engineering at the Massachusetts Institute of Technology" can be obtained from the Committee office, Room 16-512, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

BIOMEDICAL ENGINEERING STUDIES

Department	*Major Areas of Interest*
Aeronautics and Astronautics	Visual and vestibular control systems Postural control The human operator Vehicle and display systems
Chemical Engineering	Biomaterials Artificial organs Mass transfer in artificial lungs and kidneys Aerosol technology
Electrical Engineering	Sensory- and neuro-physiology Visual, tactile and auditory psychophysics Biomedical instrumentation Speech analysis Sensory aids High energy radiation Artificial intelligence Image processing, pattern recognition
Mechanical Engineering	Biomaterials Fluid mechanics: Cardiovascular system Pulmonary system Peristaltic blood pumps Blood oxygenators Cryogenics Human control characteristics Reproduction Medical telediagnosis Musculoskeletal mechanics and joint function Rehabilitation technology Sensory and limb prostheses Ultrasonics Physiology of pain
Metallurgy and Materials Science	Metallic and polymeric surgical implants Articular joint prostheses Bone properties Metal ions in biomolecules and biomaterials Properties of hydroxyapatite
Nuclear Engineering	Activation analysis, including *in vivo* studies Neutron capture therapy Radiation instrumentation

Program for College Teaching

This program coordinates established interdepartmental procedures toward the new goal of providing a small number of Ph.D. candidates with direct preparation for college teaching. Effective teaching at the college level requires mastery of a discipline and demonstrated research competence, which many students acquire in regular Ph.D. programs. However, some students require and wish a thesis in

educational or interdisciplinary research which may enhance more directly their subsequent teaching. This program is intended to offer such an opportunity and at the same time to enable students to integrate traditional Ph.D. program activities with supervised teaching and the design and trial of new curricula.

Admission to the program will require admission to a graduate department through the normal M.I.T. procedure. The regular M.I.T. graduate school application material, together with a statement of interest in the program and career objectives, should be submitted to Dr. Edwin F. Taylor, Room 20C-228. Following concurrent department and program acceptance, applicants will be notified before April 15 of admission to the program for the subsequent academic year. Application for financial aid should accompany the admissions application in the normal manner.

Because of the small size of the program and its innovative nature, degree requirements will be based on the individual's interests and career objectives and the requirements of his department for registration. In accordance with established procedure for interdepartmental graduate programs, the Dean of the Graduate School will appoint a faculty committee to supervise all aspects of the Ph.D. program for each student. One or more members of this committee will be drawn from the student's department of registration. A thesis will be presented in educational or interdisciplinary research. The Ph.D. degree will be awarded through the student's department on recommendation of his faculty committee. Further information may be obtained by contacting the Dean of the Graduate School, Room 3-134, or Dr. Edwin F. Taylor, Room 20C-228.

Environmental Studies

Environmental studies for undergraduates at M.I.T. are available through a variety of departmental and interdepartmental courses and laboratories which are growing in number. Although there is no separate degree program at either the graduate or undergraduate level, many departments offer educational and research opportunities in those aspects of the environment which are closely related to their own disciplinary interests. Undergraduate students who are uncommitted to any of the standard disciplines may arrange a coordinated program of interdisciplinary environmental study by entering one of the unspecified degree programs sponsored by many of the departments. Undergraduate students who have a disciplinary commitment but wish a coherent minor program of environmental study may do so through use of the unrestricted electives available to them. Departments have appointed advisors on interdisciplinary environmental concentration. Further information, lists of departmental advisors and sample programs of studies on environmental issues are available through the Office of the Provost, Room 3-240.

The Institute has formed an Interdisciplinary Environmental Council whose purpose is to take an overview of all educational and research activities that relate to environmental concerns. The establishment of the Council reflects the recognition that successful education and research in this area requires the involvement of a number of disciplines drawing on expertise of many departments. The Council will be available to any group at the Institute for advice and assistance concerning research and educational programs dealing with problems of the environment.

The Council will have continuing responsibility for the formulation of policy on issues that relate to interdisciplinary environmental teaching and research at the Institute. A primary concern of the Council will be to review the development of interdisciplinary educational opportunities both at the undergraduate and graduate level. When appropriate, the Council will take the initiative for the establishment of new educational programs, subjects, seminars, or interdisciplinary research projects. The Council will work closely with the newly created M.I.T. Environmental Laboratory.

Program in Health Sciences and Technology

Harvard University and the Massachusetts Institute of Technology are engaged in a major collaborative effort designed to focus science and technology on human health needs. To promote this joint effort, the Harvard Faculty of Medicine-M.I.T. Program in Health Sciences and Technology has been established. The complementary strengths of both institutions are directed to developing new kinds of physicians and other health scientists, to applying modern science and technology to health problems, and to better integration of the natural, social, and behavioral sciences, engineering, and management with medical education and health care.

Important problems of health often require for their solution the concerns and competences

Interdisciplinary Programs and Research Facilities

not only of the biological sciences and the medical professions but also of other disciplines and professions such as the physical, social, and behavioral sciences, engineering, management, public administration, and law. But until now the application of these scientific and technologic disciplines to health and medicine has been far too limited. The aims of the Harvard-M.I.T. Program are to promote new and productive interactions of these disciplines and professions with biology and medicine and to integrate education for health and medicine into general university education.

The Program's activities cover three broad areas, education, research, and development, and are related to ongoing programs in health care planning and management at M.I.T. and Harvard.

The programs are planned to promote continuity in education for health and medicine beginning in college and extending through graduate education into the postdoctoral period; to reflect the specific opportunities available at M.I.T. and Harvard; and to take advantage of each student's previous educational experience.

The Program will offer prebaccalaureate, predoctoral, and postdoctoral curricula leading to a range of career opportunities in the health sciences. Selected undergraduates will be able to enter programs leading to combined bachelor's and graduate degrees. Students will have numerous options among the curricula, and programs will be flexible to allow changes in direction or career path without undue loss of time.

Programs are designed to achieve progressive penetration of the physical sciences and engineering into biology and medicine and to develop an informed social and behavioral analysis of the human goals and costs and the human meaning of health activities. The curricula reflect the joint efforts of biological scientists, physicians, physical scientists, engineers, and social and behavioral scientists.

The following programs are planned:

1. Curricula which qualify the student to enter the clinical years of medical school or of dental school. Some students will be admitted to the Program and enrolled at Harvard Medical School as candidates for the M.D. degree. These curricula are directed at developing physicians and dentists with a strong scientific base in engineering and the physical sciences, or in the behavioral and social sciences, e.g., a cardiologist with a knowledge of electrical engineering, an orthopedic surgeon with mechanical engineering skill, a dentist with an understanding of biomaterials science, a neurologist or psychiatrist firmly grounded in the neural and behavioral sciences, a physician-administrator with extensive knowledge of economics and public policy, or a public health expert with a deep appreciation of human ecology.

New subjects in human biology to be offered in 1971-72 are:

FUNCTIONAL ANATOMY OF MAN (fall)
HUMAN PATHOLOGY (fall)
CARDIOVASCULAR PATHOPHYSIOLOGY (spring)
HEMATOLOGY (spring)
ENDOCRINOLOGY (spring)
MUSCULOSKELETAL SYSTEM AND SKIN (spring)
GASTROENTEROLOGY (spring)
REPRODUCTIVE PHYSIOLOGY AND HUMAN SEXUALITY (spring)

These subjects are available to M.I.T. and Harvard students, although enrollment in some may be limited. Subject descriptions and prerequisite requirements will be available in September, 1971. Also available as part of the new curriculum are regular subjects in the Department of Biology such as Biochemistry, 7.05, and General Microbiology, 7.21.

New courses in human biology to be offered in 1972-73 include:

RESPIRATORY PATHOPHYSIOLOGY
RENAL PATHOPHYSIOLOGY
HUMAN SYSTEMS PHYSIOLOGY
THE HUMAN NERVOUS SYSTEM
BIOCHEMICAL AND PHYSIOLOGIC PHARMACOLOGY
PATHOGENIC MICROORGANISMS AND HUMAN INFECTIOUS DISEASES

2. Curricula at the interfaces of human biology with engineering, the physical sciences, and mathematics. These curricula are aimed at developing biomedical engineers oriented toward the application of engineering to biological systems and to the solution of health problems, e.g., bioengineers concerned with control systems and instrumentation for life support mechanisms; biomaterials scientists involved in the development of materials required for artificial organs and prosthetic devices; experts in fluid dynamics seeking a deeper understanding of cardiac function and blood flow. (See Biomedical Engineering on page 168.)

New courses offered for the first time in 1969-70 or 1970-71 are:

INTRODUCTORY PHYSICS, OUTLINE OF (with illustrative material from biology and medicine)
M.I.T. Physics 8.01Y and 8.024
BIOPHYSICAL CHEMISTRY
M.I.T. Chemistry 5.64 and Biology 7.07J
TOPICS IN BIOMEDICAL ENGINEERING
M.I.T. Mechanical Eng. 2.74

BIOMECHANICS
M.I.T. Mechanical Eng. 2.75
BIOMEDICAL FLUID MECHANICS
M.I.T. Mechanical Eng. 2.277
BIOMEDICAL HEAT AND MASS TRANSFER
M.I.T. Mechanical Eng. 2.52
BIOMEDICAL MATERIALS
M.I.T. Mechanical Eng. 2.900J and
Metallurgy and Materials Science 3.101J
ULTRASOUND AND ITS BIOMEDICAL APPLICATIONS
M.I.T. Mechanical Eng. 2.76
PHYSICAL ASPECTS OF NUCLEAR MEDICINE
M.I.T. Nuclear Eng. 22.83s
INTRODUCTION TO SYSTEMS ANALYSIS WITH
PHYSIOLOGICAL APPLICATIONS
Harvard Engineering Science 145
FLUID FLOW IN THE HUMAN BODY
Harvard Engineering Science 146
PSYCHO-SOCIAL IMPACT OF TECHNOLOGY
Harvard-M.I.T. Policy Seminar #2

See also many of the regular subjects presented by the departments in the School of Engineering and School of Science.

3. Curricula in human biology which may lead to a graduate degree in Life Sciences is envisaged. Particular attention is being paid to the development of a program in the neural sciences and human behavior. These curricula will help develop biochemists, biophysicists, and biomathematicians oriented toward human biology and biologists concerned with human evolution, human genetics, human behavior, ecology and population biology, the structure of the human body, and human physiology and pathophysiology.

Many of the regular courses offered by the Department of Biology, the Department of Nutrition, and the Department of Psychology (see Section 4), are relevant to this program. (See also courses offered by Harvard College and Harvard Medical School.)

RESEARCH AND DEVELOPMENT

An educational program in health services planning and management is being developed at M.I.T. This program will try to provide educational opportunities for individuals currently involved in the operation of health care programs and for students interested in careers in the planning, operation, and management of health services. (See Department of Urban Studies and Planning, Section 4, and the Sloan School of Management, Section 4).

In research the Program will concentrate on areas that deserve particular emphasis because of their importance to health and medicine and that are especially suited to the strengths afforded by both universities. Numerous joint M.I.T.-Harvard research projects involving faculty members and students are in progress and wherever possible; new programs will build upon ongoing efforts. A major interdisciplinary program in biomaterials science has been developed; it involves physicians, surgeons, biochemists, biophysicists, physical chemists, physicists, and chemical, electrical, and mechanical engineers in 18 collaborative research projects.

The development programs selected will be those in which basic scientific knowledge is abundant, for such knowledge can be applied rapidly and efficiently by a systematic engineering approach. Typical development projects include the design and production of prototypes such as instruments for diagnosis and treatment, sensory devices for the blind and deaf, prostheses such as the "Boston Arm," artificial organs, organ and cell cultures, automated laboratories, and model rooms, operating rooms, and other patient facilities.

Further information about the Program may be obtained from the office of the Director of the Program, Room 16-512 at M.I.T.

Operations Research

Students wishing to concentrate specifically in operations research at the doctoral level may apply directly to the interdepartmental doctoral program. This can be done by inserting the phrase "Operations Research — Interdepartmental Program" at all places in the admission materials which require filling in "Department of _____."

Students wishing to enter a specific department, either because they wish to combine substantial content in some specific field with their operations research study or because they are uncertain as to their interests at the time of application, should apply to the academic department of their choice. Subsequent steps to the attainment of an interdepartmental operations research degree are the same for these students as for those entering directly. Students seeking a Master's degree should apply to a specific academic department.

The following basic subjects, or equivalents thereof, are recommended to Master's degree candidates who wish to concentrate on operations research. This program is designed to prepare graduates to do professional work in the field. Also, these subjects will provide a solid background for students who wish to continue their work towards a doctorate in operations research.

6.28	PROBABILISTIC SYSTEMS ANALYSIS	4	0	8
6.536	PROBABILISTIC MODELS IN SYSTEMS ENGINEERING AND OPERATIONS RESEARCH (A)	3	0	9

Interdisciplinary Programs and Research Facilities

PROGRAMS

15.065	STATISTICAL DECISION THEORY (A)	3	0	6
15.081	MATHEMATICAL PROGRAMMING (A)	3	0	6
18.700	LINEAR ALGEBRA	3	0	9
15.075	MATHEMATICAL STATISTICS (A)	3	0	6
	MASTER'S THESIS			

Students may, of course, elect to take any additional subjects from the listing provided under the Ph.D. program.

The ultimate goal of the doctoral program in operations research is to enable the doctoral candidate to contribute to research in his speciality both at M.I.T. and later during his professional career. The program provides a strong background in the theoretical foundations of operations research and the techniques used to develop and analyze mathematical models of complex systems arising in economic, social, and physical contexts.

Candidates for the doctorate in operations research will normally complete the subjects listed below. An individual student in consultation with his advisor may make adjustments in this program to reflect his special interests.

1. The subject list above for the Master of Science degree
2. 18.100 MATHEMATICAL ANALYSIS (A)
   15.083 COMBINATORIAL OPTIMIZATION (A)
   15.073 STOCHASTIC SYSTEMS (A)
3. One additional graduate subject in mathematics
4. A research seminar in operations research
5. A minor consisting of an approved program of three subjects

Additional subjects in operations research or closely related to the field are listed in this Catalogue and represent some of the electives which the student can select in constructing his program.

The doctoral candidate must fulfill the general Institute requirements and pass a qualifying examination, normally taken during his second semester at M.I.T. The Institute requirements include a general examination consisting of both oral and written parts, normally taken in the fourth semester of graduate study, and the completion of a dissertation which represents an original contribution to knowledge, expressed in a satisfactory form.

The Operations Research Center (which is described in the Facilities section of this chapter) offers research and teaching assistantships as well as some fellowships for graduate study. Research assistantships are available in most of the fields in which the Center is active.

Further information on financial assistance and on admissions procedures in general can be obtained by writing directly to the Center. Inquiries may be addressed to: Administrative Assistant, Operations Research Center, Room 24-215, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

Polymeric Materials

Synthetic high polymers — plastics — comprise one of the most rapidly expanding areas in the field of materials today. Originally the domain of organic chemistry, as the versatility and complexity of these materials have expanded, other disciplines have been needed to solve the problems encountered. For example, many polymers possess crystalline and amorphous regions simultaneously in a macroscopic volume of the material; depending upon the relative proportions of the two, and the nature of the crystalline phase present, the substance can be rubbery, leathery or glassy, strong, ductile and tough, or weak and brittle. Finding relationships between the microstructure and such properties and identifying ways to control the microstructure offer challenging problems to the researcher today.

Interdepartmental graduate degree programs focusing on the study of polymeric materials are available. Each candidate arranges an individual curriculum of subjects and research in consultation with a small faculty committee chosen for that purpose. Usually this involves the core subjects noted below, plus additional electives which treat in detail some aspect of polymer science and technology. Formal registration by the student may be in the Departments of Metallurgy and Materials Science, Civil, Mechanical, or Chemical Engineering, depending upon the principal research activity in the individual's degree program. The overall program is administered by a faculty committee from these various departments.

For further information contact Professor F. J. McGarry, Civil Engineering, or Professor D. R. Uhlmann, Metallurgy and Materials Science.

Power Engineering

Academic programs and research in power engineering are active on an interdepartmental basis in the Departments of Aeronautics and Astronautics, Electrical Engineering, Mechanical Engineering, Ocean Engineering, and Nuclear Engineering. These programs cover a wide range of activities in various aspects of power systems.

Many of the subjects offered are taught jointly by faculty from two or more of the de-

partments. Among the subjects offered are the following: Thermodynamics of Power Systems, Thermal Power Systems, Electric Power System Engineering, Dynamics of Fluid Machines and of Electric Machines, Gas Turbines, Aircraft Engines and Turbine Engines, Nuclear Rockets, Internal Combustion Engines, Ocean Engineering Power Systems, Environmental Pollution, Fission and Thermonuclear Reactor Design and Operation, Economics of Nuclear Power, and Economics of Fuel and Power.

In addition to these subjects treating specific topics in power engineering, many other related subjects are available on thermodynamics, fluid mechanics, heat transfer, control theory, materials, stress analysis, vibrations, cryogenics, and combustion as listed in the Catalogue.

Research in power systems is carried on by individual professors in various departments as well as at the Gas Turbine Laboratory, Electric Power Systems Laboratory, Sloan Automotive Laboratory, Engineering Projects Laboratory, Heat Transfer Laboratory, Cryogenics Laboratory, and at the Nuclear Reactor.

A student enrolled in any department may construct from these many subject offerings and research activities an academic program and thesis research which he wishes to pursue.

The following subjects are offered in power engineering by various departments. A description of these subjects is included in the section at the end of this Catalogue.

2.23	ENVIRONMENT POLLUTION SEMINAR
2.275	DYNAMICS OF FLUID MACHINES
2.615	ADVANCED INTERNAL COMBUSTION ENGINES
2.616	ADVANCED INTERNAL COMBUSTION ENGINES
2.618	AUTOMOTIVE VEHICLES
2.621	GAS TURBINES
6.551	POWER SYSTEM ENGINEERING I
6.552	POWER SYSTEM ENGINEERING II
6.553	SPECIAL TOPICS IN POWER SYSTEM ENGINEERING
6.556	DYNAMICS OF ELECTRIC MACHINES
13.21	SHIP POWER AND PROPULSION
13.22	NAVAL SHIP PROPULSION
13.25J-2.41J	THERMODYNAMICS OF POWER SYSTEMS
13.26J-2.601J	THERMAL POWER SYSTEMS
13.27	OCEAN ENGINEERING POWER SYSTEMS
14.23	ECONOMICS OF FUEL AND POWER
16.53	ROCKET PROPULSION
16.54	AIRCRAFT ENGINES
16.541	AIRCRAFT TURBINE ENGINES
22.312	ENGINEERING OF NUCLEAR REACTORS
22.313	ADVANCED ENGINEERING OF NUCLEAR REACTORS
22.32	NUCLEAR POWER REACTORS
22.33	NUCLEAR REACTOR DESIGN
22.34	ECONOMICS OF NUCLEAR POWER
22.35	NUCLEAR FUEL MANAGEMENT
22.39	NUCLEAR REACTOR OPERATIONS
22.62	THERMONUCLEAR REACTOR DESIGN

Program for the Social Application of Technology

The Program for the Social Application of Technology (P.S.A.T.) is an experimental Master's degree program. The primary objective of the program is to provide an environment in which a new type of professional may develop — a person who will have the ability to confront complex multidisciplinary problems and obtain whatever knowledge, tools, and resources he may need to handle such problems in a professional way. Another objective of this new educational program is to bring some of the faculty and student resources of M.I.T. to bear directly on important societal problems which have strong technological components. To meet these objectives, P.S.A.T. is an interdisciplinary graduate program of problem-focused education.

Work on specific projects will be the primary educational experience of P.S.A.T. students. By providing students with an opportunity to grapple with complex social and technical problems, it is expected that they will acquire whatever information they require to handle the problem regardless of the disciplinary or pragmatic nature of the knowledge. In this way, these students can develop multidisciplinary capabilities which, while they will differ from capabilities which would be gained through the deeper study which is possible in single-discipline specialization, will allow the student to recognize the important components of the problem and determine what types of resources must be marshalled if the problem is to be effectively confronted.

P.S.A.T. will innovate in accomplishing its educational objectives. The new educational experience to be provided by P.S.A.T. calls for structural innovations in the degree-achievement process. These include seminar and tutorial subjects of wide scope and diversity, special problem-oriented subjects, self-study programs, affiliations with action and policy groups in other institutions and public agencies, and substantial academic credit for such activities in addition to a predetermined program of subjects and degree requirements. Students will also take appropriate subjects in M.I.T. departments and at other schools through the normal cross-registration opportunities.

Students admitted as degree candidates to P.S.A.T. must be action-oriented individuals who combine a balance of concern and competence. They must be able to think in broad terms but be willing and able to pursue in depth whatever narrow areas may be relevant to the

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ultimate solution of the problem before them. Prospective students will be carefully screened for relevant experience and the personal qualities which will be required for successful entrepreneurial and team work.

The Director of the Program is Professor Carroll L. Wilson of the Sloan School of Management. Further information may be obtained from Professor Wilson, Room 26-169, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

RESEARCH FACILITIES

The Artificial Intelligence Laboratory

The Artificial Intelligence Laboratory is a center for cognitive science and engineering. "Cognitive science" suggests a primary interest in understanding the class of phenomena associated with the layman's use of words like "mind," "mental," "intelligence," "purpose," and "perception." "Cognitive engineering" suggests a fundamental respect in which the Laboratory's approach to such problems differs from that of philosophers and psychologists: the cognitive engineer tries to produce intelligence. In the Artificial Intelligence Laboratory this leads to these branches of activity:

1. *Heuristic Programming and Robotics.* The Laboratory is well known for its work in Artificial Intelligence in the narrow sense of constructing machines capable of such cognitive functions as seeing, understanding English, and learning.

2. *Mathematical Studies.* The Laboratory is equally distinguished for its tradition of mathematical investigation into the computational complexity and forms of cognitive functions.

3. *Education.* The computational analysis of intelligence has led to new insights into how intelligence develops in people and to some radically new concepts of how it can be made better. We increasingly see the fundamental problems of robotics and of education as convergent. For both areas the key problems turn around questions such as, what is knowledge? how can it be represented? what mechanisms can govern the interaction of diverse goals and purposes? In the Laboratory, work on education takes several forms: experimental and theoretical studies of children in the style of Piaget; curriculum development and experimental teaching aimed at finding a substitute for the elementary school as an educational environment for young children; studies of riding bicycles, juggling, eye-movements, musical perception, philosophical puzzlement, mathematical thinking, and other human abilities.

Work on these problems requires knowledge of mathematics, of subjects related to machine intelligence, such as programming techniques, and subjects related to "natural intelligence," such as epistomology, linguistics, the history of ideas, dynamic psychology, and so on. Perhaps the unique feature of the Laboratory's methodology is the goal of uniting sophistication in these areas so as to create a coherent new discipline rather than an "interdisciplinary" interaction. In following this goal the Laboratory is developing a new program of graduate studies which will include seminar courses in appropriate mathematics, philosophy, and psychology; laboratory work in heuristic programming and robotics; and work with children towards the goal of creating new educational forms. The Laboratory has faculty and material resources to support Ph.D. theses in any of these areas. Students interested in joining the program should contact Professor Marvin L. Minsky or Professor Seymour A. Papert at the Artificial Intelligence Laboratory, M.I.T. The criteria for selecting participants emphasize general intellectual and personal qualities as much as prior formal studies. Although this is a graduate studies program, mature undergraduates or open-minded postdoctoral students will also be considered. A brochure will be sent on request.

Francis Bitter National Magnet Laboratory

The Francis Bitter National Magnet Laboratory is a center for research and teaching in the science and technology of magnetism and magnetic materials. Twenty-four water-cooled high field magnets, powered by a ten megawatt motor generator, provide continuous magnetic fields from 100,000 to 250,000 gauss in a variety of configurations. Pulsed fields exceeding 500,000 gauss are generated by large currents from a capacitor bank. Superconducting magnets are also in use. A hybrid magnet consisting of both superconducting and water-cooled sections is under construction. At the other end of the intensity scale, a magnetically shielded chamber provides an environment of near zero magnetic field which is used to study the very weak fields generated by electrical currents in the human body.

A broad program of experimental and theoretical research on magnetism, superconductivity, and the electronic and optical properties of semiconductors and semimetals is conducted by

the research staff and students under the sponsorship of the National Science Foundation and the Air Force Office of Scientific Research. Electromagnetic radiation from radio frequencies to gamma rays is employed to probe the properties of matter in intense magnetic fields. Particular emphasis is placed on the submillimeter and far infrared region of the spectrum where recently developed laser sources and new spectrometers and detectors have permitted exploration of this hitherto inaccessible range where many important radiative interactions occur in solids. Low-temperature facilities are available for the study of superconductivity and other low temperature properties of metals and semiconductors. Intense magnetic fields are vital for the studies of magnetic phenomena in metals which are leading to a more comprehensive understanding of the basic atomic interactions responsible for magnetism.

Novel applications of magnetic fields to practical problems in medicine and technology are pursued with support from a variety of public and private sources. A system for magnetically guiding and propelling catheters through the blood vessels of the human body has been tested and is undergoing further development. Pulsed magnetic fields are being studied as a means of inducing electrical currents in the heart without the need for electrodes on the skin. The electrical activity of the heart, brain, and stomach are being measured in the shielded chamber. In conjunction with the Plasma Physics Group of the Research Laboratory of Electronics, a high magnetic field toroidal plasma heating device similar to the Russian Tokamak is being designed. This device, ALCATOR, is expected to more nearly approach the density, temperature and confinement time needed for a controlled thermonuclear reaction than any previous attempt. This work is sponsored by the Atomic Energy Commission. In the past several years, superconducting magnets capable of producing 100 kilogauss or more have been developed by several organizations. The Laboratory's high field facilities were utilized extensively to test the super-conducting wires used in these magnets. With these intense fields now available at reasonable cost, new technological applications of high magnetic fields have been recognized. The extension of magnetic ore separation techniques to weakly magnetic materials is being explored. The removal of both magnetic and nonmagnetic pollutants from water appears to be feasible. Studies of the technical and economic aspects of this process are underway.

The Laboratory is closely associated with the Department of Physics and provides opportunities for graduate and undergraduate research for students in the department, as well as for those in the Departments of Electrical Engineering, Metallurgy, Chemistry, and Mechanical Engineering. Students from other local universities are also in residence. Cooperative research programs are entered into with other M.I.T. laboratories such as the Lincoln Laboratory, the Center for Materials Science and Engineering, and the Research Laboratory of Electronics. The facilities of the Laboratory are also available to scientists and graduate students from throughout the country and the world who need high magnetic fields in their research programs.

Cambridge Electron Accelerator

The Cambridge Electron Accelerator, a 6-BeV synchrotron built and supported by funds from Atomic Energy Commission contracts, is operated jointly by M.I.T. and Harvard University for research in particle physics by faculty and students from both institutions and other qualified scientists. The laboratory is developing a facility to store and clash high-energy contrarotating beams of electrons and positrons.

The Cambridge Project

The Cambridge Project is a cooperative effort to make the digital computer more useful in the behavioral sciences. The participants include computer scientists, statisticians, and behavioral scientists from a wide range of specialities. Many of them are faculty members and students of Harvard University.

The current work of the project has two main parts: first, the development of computing methods needed in the behavioral sciences; and second, assembling those methods, and others, into an integrated collection of tools that a behavioral scientist can use in his work. At present the collection is being assembled within the framework of the MULTICS time-sharing system at M.I.T.: the goal is to give the scientist who is not a programmer a set of tools that he can use on-line, combining them in whatever manner his problem seems to require.

The Project is advised by an Advisory Committee consisting of faculty from M.I.T. and Harvard University. The committee is chaired by Dean William F. Pounds and reports to the Provost of the Institute.

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Center for Advanced Visual Studies

The Center for Advanced Visual Studies provides artists of achievement with the opportunity to explore new artistic forms of civic dimensions warranted by the sophisticated technology and complex scale of our urban world. Collaboration through a working dialogue between the artists and the scientists and engineers is of primary importance in the exploration of new creative objectives. This mutually beneficial contact between artist and scientist allows the artist to develop the technical competence to utilize advanced technology and test its applications to new creative challenges.

Some of the distinguished artist-fellows currently working at the Center are Mauricio Bueno, Paul Earls, John Goodyear, Michio Ihara, Ted Kraynik, Otto Piene, Alan Sonfist, Wen-Ying Tsai, and Stan Van Der Beek.

A limited amount of work space is available for a small number of research affiliates and special students, though there is no formal program of study offered and no degrees are granted.

Center for International Studies

The Center for International Studies reflects the strong interest of M.I.T. in the social, political, and economic problems of the contemporary world. Although the Center has no teaching program of its own, most of its senior staff are faculty members of the Departments of Economics or Political Science. The Center provides research opportunities that are important to the professional development of these departments. There are also opportunities for graduate students to participate in the Center's research programs.

Current research includes studies on economic and political development of nations in Asia, Africa and Latin America; international communications; Communism, revisionism, and revolution; arms control; various aspects of American foreign and defense policy; and computer handling of social science data. Research on arms control and defense policy is done in collaboration with M.I.T. physical scientists and engineers. It is believed that research bringing together social and physical scientists will increase steadily.

Center for Materials Science and Engineering

The aims of the Center for Materials Science and Engineering (C.M.S.E.) are to encourage, promote, and support interdisciplinary research in materials. Associated with the C.M.S.E. are faculties from numerous science and engineering departments; excellent, modern central facilities for the preparation, analysis, testing, and evaluation of various classes of materials; and groups of undergraduate, graduate, and postdoctoral students doing all, or some part, of their research at the Center. The central facilities are available to all students of the Institute.

Graduate and undergraduate research assignments are arranged through individual faculty members (and their departments) who receive support through the Center. Faculty groups from the Departments of Physics, Metallurgy and Materials Science, Electrical Engineering, and Chemistry are presently found in the C.M.S.E.

The materials research activities of the Center, as well as those of the entire Institute, are described in the Annual Report on Materials Science and Engineering at M.I.T., available through the Center.

Funding of research at the C.M.S.E. comes from numerous sources; major support of a broad effort in materials research is obtained from the Advanced Research Projects Agency.

Center for Space Research

The Center for Space Research offers an opportunity to students, faculty, and professional research staff to participate in a broad program of space-related research. Its projects draw upon the interests and expertise of physical, social, and life scientists and engineers from many disciplines. Topics of current research include theoretical studies in cosmology and astrophysics such as: stellar evolution and stellar pulsation; the behavior of supernovae, pulsars, and quasars; and the development of models illustrative of the processes associated with novae, planetary nebulae, neutron stars, and protostars.

Space science studies include measurement of the properties of the interplanetary plasma, hard and soft X-rays, and gamma rays using experimental techniques such as high altitude balloons, sounding rockets, and orbiting satellites. Coupled with the foregoing flight measurements are ground-based optical and radio frequency observations of related astrophysical phenomena. The Center supports these field measurement programs with exploratory and developmental studies in the laboratory on interference spectrometry, X-ray counters, high resolution collimators, high accuracy pointing

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and stabilization systems, and star sensor aspect systems. Laboratory facilities include X-ray sources, particle accelerators, vacuum chambers, and conventional electronic test and machine tool equipment. Extensive data handling and computational facilities are available for the analysis and reduction of scientific data. An experienced and well equipped Laboratory for Space Experiments group provides design, construction, and testing support of the flight programs.

In other fields the Center has active projects for the measurement of lunar surface electrical properties, studies and assessment of future domestic communication services, multiple loop control characteristics of the human operator and biophysical evaluation of the human vestibular system, life support in unusual environments and, finally, properties of planetary surfaces and atmospheres.

The variety of scientific and technical problems that arise in these investigations affords numerous opportunities for graduate thesis research as well as for student participation as research assistants.

Clinical Research Center

The M.I.T. Clinical Research Center, a small, fully equipped and staffed research hospital on campus, opened in 1964. The major purposes of the Center are to enable interested scientists to perform research with human subjects and to allow students at all levels to gain experience in working directly with human subjects and human disease. Many research projects are in progress including those in nutrition, psychology, cardiology, endocrinology, and mechanical, chemical, and electrical engineering. The studies in most cases are collaborative, involving both basic scientists and clinicians.

Patients and normal subjects may be seen as outpatients or may stay in the Center as inpatients for long periods of time at no cost to them. The facilities of the Center are open to all departments in the Institute, and its staff consists of members from many of those departments. Although most patients hospitalized in the Clinical Research Center come from the Boston metropolitan area, a significant number are referred from other parts of the United States, and some are referred from abroad.

Numerous routes of entry are available to undergraduates and graduate students who wish to take advantage of the Center's programs. These include a freshman seminar in medicine, undergraduate research projects, graduate study with human subjects in medical sciences and biomedical engineering, and postdoctoral research for those who already have the M.D. or Ph.D. degrees.

The Center, which is federally funded, is a basic resource for M.I.T. as the Institute moves into the fields of research and teaching in medicine, physiology, and biomedical engineering.

Commodity Transportation and Economic Development Laboratory

Formation of this new interdepartmental laboratory reflects the growing need for transportation engineers in the field of commodity transportation and reflects the fact that transportation of raw materials and processed goods is crucial in the economic development of society, whether on a national or an international scale.

The projects carried on in this laboratory will be of a multidisciplinary nature and will be strongly oriented to specific problem solving. The main emphasis will be on the analysis of effective commodity transportation systems in the context of regional, national, and international economic development and the education of modern commodity transportation engineers.

This new laboratory will supplement transportation efforts presently underway at M.I.T. in the Departments of Aeronautics (Air Transportation), Naval Architecture and Marine Engineering (Ocean Transportation), and Civil Engineering.

It will also interlock strongly with many of the dispersed activities related to social, political, economic and legal aspects of commodity transportation in an effort to develop integrated approaches to the solution of transportation problems. Though the new Laboratory is established in the School of Engineering, close cooperation will be sought with other activities at M.I.T., as well as other universities, institutions, and organizations vitally concerned with the development and impact of commodity transportation.

Charles Stark Draper Laboratory

The Charles Stark Draper (formerly the Instrumentation) Laboratory is a separate division within the M.I.T. corporation structure. For approximately 30 years prior to June 1, 1970, it was an oncampus Special Laboratory in the academic responsibility of the Department of Aeronautics and Astronautics. The professional field of interest has traditionally been the in-

strumentation, guidance, and control of aerospace and marine vehicles. The Laboratory is mission-oriented, in that its goal is the design, development, and realistic testing of the theory, components, subsystems, systems, and their mutual interrelationships that lead to a complete operational system. Probably the most outstanding achievement of the Laboratory has been the technical development and supervision of the Apollo guidance and control systems. The one-half mile splashdown accuracy of the problem-plagued Apollo XIII is an example of the exact and precise work of the Laboratory's technical competence.

The Laboratory offers thesis research opportunities in all phases of systems engineering beginning with basic theory, mathematical analysis, computer studies, component design and evaluation (mechanical, electrical and optical), and system synthesis. These areas of research are live and up to date with the student in direct daily association with the professional staff of engineers and scientists of the Laboratory. In this way, the student learns to appreciate the economic and human, as well as the technical aspects of a system. Students may also be employed by the Laboratory and work directly in the project itself. This provides an excellent technical internship which greatly broadens the student's educational experience.

The Draper Laboratory is a teaching laboratory. It is directed by a professor, and all faculty members in the Laboratory maintain teaching and thesis supervision, as well as doing research. The principal faculty members associated with the Laboratory are: Professor Charles Stark Draper, President; Professor Walter Wrigley, Educational Director; and Professor Wallace E. VanderVelde, Director for Campus Coordination. Many other faculty members and full-time professional staff make up the personal professional competence of the Laboratory.

The research work at the Laboratory is done under sponsored contracts. Such sponsorship has been primarily by the Department of Defense, the National Aeronautics and Space Administration, and the Department of Transportation. However, no restrictions exist that limit the nature of the sponsoring agency. The sponsored research provides challenging work in the most advanced and new aspects of aerospace science and engineering. The Laboratory is large enough to have all the facilities needed to study, design, develop, and test the engineering model of a complete aerospace system. The Laboratory is the home of inertial guidance and is world-famous and academically unique in its work in this field.

The Interdepartmental Doctorate in Instrumentation, which is described in section on the Department of Aeronautics and Astronautics, receives much of its vitality from its close association with the Draper Laboratory. Doctoral students with backgrounds in Aeronautics and Astronautics, Electrical Engineering, Mechanical Engineering, Physics, or Mathematics will find this doctoral program of interest.

Specific areas of interest for research in the Draper Laboratory are: inertial navigation systems — air, marine, space; air-traffic-control systems; components — gyroscopes, accelerometers, vehicle-borne computers; and modern control theory.

Education Research Center

The Education Research Center (E.R.C.) seeks better ways of teaching and learning in colleges and universities through the development of new materials for conventional courses of study; through experimentation with course structure and with curriculum structure; by exploring really useful and practical ways for applying technology to teaching; and in searching for deeper understanding of the human effects of curricula, of the nature of the teaching and learning process, and of ways to create viable curriculum innovations.

The projects of the Center involve several hundred M.I.T. students in regularly offered subjects, and, in addition, the Center offers to a small number of students the opportunity to work on the development of educational materials or to assist with the projects of the Center. One of these projects is the Unified Science Study Program (U.S.S.P.), a complete full-time curriculum for freshmen and sophomores, which is described in more detail in Section 2.

An E.R.C. research group of psychiatrists, psychologists, and others studies the "human effects of the curriculum;" that is, how life at the Institute, including both formal instruction and the M.I.T. environment, affects students both intellectually and emotionally. Questions of this nature continue to be explored, and, with the advice of those making the studies, the E.R.C. hopes to find new and better formats for teaching.

One of the earliest E.R.C. projects, which is continuing, is the development of textbooks, lecture demonstrations and lecturettes, films,

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and demonstration apparatus for a new physics course called simply *Physics, A New Introductory Course.* Known by its acronym PANIC, this course has been offered in its preliminary versions to several thousand M.I.T. students over a period of years. Final versions of some of the textbooks have already been published and others will be published in time. M.I.T. students have participated in this project by designing and developing demonstration apparatus and by helping in the criticism and evaluation of textual and other materials.

Several M.I.T. subjects are being taught by a personalized self-paced study system called the Keller plan. Already used in some other universities, the Keller plan was introduced at M.I.T. by the Center in an attempt to provide an alternative mode of learning to suit the different capabilities of different students. In a Keller-plan subject, each student has a tutor who is usually a student who has taken the course previously. The student works at his own pace using carefully written study materials provided by the instructor and organized in units.

Another format of course organization conducted by the Center is called Concentrated Study. In this program, the material of a one-semester subject is studied in one month of full-time work. Class meetings, laboratories, individual tutorials, demonstrations, and films present different aspects of the material and vary the pace of concentration. Early trials have been effective and have received enthusiastic student reaction, and further experiments are planned.

The E.R.C. has a program and a facility for producing educational films by computer-graphic techniques, and for producing interactive computer-graphic routines. Films and film loops have been prepared for commercial distribution, and students have used the facility to produce a variety of films for senior theses, to gain an intuitive sense of otherwise inaccessible phenomena or merely to get some experience in the field of computer graphics.

A weekly colloquium is held to stimulate public discussion of the many educational experiments underway at M.I.T. and elsewhere. The subjects range from status reports on current projects to broad philosophical discussions of long-range social and educational issues. The colloquium is open to students, as well as faculty and staff.

Members of the E.R.C. staff are pleased to speak with students who may be interested in working on educational projects or who may have a long-range interest in education. Further information may be obtained at the E.R.C. headquarters office, Room 20C-228.

Electric Power Systems Engineering Laboratory

The Electric Power Systems Engineering Laboratory of the School of Engineering consists of students, faculty, and staff from departments in the School of Engineering who are engaged in educational research activities associated with the generation, transmission, distribution, and utilization of electric power. Many members of the faculty in the group have worked in the power industry while on leave and maintain continuing relations with the industry through on-campus research, consulting activities, and professional society participation.

The Laboratory offers research opportunities on a wide variety of topics. Among them are the design and construction of an alternator with a superconducting field winding, the study of audible noise from conductors using a 100 kV supply, and the design construction and study of an electromagnetically scaled power system model. Other opportunities are available in the areas of circuit breaker design and diagnostics, contamination flashover mechanisms, and the consideration of new applications of cryogenic technology to power system devices.

At present eight to ten faculty members and 30 students are associated with E.P.S.E.L.

Joint Center for Urban Studies

The Joint Center for Urban Studies was established in 1959 to link urban research activities at M.I.T. with similar activities at Harvard University and to develop a new level of interest in urban and regional studies at both institutions. The Center, with offices at 66 Church Street, Cambridge, 02138, has encouraged basic and applied research on the problems of cities and regions, and sponsors colloquia, seminars, and professional conferences.

The Joint Center provides important research opportunities for faculty members and advanced graduate students at both institutions. During the past year the Center's mission has been redefined, and the broad field of housing is expected to be a major focus for the Center's research activity during the next several years.

Laboratory for Nuclear Science

The Laboratory for Nuclear Science performs basic research in nuclear physics, supporting

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research interests of faculty in the Department of Physics by maintaining and administering a number of special research facilities adapted to studies in high-energy and nuclear structure physics. A 400 MeV, high-intensity electron linear accelerator is being constructed for nuclear physics research. This will extend greatly the Laboratory's capabilities in this field. The Laboratory operates an IBM 360-65 computer as an open-shop facility available to staff and students. Among many projects are theoretical studies of the atomic nucleus; studies of the photoproduction of mesons and other high-energy phenomena; studies of the new fundamental particles involving broad experimental endeavors using bubble chambers, spark chambers, and complex electronic hodoscopes; studies of cosmic rays, including a program oriented toward the astrophysical aspects of these rays; programs oriented toward the application of high-speed electronic computer techniques to the problems of nuclear and elementary particle data analysis; a broad program of precise nuclear energy level measurements; a program of heavy ion oriented nuclear studies at the double tandem facility of the Brookhaven National Laboratory; and programs in radioactivity and in medium- and low-energy photonuclear and nuclear particle research. As part of its program, the Laboratory is engaged in experiments in high-energy physics at the Brookhaven and Argonne National Laboratories as well as the Stanford Linear Accelerator. Experiments are also under way in conjunction with the 6-GeV Cambridge Electron Accelerator and at the German high energy electron synchrotron (DESY) at Hamburg. The implementation is beginning also of collaborative experiments involving L.N.S. staff at the National Accelerator Laboratory, Batavia, Illinois.

Lincoln Laboratory

The Lincoln Laboratory, located in Lexington, Massachusetts, is a Federally sponsored center for research and development in advanced electronics, with special emphasis on applications to national defense. The Laboratory is staffed and operated by M.I.T.

Lincoln Laboratory activities extend from fundamental investigations in science, through technological development of devices and components, to the design and development of complex measurement systems. A continuing program of research in advanced electronics techniques provides a background of experience and ideas for work in specific programs, as well as a source of new scientific and technological advances with civilian and military applications.

Specific programs include space communications, re-entry studies and technology, seismic detection and discrimination of earthquakes and underground nuclear explosions, computer systems and digital signal processing, design of a prototype ambulatory medical service program, educational technology, and air traffic control. Research is also conducted in the fields of optics, solid state, radio physics, and radar systems.

Opportunities for research in many of these technical areas are available to M.I.T. faculty members and qualified students. Recent thesis and faculty research projects have dealt with such topics as molecular absorption, lasers, speech analysis and synthesis, radio interferometry, and properties of structural systems.

Operations Research Center

Operations research seeks to build a science and technology of decision making. The field is concerned with the operational and systems aspects of engineering, scientific, and management problems. For example, operations research deals with traffic control systems rather than the design of cars, with the scheduling of production rather than the technology of machines, and with the collection, allocation, and distribution policies of a blood bank rather than the chemistry of preserving blood. In these and other cases, the operational analysis of a system may influence the technological developments, and vice versa, so that operations research studies are frequently interdisciplinary in character and may arise in widely different fields.

The M.I.T. Operations Research Center was established in 1953 in order to provide an interdepartmental focal point for faculty and students engaged in operations research. Since that time, the Center has pursued a goal of sponsoring research in both theoretical and applied areas. In particular, the fields of probabilistic systems, mathematical programming, queuing, and simulation of operational systems have received continued special attention. Considerable interest is presently focused on the applications of operations research techniques to specific problems arising in diverse operations of government, industry, and nonprofit institutions. This has led to studies in the areas of transportation, traffic, education, municipal

services, marketing, and scheduling of industrial production.

The Operations Research Center supervises graduate programs of study leading to S.M. and Ph.D. or Sc.D. degrees. (See the first part of this section for an outline of these programs.) In addition, it affords an opportunity for all students at M.I.T. who have an interest in operations research to meet with faculty and each other for formal and informal exchange of ideas.

Project MAC

Project MAC is an interdepartmental facility devoted to research in the computer and information sciences. The name MAC is an acronym derived from two titles: machine-aided cognition and multiple-access computer. The broad goal of machine-aided cognition implies the development of new ways in which on-line use of computers can aid people in their creative work, whether it be research, engineering design, management, or education.

Most of the research activities of Project MAC are carried out by professors, graduate and undergraduate students, and research staff members working together informally in small groups, often with a system of computer hardware and software as a facility or as the object of research. One group, having developed the first general-purpose time-sharing system and, more recently, the much more advanced multi-access information and computing service, MULTICS, is now in the process of investigating the engineering tradeoffs among the many parameters of the new system and integrating it into a computer network that will interconnect the interactive computer systems of several universities. During the next two or three years, several groups will create and perfect the user-oriented programs and data bases required to make MULTICS a comprehensive computer and information service and others will conduct research on problems in the management and operation of such a service, sometimes called a "computer utility."

Other groups are active in theory of computation, theory of finite-state automata, design of advanced parallel-processing computers, theory and implementation of programming languages, man-computer interaction, computer graphics, management of information, computer networks, and applications of computers in education and management. Examples of their research results that may convey an idea of the nature of their undertakings are: determination of the inherent computing capabilities of cellular automata consisting of very simple computers disposed in regular spatial arrays, each computer communicating only with its immediate neighbors; a way of designing a modular digital system that makes it possible to guarantee that it will work properly if (1) the individual modules operate correctly and (2) the wiring of their interconnections is correct; the computer as an assistant to a mathematician accepting suggestions from him and carrying out for him, very rapidly and accurately, manipulations of symbolic formulas that would be far beyond the limits of his capability or patience; programming languages (such as PAL) designed to simplify and clarify the basic ideas of programming; a program (ELIZA) that permits the user to interact with a computer in natural English; the prototype of storage-tube graphical displays currently coming into use in time-sharing computer systems; several on-line data-management and data-analysis systems; systematic standards of format and protocol for intercomputer communication; a program (TEACH) that teaches programming; a program system (SIMPL) for on-line simulation and modeling; and a program designed to facilitate medical diagnosis.

Research assistantships are available for work in all aspects of the research program of Project MAC. Also, facilities are provided for thesis research and special projects on the part of both undergraduate and graduate students.

Project MAC is sponsored in large part by the Office of Naval Research on behalf of the Advanced Research Projects Agency and in lesser parts by ONR directly, the Army on behalf of ARPA, and the National Science Foundation. All the work of Project MAC is unclassified and open.

Research Laboratory of Electronics

Established at the end of World War II as the Institute's first interdepartmental laboratory, the Research Laboratory of Electronics has evolved an on-campus research environment in which faculty members and their students have both the freedom of action which is essential in an academic institution and the availability of diverse services and facilities of a large laboratory. The Laboratory offers opportunities for creative research in a broad range of topics and has had projects involving par-

ticipants from as many as a dozen departments. The research groups, currently numbering about 30, conduct research in three broad areas: communication sciences, general physics, and plasma dynamics. Approximately half of the total effort is in communication sciences, a fourth in general physics, and a fourth in plasma dynamics.

The research in general physics includes a variety of activities, based primarily on atomic phenomena. The experimental techniques used in this work span most of the electromagnetic spectrum from radio wavelengths to X-rays. Other experimental requirements include the use of extremely high frequency acoustic waves, the use of liquid helium temperatures, and extensive use of computers.

A few of the research topics in this area include the following.

The molecular beams group is conducting experiments on hydrogen and helium atoms at temperatures near absolute zero. Some of the techniques used in these basic studies are being applied to the development of a scanning molecular microscope which will be used to observe biological macromolecules. In addition, new techniques in electron microscopy are being investigated. The microwave spectroscopy group is studying the electronic structure of metals by making surface impedance measurements of thin films. The radio astronomy group is exploiting long-baseline interferometry for high-resolution observations of distant radio sources and for a number of other astrophysical problems. Observations and supporting theoretical work include studies of earth and planetary atmospheres, as well as distant radio sources such as pulsars. Gravitation research includes a variety of experiments related to gravitational interaction and measurable consequences of cosmological models. Research in microwave electronics involves the application of solid-state devices to the design of millimeter-wave receiver components. Increased sensitivity through reduction of noise is a major goal of this work. In a related study, reduction of interference between adjacent channels is being sought by the design of high-dynamic range receiving systems.

Research using high-power CO_2 lasers includes consideration of frequency stability and methods of reducing noise. In addition, nonlinear optical phenomena are being exploited by the generation and shaping of very brief optical pulses. The work on physical acoustics includes a variety of topics such as the speed of sound in a semiconductor and measurements of the characteristics of supersonic jets in a plasma wind tunnel. The nonlinear interaction between sound and liquid surfaces is also being studied. Physical electronics and surface physics is concerned with electronic processes such as thermionic emission, surface ionization, adsorption and desorption, oxidation, and so forth at the gas-surface interface.

The plasma dynamics program seeks to extend the basic knowledge of ionized media with emphasis on such applications as controlled fusion, space physics, and collective phenomena in solids. The research includes methods of producing highly ionized plasmas by electron beam injection, high powered lasers, microwaves, low pressure arcs, and so forth. Plasma diagnostic techniques involve measurements in various portions of the electromagnetic spectrum (microwave, millimeter wave, infrared, optical).

A substantial portion of the effort is being devoted to studies aimed at controlled fusion as a means of power generation. In connection with this work, an experimental plasma machine called ALCATOR is being designed in collaboration with the Francis Bitter National Magnet Laboratory. Using intense magnetic fields and taking advantage of toroidal symmetry, this device will provide means of studying the high density, highly ionized plasmas required to achieve controlled fusion.

Research in communication sciences and engineering spans a broad range of topics pertinent to communication processes in man-made and living systems, as well as interactions between them. Fundamental studies of signals and systems are coupled with various applications such as speech and picture transmission, seismic detection, and optical communication channels.

The major areas of interest in living systems include neural and sensory physiology, auditory psychophysics, visual image processing, pattern recognition, sensory aids, speech communication, and linguistics.

The linguistics group has carried out fundamental studies of the structure of natural languages and of the semantic problems of communicating an idea unambiguously, as well as work on the relationship between the formulation of an idea and its expression in verbal or written form.

Neurophysiological and psychophysical studies of the auditory and visual mechanisms

Interdisciplinary Programs and Research Facilities

conducted over a period of years have added to the general understanding of neural organization and coding and to behavioral aspects of these senses.

Work is also under way on the application of these and other studies to medical problems. One project concerns the development of reading machines for the blind, with printed pages as input and synthetically-generated speech as output. Such machines can also produce a Braille output or a spelled-speech output. Computer pattern recognition forms the basis for a number of related studies in biological image processing. These are aimed at automation of some of the tedious clinical laboratory work such as differential blood-cell counts, analysis of X-rays, and malignant cell detection.

Studies of digital system design automation are aimed at computer-aided methods for handling the ever-growing complexities in digital systems.

Other communication research projects include work on coding theory, quantization, modulation theory and detection theory, together with their applications to a variety of signal channels. Application of the principles of information theory to the organization of large communication networks is also being investigated.

Essentially all of the research in R.L.E. is conducted or supervised by academic faculty members and students. Approximately 100 members of the faculty are affiliated with the Laboratory, working with 250 to 300 graduate students and 50 to 100 undergraduates. The research in R.L.E. spreads over a broad spectrum of topics and thus provides opportunities for a wide variety of student thesis work.

Sea Grant Project Office

In 1970 the Institute established the Sea Grant Project Office under the Provost to serve as a focal point for projects and programs at the Institute, having a common interest in ocean utilization and coastal zone development and to administer all projects supported by the National Sea Grant Program.

The National Sea Grant Program was authorized by Congress in 1966 to support education and training, research, and advisory services for the development of our marine resources. This vital program, a division of the National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce, attacks many of the current ecological, economic, sociopolitical, and technological problems by providing funding grants for institution project efforts.

The objective of M.I.T.'s Sea Grant Program, in support of the Federal goals, is to concentrate its resources and bring its experience to bear on efforts leading to greater ocean utilization and better coastal zone development with due regard for resultant ecological changes. Emphasis will be on those problems which are crucial on a national scale while, at the same time, paying close attention to problems of the New England coastal regions.

Inherent in these efforts is the search for increased application of existing and newly-emerging technology, along with understanding the impact of foreseeable marine-related developments on the social, economic, and political fields, both nationally and internationally, as well as the restraints these fields may have on further developments.

Therefore, the goals of the M.I.T. Sea Grant Program are as follows:

1. To facilitate the application of experience and progress gained in related fields to ocean utilization and coastal zone development in a manner to avoid or minimize detrimental ecological changes,
2. To plan and execute research and development in areas crucial for the established objective,
3. To broaden the educational program for ocean utilization and coastal zone development, and
4. To assure expeditious dissemination and utilization of the results of research and development.

A Sea Grant Council, composed of selected faculty members, works with the Sea Grant Program Director to:

1. Evaluate the various proposals against M.I.T.'s Sea Grant goals and objectives and to establish orders of priority therefor,
2. Review progress made under this program, and
3. Encourage interest and cooperation of Institute faculty and students in attacking ocean utilization and coastal zone development on a broad front.

Further information on specific projects or on program participation can be obtained from the Sea Grant Project Office.

Spectroscopy Laboratory

The Spectroscopy Laboratory has pioneered in the ruling of large, high-performance diffraction gratings and in designing, building and utilizing high-resolution spectrometers throughout the optical range of the spectrum from the vacuum ultraviolet to the far infrared. These instruments are used in studies of molecular geometry, the properties of solids and liquids, and the structures and interactions of molecules of

importance to biology. Investigations are in progress in the application of lasers to such problems as excitation of Raman spectra from very small samples of biochemicals, molecular double-resonance phenomena and generation of Brillouin scattering in liquid and solid systems of special interest.

Urban Systems Laboratory

The Urban Systems Laboratory is an interdepartmental laboratory for multidisciplinary applied research and development. The Laboratory provides a framework and facility for conducting action- and mission-oriented projects which involve a broad range of disciplines from engineering, management, architecture, planning, and the social sciences. While the principal focus is on urban problems, the work of the Laboratory encompasses a wide range of societal problems.

The working unit of the Laboratory is the individual sponsored research project, conducted under the supervision of a member of the faculty. The activities of the Laboratory consist of the set of projects active at any point in time and reflect a matching of faculty and sponsor interests. The Laboratory exists to facilitate the initiation, administration, and execution of the projects. The Laboratory also serves as the administrative unit for a number of interdepartmental research and training grant programs.

The Urban Systems Laboratory stresses the involvement of both undergraduate and graduate students in all of its projects and programs. Extensive opportunities are provided for students to gain practical and field experience on real-world problems in parallel with the student's academic studies. Through such participation, the education experience is enriched and broadened and made more meaningful. While the research project result is the important short-term output of the Laboratory, the young men and women who initiate their professional careers in the Laboratory and go on to potential lifetime contributions to society constitute the most important long-term output.

The research application areas of recent interest have included innovative transportation systems, information systems and computer modeling, building systems and housing, and environmental systems. Urban transportation has been the largest area in the past, but it is expected that the other areas will expand as Federal funding becomes available.

To insure that the work of the Laboratory is realistic and can be implemented in the field, considerable interaction with private and public action agencies is encouraged. A subset of the Laboratory's projects are field-oriented, such projects having been conducted in New York, Puerto Rico, and California as well as in a number of cities and communities in Massachusetts. The Urban Systems Laboratory is temporarily housed in Building E40, a converted industrial building on the East Campus.

George R. Wallace, Jr. Astrophysical Observatory

The new George R. Wallace, Jr. Astrophysical Observatory brings to M.I.T. a versatile facility for research and teaching in optical astronomy, one of the oldest branches of science. It directly supports the growing student and faculty interest at M.I.T. in astronomy and related sciences.

Located in Westford, Massachusetts, the Observatory is linked electronically with the renowned Haystack Radio and Radar Observatory, a 120-foot diameter radio telescope operated by M.I.T.'s Lincoln Laboratory, enabling collaboration on a wide variety of research studies in optical, radar, and radio astronomy. The nucleus of the facility is a 24-inch optical telescope which is operated and controlled through a computer-directed system and which permits the monitoring of data outputs to a degree which has not been possible at other observatories. A 16-inch telescope primarily for instruction purposes has also been installed, providing the Observatory with the flexibility to support a range of activity from observation to instruction, including the testing of new instrumentation and methods of data analysis. Several departments of the School of Science and the School of Engineering are participating in the work of the Observatory along with interdepartmental centers and laboratories on the campus.

OTHER INTERDISCIPLINARY ACTIVITIES

In addition to the above facilities and programs, other interdepartmental activities are being undertaken within the various schools of the Institute. Listed here, as cross-reference, are some of those described elsewhere in this Catalogue:

Instrumentation — see Department of Aeronautics and Astronautics (Section 4).

Civil Engineering Programs — see Department of Civil Engineering (Section 4).

Woods Hole Oceanographic Institution — see (Section 4).

Physical Sciences — an undergraduate program in the physical sciences leading to the S.B. degree without designation of field — see Department of Earth and Planetary Sciences, Course XII-B (Section 4).

Community Fellows Program — see Department of Urban Studies and Planning (Section 4).

Special Program for Urban and Regional Studies of Developing Areas (*SPURS*) — see Department of Urban Studies and Planning (Section 4).

In Section 3 of this Catalogue, procedures are described for graduate students who wish to pursue specialized interdepartmental programs which will be supervised by special doctoral committees. At present over 40 such programs are being undertaken.

The Institute is one of nine universities operating the Brookhaven National Laboratory at Upton, Long Island, New York. Its facilities are available to faculty and qualified students in all M.I.T. departments.



Student Housing

UNDERGRADUATE RESIDENCE

At the undergraduate level, the Massachusetts Institute of Technology is essentially a residential university. Of the total undergraduate student body of about 4,000, about 2,000 single men and women live in the seven Institute houses on the campus and about 1,300 single men and women live in 29 fraternity chapters and the cooperative M.I.T. Student House.

The central purpose of the residential system is to provide environment and programs conducive to personal development as well as to academic achievement, and in this way to extend the experience of higher education which M.I.T. offers its undergraduates. Great reliance is placed by the Institute on the initiative and responsibility of both individual students and student government organizations in the residences.

Faculty families chosen for their understanding of and deep interest in students live in each of the Institute Houses. They are not charged with formal academic or operational responsibilities; instead, they welcome informal associations with their fellow residents. In all of the Institute Houses and in many fraternities, resident graduate student tutors also provide personal and academic assistance to undergraduates.

Determination and maintenance of living conditions in the residences are the responsibility of the Dean for Student Affairs in cooperation with student governments and those members of the faculty in residence. Many responsibilities are delegated to student governing groups for establishing and administering House regulations and acceptable standards of community behavior.

Residential student governments also organize a wealth of social, athletic, and intellectual programs for House members. In the Institute House system a House Tax determined by the residents of each house is collected by M.I.T. and turned over to the House government to help support these activities. Individual fraternity chapters have similar taxes to support their extracurricular programs.

The Institute believes that it is to the great advantage of all undergraduates who do not live at home to reside "on campus" — that is, to live in an Institute House, one of the 29 fraternities, or the M.I.T. Student House. Freshmen particularly gain from associations with upperclassmen and participation in residence programs. Therefore, all unmarried freshmen who cannot commute daily from their own homes or those of close relatives in the Greater Boston area are required to live "on campus." Exceptions to this "on-campus" living requirement are made only with the specific approval of the Dean for Student Affairs.

The Institute Houses

The Everett Moore Baker House, located on the river front at 362 Memorial Drive, on the west campus, accommodates 350 men in single, double, or triple rooms. The House has its own dining facilities, where residents may choose to take Commons meals.

Bexley Hall, an apartment house at 46–48–50–52 Massachusetts Avenue, directly across from the main entrance to the Institute, has been furnished as an apartment dormitory for men. There are suites for two, three, and four students, each with bath and kitchenette. A total of 128 men are accommodated. Residents may, if they wish, take their meals at any of the Institute's dining facilities.

The Alfred Edgar Burton House, located on the Charles River at 410 Memorial Drive, on the west campus, is undergoing extensive renovations and will reopen in September, 1971. Burton House will house 310 men and 34 women in single and double rooms grouped in suites for three to eleven students. Each suite has its own living room, kitchen, and bath, and the suites are arranged in floor groups of 30 or 50 students. Residents of Burton House may prepare their own meals in the suite kitchens or purchase Commons meals in any of the nearby House dining halls. The Russian House, located on one floor of Burton House, offers a unique opportunity for undergraduates interested in Russian to obtain a speaking knowledge of that language. The 20 residents, including four women, prepare their meals and eat as a group and converse primarily in Russian while in the House.

The East Campus Houses — Munroe, Hayden, Wood, Goodale, Bemis, and Walcott — on

the east side of the campus near Walker Memorial, house about 360 undergraduate men and about 25 undergraduate women, mostly in single rooms. Residents of East Campus may take their meals in nearby Walker Memorial. The Walker dining room offers both Commons meals and a la carte service and the Pritchett Lounge offers sandwiches, beverages, and other snacks.

The Frank S. MacGregor House, located on the Charles River at 450 Memorial Drive on the west campus, houses 324 men in singles arranged in six- or eight-man suites. Each suite has its own living room, bath, and galley kitchen. The suites are arranged in entries of about 40 men. The House has its own dining hall, where residents may choose to take Commons meals.

Stanley McCormick Hall, located at 320 Memorial Drive overlooking the Charles River on the west campus, has accommodations for 220 women students in single and double rooms. Half of the House is arranged in suites with nine single rooms, a bath, and a kitchen-lounge. The other half is arranged in floor groups of 20 students in single and double rooms with baths and a kitchen-lounge shared by the residents of each floor. Residents may take Commons meals in the House dining hall or prepare their own food in the suite and floor kitchens.

The Senior House — Ware, Atkinson, Runkle, Holman, Nichols, and Crafts — on the east side of the campus at the corner of Ames Street and Memorial Drive, houses about 175 undergraduate men and about 20 undergraduate women. The accommodations consist of one-, two-, and three-person rooms and suites. Residents of Senior House may take their meals in nearby Walker Memorial. The Walker dining room offers both Commons meals and a la carte service and the Pritchett Lounge offers sandwiches, beverages, and other snacks.

Rooms in the Institute Houses are engaged for the full academic year. For the year 1971–72, the residence fees range from $235 to $370 per term. Commons meals are served Monday through Friday — 15 meals per week, on an "unlimited seconds" basis. For the academic year 1971–72, the Commons fee is $300 for the fall term, $320 for the spring term, and $40 for the Independent Activities Period. (This latter is available only to students who sign up for Commons during both regular terms.) Residents of the Houses with dining halls — Baker, MacGregor, and McCormick — will receive a $15 discount on their Commons fees for both the fall and spring terms if they take Commons in their House dining hall.

Fraternities

Recognized fraternities at the Massachusetts Institute of Technology include 28 chapters of national fraternities and one local residential group with no off-campus affiliation. All of the fraternities maintain houses in Cambridge, Boston, or Brookline. Fraternities participate in M.I.T. student government through the Interfraternity Conference. Each house has one or more members of the Institute faculty or alumni as advisors and several chapters have resident graduate student tutors.

Each fraternity chapter is self-governing and is responsible for management of all its operations and maintenance and for development of its academic, social, membership, recreational and external relations policies and programs. The fraternities provide a unique experience in leadership, community planning, and group interactions.

Approximately 95 per cent of the fraternity freshmen are pledged during "Rush Week," which is held in September just prior to Freshman Weekend. Normally, about 400 freshmen accept invitations to join fraternities. A few upperclassmen, including college transfer students, also pledge fraternities at the beginning of each term.

Cooperative Living

The M.I.T. Student House is an independent, coeducational, cooperative living group sponsored by a group of House alumni. The 30 undergraduate members maintain the residence and do all the work except for cooking and major repairs. Cooperation by the students extends to the management of the House and to the academic, recreational, and social aspects of student life. Savings per member are about $400 a year.

The Non-Resident Student Association

Those unmarried undergraduate men and women who commute daily from their own homes or off-campus quarters and who are not affiliated with one of the Institute Houses, fraternity chapters, or the M.I.T. Student House are considered members of the Non-Resident Student Association (the N.R.S.A.). A small fee is charged members to help support the social and cultural programs undertaken by this student organization.

Student Housing, Activities, and Services

The focus for N.R.S.A. activities is a house on the campus which provides social and study facilities for commuting students and limited overnight accommodations. The student governing group has responsibilities similar to those of student governing bodies in the residences.

Additional Information

Additional information on undergraduate housing, and application procedures is contained in the publication *Undergraduate Residence at M.I.T.* Each new first-year student and each new college transfer student is automatically sent a copy of this brochure about three months before registration day of the term for which he has been admitted to M.I.T. Others may request copies from the Office of the Dean for Student Affairs, Room 7-133, M.I.T., Cambridge, Massachusetts 02139. Information on fraternities may also be obtained by writing to Interfraternity Conference, Room W20-413, M.I.T., Cambridge, Massachusetts 02139. Information on the M.I.T. Student House may be obtained by writing to the President, M.I.T. Student House, 111 Bay State Road, Boston, Massachusetts 02215.

GRADUATE STUDENT RESIDENCE

Although the graduate student body numbers about 3,100, a comparatively small number reside on the campus. About 400 single men and 30 single women are accommodated in Ashdown House. Housing for married students and their families is available in two modern apartment complexes, Eastgate and Westgate, at the east and west ends, respectively, of the M.I.T. campus. Westgate accommodates 210 families and Eastgate 170. For graduate students who reside off campus, the M.I.T. Community Housing Service will assist in locating suitable accommodations.

The Avery Allen Ashdown House

Ashdown House is the primary graduate residence of the Institute for single graduate students; the House is located on the corner of Massachusetts Avenue and Memorial Drive directly across from the main buildings of M.I.T.

A member of the Faculty who is familiar with the aims and problems of graduate students is Master of the House. A student House Executive Committee, acting with the advice and assistance of the Master, plans and operates the activities program. The many facilities for social and cultural activities in Ashdown House make it a center of graduate student activities.

Rooms in Ashdown House are engaged for a full academic year; rents range from $230 to $310 per term.

The main dining room provides a la carte cafeteria service Monday through Friday, except during the summer and other school vacation periods, and contract meal service for those who may choose to purchase this service. For the academic year 1971–72, the cost of the contract is $300 for the fall term, $320 for the spring term, and $40 for the Independent Activities Period. (The latter is available only to students who sign up for Commons in both regular terms.)

Cafeteria and restaurant food service is also available seven days a week year round at the Student Center.

More complete information is found in *Graduate Residence at M.I.T.*, which is automatically mailed to all entering graduate students.

In general, accommodations in Ashdown House are insufficient to meet the demand at the beginning of each year, and there is usually a waiting list. Priority is granted to graduate students already living in the House whose applications are filed in accordance with instructions distributed each spring. Information on Ashdown House may be obtained by writing to the Office of the Dean for Student Affairs, Room 7-133, M.I.T., Cambridge, Massachusetts 02139.

MARRIED STUDENT HOUSING

Two modern apartment complexes, one at either end of the M.I.T. campus, contain a total of 380 family units for married students.

Residence in married student housing is limited to regular undergraduate and graduate married students registered and attending M.I.T. for at least two terms of each year. The summer session is considered a term. Assignments are made on a one-year lease basis. Rents range from $121 to $210 per month including utilities and heating.

A nursery school, with one classroom in Westgate and two in Eastgate, is operated by Technology Nursery School, Inc., a non-profit student-faculty organization. It is open to children of students residing off-campus, as well as those residing in Westgate and Eastgate.

Married student housing is managed by the Campus Housing Office, Room E18-307, Massachusetts Institute of Technology, 77 Massachu-

setts Avenue, Cambridge, Massachusetts 02139. Since accommodations in Eastgate and Westgate are limited, married students are well advised to contact the Community Housing Office regarding off-campus housing.

Westgate

This fire-building complex, located at the west end of the M.I.T. Campus, provides 210 apartments for married student families. The West Campus location near Memorial Drive and the Charles River is within ten minutes' walk of the Institute's main buildings.

Westgate consists of a 16-story tower with 90 one-room efficiency apartments and 60 one-bedroom units, and four three-story garden-type buildings with a total of 60 two-bedroom apartments. Community facilities are available and free parking is provided for a majority of the residents. Rents in Westgate range from $121 to $170 per month.

Eastgate

Located adjacent to Kendall Square at the east end of the M.I.T. campus is Eastgate, a 30-story apartment tower with 204 family units for married students and faculty. The site adjoins the Alfred P. Sloan Campus with the School of Management and the Departments of Economics and Political Science. It is convenient to the main campus and public transportation.

The tower building contains 96 one-bedroom apartments, 84 large one-bedroom apartments, and 24 two-bedroom apartments. About 80 per cent of the apartments are allotted to married students; the remainder are available to faculty members. Rents in Eastgate range from $135 to $210 per month. Community facilities are available and free parking is provided for a majority of the residents.

COMMUNITY HOUSING SERVICE

Married students, single upperclass men, and single graduate men and women who do not live on campus will find help in locating accommodations in the Community Housing Service. Listings of available rentals in the Greater Boston area are maintained, and the staff attempts, on an individual basis, to help students locate the type of accommodations that will best suit individual preferences and financial resources and to advise on many additional aspects of off-campus living.

The Community Housing Service is located in Building W31 at the corner of Massachusetts Avenue and Vassar Streets. All correspondence should be addressed to Community Housing Service, Box 42, M.I.T. Branch Post Office, Cambridge, Massachusetts 02139.

Campus Activities

M.I.T. is a community with wide extracurricular interests and liberal opportunities to enjoy them. More than one hundred student-directed activities supported by excellent facilities and capable staff provide the student with opportunities to develop his interests, to acquire new skills and talents and most important, to participate actively in the life of the M.I.T. community.

Lectures, music, drama, art, athletics, and hobbies all make for a many-sided and busy campus. Moreover, Greater Boston provides a wide range of cultural activities to enrich further the total college experience.

Student Government — Undergraduate

The M.I.T. Undergraduate Association, to which all undergraduates belong, is the major undergraduate governmental body. The Association operates primarily through its legislative branch, the General Assembly, which is comprised of members elected from the living groups. The Assembly distributes information, collects student opinion, and passes resolutions on important campus matters. Implementation of its decisions is made mainly through its Executive Committee, Operations Group, and various Task Forces. Its Nominations Committee recommends to the General Assembly student representatives for M.I.T. faculty and administrative committees (of which there are over 80).

Among its activities during the past year, the General Assembly requested cancellation of classes and quizzes for the Vietnam Moratorium, condemned acts of violence on campus, spoke out against weapons research, requested open speaking privileges at faculty meetings, requested an end to compulsory student meal plans, and set up task forces on special programs, the Campus judicial process, bulletin boards, and conversion of M.I.T.'s special laboratories.

The various committees of the Undergraduate Association attempt to improve conditions at M.I.T. in a variety of ways. The Finance Board coordinates budgets and allocates funds to student organizations; its budget hearings

are open. The Student Center Committee administers part of the Student Center, including building improvements and Center activities. The Student Committee on Environment tries to improve classroom and building design and atmosphere, obtain better living conditions in the dorms, and implement coed living in more living groups. The Student Committee on Educational Policy proposes educational reforms such as a pass-fail system or an independent study calendar. It also sponsors feedback programs and attempts to involve more students in academic departmental decision processes. The Student Information Processing Board operates free computer services for student use and advises on computer policy at the Institute. The Association of Student Activities coordinates activities and tries to improve their facilities and settle disputes among various activities. The Foreign Opportunities Committee publicizes and arranges for work or study abroad.

The International Students' Council represents the interests of foreign students at the Institute and sponsors a newsletter, assemblies, and other events in this regard.

Each of the four undergraduate classes has an elected government structure. These governments are free to sponsor a variety of events during the year relevant to their particular class.

All living groups, both fraternities and Institute Houses, elect governing councils responsible for the functioning of their houses. In addition to sponsoring social events, these House councils also handle all judicial matters with the respective Houses. To deal with the problems of common concern, the fraternities have joined in the Interfraternity Conference (I.F.C.), while the Institute Houses have formed the Dormitory Council. The I.F.C. operates a central food purchasing agency, coordinates and supervises Rush Week, and works to improve relations between fraternities and Boston's Back Bay community by sponsoring an area clean-up and beautification program. The Dormitory Council coordinates such common House activities as freshman orientation, major social events, and intra-House judicial problems.

The elected officers of the Non-Resident Student Association run a program of tutorial, athletic, and social events for commuting students which centers around the N.R.S.A. house on Memorial Drive.

Each class at M.I.T. elects a president and executive committee to handle class affairs such as Field Day, Junior Prom, and Graduation. Freshmen participate in class government through the Freshman Council, whose members are elected early in the fall.

Student Government — Graduate

All graduate students at the Institute are included in the Graduate Student Organization. Its executive body is an elected Council, whose membership includes representatives of all Courses, Ashdown House,, women graduate students, foreign students, and off-campus graduate residents. The Organization is concerned primarily with the general welfare of the graduate student body; encouraging social, athletic, cultural, and other extracurricular activities; promoting closer relations between graduate students and faculty outside formal academic exercises; and giving voice to ideas and suggestions of graduate students. The Graduate Student Council sends two students to represent the Organization on the Committee on Graduate School Policy, the faculty committee responsible for the administration of the Graduate School.

Ashdown House residents have an Ashdown House Student Organization, which functions autonomously and in a similar way through its Executive Committee.

Athletics

A major purpose of the athletic program at the Institute is to encourage all students to develop interests leading to participation in some form of physical recreation. Instruction is offered in those activities which may be continued in the years following graduation.

The intercollegiate program last year attracted approximately 900 students to competition in 22 sports, while 4,000 undergraduates seeking more informal activities joined intramural and club teams. The M.I.T. sailing program attracts another 1,500 students, faculty, and alumni including sailing privileges for their families.

M.I.T. has varsity and freshman intercollegiate teams in track and field, cross-country, lightweight crew, heavyweight crew, baseball, skiing, gymnastics, hockey, basketball, fencing, golf, lacrosse, rifle, swimming, tennis, soccer, squash, pistol, sailing, water polo, and wrestling. Competition includes many New England colleges and Ivy League schools.

The intramural athletic program is noteworthy; last year over two-thirds of M.I.T. undergraduates participated in over 1,500 intra-

mural contests. There were league competitions in touch football, cross-country, basketball, cycling, softball, volleyball, swimming, track, tennis, table tennis, sailing, badminton, hockey, golf, squash, water polo, wrestling, rifle, and bowling. Club sports, with intercollegiate competition but less formal organization than varsity teams, include badminton, bicycling, rugby, cricket, judo, white water, and weightlifting. Undergraduate and graduate students participate in both intramural and club programs.

Excellent facilities for these sports are provided by the du Pont Athletic Center, Rockwell Cage, the du Pont Gymnasium, Briggs Field, the Alumni Swimming Pool, 14 tennis courts, an outdoor skating rink, and the Sailing Pavilion and Pierce Boathouse on the Charles River.

Through the M.I.T. Athletic Association, undergraduates share with the Athletic Department the responsibility for planning and operating athletic programs.

Theater

A variety of theatrical performances is presented on the campus by both student organizations and professional groups.

Dramashop, the student drama group, presents a varied program under the professional supervision of the Director of Drama and his three assistants: a set and a costume designer and a technical director. This program includes each year at least two major productions of full-length plays and four workshop productions of one-act plays directed, designed, and acted by students. Dramashop, in conjunction with the Department of Humanities, also sponsors a Celebrity Series including lectures by prominent theatrical people, productions of plays by well-known theater groups, and performances by modern dance and ballet groups. Tech Show is an annual musical comedy produced by students. The Gilbert and Sullivan Society presents two Gilbert and Sullivan operettas each year.

The M.I.T. Community Players, a group of graduate students and staff and their families, present under professional direction a number of plays each year.

Lectures and Seminars

The Lecture Series Committee, an all-student group independently financed by its popular program of classic and current films, brings outstanding and controversial speakers to the campus. Such men as Ralph Nader, Edward Teller, and Isaac Asimov — all have recently delivered talks to the M.I.T. community. L.S.C. has also co-sponsored, with M.I.T. or other campus groups, events of cultural, entertainment, or educational significance. L.S.C. has presented several plays and ballet performances with the Department of Humanities and a popular series of sex education lectures with another student group.

Music

M.I.T. is a musical community. It has a busy season of musical activities and programs performed by many different musical groups, all of which are open to both undergraduate and graduate students. The Combined Musical Clubs include a Glee Club, Symphony Orchestra, Concert Band, Woodwind and Brass Ensembles, Concert Jazz Band, and a barbershop group — the Logarhythms; there is also a Choral Society, which draws its members from the entire M.I.T. community. These organizations give public concerts on the campus, participate in joint concerts on other northeastern college campuses, and take periodic concert tours throughout the East and Midwest. In 1969–70, the Glee Club, in collaboration with the Smith College Choir and the Mount Holyoke Glee Club, performed works of Bach, Schubert, Poulenc, Stravinsky, and Ives in concerts in the M.I.T. area and on tour in major midwestern cities. The Concert Band, which specializes in contemporary compositions written for band and which for several years has commissioned a composer each year to write a new work for the Band, gave concerts in the Boston area and toured the eastern United States and Canada. The Symphony Orchestra played a well-received concert in Carnegie Hall in 1969; 1970's tour included a concert in Washington, D.C. of works by Bach, Dvorak and David Epstein. The Concert Jazz Band has frequently played in jazz festivals throughout the country and has been invited to an international competition in Switzerland. The Choral Society has three European concert tours to its credit, including appearances in London, Cambridge, Paris, Bonn, Berlin and Munich. Last season they performed the Brahms *Requiem* and the *St. Matthew Passion* of Bach.

Chamber music groups, symphonic groups, and concert soloists appear at M.I.T. each year as part of the Humanities Series. Additional chamber music concerts employing faculty and students are regularly scheduled throughout the

year. Other professional musical events are sponsored at the Institute by the Baton Society (the student musical honorary group) and various campus organizations.

Exhibitions and Activities in the Visual Arts

The Exhibitions Office of the Committee on the Visual Arts presents approximately eight major exhibitions a year in the Hayden Gallery, extending occasionally to the Hayden Courtyard and Plaza. Hayden Lobby has been renovated to accommodate monthly exhibitions of prints, drawings, and photographs. Scheduling is geared to a wide range of interests. Important exhibitions of the year included painting (Leon Golub, Robert Moskowitz), sculpture (Seymour Lipton), photography ("Be-ing Without Clothes," organized by Minor White), art and technology ("Tsai: Cybernetic Sculpture Environment") and the work of Boston artists ("Six Boston Artists"). In addition, the Committee on the Visual Arts sponsors lectures, films, special events, performances, and informal discussions with artists exhibiting at the Institute.

The Francis Russell Hart Nautical Museum, housed in the Department of Naval Architecture and Marine Engineering, maintains a fine collection of paintings, prints, photographs, ship plans, and working drawings of yachts and small craft by well-known twentieth century designers. On display are rigged models of merchant and warships ranging from Viking ships to those of the present, half models of yachts and merchant vessels from about 1850 and engine models. A representative group of prints from the Allan Forbes and Arthur H. Clark Collections are permanently exhibited in areas within the Institute.

The Creative Photography Gallery displays changing exhibitions of important contemporary photography. Highlighted this year were group exhibitions showing the work of individual photographers, "Derivations" (computer-programmed art based on photographic negatives), "The Innermost House" (architectural photography), "The Metropolitan Middle Class" (emphasizing contemporary urban and suburban America) and an exhibition of student work.

The Catherine N. Stratton Collection of Original Graphics is offered to students for use in their own living areas. These works may be borrowed at the beginning of each school year from the Committee on the Visual Arts.

The M.I.T. permanent Art Collection, which now includes nearly 300 paintings, indoor and outdoor sculpture, photography and graphics is on view throughout the Institute.

Recent acquisitions include important works by Jim Huntington, Jasper Johns, Conrad Marca-Relli, Tamara Melcher, Richard Merkin, Niel Williams, and Robert Rauschenberg. Important extended loans to the collection include works by Darby Bannard, Allan D'Arcangelo, Howard Mehring, James Melchert, and a collection of graphics from the Frederick and Marcia Weisman Foundation. The entire exhibition, "Light[7]," constitutes the beginning of the M.I.T. Collection of Photography which is being further developed by the purchase of works from the exhibition, "Being Without Clothes."

Religious Organizations

The long-established programs of the several student religious organizations on the campus are focused about the Chapel and the Student Center. Ministers representing the major faiths devote all or a large part of their time to on-campus activities, counseling with individual students, and advising the student religious organizations. The offices of the Religious Counselors are located at 312 Memorial Drive.

Students take an active part in the religious activities of many of the neighboring churches in Boston and Cambridge. In the past few years, the new chapel has made it possible for the religious groups to center more of their activity, especially their services of worship, on the campus.

In accordance with the chapel s interdenominational status, the Institute has not appointed an Institute Chaplain or Dean of the Chapel. M.I.T. considers that one of its responsibilities is to maintain an atmosphere of religious freedom for the individual and, within this environment, to provide adequate opportunity for the development of spiritual maturity and the exercise of spiritual interests.

Student Publications

Student publications at M.I.T. include *The Tech*, a student newspaper published twice each week; weeklies, *Thursday* and *Ergo; Technique*, the senior yearbook; *Tech Engineering News*, a monthly student magazine of science and engineering; and *Rain*, a literary magazine. There are less formal outlets for journalism talents in the newspapers of the Institute Houses and in departmental newsletters of many kinds. The Graduate Student Council sponsors publication of *A Guide to Graduate Life* and *The Catalyst*, a monthly of news and opinion.

Technology Community Association

Managed by undergraduates and operated with the help of a permanent staff, T.C.A. conducts a diversified program of year-round services to the M.I.T. community. A theater ticket service, a book exchange, duplicating machines for student use, a print exchange, and annual blood donor and charity drives are a few of the activities sponsored by the student members.

Special Interest Groups

There are more than 80 non-athletic activities and clubs at M.I.T., many of them open to both faculty and students. Among the most active are the Outing Club, the White Water Club (canoe and kayak), the Hobby Ship, the Debate Society, the "ham" radio station WLMX, WTBS (the FM local broadcasting station), and the Student Art Association.

More than 500 students are actively engaged in social service work in the Greater Boston area. The M.I.T. Urban Action Program sponsors many major projects in this area, such as the Urban Fellows program in which students do major community service work for academic credit. Other groups such as the Inter-Fraternity Council and Alpha Phi Omega, the national service fraternity, also sponsor active social service programs in the community.

The performing arts draws many talented singers, dancers, and musicians from among the students. The Gilbert and Sullivan Society, Tech Show, Dramashop, Symphony, Logarhythms, Choral Society, Jazz Band, and the Dance Workshop offer opportunities for them to put on professional performances.

Political groups are now playing a more significant role in the affairs of M.I.T. Groups such as the Science Action Coordinating Committee, Center for Community Action, Students for a Democratic Society, Rosa Luxembourg Committee, Young Americans for Freedom, Young Democrats, Young Republicans, and the Student Mobilization Committee to End the War in Vietnam have provided a forum for a wide variety of political sentiments and actions. During the past year, these groups have sponsored teach-ins, rallies, lectures, and discussions.

Professional societies sponsor lectures on topics of current interest, as well as feedback programs to collect opinions concerning education at M.I.T. and to take corrective action.

Many students work in mass media fields, participating in several campus newspapers or radio stations.

The M.I.T. Black Student Union (B.S.U.) runs a variety of programs in education, culture, and black students' problems. Numerous nationality clubs sponsor programs for foreign students from various nations, including discussions and social events.

The wives of M.I.T. students, both undergraduate and graduate, form the Technology Dames. A social and service organization that begins activities in mid-October, the group numbers nearly 400 and sponsors monthly programs to suit a variety of interests. Special events of the year include a bake sale, International Night, a spring fashion show, craft sales, and a banquet at the end of the year. Smaller interest groups include bridge, folk and square dance, model rocket and railroad clubs. Joining the Dames is an excellent way to meet new friends and become better acquainted with the M.I.T. community. For more information, contact Lyn Anderson, 12 Thorpe Street, Somerville, telephone 623-0939.

Student Services

Counseling

The Institute offers a variety of counseling resources. By intention they are not centralized in a "counseling center." A student is free to choose the resource which appears to be most likely to be of help and to state his or her situation or problem in the student's own terms. Counseling, as the word is used here, refers to casual conversations and to scheduled appointments; it runs from the providing of information to skilled psychotherapy.

Other publications, *The Freshman Handbook* and *How to Get Around MIT*, list in detail the counseling resources. Only a short summary is given here. Each student has a faculty advisor. Housemasters and tutors are available in the Institute houses, and some fraternities have graduate tutors. Frequently a student is able to get the help he wants from a fellow student or from an instructor who is not officially a faculty advisor. Coaches and activity advisors can also often be helpful. Several offices specialize in particular areas, such as the Financial Aid Office which includes student employment, the Office of the Foreign Student Advisers, the Selective Service office, the Religious Counselors, and the Placement Bureau. The Campus Patrol is frequently of help to students. There is a Pre-

medical Advisory Committee, a Prelaw Advisor, a Foreign Study Advisor, and an Advisory Committee on Education for those students considering these fields.

The office of the Dean for Student Affairs has several members whose time is almost entirely devoted to student counseling, whether the situation is academic or personal or both.

The services provided by the Medical Department are described below. Many students consider the members of the psychiatric staff to be among the Institute's most skilled counselors; most of those who visit them looking for help have found the experience useful.

In summary, the purpose of the counseling resources is to be of help to young men and women who are in a period of their lives in which maturing frequently involves stress. E. B. White, in *The Points of My Compass*, makes several pertinent comments as he reflects on his own adolescence. One will suffice. "There is a period near the beginning of every man's life when he has little to cling to except his unmanageable dream, little to support him except good health, and nowhere to go but all over the place."

Medical Services

The Institute maintains a well-equipped Medical Department staffed by specialists, centrally located in the Homberg Memorial Clinic building, a wing of M.I.T.'s main buildings. In addition to general medical care given by specialists in internal medicine and surgery, the Medical Department provides consultants in allergy, dentistry, dermatology, gynecology, neurology, ophthalmology, orthopedics, otolaryngology, psychiatry, and urology. The Infirmary with 28 beds and an operating room is located on the campus between Baker House and McCormick Hall. Facilities of the Boston and Cambridge hospitals are used in cases involving major operations or critical illnesses, after which students may return to the Infirmary for convalescence.

The Student Health Program consists of two parts. The first part covers ambulatory and infirmary care provided by the M.I.T. Medical Department and is required for full-time students at an annual cost of $110.00. The second part covers hospitalization (other than in the M.I.T. Infirmary) due to accidents or illness at an annual cost of $54.00; this portion of the program is optional, however, the students are urged to purchase this, unless they have equivalent insurance, as hospital care is very expensive. A medical insurance plan for the wife of a student and for his children is available. The additional cost of coverage for the wife, which includes care in the M.I.T. Medical Department and outside hospital care with a $300.00 maternity benefit, is $219.00. Hospital coverage for one or more children may be purchased for $49.00.

	M.I.T. Medical Department	*Outside Hospital*	*Both*
Student	$110.00	$54.00	$164.00
Student wife	$110.00	$109.00	$219.00
Children, one or more	Not provided	$49.00	—

Initial consultations with a member of the psychiatric service are available to all students and their wives without charge. Prolonged psychiatric treatment cannot be provided by the Institute psychiatric staff, nor is it underwritten by the Student Health Program. Students requiring such treatment will be referred to private psychiatrists or psychiatric clinics in the area.

Prior to matriculation, every student, undergraduate or graduate, is required to submit a report from his own physician recorded on an Institute Medical Form, which is to be mailed by the physician to the Associate Medical Director, stating that he or she is free from active tuberculosis as evidenced by an intradermal skin test or chest X-ray or both. This is a public health measure and cannot be waived. Immunization against small-pox and tetanus are also required before entrance.

Career Planning and Placement

The Career Planning and Placement Office serves students seeking information and advice on employment, opportunities of further study, and careers. It works in close cooperation with the Office of the Dean for Student Affairs, the the Office of the Dean of the Graduate School, the Foreign Study Advisor, the placement counselors in the departments, and the faculty advisors on careers in education, law, and medicine.

The Office staff are happy to talk with students on an individual basis about career plans. The Office also arranges seminars at which alumni discuss the rewards and frustrations of their own career fields. The Office maintains a comprehensive library containing information on careers, specific employers in

industry and government, courses of graduate study, and fellowships. Information is available on opportunities of work and study abroad. The Office works actively to help students find summer jobs abroad, for example through I.A.E.S.T.E. (International Association for the Exchange of Students for Technical Experience).

Over 300 companies, government agencies, and graduate schools make recruiting visits to the Career Planning and Placement Office each year. Their visits are publicized in descriptive notices which are posted throughout the Institute. All bona fide employers (employment agencies are excluded) are given access to the facilities of the Office on equal terms. Their presence gives students a valuable opportunity to discuss employment prospects with different firms.

The Office, through its Alumni Placement section, is in continuous correspondence with employers seeking experienced personnel. Notices of vacancies are received from all parts of the nation and abroad. The Office is happy to match experienced graduates with employers.

Foreign Study Office

The Foreign Study Advisor assists those students seeking foreign study opportunities on various levels. Aside from helping undergraduates define their "junior year abroad" (see Section 2) programs, the Foreign Study Advisor is the M.I.T. representative for a number of foreign scholarship programs such as Churchill, Marshall, and Fulbright. A number of other sources of support exist for graduate and postdoctoral study overseas for which M.I.T. students are eligible. Generally, the deadlines for many such foreign scholarships are as early as November so that inquiries and plans should begin early in the academic year. Students interested in such opportunities are encouraged to consult the Foreign Study Advisor, Dean H. L. Hazen, Room 10-303, ext. 5243.

Selective Service

M.I.T. undergraduates who are subject to Selective Service will find information at the Institute's Selective Service Office, Room 3-140.

The Office of the Graduate School counsels and assists enrolled and prospective (admitted) students in their representations to Selective Service Boards relative to classification and deferment and is prepared to help in every way possible.

The Committee on Graduate School Policy has resolved that: A graduate student, in good standing, whose education is interrupted for reasons related to Selective Service will be readmitted irrespective of whether he enters the armed forces or does not serve because of moral or conscientious objection, provided he applies for readmission within five years after leaving M.I.T. Students are urged to keep abreast of such forthcoming developments through the Graduate School Office and their Selective Service Boards.



Costs and Fees

M.I.T. is an independent, endowed institution; the tuition paid by each student covers less than half the cost of facilities and teaching. The balance is met by income from endowment and by gifts.

The following list gives an estimate of the average student's basic costs for the academic year 1971-72 at M.I.T.:

Tuition	$2,650
Board and room	1,500
Books and materials	200
Medical insurance	110
	$4,460

In addition to these costs, there are variable personal expenses and costs for transportation. Typical costs for clothes, laundry, recreation, optional medical insurance and personal necessities average about $450 per academic year; but there is a great range, depending on interests and tastes. Cost of travel obviously varies significantly and is not included in the above.

The tuition for all regular full-time students, including academic and graduate student staff, in the first and second terms is $1,325 per term. The two-term tuition fee for full-time students who are registered both terms covers the January Independent Activities Period. The regular term tuition for full-time students who are registered only one term covers the January Independent Activities Period. The tuition for graduate fellows, trainees, and academic staff in the Summer Session is $890. (Special tuition rates apply to other students in the Summer Session; these are published each year in the Summer Session Catalogue, available about March 25.)

Special Students (including M.I.T. sponsored-research staff), and regular students other than fellows and academic and graduate student staff, who are permitted by their Registration Officers or Faculty Counselors to take only a few subjects in the first or second term, will be charged at the rate of $42 per unit taken either for credit or not for credit. This unit fee applies up to a maximum of $1,325 per term and is subject to the following minimum fees:

Members of the M.I.T. Community*	$250
Other Special Students	$500
S.B. thesis only	$110

* Includes Special Students who are full-time employees of the Institute or who are dependents of full-time employees or regular students.

Special graduate students in the Alfred P. Sloan School of Management may take no more than two subjects per term. Except for employees of the Institute or their children, the tuition fee is $100 plus $65 per unit of registration. There is no specified maximum charge for such students.

Any graduate student making progress on his thesis is expected to register for thesis and is considered a full-time student. If a graduate student requires only part of a term to complete his thesis, he must pay, initially, full tuition for the term; but if he was registered in the immediately preceding term, regular or summer, his tuition for thesis will be adjusted after delivery of the completed document on the basis of a charge of $110 per week from the starting date of the term, with a minimum of $110 for the Bachelor in Architecture, Master's or Engineer degree and $220 for the doctor's degree. If the immediately preceding term was the summer term and if the graduate student was not registered for thesis in that summer term, but was registered in the previous regular term, the minimum tuition for thesis is $650. If the immediately preceding term was the first term and if the graduate student was not registered for thesis in that first term, he must pay full tuition for thesis in the second term with no tuition adjustment for early completion of thesis. A student who continues to hold a fellowship, traineeship, or academic or graduate staff appointment for the remainder of the term after delivery of the thesis continues to be regarded as a full-time student and his tuition will not be adjusted.

Upon recommendation of a department, the Dean for Student Affairs, in the case of an undergraduate student, may set a special tuition rate in unusual circumstances.

The tuition fees for cooperative programs are as follows:

Electrical Engineering (Course VI-A)	July 1 to June 30	$2,650
Chemical Engineering Practice (Course X-A)	Sept. through Jan. or Feb. through June	$1,325
Mechanical Engineering (Course II-B)	15 months — June through August	$2,650
Aeronautics and Astronautics (Course XVI-B)		

In each case, the first $1,325 is due on the date when the first-term tuition is normally due, and the additional $1,325 is due on the date when the second-term tuition is normally due. Upon recommendation of the Department, a special tuition rate may be set for an unusual case.

Tuition Refunds

Students withdrawing during the first or second term are charged one-twelfth of the stated tuition for the term for each week from the starting date of the term, with a minimum two week charge. A student is financially obligated to the Institute for the fees appropriate to the program approved by his Faculty Counselor or Graduate Registration Officer at the first of the term. Any subsequent reduction in fees is based on the date that cancellation of a subject or withdrawal from the Institute is effected.

Institute House Rentals and Meals

All term rentals, both for Ashdown House and all undergraduate houses, and all fees for commons meals are to be paid to the Bursar at the beginning of each term.

Application Fee

Anyone who files a final application for admission as a regular undergraduate or graduate student, or as a beginning special student, is required to pay a $15 application fee. This fee is not required of a student who applies for readmission as a candidate for the same degree, or, in the case of a graduate student, for a higher degree after a lapse of less than two years.

Other Fees

If, in complying with the doctoral degree language requirement, a graduate student requests a written examination in French, German, Russian, or Spanish at an unscheduled time, he is required to submit with his application a receipt from the Bursar indicating that he has paid a special fee of $30 for this purpose. Any student who fails to appear for a predoctoral language examination is subject to a fine of $10.

The fees for the Student Health Service Program are listed under Medical Services in Section 6 of this Catalogue.

Late Registration or Payment Fine

A fine of $5 is imposed for late registration or late payment of fees. Registration is not complete until all fees are paid or arranged for.

Program Change Fee

There is a $5 charge for each change in a student's program addition, cancellation, or change of units which is made in the last two weeks of a regular term.

Deposits for Laboratory Supplies and Military Uniforms

A deposit of $50, from which will be deducted the costs of laboratory chemicals and supplies, damage to military uniforms, and shoes and other non-returnable equipment, is required of:

1. All first-year students taking MILITARY SCIENCE or AIR SCIENCE requiring uniforms.
2. All undergraduate and graduate students taking subjects requiring supplies from the Office of Laboratory Supplies.

All deposits must be made at the beginning of the academic year. Refunds are made at the end of the year; if the total cost of chemicals and supplies used exceeds the amount of the deposit, the extra charges must be paid at the end of the year. No refunds are made during the academic year except to students who leave the Institute.

Payments

All payments are to be made to the Bursar, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, by the time specified in the registration instructions issued prior to the opening of each term. (For convenience, checks may be made payable to "Bursar, M.I.T.") Many students choose to make their payments under the budget plan described below.

Deferred Payment Plan for Fees

A student or his parents may arrange with the Bursar, by mail or in person, to pay fees in eight (or less) equal installments during the academic year. This arrangement may include all or part of the total charges incurred by the student. Such an arrangement should be made on the Bursar's Registration Form included with each student's registration material, in the section captioned "Financial Plan."

These financial arrangements will be confirmed to the student by a "Fees Receivable

Statement" shortly after the start of each term. These statements will be continued monthly as long as there is a balance in his account.

An example of a maximum arrangement for the fees for men students is shown below. Note that this covers certain fees only and does not represent the total expense for an academic year.

EXAMPLE OF DEFERRED PAYMENT PLAN

Fees		*Payments*		
Tuition	$2,650.00	September	8	$ 513.00
Average dormitory rent	620.00	November	1	511.00
		December	1	511.00
Commons meals	660.00	January	3	511.00
Medical insurance	110.00[1]	January	28	514.00
Laboratory and/or military equipment deposit	50.00	March	1	514.00
		April	3	514.00
		May	1	514.00
Deferred payments (3 per term)	12.00			
	$4,102.00			$4,102.00

[1] Covers ambulatory and infirmary care by the M.I.T. Medical Department for a 12-month period for a single person.

In the event of the termination of the student during the term, all fees due must be paid by special arrangement with the Bursar.

General Regulations

Academic Year

The academic work of the Institute is given principally in two 14-week terms, as indicated in the academic calendar elsewhere in this book. There is a period of four weeks between the terms set aside for independent activities. In addition, a limited number of subjects are given during a 10-week Summer Session in June, July, and August. This Session includes also a number of Special Summer Programs, intensive reviews of special technical fields for those not regularly enrolled at M.I.T. Most classes during the 14-week terms are scheduled between 9 a.m. and 5 p.m. on weekdays. During the Summer Session, most classes are held between 8 a.m. and 5 p.m. on weekdays.

Registration

Each student is required to fill in registration forms and present them to the Registrar on a date before the opening of each term specified in registration instructions. First-term registration material is mailed early in August to regular students whose home address is in the U.S. or Canada and should be returned by the last week in August. Second-term registration material is available at the Registrar's Office late in the first term. An individual who has not completed the registration procedures by the start of the sixth week of a term will be considered as withdrawn and not to be a student.

Subject Registration

It is not usually necessary to restrict the number of students admitted to a subject. If an unexpectedly large number apply for an elective subject, however, it may be necessary to limit enrollment for the term to a number commensurate with the available staff and with the subject's educational objectives.

Subject Cancellation

In the last two weeks of a regular term, registration in any subject may not be cancelled by an undergraduate without the additional approval of the Committee on Academic Performance. The final date for cancelling subjects without this approval will be posted outside Room 7-111 (Information Center).

Faculty Counselors and Registration Officers

Every student is assigned to a member of the Faculty who serves as his academic advisor. Each student's program must be approved by this faculty member, and changes may be made only with his approval. All freshmen have as their advisors members of the Freshmen Advisory Council. Sophomores who have not selected a department are assigned to undesignated sophomore advisors. Other undergraduates enrolled in a department have a Faculty Counselor from that department, and graduate students have Graduate Registration Officers.

The deans, department heads, and all members of the Faculty are also available as consultants to students who seek advice relating to their professional careers.

System of Credits

The credit hours (units) for each subject indicate the number of hours spent each week in class and laboratory, plus the estimated time which the average student spends each week in outside preparation, for one regular term. Each subject is listed with three credit numbers, showing in sequence the units allotted to: class; laboratory, design, or field work; and preparation. Each unit represents 14 hours of work per term. The total unit credit for a subject is obtained by add-

ing together all the units shown. The typical undergraduate student load, based on a four-year program, is 45 to 51 units per term. However, if approved by his Faculty Counselor, a student may follow a program leading to an S.B. degree in either more or less than eight terms.

Graduate Academic Standards

Continuing registration of graduate students from term to term is contingent upon satisfactory academic performance. At the end of each term the Committee on Graduate School Policy reviews the performance of all graduate students whose grades during that term average less than midway between C and B. In addition, departmental graduate committees may at any time recommend to the Committee on Graduate School Policy that a student be refused further registration or that he be allowed to register only for a less advanced degree.

Attendance

The Institute expects regular and prompt attendance in classes and other meetings of the subjects for which a student is registered.

Freshman Grading

Beginning in 1968–69 and continuing for a trial period of four academic years, the grades recorded by the Registrar for freshman students are on a pass-fail basis. At the middle and end of each term, every freshman student shall prepare an evaluation of his work and achievement in each subject and submit it to his instructor on a form provided. The instructor in turn writes his evaluation. The forms are returned to the student via his advisor.

Grade Reports

Grade reports are issued by the Registrar at the end of each term and summer session to all registered students.

Transcripts

Students may order transcripts of their academic record at the Registrar's Office (Room E19-335) upon presentation of a receipt from the Cashier's Office (Room E19-215) at a cost of $1 per copy.

Final Examinations

Final examinations are held at the end of each term; the schedule is issued about a month before the examination period. Each student is held responsible for obtaining an examination schedule at the Information Center (Room 7-111), for reporting any conflicts in his examinations before the time limit given on the examination schedule, and for attending the final examinations required in the subjects for which he is registered.

No member of the instructing staff is empowered to grant excuse from a scheduled final examination. Absence from any final examination is equivalent to complete failure except as, on presentation of adequate evidence of sickness or other valid reason for the absence, the Dean for Student Affairs or the Dean of the Graduate School may permit a student whose term work has been satisfactory to take the next scheduled examination on the subject. The instructor may, if the evidence warrants, issue a final grade without requiring a postponed final examination.

Examinations for Advanced Standing

Registered undergraduate students of outstanding ability may take examinations for advanced standing during the examination periods in each term, provided that they have never been registered for or attended classes in the subject concerned. Notice of intention must be filed with the Registrar at least three weeks before the examination period. Endorsement by the member of the Faculty in charge is required in all subjects which involve laboratory instruction or design.

The grade for an advanced standing examination is entered on the student's permanent record; a passing grade entitles him to full credit for the subject, as well as to the appropriate placement if the subject is in a sequence.

Withdrawal

Undergraduate students who withdraw from the Institute must do so through the office of the Dean for Student Affairs.

Conduct and Discipline

M.I.T. assumes that all students come to the Institute for a serious purpose and expects them to be responsible individuals who demand of themselves high standards of honesty and personal conduct. Therefore, it is M.I.T.'s policy to have as few rules and regulations as are consistent with efficient administration and general welfare.

Fundamental to the principle of independent learning and professional growth is the requirement of honesty and integrity in the performance of academic assignments, both in the classroom and outside, and in the conduct of personal life. Accordingly, M.I.T. holds its students to the

highest standards of intellectual integrity and thus the attempt of any student to present as his own any work which he has not performed or to pass any examinations by improper means is regarded by the Faculty as a most serious offense and renders the offender liable to immediate expulsion. The aiding and abetting of a student in any dishonesty is also held as a grave breach of conduct.

M.I.T. has traditionally placed considerable responsibility on undergraduate governing groups to deal with problems in the student community. Each residential unit has its own judicial system which is responsible to an overall undergraduate judicial system, which in turn is responsible to the Dean for Student Affairs and the Faculty Committee on Discipline, a standing committee of the Faculty. Minor infractions are handled by that student judicial group which is closest to the problem. Serious infractions which occur on campus and almost all off-campus infractions are considered by the Faculty Committee on Discipline. The Faculty Committee on Discipline is composed of eight faculty members, five students, and the Dean for Student Affairs (*ex officio*).

At the graduate level, no formal student judicial system exists. The majority of cases calling for disciplinary considerations resulting from infractions within the Institute community are handled by the Student's Graduate Registration Officer in consultation with the Dean of the Graduate School and the Dean for Student Affairs. More serious cases are considered by the Faculty Committee on Discipline.

It should be noted that the Institute reserves the right to dismiss at any time a student whom it deems undesirable for any reason. Unethical conduct, wherever it may occur, is held to be sufficient grounds for dismissal.

If a student's infraction involves him both in Institute judicial proceedings and in court proceedings, and if an Institute decision might prejudice his court case, the Institute will hold its decision in abeyance until after the court proceedings have been concluded.

The office of the Dean for Student Affairs is responsible for all matters pertaining to general student welfare.

Official Notices

It is each student's responsibility to keep informed of all official notices on the bulletin boards.

Motor Vehicles

All motor vehicles operated by students must be registered each term with the Campus Patrol within 30 days after Registration Day. Students should also note the requirement that out-of-state automobiles operated by M.I.T. students must be registered with the M.I.T. Campus Patrol.

Parking

Parking facilities at M.I.T. are limited. In general, the Institute cannot provide parking for the use of resident students. A limited number of spaces are available for assignment, with the approval of the Dean for Student Affairs, to students with physical handicaps demanding use of an automobile and to a few other undergraduates.

Because demand for student parking far exceeds supply, the matter is under study at the present time. A system of paid parking may be instituted. Students who plan to bring motor vehicles to Cambridge should take careful note of the information regarding pertinent Massachusetts laws which is mailed with their registration material.

Undergraduate Admission to M. I. T.

The great majority of undergraduate men and women enter M.I.T. as members of the freshman class, directly following completion of secondary school studies. Each year a limited number of students whose previous studies at other colleges and universities entitle them to advanced standing are accepted for entrance.

First-year students may enter only at the beginning of the first term, which is the second Monday in September.

ADMISSION FROM SECONDARY SCHOOLS

The size of the first-year class is limited. The Committee on Admissions will give preference to applicants who appear particularly qualified to pursue courses of study at the Institute on the basis of academic fitness and readiness to accept the challenges which society and the professions offer. It is the intention to admit candidates whose qualities of intellect, initiative, and energy demonstrate desire for both intellectual and personal self-fulfillment. Exceptional academic records and test scores, while expected, do not in themselves assure admission.

Academic Preparation

Most good public, parochial, and independent secondary schools in the United States and equivalent schools in other countries will provide suitable preparation for the student who takes full advantage of the opportunities which such schools afford.

Students should bear in mind that the wider their intellectual development and the more extensive their attainments, the greater will be the advantages they may expect to gain from study at the Institute. The preparatory course in high school should be a broad one, not confined to technical subjects.

Attention is called particularly to the necessity for thorough preparation in English and mathematics. The applicant should be able to read with intelligence and sensitivity and to express ideas clearly in oral and written form. In mathematics, emphasis should be on thorough mastery of fundamental principles, operations, and definitions rather than on covering a wide range of topics.

Each applicant is required to have completed the following specific preparatory subjects; the figures in parentheses represent the usual "unit" rating, a unit being a full year's study in a secondary school subject taken four or five times a week:

English (4)	Physics (1)
Algebra (2)	Chemistry (1)
Plane Geometry (1)	Trigonometry (½)

The precise content of the mathematics curriculum is not prescribed; but the applicant must, as a minimum, have sufficient preparation to be ready to study calculus. For courses which go beyond the normal levels of high school algebra and trigonometry, work in analytic geometry, elementary functions, advanced algebra, and such topics as probability and logic is recommended.

In addition to the subjects specifically required, the applicant normally will have completed at least 6 additional units in secondary school studies; no limitations are imposed in the choice of these elective subjects. In the selection of the entering class, the Committee will be guided by the quality of the applicant's work and by his apparent promise on grounds of intellect and character, rather than by his choice of electives.

It is recommended that the elective subjects include one or more years' study of history.

While there is no language requirement for admission, the study of modern foreign languages in secondary school is obviously desirable and is recommended. The choice of languages should be guided by the educational opportunities open to each student, by special interests or cultural ties, and by the nature of his probable future work.

In unusual cases, students of exceptional promise may be considered for admission without having fulfilled all of the stated requirements.

Minority Group Programs

The Institute desires to make its facilities available to all, regardless of financial condition, cul-

tural background, or quality of schooling, to the extent that the student appears ready to pursue an M.I.T. program. To this end special efforts are made to acquaint members of educationally-deprived minority groups of the opportunities at M.I.T. Much flexibility is used in interpreting C.E.E.B. test scores, wherever there is evidence of disadvantaged education or cultural background. For those who seem qualified but may need more exposure in specific academic areas, a special pre-freshman summer session, Project Interphase, is available at no expense to the student. In addition, financial aid for minority-group students is adjusted to reflect background conditions, both in terms of calculation of need and in terms of the amount of self-help expected.

Interested members of minority groups who want more information relative to admissions procedures, financial aid, and life at M.I.T., should write for a copy of the pamphlet "M.I.T. Considers Minorities; Minorities Consider M.I.T."

Application Procedure

Upon initial inquiry, applicants will receive information about M.I.T. as well as about the application procedure. At the same time, they will receive a Request for Application Material form which may be filed as early as desired in advance of the anticipated date of entrance. Filing of this form will assure that the applicant will receive Final Application forms at the proper time (in the fall preceding the desired date of entrance), any announcements which may be issued, as well as information about a personal conference (as noted below).

Candidates should complete the Final Application and submit it with a non-returnable fee of $15 (this may be waived in cases of extreme financial hardship). Application and fee are due by January 10 of the year of intended entrance.

Interviews (Conferences)

Each applicant for admission to the freshman class is expected, if possible, to have a personal conference either in the Admissions Office or with a designated member of the M.I.T. Educational Council near home. Council members are alumni who have been selected for their ability to represent M.I.T. and for their interest in and liking for young people. They welcome the opportunity to meet students interested in M.I.T. and to help them in their educational plans.

Each applicant will be referred for a personal conference to a member of the Council at the time of receipt of a Request for Application Material in the Admissions Office. This personal conference is an essential part of the final application and should take place prior to January 10 of the year of entrance.

Counselors are glad to speak with applicants at any time for general information and counseling purposes. If an applicant sees a counselor before the spring of the junior year, another conference should be arranged after May 1 of that year.

Prospective applicants and their families are welcome at the Admissions Office Monday through Friday between 9 and 5, except during February; it is not necessary to make an appointment. Visitors may wish to plan their time to include a student-guided tour of the campus, available at 10 and 2 o'clock each day that the Admissions Office is open. If planning a visit from a distance, be sure to check up on local holidays.

Entrance Examinations

All candidates are required to take the following tests given by the College Entrance Examination Board: the Scholastic Aptitude Tests and three one-hour achievement tests; (1) Level I Mathematics *or* Level II Mathematics, (2) Physics *or* Chemistry, (3) English Composition or one of the History tests.

The Board offers these examinations in the principal cities of the United States and abroad. The test dates, locations, and fees for the current year are outlined in an Information Bulletin which may be obtained by writing directly to the College Entrance Examination Board, Box 592, Princeton, New Jersey 08540. (Residents of western North America, Mexico, Australia, Pacific Islands, Japan, and Formosa should apply to the College Entrance Examination Board, Box 1025, Berkeley, California 94701.)

Candidates should plan to complete the required series of tests not later than the January test date of their senior year, but may choose any date they wish or divide the tests among two or more dates in the same or in different years. A student taking physics or

chemistry in the junior or eleventh-grade year should probably take the achievement test in that subject, along with the Scholastic Aptitude Test, in May or July of that year. The Board should be requested to send the scores directly to the Institute.

Candidates who complete the tests in January and have submitted all other required material will be notified about admission to M.I.T. early in April.

Early Decisions on Applications

M.I.T. requires a complete set of application materials before considering a candidate for admission; there is no "early decision" plan in the usual sense. The Institute believes the freshman class is selected with most fairness to the candidates by comparing them with each other on the basis of their records through the first half of their senior year. A student who takes all the required College Board tests before the senior year and files all of the application material by November 1 of the senior year may request the Committee on Admissions to review the application by December 1. If his test scores, school grades through the junior year, and other qualifications are so excellent that the applicant will clearly be acceptable later, the Committee will offer admission immediately; if it feels that it should compare application with those of other candidates, it will hold the application until the usual time. A student who seeks early consideration in this way is free to file applications at other colleges and, if offered admission at M.I.T., is not required to reply to the Institute before the colleges' common reply date, May 1 in 1971. A student interested in his academic standing relative to M.I.T.'s standards should consult the published M.I.T. Report to Secondary Schools, available in the high school guidance office or through the M.I.T. Admissions Office.

Advanced Placement

M.I.T. has always encouraged students to move ahead academically according to their capabilities. It offers three procedures by which students entering from secondary schools may go directly into a subject at an advanced level: by the College Entrance Examination Board Advanced Placement Program; by college transcript; and by Advanced Standing Examination at M.I.T.

Qualified juniors and seniors who take college-level subjects offered in their schools in cooperation with the College Entrance Examination Board Advanced Placement Program should take the appropriate three-hour examinations administered by the Board each year in May and instruct the Board to send the scores, test papers, and reports from the school to M.I.T. Degree credit for M.I.T. subjects, and, where appropriate, advanced placement, is given on the basis of a high achievement in the tests (normally a score of four or five). The students are notified before registration of the credit offered so that they may discuss with their Faculty Advisor an optimum schedule.

In some secondary schools, selected students take college-level subjects directly under the auspices of the faculty of a local college. Such students may submit an official transcript from the college showing subjects taken and grades earned in order to receive M.I.T. credit under the regular college transfer procedures.

Students whose advanced study does not follow either of these patterns and who are interested in being considered for M.I.T. degree credit at entrance should write to the Director of Advanced Placement at M.I.T. before August 1 about their studies and should request information about the Advanced Standing Examinations at M.I.T.

A special leaflet concerning Advanced Placement and Degree Credit at M.I.T. is available upon request.

FOREIGN STUDENTS

The basic distinction, for application purposes, between U. S. and foreign student candidates, is the location of the secondary school where the applicant completes his preparation for M.I.T. Thus the student, regardless of citizenship, who prepares in the United States or Canada, follows the procedures outlined above; whereas the foreign citizen, preparing anywhere other than in U. S. or Canada, follows the foreign student procedures outlined below. The only exception to this generalization is that the U. S. citizen studying abroad follows normal procedures regardless of where he prepares for college.

The M.I.T. undergraduate student body includes a number of students who are citizens of other countries. These students normally join the freshman class after completing secondary school at the highest level. Students from British Commonwealth countries, or those with

similar educational systems, should plan on completing the Higher School Certificate Level or the General Certification of Education at the Advanced Level in three subjects, two of which should be in physics and mathematics. Competence in English is assumed.

Application Procedure

Students are welcome to write to the Office of the Advisor to Foreign Students at M.I.T. in September or October of their final year in secondary school for information about application procedures. Upon the receipt of initial letters of inquiry, such applicants will be sent the leaflet, "Information for Prospective Foreign Students." This will be accompanied by a Request for Application form which is to be completed and returned as promptly as possible. The Final Application form and the additional forms for academic records and recommendations required in support of a formal application for admission will be forwarded to those whose Request for Application form is approved by the Foreign Student Advisor. All documents must be completed in English or accompanied by attested translations of the original into English. In order to receive consideration, the Final Application must be completed and returned by January 10, including the required College Entrance Examination Board test scores and, if appropriate, the score of the Test of English as a Foreign Language. A non-returnable $15 application fee is also required.

It should be noted that Request for Application forms or letters of inquiry about admission received after January 1 will be considered as having been received too late for the fall term.

Interviews

Applicants may be asked to arrange an interview with a local M.I.T. alumnus or representative of the Institute for International Education.

Examinations

Applicants are required to take three one-hour achievement tests given by the College Entrance Examination Board in major cities of most nations. The tests must be taken in May, July, December, or January in order to be considered for the September term. M.I.T. requires the Physics, Chemistry, and Level I or Level II Mathematics achievement tests. The English Composition test may be substituted by any applicant for either (but not both) the Physics or Chemistry test. See the preceding section on Entrance Examinations for details about requesting a test information bulletin and registration form.

Facility in English

Lectures, laboratory sessions, and written or oral examinations at M.I.T. are conducted in English. All applicants must present evidence of their ability to carry on their studies in English and must submit the results of the Test of English as a Foreign Language (TOEFL). Exceptions to this rule are granted for those whose native language is English. Those students whose schooling has been in English or who feel their competence in English is such that they can successfully pursue a full program of studies may request a waiver of the TOEFL from the Advisor to Foreign Students. Documentary evidence of this competence must accompany the request for waiver. Formal admission can not be granted to those who have not satisfied this requirement.

TOEFL is administered by the Educational Testing Service. We recommend that applicants for admission to M.I.T. take this test no later than the January administration; applications for this testing date must be submitted no later than the preceding December. Write directly to the Educational Testing Service, Princeton, New Jersey 08540, U.S.A., for registration material and information about this test.

COLLEGE TRANSFERS

Students who have completed two or more semesters with high standing at a recognized college, university, engineering school, or junior college and who are entitled to honorable dismissal may be admitted to M.I.T. by transfer.

Applications from upperclassmen should be completed by May 1. Applications from students in their first year in college will normally be considered only after the college record for the entire year becomes available.

Selection of Students

Transfer students' eligibility for admission will be determined by the Committee on Admissions after a review of their records. They will be expected in every case to have completed the academic preparation required of students entering the Institute from secondary schools.

Such applicants should take the test program prescribed above for entering freshmen. The tests may be waived by the Committee on

Admissions for applicants who have completed a substantial amount of college-level work in mathematics and science.

Advanced Credit

Students admitted by transfer may expect to receive credit for subjects of study completed elsewhere which are substantially equivalent to corresponding Institute subjects. A grade above the lowest passing grade is necessary.

Students whose records appear not to warrant credit in a subject may be permitted to demonstrate, by passing an Advanced Standing Examination, that they are entitled to such credit.

A student in another college contemplating later transfer to M.I.T. should plan a program of studies to include as many as possible of the basic subjects in mathematics and science.

Applicants admitted with advanced standing in architecture will be placed in the DESIGN sequence in accordance with their performance in their first problem.

All remaining questions concerning credits must be settled within two weeks after the opening of the academic year. In these cases, the student should consult the Director of Admissions.

Application Procedure

College students considering transfer to the Institute should file a Preliminary Application for Admission with Advanced Standing on a form obtainable from the Admissions Office. The Director of Admissions will advise the applicant of those parts of the regular entrance requirements which must be fulfilled and will arrange to have the final application materials sent. The Director will also request a report directly from the applicant's secondary school.

The applicant should then submit the following to the Director of Admissions:

1. A completed Application for Admission with Advanced Standing, indicating all subjects which he will have completed at the time of transfer, and a non-returnable fee of $15.

2. A certified transcript of his college record to date, including a statement of good standing. A certified statement covering subjects subsequently taken should be sent as soon as it is available. (Students in their first year in college may wait until the end of the year before sending the first transcript of record.)

3. Catalogue pages describing all subjects which will have been completed; the applicant's name should be written on each page and each subject indicated by a check mark in the margin. Complete catalogues should not be sent.

4. Three evaluation reports, including two from faculty instructors and one from the Dean of Students or the applicant's chief faculty advisor. These forms should be sent directly to the Director of Admissions by the endorsers.

As soon as the applicant's status is determined, he will be informed of whether or not he is admitted and how much advanced credit he will be granted. In some cases, action may be deferred until final grades are available.

Transfer applicants seeking financial aid should submit applications for aid and Parents' Confidential Statements not later than April 15.

The Two-Degree Plan

A number of liberal arts colleges grant their Bachelor's degree to students who have attended for three years and who have then gone on to qualify for a Bachelor's degree in engineering, management, or architecture at M.I.T. or a similar institution. A student who plans his three college years carefully to include the requisite mathematics and science, as well as humanities and social science, can usually obtain the Bachelor of Science degree at M.I.T. in two additional years.

Students interested in this plan should communicate with the college they wish to attend first and secure admission there. Later acceptance at M.I.T. will depend, as with all transfer applicants, on the quality of the college record.

Foreign Transfers

Foreign students applying for admission with advanced standing should refer to the leaflet "Information for Prospective Foreign Students," which may be obtained from the Office of the Advisor to Foreign Students. They may be required to take part or all of the test program. The tests will be waived by the Committee on Admissions for candidates who are enrolled in programs which have substantial amounts of advanced college work in physics, chemistry, and mathematics.

The usual $15 application fee is not required of foreign students, except those studying or living in the United States or Canada.

SPECIAL STUDENTS

A limited number of undergraduates who wish to carry on special studies and who are not degree candidates may enroll as Special Stu-

dents. The Admissions Office will act on the application after seeking approval of the individual instructors if there is doubt about the applicant's ability to take the particular subjects for which application has been made or if there is a question of space in these subjects. Applicants must present academic credentials of high quality or evidence of professional experience which justifies undertaking the program planned.

Admission to the Graduate School

The term Regular Graduate Student designates a student who is in residence at the Institute and registered for a program of advanced study and research leading to any of the post-baccalaureate degrees offered by M.I.T. A Regular Graduate Student may concurrently hold an academic staff appointment such as research assistant, teaching assistant, instructor, or, rarely, assistant professor. A student registered in a program of study leading to the simultaneous award of the degrees of Bachelor of Science and Master of Science is considered for admission as a Regular Graduate Student in competition with other applicants during his fourth undergraduate year.

To be admitted as a Regular Graduate Student, an applicant must have received a Bachelor's degree or its equivalent from a college, university, or technical school of acceptable standing. His academic record and other credentials must indicate ability to accomplish satisfactorily an approved program of study and research. Admission to each department is by competition among the applicants for the places available.

Applicants are evaluated by the department in which they propose to register, on the basis of their prior performance and professional promise. These are evidenced by academic records, letters of evaluation from individuals familiar with the applicants' capabilities, and any other pertinent data furnished by the applicants. While high academic achievement does not guarantee admission, such achievement, or other unusually persuasive evidence of professional promise, is expected.

The engineering departments normally require students seeking a doctor's degree to qualify for a Master's degree first. At the time of registration the student decides, with the advice and consent of his department, for what degree he will register.

UNDERGRADUATE PREPARATION FOR ADVANCED DEGREES

In line with the Institute's conception of a broad undergraduate curriculum with emphasis in mathematics and science, most departments require the following preparation:

Mathematics. Preparation substantially equivalent to that provided by the Institute subjects 18.01, 18.02, and 18.03 (calculus and differential equations).

Physics. Preparation substantially equivalent to that provided by the Institute subjects 8.01, 8.02, and 8.03 (particles, Newtonian mechanics, relativity, oscillations and waves, electricity and magnetism).

Chemistry. Preparation substantially equivalent to that provided by Institute subject 5.01 (atomic theory, kinetic theory, chemical equilibrium, electrochemistry).

Some departments, however, require only a year of college mathematics and some only a year of physical science.

Humanities and Social Science. All M.I.T. departments require at least six semester subjects in the humanities or social sciences equivalent in scope to those included in the undergraduate humanities curricula of the Institute. Deficiencies may be satisfied by completing appropriate subjects from fourth-year or graduate electives in the humanities and social sciences.

Languages. Several departments require a candidate for the doctor's degree to demonstrate competence in one or more foreign languages. A prospective doctoral candidate is urged to include language study in his college preparation.

Professional subjects. Requirements of individual departments are given in each department's statement on graduate education.

Deficiencies in Preparation

Students with minor deficiencies in preparation may be admitted to the Graduate School; however, deficiencies in prerequisite, general or professional subjects must be made up before the student may proceed with graduate work dependent on them.

If an applicant lacks so many undergraduate requirements that his work for the advanced degree is likely to be unduly protracted, he may be advised to postpone his application until some of his deficiencies have been made up.

In an exceptional individual case, the Committee on Graduate School Policy will entertain a departmental proposal for altering admission

requirements and can modify any of the above requirements.

Application for Admission to the Graduate School

Students normally enter the Graduate School in September. However, in several of the departments suitable programs can be arranged for students entering in June or February. Customarily, the Department of Psychology does not admit students in February.

Students wishing to enter in June or September should apply on the prescribed forms by January 15; candidates for admission in February should apply by November 1. However, applications submitted later by students who are not also candidates for financial aid may be considered if vacancies still exist.

Candidates for admission in June or September who are also applicants for financial aid should be careful to observe the deadline of January 15.

An applicant attending a college or university which is on the semester system should not wait until the end of the fall semester at his institution to submit an application for admission in June or September but should apply before the end of the term, submitting a transcript of his fall semester grades as soon as it is available.

Applications for admission should be submitted to the Director of Admissions, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139. A $15 application fee should accompany the application form. Payment should be by check or money order, payable to the Bursar, M.I.T. The fee is not required of a student who applies for readmission as a candidate for the same degree or for a higher graduate degree after a lapse of less than two years.

Notification about admission is sent as soon as action is taken (usually before April 1).

The admission of a student who is in his final year of work toward a Bachelor's degree is made conditional upon his subsequently providing evidence that he has been awarded the degree.

Correspondence concerning admission, including requests for application material, should be addressed to the Director of Admissions. Inquiries about preparation or subject content should be addressed to the chairman of the appropriate departmental Committee on Graduate Students.

Graduate Record Examinations

Applicants for admission to graduate study in the Departments of Biology, Political Science, Mathematics, and Psychology are required to submit scores in the Aptitude Test and in the appropriate Advanced Test of the Graduate Record Examination. The Department of Biology will accept such test scores resulting from the advanced test in either chemistry, physics, or biology. The Department of Psychology requires the Aptitude Test for Verbal and Quantitative Ability, as well as the appropriate Advanced Test of the Graduate Record Examination. It is recommended that the Miller Analogy Test be taken. The Department of Physics does not require, and makes no recommendation regarding, these examinations. All other departments recommend, but do not require, the submission of such scores, with the exception of the Sloan School. The Sloan School of Management requires applicant scores on the Admission Test for Graduate Study in Business (an aptitude test) only. Applicants are urged to consult with appropriate departments to confirm test requirements and recommendations.

Information as to time and location at which these tests are given can be obtained by writing to Graduate Record Examinations, Educational Testing Service, Box 955, Princeton, New Jersey 08540. Inquiries from students in western states should be addressed to 1947 Center Street, Berkeley, California 94704.

Admission as a Provisional Graduate Student

Admission as a Provisional Graduate Student may be granted to an applicant who, although unable to meet all of the above requirements for acceptance as a Regular Graduate Student, is judged by a departmental Committee on Graduate Students to be able to pursue graduate studies successfully. Provisional graduate student status will be changed to that of Regular Graduate Student upon demonstration of such ability.

ADMISSION OF FOREIGN STUDENTS TO THE GRADUATE SCHOOL

Students who are citizens of countries other than the United States, to be eligible for admission to the Graduate School, must have received a Bachelor's degree or its equivalent from a college, university, or technical institute. The academic record and all credentials must indicate the ability of the candidate to achieve distinction in an approved program of study and research. Admission is granted on a competitive basis. Successful applicants are chosen by

the academic departments concerned according to an evaluation of their academic records and professional promise. Competence in written and spoken English is expected.

The leaflet entitled, "Information for Prospective Foreign Students" and the Final Application for Admission from Foreign Citizens form may be obtained from the Office of the Advisor to Foreign Students, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

Action on admission is not taken until complete application materials have been received by the Advisor to Foreign Students.

Students whose native language is not English and whose schooling has not been predominantly in English, must take the Test of English as a Foreign Language (TOEFL). This test is described in the paragraphs on Admission of Foreign Students (Undergraduates).

Some graduate departments recommend or require that an applicant take the Aptitude Test and the appropriate Advanced Test of the Graduate Record Examinations as a regular part of the admissions process. Candidates will wish to consult the section on the Graduate Record Examinations, as well as the specific admission requirements set forth in the descriptions of departmental graduate programs.

SPECIAL STUDENTS

A Special Graduate Student is one whose intended program of study is essentially graduate in nature but who is not registered as a candidate for a degree; normally he will have received a Bachelor's degree. The applicant's qualifications for the specific program desired will normally be evaluated by the Chairman of the Graduate Committee of the department which best corresponds with his major area of interest. Admission is valid for only one term; a student must seek readmission each term to continue at the Institute. To be allowed to continue as a Special Graduate Student, he must receive grades satisfactory to the Committee on Graduate School Policy.

A Special Graduate Student who is subsequently admitted as a Regular Graduate Student may offer subjects which he has completed in partial fulfillment of requirements for an advanced degree. His department will determine to what extent such subjects are acceptable and whether he will receive residence credit for them.

Correspondence concerning admission as a Special Graduate Student should be addressed to the Director of Admissions, from whom application material may be obtained. Applications must be filed at least two weeks prior to the beginning of the term.

RELATIONSHIP OF THE D.S.R. STAFF TO GRADUATE SCHOOL ADMISSION

In view of their full-time responsibilities on assigned research and corresponding non-academic salary scales, staff members of the Division of Sponsored Research do not enjoy full academic privileges but may, under conditions outlined below, be granted the status of Special or Limited Graduate Student.

A graduate student may not interrupt his academic program to accept a staff appointment in the Division of Sponsored Research (D.S.R.), the Charles Stark Draper Laboratory, or Lincoln Laboratory either during the academic year or during the summer unless he has the approval of his Department Head and of the appropriate Academic Dean and unless his work as an employee is unrelated to his thesis research. No graduate student may present as thesis any material based in whole or in part upon work done while holding a D.S.R. appointment.

Many members of the staff of the Division of Sponsored Research (D.S.R.) study graduate subjects as Special Graduate Students. However, a D.S.R. appointee who desires to work for an advanced degree must meet the residence requirement by becoming a Regular Graduate Student at some time during his degree program.

Any D.S.R. appointee may, by written permission from the director of his division (or his designate), apply for enrollment as a student in one subject only per term (but not thesis), either as auditor or for academic credit; he will be accepted for such enrollment if, in the opinion of the instructor in the subject, he is qualified to undertake it and if section size permits. For this type of enrollment, he will be assigned to an appropriate Registration Officer and will pay, whether as a student or listener, the fee established at the Special Student rate and will be recorded as a Special Student. (For details, see "Fees" in Section 7 of this Catalogue.)

A D.S.R. appointee who at some previous time has held Regular Graduate Student status may, upon joint recommendation of a department Committee and the D.S.R. to the Dean of the Graduate School, be permitted to enjoy the status of Limited Graduate Student for the following purposes:

1. To undertake general doctor's or comprehensive Engineer degree examinations;

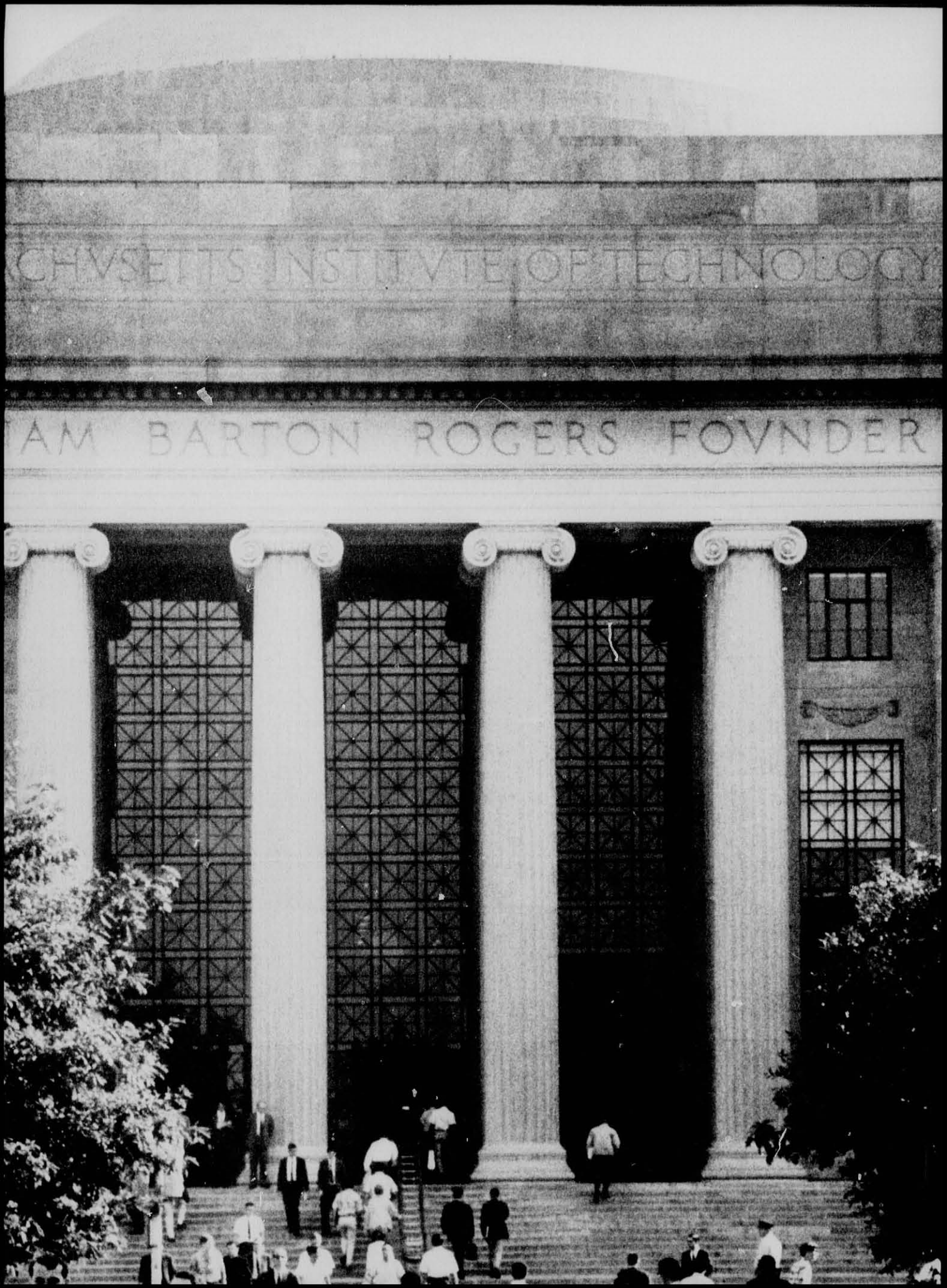
2. To undertake language examinations prescribed for advanced degrees;

3. To complete thesis presentation with or without thesis examination, and either with or without simultaneous enrollment on a degree list;

4. To enroll on a degree list and in one subject.

Not more than one of the preceding four aspects will be permitted in any single term, nor will the privilege of taking one subject apply to terms in which permission is given for registration under aspects 1, 2, or 3 above. Furthermore, no request for enrollment on a degree list will be entertained (except under 4) until all degree requirements other than thesis presentation have been satisfactorily completed. D.S.R. appointees pay the fees or tuition as prescribed for Regular Students, not those applying to students holding academic staff appointments.

By approval of a Graduate Registration Officer, credits recorded for subjects completed as a Special Student may be accepted in partial fulfillment of advanced degree requirements.


CHVSETTS INSTITVTE OF TECHNOLOGY
IAM BARTON ROGERS FOVNDER

Financial assistance in three basic forms is available at M.I.T. to both graduate and undergraduate students. The three broad categories are: gift aid (scholarships, fellowships, etc.), loan aid (with varying conditions of repayment and interest rates), and employment. The precise types of aid granted within these categories vary with each student's academic status and financial circumstances.

Any student whose tuition is not paid by a grant or Institute loan may arrange to have that payment made in installments; details regarding arrangements are available from the Bursar.

The Institute's Student Employment Office is designed to assist students searching for jobs. Employment is usually available on campus in dining facilities, residence halls, libraries and laboratories. Listings of off-campus positions are also maintained. Students can earn from $500 to $700 per year from part-time work, depending on experience and, of course, availability of time.

Students considering M.I.T. are strongly urged to explore all areas of assistance, including government scholarship and loan programs. A number of the states sponsor scholarship programs for residents, and information concerning eligibility is usually obtainable at the state capitals. The Guaranteed Loan Program is a broadly based, federally guaranteed loan program administered by the several states. Local banks and lending institutions are usually able to answer initial inquiries concerning the availability of loans under the Program.

Financial Aid for Undergraduates

The Institute Financial Aid Office provides scholarships, loans, and employment on the basis of the financial need of the individual student, as determined by analysis of the Parents' Confidential Statement of personal finances. This form is submitted through the College Scholarship Service of the College Entrance Examination Board. In addition, an official copy of the most recent parental Federal tax return is required in support of aid applications.

SCHOLARSHIPS

The Student Financial Aid Office reviews applications and makes awards from the most suitable scholarship resources; *applicants need not request aid from a specific fund.* That portion of an applicant's need which results from travel costs, as fixed by the Committee, will be covered by scholarship funds. Need in addition to travel costs, not met by scholarship, may be offset by long-term loans or term-time employment.

LOANS

Loan funds allow the student to pay part of the cost of his education on long-term credit under favorable financial terms. However, loan fund capital is limited, and loans are granted only on the basis of financial need as established by the Parents' Confidential Statement.

Undergraduate loans are provided from a number of sources, including the Institute's own Technology Loan Fund, the National Defense Student Loan Program, and the Federal Government's Guaranteed Loan Programs.

EMPLOYMENT

Students may be offered a choice between a loan and a job of equal dollar value as an incremental portion of their aid. Jobs are not assigned; rather, students are expected to arrange employment most suitable to their own talents and available time. The Student Employment Office maintains listings of positions to assist students seeking jobs.

APPLICATIONS FOR FINANCIAL AID

Entering Freshmen

Students who wish to be considered for financial aid should complete and return the Financial Aid Application which is included with the Final Application for Admission. In addition, a Parents' Confidential Statement (P.C.S.) must be submitted to the College Scholarship Service, designating M.I.T. as a recipient. The P.C.S. form may be obtained from a secondary school or from the College Scholarship Service, P.O. Box 176, Princeton, New Jersey 08540, or P.O. Box 1051, Berkeley, California 94701. Both the application form and the P.C.S. must be submitted prior to January 10.

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An application for admission is not prejudiced by an application for aid. There is no reason for a person with the ambition to attend M.I.T. to be deterred from applying concurrently for admission and aid.

Upperclassmen

Most M.I.T. awards are on an annual basis, and recipients are asked to reapply in December or January each year for continued assistance in the following year. Upperclassmen who have not received prior assistance may make application at this time.

Upperclass financial aid application forms are available from the Student Financial Aid Office about December 15. A new Parents' Confidential Statement must be completed, and both forms must be returned to the Financial Aid Office during January. An official copy of the most recent parental Federal tax return will be requested later in the year.

Foreign Students

M.I.T. has small amounts of scholarship and loan funds which are made available to exceptionally well-qualified foreign students who can demonstrate financial need. Students who wish to be considered for financial aid should so indicate in their letter requesting final application material for admission. Because our financial aid funds are quite limited, students should seek aid from sources other than M.I.T. Students applying for financial aid must submit the completed application forms for admission and financial aid by February 10.

Foreign students should make all arrangements for their financial obligations to M.I.T. and for their entire stay in the United States before leaving their countries. For details regarding expenses at M.I.T., please refer to Section 7.

Application material and further information about the admission of foreign students is available from the Advisor to Foreign Students, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, U.S.A.

Transfer Students

Transfer applicants who wish to be considered for financial aid should request a Financial Aid Application and submit it, together with a Parent's Confidential Statement, to the Director of Student Financial Aid. Both forms must be submitted by April 15.

Scholarships for Undergraduates

The following is an alphabetical list of some of the funds from which scholarship awards are made. The figures in parentheses are the dates of establishment.

Frank W. and Carl S. Adams Memorial Fund (1955)
Established by Mr. and Mrs. Charles E. Adams, with The First National Bank of Boston as Trustee, and named in memory of their two sons as the Frank W. and Carl S. Adams Memorial Fund, this fund is used to assist needy and deserving students at M.I.T. A limited amount may also be available to assist an impecunious student who is unable to participate in recognized functions incident to graduation.

Alcoa Scholarships (1965 and 1968)
Two annual awards of $750, for needy and deserving undergraduate students in metallurgy and the information sciences.

Caroline Hadley Allen Fund
The income from this fund is to be used for purposes that the Institute may define, including financial aid.

Nils Anderson Scholarship (1961)
This scholarship, founded by a gift and added to by a bequest of Nils Anderson, Founder and Chairman of the Board of Debevoise-Anderson Company, Inc., is intended to assist promising students interested in entering the foundry industry.

William P. Anderson, Jr. Fund (1965)
The income only to be expended for such purposes as the Institute may, from time to time, deem most appropriate, preference to be given to student financial aid.

Louie G. Applebee Fund (1942)
This bequest is "to be expended in assisting deserving students."

Army and Navy Scholarships (1930)
Sons of regular Army, Navy, Air Force, Marine Corps, and Coast Guard officers who are admitted as undergraduate students to the Institute will be considered for grants toward their tuition based on their demonstrated need, with a maximum of one-half tuition, upon recommendation of the Financial Aid Office — the total number not to exceed ten each year. Preference will be given to qualified applicants admitted to the first-year class. Applications should be accompanied by documentary evidence that the applicant's father is a regular commissioned officer, active, retired, or deceased. These scholarships may be renewed upon annual reapplication.

Association of Iron and Steel Engineers — Madsen Scholarship Fund (1966)
The income of this fund, established by the Association of Iron and Steel Engineers as a memorial to Ingvald Elias Madsen '33, is used to support one or more undergraduate students with preference given to those enrolled in the School of Engineering.

Athan Scholarship (1962)
This annual scholarship was established by D. J. Athan '54, for upperclassmen in the Department of Architecture. Demonstrated need and professional competence are the basic criteria for the grant. Selection and recommendations are based in part on nominations made by the Department of Architecture.

Elisha Atkins Fund (1894)
This fund, established by Mrs. Mary E. Atkins of Boston with a gift of $5,000, is used for undergraduate scholarships.

Hattie G. Atkins Fund (1962)
The income of this fund, established by the bequest of Mrs. Hattie G. Atkins in memory of her ancestor, Matthew Gannett, is used to provide not more than two annual grants "to worthy students."

Julian M. Avery Fund (1957)
Established by Julian M. Avery '18, this fund is designated for undergraduate scholarships in metallurgy.

Jason S. Bailey Fund (1952)
Established by the estate of Jason S. Bailey, this fund is used for undergraduate scholarships at the Institute.

Thomas Wendell Bailey Fund (1914)
The income from this bequest of Thomas Wendell Bailey is used to assist "needy students in the Department of Architecture."

Charles Tidd Baker Fund (1922)
One-half of the net income of this bequest from Charles Tidd Baker is "applied each year to the assistance of poor and worthy students."

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Constance and Arthur H. Ballard Memorial Scholarship Fund (1969)
This fund, established by the bequest of Constance Ballard, is used for four-year undergraduate scholarships to students in electrical or mechanical engineering, physics, or chemistry. Recipients are selected on the basis of character, ability and demonstrated financial need.

John Rice Bell Memorial Scholarship (1961)
The income of this fund, established by Kenneth E. Bell '17, in memory of his brother, John Rice Bell '11, is used to assist undergraduate students, preferably in chemical engineering.

Alf K. Berle Memorial Scholarship Fund (1960)
Income of this fund, established by his wife in memory of Alf K. Berle '27, is used to assist worthy and needy young men at M.I.T.

Billings Student Aid Fund (1900)
A bequest of $50,000 from Robert C. Billings founded the Billings Student Fund. "Any student receiving benefit from this fund is expected to abstain from the use of alcohol or tobacco in any of their varied forms."

Ernst Henri Birnbaum Memorial Fund (1964)
The income of this fund, established by bequest of Mr. David Bingham in memory of his son, is used for one or more scholarships for students in chemical engineering.

Huse Templeton Blanchard Fund (1946)
This bequest of Huse T. Blanchard '01 is for "the benefit of worthy boys of the State of New Hampshire."

Levi Boles Fund (1915)
The net income of this bequest from Frank W. Boles in memory of his father, Levi Boles, is "applied annually to the assistance of needy and deserving students."

Jonathan Bourne Fund (1915)
This bequest from Hannah B. Abbe constitutes a fund "known as the Jonathan Bourne Scholarship Fund, the income only to be used in aid of deserving students."

Albert G. Boyden Fund (1931)
This bequest from Elizabeth R. Stevens is a permanent fund, known as the Albert G. Boyden Fund, "income only to be awarded as scholarships to assist worthy and needy students, preference to be given to young men or women residents of the town of Swansea or the city of Fall River (Mass.)."

Bertram Brewer Scholarships (1952)
The income from this bequest under the will of Bertram Brewer is used "to provide annual scholarships for deserving undergraduates of good character and ability. . . ."

Hubert D. Broderic (1965)
The income of this fund, established by Stuart C. Broderic '47 and Mrs. Guyetta G. Custance in memory of Hubert D. Broderic, is used to provide scholarship assistance to worthy and needy students at M.I.T.; first preference is given to residents of Lexington, Massachusetts.

Harriet L. Brown Fund (1932)
This bequest of Harriet L. Brown is "to be held in trust as a scholarship . . . the income to be given to such needy and deserving young women desiring to become students at M.I.T., as would otherwise be unable to attend, and in case of two or more applicants of equal merit, preference shall be given to a native of either Massachusetts or New Hampshire."

Walter Stanley Brown Scholarship Fund (1968)
The income of this fund, established by the bequest of Maud M. Brown, is used for undergraduate scholarships, with preference for students from Vermont.

Denison K. Bullens Scholarship Fund (1958)
A gift of Denison K. Bullens '09, this fund is used to provide scholarships for needy and worthy undergraduates, with first preference to students in metallurgy.

Vannevar Bush Scholarship Fund (1960)
This fund, named in honor of Vannevar Bush '16, represents unrestricted gifts used for undergraduate scholarships.

Cabot Corporation Scholarships (1955)
The income of a fund established by the Cabot Foundation, Inc., provides scholarships for children (sons *and* daughters) of employees of the Cabot Corporation and its subsidiary and associated companies. Candidates are required to have certification of their eligibility for scholarship grants by first applying to the Personnel Office of the Cabot Corporation and are expected to comply with the usual policies governing the award of Institute scholarships. In any year when there are no applicants admitted to the Institute included as children of employees of the Corporation, the income may be used for scholarships for other qualified applicants for admission to the Institute.

Godfrey L. Cabot Fund (1950)
Scholarships made possible by this gift are awarded with preference to students of chemistry or chemical engineering.

Thomas D. Cabot Scholarship Fund (1960)
Two-thirds of the income of this fund, established by Mr. and Mrs. Thomas D. Cabot, is used to assist worthy students with financial aid, and one-third is used for salaries for teachers.

Cambridge Scholarships (1916)
A limited number of scholarships are granted to students entering the first-year class at the Institute who are graduates of schools in Cambridge and children of legal residents of that city. These Cambridge Scholarships, which carry a stipend of full tuition, are confined to students who make application furnishing evidence of need. An award may be continued in the second, third, and fourth years upon annual reapplication, providing the holder maintains a satisfactory scholastic record and continues to furnish evidence of need.

Mabel Blake Case Fund (1920)
This bequest from Caroline S. Freeman is "known as the Mabel Blake Case Fund, income to be used to aid deserving students (preferably women) who are in need of assistance."

Nino Tesher Catlin Fund (1926)
A gift from Maria T. Catlin established this fund in memory of her son, Nino T. Catlin '18, the income "to be awarded to needy and deserving students."

Francis Ward Chandler Memorial Fund (1969)
Established by H. Daland Chandler in memory of his father, this fund is used to provide scholarship assistance to graduate or undergraduate students, with first preference being given to students in architecture.

Clapp and Poliak Scholarships (1966)
This annual gift of $20,000 from a fund established by Clapp and Poliak Inc. in honor of the Design Engineering Show Exhibitors, is for undergraduates in the field of design engineering, to provide awards up to full tuition and living expenses.

Lucius Clapp Fund (1905)
This gift from Lucius Clapp formed a fund "to aid worthy students who may not be able to complete their studies without help."

Clark Foundation Scholarships (1953)
This fund, established by the Edna McConnell Clark Foundation, provides scholarships for foreign students entering as freshmen, who would otherwise have insufficient means to allow them to matriculate.

Thomas L. Clark Memorial Scholarship (1956)
The income from this endowment, established in memory of Thomas Lynn Clark '59, by a number of his friends at M.I.T., is used to assist an entering freshman.

A. V. Clarke Fund (1950)
The proceeds of this gift by Mr. Clarke are "used for student aid at the discretion of the Financial Aid Office."

Class of 1887 Scholarship Fund (1967)
This fund was established by members of the M.I.T. Class of 1887. Its income is used for undergraduate scholarships.

Class of 1895 Scholarship Memorial Fund (1945)
This fund was given by the Class of 1895 on its fiftieth anniversary, "the income annually to be used to provide scholarships for suitably qualified descendants of members of the Class of 1895. If in any year the total income is not required for this purpose, the balance shall be added to the Technology Loan Fund."

Class of 1906 Scholarship Fund (1967)
This fund was initiated by members of the M.I.T. Class of 1906. A portion of the interest is to be used for general purposes, with preference for scholarships.

Class of 1909 Memorial Fund (1957)
The income of this fund, initiated by gift from the widow of Carl W. Gram '09, and augmented by subsequent gifts in memory of Felix A. Burton, James H. Critchett, Benjamin W. Dow, Harold I. Eaton, Harry L. Havens, Reginald L. Jones, George A. Haynes, Helen Longworth Paul, William R. Reilly, and Clark S. Robinson, all members of this class, is used for scholarship aid, with first preference to descendants of members of the Class of 1909.

Class of 1910 Scholarship Fund (1967)
This fund was established by the members of the M.I.T. Class of 1910. The income is to be used for undergraduate scholarships.

Edwin E. Aldrin Jr. Scholarship Fund
A gift of the Class of 1917, this fund is restricted to undergraduates in the field of Aeronautics and Astronautics.

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Class of 1931 Compton Memorial Freshman Scholarship Fund (1956)
The income from this fund, established at the twenty-fifth reunion of the Class of 1931 as a memorial to Dr. Karl Taylor Compton, is used for freshman scholarships.

Class of 1932 Fund (1951)
The income from this fund, the twenty-five year gift of the Class, provides undergraduate scholarship grants.

Class of 1933 Fund (1958)
The income of this fund, a gift of the Class at its twenty-fifth reunion, is available for scholarship grants to undergraduates.

Class of 1934 Fund (1959)
The income of this fund, an endowment by the Class as its twenty-five-year gift, provides awards known as the Karl T. Compton Scholarships.

Class of 1938 Scholarship Fund (1938)
The income of gifts from the Class of 1938 is used for scholarships, preference being given those applicants "who have shown their desire for an education by earning part of their expenses; and/or to those applicants who are descendents of the Class of 1938."

Fred L. and Florence L. Coburn Fund (1932)
The income of this bequest from Fred L. Coburn "shall be expended by the Trustees in giving aid and assistance to students of M.I.T. . . . preference being given by said Trustees to students residing in Somerville, Massachusetts."

Coffin Memorial Fund (1929)
This gift from the executors of the estate of Charles A. Coffin — a bequest — carried out the wishes of Mr. Coffin. The fund is used for loans or other aid to students as determined by the Executive Committee of the Corporation.

W. A. Conant Scholarship Fund (1943)
This bequest was made "for the purpose of establishing a permanent fund to be known as the W. A. Conant Scholarship Fund, the income therefrom to be used for the education of native born American Protestant boys of New England of American Protestant parents, who are graduates of some high or preparatory school, public or private, in New England, preference to be given to the graduates of the public schools of Brookline, Massachusetts, but without limitation thereto, and whose parents are financially unable to send them to the Institute and whose own means are insufficient to allow them to attend the Institute."

Albert Conro Scholarship Fund (1943)
This bequest of Mary T. Conro, sister of Emma O. Conro '84, in memory of their uncle, is "for the purpose of establishing and maintaining a scholarship . . . to be known as the Albert Conro Scholarship." Awards are made to students in metallurgy.

The George R. Cooke Fund (1939)
Established by a gift in memory of George R. Cooke '08, the income of this fund is awarded preferably to a student in civil engineering or a related field. Consideration is given to those who have had experience through employment in a field before undertaking formal study; the recipient need not necessarily be a candidate for a degree. Grants will be based on character, achievement, need, and future promise.

John G. Crane Scholarships (1951)
This gift of J. G. Crane '90 is for undergraduate awards.

Allen S. Crocker Memorial Fund (1961)
The income of this fund, established as a memorial by the wife of Allen S. Crocker '97, is used to assist worthy and needy young men. Stipendiary awards will be according to demonstrated financial need up to a maximum of tuition in any one year. First preference in the selection is given to students domiciled in the Rochester, New York, area.

Lucretia Crocker Fund (1916)
By the will of Matilda H. Crocker, the Institute was made the residuary legatee of her estate "for the establishment of one or more scholarships for women in memory of my sister, Lucretia Crocker . . . the income to aid one or more young women in need of pecuniary assistance in obtaining instruction at said Institute."

Eunice McLellan Cruft Fund (1949)
This bequest of Eunice McLellan Cruft was made "to assist young men whose means are inadequate to pay their expenses at the Institute."

Ralph E. Curtis Scholarship (1960)
Income of this fund, established by gifts of the Curtis Universal Joint Company, Inc., is used to assist needy and worthy young men of Springfield, Massachusetts, to achieve their educational objectives at the Institute. Open to entering freshmen, initial preference is given to children and nephews and nieces of five-year employees of the Curtis Universal Joint Company, Inc. In the selection of awards for entering students, first preference is given to graduates of Springfield Technical High School; second preference to graduates of other Springfield high schools; and third preference to secondary school graduates resident in western Massachusetts.

Louis R. Damiano Memorial Scholarship Fund
This fund was established by Vincent Damiano in honor of his father. Scholarships are to be given to undergraduates chosen by the Institute.

Isaac W. Danforth Fund (1903)
This bequest from James H. Danforth for scholarship purposes was a memorial to his brother, Isaac Warren Danforth.

Tenney L. Davis Scholarship Fund (1967)
This fund, established in memory of Tenney L. Davis '13, is to be used in assisting students with need who show great ability in the study of chemistry.

Robert Taylor Dawes Scholarship Fund (1969)
The income of this fund, established by Mrs. Robert T. Dawes in honor of her husband, is used for scholarships for deserving and needy undergraduates.

The Delafield Memorial Fund (1960)
This fund was established by the parents of Benjamin T. Delafield '60 to be used to assist needy and deserving students at M.I.T. Preference is given to students from Pittsburgh or Sewickley, Pennsylvania.

Orville B. Denison Memorial Fund (1960)
The income of this fund, donated by the members of the Class of 1911 as a memorial to Orville B. Denison '11, is used to assist worthy and needy undergraduates at the Institute.

Carl Pullen Dennett Memorial Scholarship Funds (1956 and 1959)
Established by gifts in memory of Carl Pullen Dennett, these two funds provide awards for students in the School of Science, either graduate or undergraduate, who are deemed qualified by scholastic performance, intelligence, character, and promise. The annual selections are made by the Director of Financial Aid and the Dean for Student Affairs.

Marie G. Dennett Scholarship Fund (1963)
Established by gift of the Marie G. Dennett Foundation, this fund provides awards for students in the School of Science, either graduate or undergraduate, who are deemed qualified by scholastic performance, intelligence, character and promise. The annual selections are made by the Director of Student Aid and the Dean for Student Affairs.

Thomas C. Desmond Scholarship Fund (1960)
The income of this gift of Thomas C. Desmond '09 is awarded to deserving undergraduates at the Institute in accordance with the general policies of the Institute.

Development Fund Scholarships (1950)
Scholarships provided by gifts to the M.I.T. Development Fund consist of grants to students who demonstrate need for financial assistance. They are open to all candidates from secondary schools.

Ann White Dickinson Fund (1898)
This bequest from Ann White Dickinson was made "to establish free scholarships in M.I.T. . . . such persons enjoying benefit . . . shall be worthy young men of American origin."

Frederick N. Dillon, Jr. Scholarship Fund (1968)
The net income of this fund, established by the will of Frederick N. Dillon, Jr. '22, is used for providing scholarships for undergraduate work to deserving students from Fitchburg, Massachusetts, and the immediate area.

Fred C. Dobbs Fund (1960)
The income of this fund, established in the name of Dr. F. C. Dobbs by his friends, is used to assist undergraduates to meet their expenses at the Institute. Selection is limited to citizens of the United States who have demonstrated a need for financial assistance and have given evidence of promise.

Dormitory Fund (1903)
This fund for scholarship purposes was raised by miscellaneous subscriptions; it was formerly known as Students' Aid Fund.

Philip B. Downing Trust
This bequest made in 1952 is available to a deserving student with financial need.

Henry C. Dresser Fund (1965)
Established from the bequest of Henry C. Dresser '92, the income is used for scholarships, preference being given to students residing in Southbridge, Massachusetts.

Thomas Messinger Drown Scholarships (1928)
A bequest from Mary Frances Drown was designated "to establish scholarships for deserving undergraduate students, to be known as the Thomas Messinger Drown Scholarships."

Charles Dyer Scholarship Fund (1968)
This fund was established by Ira Dyer '49, in memory of his father, Charles Dyer. The income is used for scholarships to undergraduates.

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Daniel W. Edgerly Fund (1964)
The income of this fund, established by bequest of Daniel W. Edgerly '98, is used for the purpose of maintaining undergraduate scholarship aid for upperclassmen in the science departments, preferably in chemistry, physics, or biology.

Robert B. and Zsabel Ehrman Memorial Scholarship Fund (1970)
Income to be used for the "education of needy students majoring in science, who have demonstrated above average capabilities."

Calvin P. Eldred Memorial Scholarship Fund (1970)
This fund was established by bequest of Calvin P. Eldred for deserving and needy Protestant students.

Leola M. Farnham Scholarship Fund (1966)
Bequest for the purpose of supporting part tuition or full tuition for undergraduate students in the field of science.

Farnsworth Fund (1889)
This fund was founded by Mrs. Mary E. Atkins of Boston, the income to be used for scholarship purposes.

Alton J. Farrel, Jr. Scholarship Fund (1967)
Income from this fund is used to provide scholarships to students with need who are residents of Ansonia, Connecticut, or its vicinity or to other residents of the state of Connecticut.

Francis Edwin Faxon Scholarship Fund (1967)
The income from this fund, established by the Charlotte F. Faxon Trust, is used to provide scholarship aid to male undergraduates.

Charles Lewis Flint Fund (1889)
This bequest from Charles L. Flint is for the "support of some worthy student, preference to be given to some graduate of the English High School, Boston."

Sarah S. Forbes Fund (1913)
Originally given in trust in 1868 by Sarah S. Forbes to William Barton Rogers and Henry S. Russell, trustees, this fund was transferred in 1913 to the Institute "for the maintenance and education of a scholar in M.I.T."

Clara and F. Joseph Ford Scholarship (1951)
The income of a fund established by Mr. and Mrs. Joseph F. Ford is awarded "to worthy and well-qualified students who have demonstrated a democratic and tolerant spirit and who are well disposed toward people of all creeds and races."

Foundry Educational Foundation Scholarships (1947)
Established by the Foundry Educational Foundation, which represents the American Foundrymen's Association, the Gray Iron Founders' Society and the Malleable Founders' Society, and the Foundry Equipment Manufacturers Association, these awards are open to third- and fourth-year students in management, mechanical engineering, and metallurgy.

Arthur E. Fowle Fund (1956)
The income of this fund established under the will of Arthur E. Fowle '93 is to be used for undergraduate scholarships.

Evert W. Freeman Scholarship Fund (1956)
The income of this fund, established by bequest of Evert W. Freeman '20, "shall be awarded annually to a student . . . who shows promise of substantial accomplishment but is in financial need."

Philip Jacob Friedlander Fund (1945)
This fund was the gift of Israel Friedlander "in appreciation of the opportunity my son, Philip Jacob Friedlander, had of spending a little more than a year at M.I.T. before enlisting in the United States Naval Reserve . . . the income to be used with the income from other such funds for the purpose of helping qualified students at M.I.T. regardless of race, creed, or color, or geographical origin, who may be in need of financial assistance . . ."

Jurgis J. Geguzis Fund (1957)
Established under the will of the late Jurgis J. Geguzis, this fund is to be used for tuition and expenses for a student of Lithuanian parentage. The recipient is selected by the Institute upon the condition that he shall repay the amount of his award "when and if able so that other students may be granted the same benefits and privileges in the future."

General Motors Scholarships (1955)
These four-year grants, established under the General Motors College Scholarship Plan, are open to citizens of the United States and are intended for individuals who give evidence of potential leadership. Awards are made to entering first-year students. Stipends will be fixed on the basis of demonstrated need.

Norman H. George Fund (1919)
This bequest of Norman H. George is "to be used for the assistar ce of needy and worthy students in obtaining an education in M.I.T."

Arthur B. Gilmore Fund (1941)
This bequest from Arthur B. Gilmore is ". . . for the purpose of assisting needy students who shall be members of the Beta Theta Pi fraternity . . . said net income to be divided among not more than two students in any one year."

James R. Glazebrook Fund (1959)
The income of this fund is to be used to assist needy and worthy undergraduates at the Institute.

Ethel A. Gleason Memorial Scholarship (1963)
The income of this fund, established as a memorial to Ethel A. Gleason '01, by her nephew, Dr. Anthony H. Gleason, is used to assist worthy and needy undergraduates.

Goodyear Scholarship (1957)
A stipend of $1,500 made available by the Goodyear Tire & Rubber Company Fund is granted to a male U.S. citizen majoring in chemical engineering in his junior or senior year. Awards will be made on the basis of academic standing, character and leadership qualities, and financial need.

Barnett D. Gordon Fund (1942)
The income from this fund, established by bequest of Barnett D. Gordon '16, is to be used "as scholarships for deserving students at M.I.T."

John H. Gregory Fund (1963)
The income of this fund, established by bequest of Sarah James Gregory in memory of her husband, John H. Gregory '95, is used to provide scholarships for juniors and seniors in civil engineering.

John A. Grimmons Fund (1952)
This fund was established by the estate of Katie M. A. Grimmons in memory of her son, John A. Grimmons '21. The income is to be used for scholarships for students . . . with preference to those in the Department of Electrical Engineering.

Robert E. Gross — Lockheed Aircraft Corporation Scholarships (1963)
The income of this fund, established by the Lockheed Aircraft Corporation to perpetuate the memory of Robert E. Gross, founder and principal officer of the Corporation for many years, is available to citizens of the United States who are studying in science, engineering, or other fields applicable to the aerospace, electronics, marine, manufacturing, and construction industries.

Rita Welch Gruber Memorial Scholarship (1961)
The income of this Memorial Fund, established by the gift of Rudolf E. Gruber '16, is used to assist undergraduate foreign students to pursue a course of study at the Institute. Grants are available to foreign students in all departments of the Institute, and there are no limitations in fields of study. In its selection the Committee gives first preference to students who are nationals and residents of Germany, Italy, or France.

Gulf and South America Steamship Company Fund (1953)
Fund established by Gulf and South American Steamship Company from which scholarship grants may be made upon initiative of the Department of Naval Architecture and Marine Engineering. Preference is given to students in the course in Shipping and Shipbuilding Management (Course XIII-B).

William T. Haebler Memorial Scholarship (1960)
This fund was established by his daughter in memory of her father, William T. Haebler '22. The income is used to assist worthy and needy students who are undergraduates and are citizens of the United States.

Humphrey M. Haley Scholarship Fund (1958)
This bequest of Humphrey M. Haley '04 is held in trust and the income used as scholarship aid to one or more deserving students, with first preference to students residing in the St. James Parish in Salem, Massachusetts.

Lucia G. Hall Scholarships (1945)
The income from this bequest of Louise K. Gunn, to "be known as 'The Lucia G. Hall Scholarships' . . . is to be used for the aid of worthy students."

Hall-Mercer Scholarship Fund (1940)
The income from this bequest of Alexander G. Mercer is to be used "for the benefit of such poor students as have passed through some of the public schools with the best reputation for character and ability."

Claire Morton Prince Hanks Fund (1966)
This fund, established by bequest of Claire Morton Prince Hanks, is to be used for "such purpose connected with financial aid as the Executive Committee may deem appropriate." Awards from this fund are made to undergraduate students who are citizens of the U.S.

Harrington Scholarship Fund (1961)
The income of this fund, established by Joseph Harrington, Jr. '30, in commemoration of his father, Joseph Harrington '96, is used for student aid purposes.

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James H. Haste Fund (1930)
This bequest of James H. Haste '96 is "for the aid of deserving students . . . of insufficient means."

Charles Hayden Memorial Scholarships (1939)
Established through a grant from the Charles Hayden Foundation, these scholarship awards are in memory of the late Charles Hayden, graduate of the English High School Class of 1886 and of the M.I.T. Class of 1890.

Delos G. Haynes Scholarship Fund (1970)
Established by bequest of Emma P. Haynes, this fund provides scholarships for "outstanding students who deserve and need assistance, with a preference for men from the city and county of St. Louis."

Joseph Hewett '96 Fund (1965)
Established from the bequest of Joseph Hewett '96, the income from this fund is used in maintaining scholarships at M.I.T.; preference is given to students from the public schools of Brockton, Massachusetts.

Bancroft Hill Memorial Fund (1957)
This fund was established by Frances G. Hill in memory of her husband, Bancroft Hill '11. The income is used for scholarship assistance to students in civil engineering who are in need of financial help.

George Hollingsworth Scholarship (1916)
A bequest from Rose Hollingsworth founded the George Hollingsworth Scholarship.

Loren C. Holm Scholarship Fund (1950)
Established by Marie Holm in memory of her father, this fund is designated for worthy and needy students.

Theodore V. Houser Scholarship Fund (1956)
The fund, established by gifts of Theodore V. Houser, is used for scholarship purposes.

Elias Howe, Jr., Scholarships (1949)
The income from a fund established under the will of Julia Howe Stockwell Smith "shall be available for aiding such students and in such amounts as shall be recommended by the Faculty."

Dr. and Mrs. Chiao-Yue (nee Yueh-Gin Gung) Hu Scholarship (1970)
Established by the gift of Dr. and Mrs. Chiao-Yue (nee Yueh-Gin Gung) Hu in honor of their beloved son, Robert Hsueh-Ko Hu '65, who graduated with high honors and was elected as an Associate Member of the Society of Sigma Xi at the time of his graduation. The stipend of this scholarship shall be awarded annually to needy undergraduate students of Chinese ancestry, restricted to students majoring in mathematics, physics, chemistry, or any branch of engineering in that order.

Huguenot Society of America Scholarship (1962)
This annual grant of $1,000 for an M.I.T. undergraduate is provided by the Huguenot Society of America. Applicants must be certified by the Huguenot Society of America as descendants of a Huguenot who came into the territory (now United States) prior to November 28, 1787. The Financial Aid Office will make a selection from certified and qualified applicants.

Samuel P. Hunt Fund (1945)
This gift of Samuel P. Hunt '95 was designated for scholarship purposes.

T. Sterry Hunt Scholarship (1894)
A bequest from T. Sterry Hunt, for seven years Professor of Geology at M.I.T., was designated to found a scholarship in his name. The award is restricted to students in chemistry, and preference is given to those in the higher years.

William F. Huntington Fund (1892)
From Susan E. Covell the Institute received a gift to constitute a fund in memory of William F. Huntington '75, the "income to apply to payments of tuition of needy and deserving students . . . preference to be given to students in civil engineering."

Cuthbert Hurd Scholarship Fund (1968)
The income of this fund, established by Cuthbert Hurd, is used for scholarships to students in the mathematical sciences.

Charles L. Ireson Scholarship Fund (1959)
Income of this fund, established by the will of Jennie E. Ireson, is devoted to the education of worthy students who may require financial assistance.

Jakobson Scholarship (1951)
Established by Jakobson Shipyard, Inc., this annual freshman scholarship carries a grant of $1,000. First preference is given to a son of an employee of Jakobson Shipyard, Inc.; second preference is to graduates of the following New York high schools: Glen Cove, Huntington, Manhasset, Oyster Bay, Port Washington, Roslyn, Sea Cliff; and third preference is to secondary school graduates who reside on Long Island, excepting the counties of Kings or Queens.

David L. Jewell Fund (1928)
The income from this bequest from Colonel David L. Jewell is "to be used to pay part of the tuition charges for five young men who may be selected by the President or Board of Trustees of the Institute as worthy of assistance, and who, were it not for such assistance, might be unable to pursue their studies at such Institute."

Edward A. Jones Scholarship Fund (1947)
A bequest from Edward A. Jones was designated to be used for the establishment and maintenance of one or more scholarships."

Joy Scholarship (1886)
Established by the gift of Nabby Joy, this scholarship was created pursuant to a decree of the Supreme Judicial Court of Massachusetts for the benefit of "one or more women studying Natural Science at M.I.T."

Sarah Maude Kaemmerling Fund (1952)
This fund was established by a gift in 1952 and subsequently added to by a testamentary bequest in 1959. The income is used for scholarships or some alternate form of student aid.

William R. Kales Scholarship Fund (1953)
This fund, endowed by a gift of the Whitehead and Kales Company for scholarship purposes, provides income to assist worthy and needy undergraduates.

Kalker Scholarship Fund (1969)
In memory of Abraham and Ida Kalker "for the purpose of aiding and assisting needy and deserving students of high scholastic standing."

Henry Donald Kemp Fund (1964)
The income of this fund is to be used to provide scholarship aid to students in the Department of Electrical Engineering.

Bo Kwang Kim Scholarship Fund (1957)
Established under the will of Bo Kwang Kim, this scholarship is for students of complete Korean ancestry. It is open to any deserving and needy Korean students. An award of $500 is made only when the income of the Fund permits.

Robert M. Kimball '33 Memorial Scholarship (1964)
This fund has been established by the Class of 1933 as a memorial to Robert M. Kimball '33. Awards are made to students with established need, and preference, whenever possible, is given to descendents of the Class of 1933.

Amelia S. Kniesner Scholarship Fund (1944)
Gift of William T. Kniesner '16 and his sisters, the income is used "to provide scholarship aid to meritorious or needy students, either entering freshmen or undergraduate students of the Institute, preference to be given to graduates of the high school or high schools of Danbury, Connecticut."

Kurrelmeyer Fund (1947)
This fund was raised by contributions by alumni "for an undergraduate scholarship award to a needy student."

George J. Leness Scholarship Fund (1969)
The income from this fund is used to aid needy and worthy undergraduate students of the Institute in good standing who take an active part in intercollegiate athletics.

Y. T. Li Fund (1959)
The income of this fund, established by Y. T. Li '38, is used to assist a worthy and needy student enrolled in the Department of Aeronautics and Astronautics; second preference is given to a student of Chinese origin.

Jacob and Jennie Lichter Fund (1949)
This scholarship fund is "for the aid of students who shall satisfy all entrance requirements of the Institute and be endorsed as to character and personality."

Gustaf Robert Lindberg Fund (1957)
This fund was established by Otto C. Lindberg, President of the General Drafting Company, to create the Gustaf Robert Lindberg Scholarships. The income is used for scholarships "that shall provide tuition, board and other necessary expenses preferably to one or more students who are citizens and residents of . . . Finland; second preference to citizens and residents of Sweden. If no worthy candidates from either Finland or Sweden, the scholarships may be awarded to the best qualified candidates who are citizens of the United States preferably of Finnish or Swedish extraction."

Paul Weeks Litchfield Scholarship (1954)
Established in honor of Paul W. Litchfield '96, this scholarship fund aids worthy and needy students at the Institute. Preference in selection is given to those students who have been members of the Boy Scouts of America.

William Litchfield Scholarship (1910)
A bequest from William Litchfield established "a single scholarship . . . known as William Litchfield Scholarship, income to be awarded and paid annually to such student in said Institute as may, . . . be determined by the President of said Institute to be entitled thereto for excellence in scholarship and conduct."

Littmann Foundation Scholarship (1960)
This four-year grant, supplied by the Littmann Foundation, is available to a male student desiring, preferably, to pursue a course of study either in engineering or management as related ultimately to manufacturing. First preference in the selection is given to a well-qualified secondary-school graduate, resident either in the general area of St. Louis, Missouri, or Charles City, Iowa. The amount of the award is based on demonstrated need.

Charles E. Locke Memorial Fund (1923)
Preference in making awards from this fund, which was established by the Class of 1896, is given to descendants of members of the Class of 1896, including freshmen.

Lockheed Leadership Fund Scholarships (1953)
Established by the Lockheed Leadership Fund, these scholarships are for worthy young men and women who are citizens of the United States. Recipients must be secondary school graduates under twenty-five years of age who plan to major in a field of engineering applicable to the aircraft industry. In the selection for this award, the Student Financial Aid Office will give recognition to factors other than scholastic achievement. Grants are for full tuition plus $500 toward living expenses, renewable for three additional years — or the total undergraduate period.

Richard W. Lodge Fund (1955)
The income of this fund, established by the will of Mary L. Lodge in memory of Richard W. Lodge '79, is used for worthy and needy students.

Sheridan A. Logan Fund (1964)
A gift of Sheridan A. Logan, the income and principal used as required to provide scholarships to outstanding young men coming from the St. Joseph, Missouri, area.

Elisha T. Loring Fund (1890)
This bequest from Elisha Thacker Loring is for "the assistance of needy and deserving pupils."

George J. Loveley Scholarship Fund (1960)
The income of this fund is used to assist needy students, with first preference to sons of widows, whose fathers were native born citizens of Massachusetts, preferably of Boston and vicinity.

Percival Lowell Scholarships (1955)
The income of this gift is used for scholarships awarded from time to time at the discretion of the President of the Massachusetts Institute of Technology to students in astronomy, physics, and mathematics.

Loyal League Scholarships (1959)
Three $1,000 scholarships established by the Loyal League Philanthropies, Inc., are available to entering freshmen, graduates of public secondary schools in the Greater New York Metropolitan Area, who have demonstrated academic excellence and great financial need.

Samuel E. Lunden Leadership Grant (1968)
From a fund established at the Institute by Samuel E. Lunden '21, a grant is made annually to an entering freshman who evidences the potential of becoming a leader in the affairs of the nation. Recipients are selected primarily on the basis of high personal promise of leadership qualities. First preference goes to applicants from the territory of the M.I.T. Club of California, second to applicants from the western region of the U.S. Recipients must be U.S. citizens.

Eugene and Margaret McDermott Scholarship Fund (1960)
The income of this fund, established by Mr. and Mrs. McDermott, is used for four-year scholarship grants for superior students. First preference is given to students resident in Texas, Arizona, New Mexico, and Oklahoma, desiring to study in the earth sciences or related fields.

Frederick F. Mackentepe Scholarship Fund (1970)
A fund established by bequest of F. F. Mackentepe '14, the income of which is to be used for undergraduate scholarships.

Alice Maclaurin Scholarship (1951)
Gifts created a scholarship in memory of Mrs. Richard C. Maclaurin.

Georgia Lamar Malone Scholarship (1961)
Income from this fund, established as a memorial to his mother by Charles B. Malone, Jr. '15, is used for scholarships for undergraduates, with first preference to students from Georgia or the Deep South.

Theodore A. Mangelsdorf Fund (1961)
The income of this fund, established by gift of the Brookdale Foundation, is used to provide undergraduate scholarships.

Francisco Marcucella Fund (1953)
This gift of Francisco Marcucella '27 was designated for undergraduate scholarship purposes.

Rupert Anderson Marden Fund (1933)
This fund was established by an anonymous gift "toward a memorial to be known as the Rupert Anderson Marden Scholarship Fund, income available annually to aid a worthy student at M.I.T. — Protestant and of American origin — preference to a student taking the Cooperative Course in Electrical Engineering."

Martin-Marietta Foundation Scholarship Fund (1954)
This fund of $25,000 functions as an endowment to provide scholarships for students majoring in fields identified with the operations of the Aerospace Group of the Martin-Marietta Corporation. Students from the Baltimore, Maryland, Washington, D.C., Denver, Colorado, Orlando-Canaveral, Florida, and Vandenberg, California, areas are eligible.

Waldo A. Martin Scholarship Fund (1950)
This fund was established by Eleanor P. Martin in memory of her brother, Waldo A. Martin '90. Until 1975 first preference in awards is to be given to male friends or relatives of Waldo A. Martin and the donor, and second preference to graduates of Milton High School, Milton Academy, or a resident of Milton. Awards are for the freshman year only, on the basis of character, integrity, and ability.

Margaret A. Matthews Fund (1947)
The income of this bequest from Margaret A. Matthews is "for the benefit of such of the women students at M.I.T. who intend to become teachers."

Thomas Mayor Fund (1963)
The income from this fund is for scholarships to aid worthy and needy young men who are citizens of the United States, with preference given to those of the Protestant Christian faith and of English or Scottish descent.

George J. Mead Prize Scholarships (1951)
This bequest of George J. Mead '16 established prize scholarships in aircraft propulsion open to juniors, seniors, and graduate students in this field. Consideration is also given to candidates from related engineering fields as applied to aircraft propulsion.

Charles E. Merrill Scholarship Fund (1955)
The gift of Charles E. Merrill, this fund is for "students having financial need . . . who have demonstrated through personality traits, initiative, or by scholastic achievement that they will become substantial democratic citizens." One-half the income is used to meet the overhead expense of the Institute.

Arthur Merkel Miller Fund (1960)
Income of this fund, established by the will of Arthur Merkel Miller 17, is to provide scholarship assistance to worthy students.

Robert W. Milne Fund (1943)
This bequest was made as "an endowment fund under the title of 'The Robert W. Milne Fund,' the income thereof to be used and applied for the assistance of worthy and needy students in obtaining an education in said Institute."

Joseph R. Minevitch Memorial Scholarship Fund (1957)
This bequest of Joseph R. Minevitch '16, in the name of his mother, Fannie Minevitch, and his brother, Borrah Minevitch, is to assist deserving young men or women with first preference to graduates of the Boston English High School, second preference to graduates of any Boston public high school, and third preference to graduates of any other public high school in the United States.

Li Ming Scholarship Fund (1969)
Income from this fund, established by bequest of Li Ming, is used for scholarships to undergraduates, preference being given to students of Chinese birth, descent, or nationality.

James H. Mirrlees Fund (1886)
This gift from James Buchanan Mirrlees of Glasgow, Scotland, constituted a scholarship in memory of his son, James Henry Mirrlees, who died in 1886 while attending the Institute. The income is awarded to the "student in the third or fourth year of the Mechanical Engineering Course most deserving pecuniary assistance."

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M.I.T. Alumni Fund National Scholarships (1957)
These four-year scholarships were established by the M.I.T. Alumni Fund Board to give opportunity to well-qualified young people in the continental United States to come to the Institute. Grants are made to outstanding freshmen on the basis of demonstrated financial need, and continued awards depend upon achievement as well as need for assistance.

M.I.T. Boston Stein Club—New England and National Scholarship Funds (1955)
The income of these funds is granted to qualified applicants for the freshman year only. One or more awards are available to New England residents as well as to residents of other parts of the United States. There are no restrictions as to sex, religion, race, or color.

M.I.T. Club of Chicago Scholarship Fund (1944)
This fund was initiated by Harold B. Harvey '05 "to establish scholarships to be known as the Technology Club of Chicago Scholarship Fund," the awards to be made by a committee composed of the Honorary Secretaries of the Chicago area and the Director of Financial Aid, and restricted to students who reside in the area of the club membership.

M.I.T. Club of Rochester Scholarship Fund (1968)
This fund was established by the M.I.T. Club of Rochester — income is used for scholarships to undergraduates, with preference given to students from Rochester, New York.

Morningstar Scholarship (1953)
This undergraduate scholarship gives first preference to students in the Department of Physics. Grants are equivalent to one term's tuition and are continued to a recipient for the entire undergraduate period.

Fred W. Morrill Scholarship Fund (1941)
The income from this bequest of Hattie B. Morrill is to be used "for the purpose of providing financial assistance to some student or students at the discretion of the Trustees of said Institute. . . ."

Frederick Taft Moses Scholarship Fund (1959)
This scholarship provides four-year awards ranging from $200 to $2,000 annually, and is offered to young people of superior talent and promise.

Gertrude B. Newman Scholarship (1952)
This bequest from the estate of Mrs. Gertrude B. Newman is to aid worthy and deserving students

Niarchos Scholarship (1956)
Established by Stavros S. Niarchos as a memorial for merchant mariners who gave their lives during World War II, these grants provide opportunities for higher education to the sons of merchant seamen. The awards are based upon demonstrated need and achievement in secondary school experience. In the selection of candidates, first preference is given to sons of merchant seamen and ships' officers who lost their lives in the line of duty during wartime. In other cases, candidates' fathers must be regularly employed in a seagoing capacity or, if deceased, so last employed. These awards are not limited to courses in marine engineering and naval architecture, but consideration may be given to the desire of qualified candidates to pursue careers in these fields.

Nichols Scholarship (1895)
This bequest from Mrs. Betsy F. W. Nichols constitutes the Nichols Scholarship in memory of her son, William Ripley Nichols '69, for sixteen years Professor of General Chemistry at the Institute. Preference is given to students in the Course in Chemistry.

Charles C. Nichols Scholarship (1904)
This bequest from Charles C. Nichols constitutes a scholarship fund.

Hart and Arthur Nichols Scholarship Fund (1966)
This fund, established by gifts from W. Hart Nichols '27 and Arthur A. Nichols '28, is used for undergraduate scholarships.

William E. Nickerson Scholarship Fund (1949)
The income from this fund, established by the Nickerson Trust, is used for a scholarship for a worthy student.

Howard A. Noble '97 Scholarships (1956)
The income of a fund established under the will of Catherine B. Noble and enriched by the bequest of Howard A. Noble, is used to maintain scholarships in engineering.

John Felt Osgood Scholarship (1909)
This bequest was made by Elizabeth P. Osgood "to establish and maintain a scholarship in electricity in memory of my husband, John Felt Osgood."

Louise Parks Knight and Charles F. Parks Memorial Fund (1952)
Established as a memorial to Louise Parks Knight and her father, Charles F. Parks '75, this fund is "used for the aid of poor but worthy students who have already entered upon a course of study but are unable to finish owing to lack of funds."

George L. Parmelee Fund (1921)
This bequest from George L. Parmelee of "one third of my property and estate" specified that "interest thereof be used for tuition of worthy students, either special or regular, according to the direction of the Faculty."

Frank E. and Seba B. Payne Foundation Scholarship Fund (1962)
A gift of the Frank E. and Seba B. Payne Foundation is used for scholarships in the School of Engineering.

Langdon Pearse Memorial Scholarship (1958)
This fund was established by gift of Mrs. Langdon Pearse in memory of Langdon Pearse '01. Income from the fund is used toward the tuition of students in the field of sanitary engineering, with second preference to undergraduate students in the field of civil engineering.

Frank Stetson Pecker Fund (1947)
This fund was established by the wills of Frank Stetson Pecker and Annie J. Pecker for scholarships.

Richard Perkins Fund (1887)
The income from half of this bequest from Richard Perkins is available for the "support of free scholarships in said Institute."

Malcolm Oliver Petri Memorial Fund
The income from this fund is "to be used for the benefit of worthy students in need of financial assistance."

St. Elmo Tower Piza Memorial Fund (1962)
The income of this fund, a bequest of Margaret Piza Crane established in memory of her brother, St. Elmo Tower Piza '15, provides for "tuition or expenses of a man or woman student in any of the five years of the Course in Architecture." The grants are awarded on the basis of scholarly achievement, demonstrated qualities of leadership, and financial need, but entirely without regard to race, color, or creed.

Charles H. and Helen Bartlett Pray Fund (1950)
Established under the wills of Charles H. and Helen Bartlett Pray, this fund provides "for scholarships for needy young men."

Florence E. Prince Fund (1943)
This bequest of Florence E. Prince is "for the aid of worthy students who may need assistance in the matter of maintenance and living expenses while pursuing their studies."

Walter R. Ramsaur Scholarship Fund
This fund was established by the Garrett Corporation in honor of Walter R. Ramsaur '28, Executive Vice President of the Corporation. An annual gift of $4,000 provides four-year undergraduate scholarships to students intending to study mechanical or aerospace engineering. Walter R. Ramsaur Scholars will be selected on the basis of their personal and academic credentials, and their awards will be administered in accordance with the established policies governing student aid at M.I.T.

George H. Rand Scholarship (1958)
The income of this fund, established by a bequest of the estate of George H. Rand, provides scholarships for deserving undergraduate students.

Thomas Adelbert Read Scholarship (1934)
This bequest from Julia A. Read was designated "to establish the Thomas Adelbert Read Scholarship, in memory of my late brother of that name; the income of said fund to be awarded to some worthy and needy student of that institution, preferably to a resident of Fall River. . . ."

Willis Ward Reeves, Jr. Fund (1945)
Established by Mr. and Mrs. Willis Ward Reeves of Hazard, Kentucky, "as a memorial to their son, Willis Ward Reeves, Jr. '46, late Lieutenant, U.S. Army Air Forces, killed in action over France during World War II . . . the income to be used for scholarship aid to deserving undergraduate students, with preference to those from Kentucky."

Arthur Reid Memorial Scholarship (1966)
This fund is available to qualified needy students from the Avon, Massachusetts, community and was established by the Institute as a Memorial to Arthur Reid, who passed away while employed at M.I.T.'s Laboratory for Nuclear Science, assisting with frontier developments in High Energy Physics.

Charles A. Richards Fund (1939)
This bequest is "known as the Charles A. Richards Fund . . . the income only for assistance of poor Protestant students in the Institute."

Frederick L. Richards Memorial Fund (1960)
The income of this fund, established as a memorial to Frederick L. Richards '95 by his sister, is used to provide scholarship assistance to undergraduate students in chemistry, chemical engineering, or other curricula based on chemistry.

I. D. Richheimer Memorial Scholarship (1961)
The income of this fund, bequeathed as a memorial by Rose N. Richheimer, is used for scholarships to worthy students.

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John Roach Scholarship Fund (1937)
This bequest from Emeline Roach constitutes a fund "to be known as the John Roach Scholarship Fund, the income to be used to provide an annual scholarship to a needy and deserving student pursuing the Course in Naval Architecture and Marine Engineering."

Karl Robbins Scholarship (1951)
First preference for this scholarship, a gift of the Robbins Foundation, is for either a graduate or undergraduate in textile technology; second preference is to a student in mechanical engineering.

Willard F. Rockwell Scholarship Fund (1961)
The income of this fund, established in honor of Willard F. Rockwell '08, is used to assist needy and worthy undergraduates.

William Barton Rogers Scholarships (1947)
A limited number of four-year grants established in honor of William Barton Rogers, founder of the Institute, enable young men of superior ability and future promise but of limited financial means to pursue an education in engineering, science, or architecture. Stipends are awarded according to demonstrated need. These scholarships are open to all freshmen with no restrictions of geographical location.

William P. Ryan Memorial Fund (1935)
The income from this fund, established by friends of the late Professor William P. Ryan '18, is used for scholarship aid (graduate or undergraduate) in chemical engineering, the award to be made on recommendation of the Head of the Department of Chemical Engineering.

John P. Schenkl Fund (1922)
This bequest from Johanna Pauline Schenkl is "to be held in trust to establish one or more scholarships in the Department of Mechanical Engineering" in memory of her father, John P. Schenkl.

George Scher Fund (1949)
This gift of George Scher established a fund to be used for scholarship purposes.

Anna and David C. Schilling Scholarship Fund (1970)
This fund was established by bequest of David C. Schilling. Its income is used to provide first-year scholarships for needy students of high scholarship and character.

William E. Schrafft Charitable Fund
An annual gift of $3000 provides scholarships to needy students of good social and academic standing.

Science Scholarship (1956)
Donated by friends of M.I.T., this scholarship is designated to assist a needy and promising student in the field of science after the completion of his freshman year. The award is made to citizens of the United States.

Science Teaching Scholarships (1955)
Established by the Institute to encourage young people who wish to follow a career in science teaching in secondary schools, these scholarships are open to students who have completed two years at the Institute and plan to follow a curriculum in science and mathematics teaching. Grants are based on demonstrated need, with a maximum of full tuition.

Paul D. Seghers, Jr. Scholarship (1948)
This award was established by the estate of May Towles Kirk Seghers in memory of Second Lieutenant Paul Dotrenge Seghers, Jr. '45, U.S. Army Corps of Engineers, who was killed in action in the Asiatic area on July 11, 1945, to aid worthy and needy Protestant students at the discretion of the Institute.

Louis E. and Theresa Seley Student Aid Fund (1961)
The income of this fund, the gift of Louis A. Seley, provides scholarships for undergraduate students who are needy and worthy.

Irving Shaknov Scholarship (1954)
The income from this fund, established as a memorial for Irving Shaknov '43, is available for an undergraduate scholarship for a student in the Department of Physics.

Frederick J. Shepard, Jr. Fund (1959)
Income from the gift of the Lewis-Shepard Fund in honor of Frederick J. Shepard, Jr. '12, is used to assist needy and worthy young men from New Hampshire with first preference to graduates of Pinkerton Academy in Derry Village.

James and Donald H. Sheridan Scholarships Fund (1961)
The income of this fund, established by the bequest of James Sheridan, is used to aid needy and worthy students.

Frank Arnold Sherman Scholarship Fund (1947)
The income from this bequest of Frank Arnold Sherman '03 is used "first and preferentially for a scholarship to some boy graduate of Westerly High School, Rhode Island, or if no suitable candidate, preferentially to a boy graduate of some other Rhode Island high school."

Thomas Sherwin Scholarship (1871)
Founded with a gift from the English High School Association in memory of Thomas Sherwin, this scholarship is limited to graduates of the English High School of Boston who are pursuing a regular course at the Institute.

Frank Langdon Smith Scholarship Fund (1968)
Established by bequest of Alice Wilder Smith, in honor of F. L. Smith '79. The income from this fund provides scholarships for needy and deserving students.

G. H. Miller Smith Fund (1945)
Established by Mr. and Mrs. George Blackwell Smith of Lookout Mountain, Tennessee, "as a memorial to their son, G. H. Miller Smith '43, late Lieutenant, U.S. Army, killed in action in France during World War II . . . the income to be used for scholarship aid to deserving undergraduate students, with preference to those from Tennessee."

H. Hilliard Smith Fund (1950)
This bequest of Grace J. F. Smith in memory of her husband, H. Hilliard Smith '96, is for the purpose of assisting young men in architecture.

Horace T. Smith Fund (1931)
This bequest from Horace T. Smith '98 provides scholarships to worthy students, with preference given to graduates of the East Bridgewater (Massachusetts) and Bridgeport (Connecticut) High Schools.

Society of Naval Architecture and Marine Engineering Scholarships (1957)
These grants were established by the Society of Naval Architects and Marine Engineers. Four scholarships, each in the amount of $1000, for students in, or planning to be in the Department of Naval Architecture and Marine Engineering. Preference will be given to secondary school graduates of outstanding promise. These awards may be renewed annually upon application.

Sons and Daughters of New England Puritan Colony Scholarship (1931)
Holders of this scholarship, made possible by a gift from the Sons and Daughters of New England Puritan Colony, must be of New England ancestry.

Anna Spooner Fund (1939)
The income from this bequest is used "in assisting meritorious students."

Standard Oil Company of California Scholarships (1955)
This annual grant, sponsored by the Standard Oil Company of California, is made to a senior in chemical engineering.

Wentworth Stevens Fund (1957)
One-half of the income from this fund, established by William Wentworth Stevens '98 in honor of his mother and father, is made available for scholarship aid.

Philip Stockton Fund (1961)
The income from this fund, given in memory of Philip Stockton by Mrs. Philip Stockton, is used for undergraduate scholarships.

Albert F. Sulzer Scholarship (1955)
Established under the will of Albert F. Sulzer, this fund is "to be used by the trustees of the Massachusetts Institute of Technology for the establishment and maintenance of scholarships for meritorious first-year students who are non-residents of the State of Massachusetts."

Tau Beta Pi Memorial Scholarship Fund (1947)
This gift from members of Tau Beta Pi, Massachusetts Beta Chapter, on their twenty-fifth anniversary, provides an annual award of $500 for freshmen to be selected by the M.I.T. Financial Aid Office. There is no restriction of geographical area, and candidates are selected on high scholastic standing, character, and future promise.

Howard F. Taylor Memorial Scholarship Fund (1962)
The income from this fund, donated by students, friends, and associates of Professor Taylor, is used for assistance to undergraduate and graduate students interested in foundry and allied fields.

Lawrence E. Teich '40 Memorial Scholarship Fund (1966)
This fund, established by the Curt Teich Foundation as a Memorial to Lawrence E. Teich, Class of 1940, who gave his life while on active duty during World War II, is used to support the undergraduate scholarship program.

Mary Thacher Scholarship (1956)
This bequest established a scholarship fund, the income of which is applied against the tuition of needy students, with first preference to students from Yarmouth, Massachusetts; second to students from the Cape Cod region; and third to students from the Commonwealth of Massachusetts.

Richard H. Tingey Memorial Fund (1962)
This fund, a gift from the Herman W. Falk Foundation, was established in memory of Richard H. Tingey '27, a noted ship propulsion engineer. Its income provides scholarship grants to undergraduate students.

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Samuel E. Tinkham Fund (1924)
Established by the Boston Society of Civil Engineers, this fund is to aid a worthy student in civil engineering.

Arthur L. Townsend Fund (1960)
Income of this fund, established by the bequest of Professor A. L. Townsend '13 of the Department of Mechanical Engineering and Director of Lowell Institute, is used exclusively for M.I.T. scholarships. Preference is given to worthy and well-qualified graduates of Lowell Institute who are in good standing and taking a regular full-time day program, preferably in mechanical or electrical engineering.

Y. T. Tsai Memorial Scholarship (1955)
This fund for worthy and needy students was established by gift.

John L. Turner Fund (1960)
Income of this fund, established by John L. Turner '31, is used to assist needy and worthy young men. First preference is given to students who are direct relatives of the donor or residents of the State of Mississippi; second preference to students domiciled in the Southeast.

Uniroyal Foundation Scholarships (1957)
These grants, established by a gift from the Uniroyal Foundation, are awarded to students in the junior or senior year who demonstrate need for financial assistance, who show capacity for higher education, and who are interested in a career in industry. The Foundation expects that beneficiaries will assume a moral obligation to repay a part of their grants after graduation and over a reasonable period of time; such repayments will be made to the Institute's scholarship fund and will then be used to help other needy students.

Susan Upham Fund (1892)
This gift from Susan Upham is "to assist students deserving financial aid."

Samson R. Urbino Fund (1927)
This bequest from Samson R. Urbino is "to be used to aid students who need assistance, Germans preferred."

Vermont Scholarship (1924)
This scholarship "in memory of Vermonters who, having received their education at the Institute, served as engineers in the Armies of the Allies in the World War" was founded by a gift from Redfield Proctor '02. The income is awarded annually "to worthy students . . . preference to any *bona fide* residents of Vermont doing undergraduate work at the Institute, and also Vermont students doing graduate work, or students who are graduates of or transfer from Middlebury College or Norwich University . . . who shall meet regular scholastic and other requirements."

F. P. von Olker Fund (1962)
The income of this fund, established by the bequest of F. P. von Olker, is to be used "yearly in giving scholarships for the benefit of deserving students."

Ann White Vose Fund (1896)
This bequest from Ann White Vose was designated "to establish free scholarships in M.I.T. . . . such person enjoying benefit . . . shall be worthy young men of American origin."

Arthur M. Waitt Fund (1925)
This bequest from Arthur M. Waitt was designated for "assisting needy and deserving students in the second-, third-, and fourth-year classes of the Mechanical Engineering Course."

Grant Walker Fund (1943)
The income from this bequest is used "for scholarships for deserving students."

Muriel Alvord Ward Fund (1960)
The income of this fund, established by the gift of Mrs. Ferrari P. Ward, is used to assist needy and worthy undergraduates.

Henry E. Warren Fund (1961)
As a memorial to Henry E. Warren '94, the Trustees of the Warren Benevolent Fund, Inc., contribute to the support of a limited number of entering freshmen. Grants are made by the Financial Aid Office to students who demonstrate financial need. The Office gives first preference to well-qualified students domiciled in New England and second preference to women students from any part of the United States or its possessions. It is hoped that beneficiaries of this fund will make contributions to the Warren Fund after graduating, so that other students may benefit from it.

Henry Arthur Waterman Scholarship Fund (1969)
The income of this fund, established by the will of Henry A. Waterman, is used for scholarships to benefit worthy and needy undergraduate students.

John J. Watson Memorial Fund (1963)
The income of this fund, given by the Watson Foundation as a memorial to John J. Watson, one of its founders, is for scholarships for needy and deserving undergraduates.

James Watt Scholarship (1942)
This bequest of Jennie A. Douglas established "a scholarship in mechanical engineering to be known as the James Watt Scholarship."

Louis Weissbein Fund (1915)
This bequest from Louis Weissbein was designated "to found a scholarship to be awarded each year to a promising student, preference to be given a Jewish boy in making the award."

Western Electric Scholarships (1956)
These two scholarships in engineering, established by the Western Electric Company, are awarded on the basis of need and ability, with a maximum grant of $1,200.

Frances Erving Weston Fund (1912)
This bequest of Frances Erving Weston is "to aid a native-born American Protestant girl of Massachusetts."

Samuel Martin Weston Fund (1912)
This bequest of Frances Erving Weston was made to found a scholarship in memory of her husband, Samuel Martin Weston, "to aid a native-born American Protestant boy, preference to be given one from Roxbury."

Archer E. Wheeler Scholarship Fund (1957)
This fund is a bequest of Archer E. Wheeler '95; its income is used for scholarship towards fees for undergraduates at the Institute.

Ray Hill White Memorial Fund (1956)
Income from this fund, established by Frances French White in memory of Ray Hill White '05, is used for scholarship assistance for poor and needy students.

Amasa J. Whiting Fund (1927)
This bequest from Mary W. C. Whiting was designated "to constitute a fund to be known as Amasa J. Whiting Fund . . . the income . . . to pay or help to pay tuition of deserving students whose means are limited . . . . Preference shall be given to students coming from the town of Hingham, Massachusetts."

Granger Whitney Fund (1957)
Income of this bequest, made by the will of Julia Whitney in the name of Granger Whitney '87, is used to assist worthy students of the Institute, with first preference being given to students residing in the area of the M.I.T. Club of Detroit.

Harold O. Whitney Scholarship Fund (1968)
This fund was established by members of the M.I.T. Class of 1916 in honor of Harold O. Whitney '16. The income of the fund is used for scholarships for male native-born citizens of the United States.

Thomas H. Wiggin '95 Fund (1965)
Established by the bequest of Thomas H. Wiggin '95, the income is used to provide scholarship assistance to needy and worthy students.

Elizabeth Babcock Willmann Fund (1935)
This bequest from Elizabeth Babcock Willmann is "to help in paying the tuition of girl students taking the Chemistry Course."

Wilson Scholarship (1953)
Gift of John J. Wilson '29 in memory of parents, the income for scholarships to worthy undergraduates.

Gilbert Williams Winslow Memorial Fund (1967)
A gift from Mrs. Edward Williams Winslow established this fund in memory of her son, Gilbert Williams Winslow '37. The income of this fund is available to assist undergraduates, with a preference for students in Civil Engineering.

Howard I. Wood Scholarship Fund (1969)
Income from this fund is to be awarded to undergraduate students with financial need.

Morrill Wyman Fund (1915)
The income from this bequest of Morrill Wyman is "applied in aid of deserving and promising students, but without exclusion in regard to rank, upon the understanding that if later in life the person receiving aid shall find it possible, he shall reimburse the said fund for moneys so applied, but there shall be no legal obligation to make such reimbursement."

Conrad Henry Young Scholarship Fund (1957)
Established by the will of Abby W. Young in memory of Conrad Henry Young '96 the income of this fund is used for scholarships.

Financial Aid for Graduate Students

Financial support is available to graduate students from a variety of sources and in several different forms — fellowships, traineeships, scholarships, teaching and research assistantships, and loans. Resident tutorial positions in undergraduate Institute Houses and fraternity houses provide room and board. Application for a tutorial position from students who have completed at least one graduate year at M.I.T. or new students who have been M.I.T. undergraduates may be made to the Dean for Student Affairs. The plan described under "Payments" in Section 7 of this Catalogue and student employment are available to students with few exceptions. Every prospective student is strongly urged to explore all the sources of aid available to him as he considers the means of financing his graduate education.

FELLOWSHIPS, TRAINEESHIPS, AND SCHOLARSHIPS

A fellowship or traineeship is a grant to a graduate student which covers his tuition and provides, in addition, a stipend to help defray his living expenses. In the context of the Graduate School, a scholarship is a grant which fully or partially covers tuition only. Awards are made on the basis of academic promise and financial need and are intended solely to assist a student in the pursuit of his studies. No services are expected in return. Under Section 117 of the U.S. Internal Revenue Code of 1954, such grants, held by degree candidates, are not subject to income tax.

The Institute is fortunate to have received funds from individual donors and corporations which provide for the support of about 200 fellowships and scholarships each year; the funds which make these possible are listed in Appendix A of this Catalogue. In addition, many government agencies and foundations offer fellowships and other grants which they award either directly to outstanding students for use at institutions of their choice or to institutions for award by them to students. Fellowships available under these national programs, including fellowships and traineeships granted by national agencies for award by M.I.T., are summarized in the adjoining column. About 800 graduate students at M.I.T. have fellowships or other grants from national agencies for the academic year 1970–71.

Application for Fellowships, Traineeships, or Scholarships Administered by M.I.T.

Applicants to the Graduate School who seek financial support from any of the fellowships, traineeships, or scholarships administered by M.I.T., including those granted by national agencies and foundations for award by the Institute, should check the appropriate items on the regular Application for Admission to the Graduate School. Each applicant is automatically considered for all awards for which he is eligible. Currently enrolled graduate students who seek financial support should consult with the appropriate departmental office.

Applications for fellowship aid for the regular academic year, beginning with the fall term, must be filed by the previous January 15. Applications for fellowship aid filed after this date are considered only as funds are available. An application for aid from a prospective student will not be considered unless he has also filed the completed Application for Admission. Final action on applications is taken on the recommendation of departments to the Committee on Graduate School Policy at the end of March after the announcement of awards to applicants by the national agencies and foundations under their national competitive programs. A student who individually secures such award is not considered further for a fellowship or traineeship by M.I.T.

Award of Fellowships, Traineeships, and Scholarships

Notices of award by the Institute are mailed for delivery by the end of March. In accordance with a resolution of the Council of Graduate Schools in the United States, endorsed by 180 graduate schools, a student has until April 15 to accept or decline an offer. If a student does not reply to an offer by this date, it may be cancelled.

Every student holding a fellowship, traineeship, or scholarship for graduate study at the Institute is expected to register as a regularly enrolled student for the period of the award, pursuing a full program of studies. If a student with an award which is paid to him through M.I.T. withdraws from the Institute before his tenure expires, the Institute will consider him to have relinquished the award, and he will be required to make such refund of any sum already paid to him as the Committee on Graduate School Policy deems appropriate. An award may also be terminated for failure to maintain a satisfactory standard of scholarship.

Financial Aids

GRADUATE

TEACHING ASSISTANTSHIPS

About 500 graduate students are appointed each year as instructors or teaching assistants. They assist the faculty in grading student quizzes, instructing in the classroom and laboratory, and conducting tutorials. They receive salaries which, after taxes, are roughly comparable to fellowship stipends. They are generally awarded scholarships to cover their tuition.

After four years or more of intensive study at the undergraduate level, many students enjoy the new view of their subject afforded by a teaching assignment. The departments consider important the benefits of a teaching assistantship as a preparation for a career in university teaching, and the Institute offers a prize each year — the Goodwin Medal — for conspicuously effective teaching by a graduate student. A student accepting a teaching assistantship typically does not prolong his time to the doctor's degree.

The units for which an instructor or teaching assistant may register as a student are determined by his department in the light of his assistantship duties, his compensation being adjusted accordingly.

Appointments to teaching assistantships are made upon recommendation of the head of a department. A student who wishes to be considered for a teaching appointment should write to his prospective department; such applications from new students will be considered only after an Application for Admission to the Graduate School has been filed with the Admissions Office.

RESEARCH ASSISTANTSHIPS

About 1,000 graduate students at M.I.T. each year hold appointments as research assistants. They assist members of the Faculty in the research projects which are a major characteristic of the academic life of the Institute and a prime reason for its vitality. It is a policy of the Institute to accept only such projects as will be in keeping with its educational objectives.

Research assistants receive stipends which are intended to be comparable in attractiveness, after payment of tuition, with fellowship stipends. Insofar as the duties of a research assistant relate to the thesis work which he is required to perform for his degree, his salary is normally considered the equivalent of a fellowship stipend for tax purposes, and taxes are not withheld. (A research assistant's stipend may be found liable to tax in an individual case.)

The units for which a research assistant may register are determined by his department in the light of his duties and his program of study, his stipend being adjusted accordingly.

Many students prize the opportunity a research assistantship gives them to participate as junior colleagues of the faculty in an ongoing research project. The experience enlivens their course work and frequently determines their choice of thesis topic. In most cases a research assistant's thesis work parallels closely his contribution to the project.

Appointments to research assistantships are made in the same manner as appointments to teaching assistantships.

STUDENT LOAN FUNDS AND EMPLOYMENT

The Institute administers a loan program under which financial assistance is available to all students. A student may borrow to support a modest budget for which he has insufficient resources. Students are expected to have explored all other sources of aid (including employment opportunities and home-state Federally-Guaranteed Loan Programs) before requesting loan funds from the Institute. To be considered, a student must submit a budget giving evidence of his need. Application should be made to the Director of Financial Aid, from whom forms may be obtained. Employment possibilities for graduate students should be discussed with Director of Student Employment.

Scholarships and Fellowships for Graduate Students

Listed here are fellowships and scholarships which have been generously given by individuals and corporations. About 200 awards are made from these funds each year. A student who files an Application for a Graduate Fellowship, Traineeship, or Scholarship with his department is considered for any awards for which he is eligible.

In addition, a number of fellowships exist to support graduate study abroad. Several of these are described in the following section. Any questions concerning these fellowships or foreign study in general should be addressed to Dean H. L. Hazen, Foreign Study Advisor.

NATIONAL FELLOWSHIPS FOR GRADUATE STUDY

Atomic Energy Commission

Grants of the Atomic Energy Commission provide for a limited number of traineeships for U.S. citizens to meet the increasing manpower demands for nuclear engineers at the graduate level. Tuition plus stipend determined by the department. Application on standard fellowship form to the Department of Nuclear Engineering.

Danforth Foundation

About 120 fellowships annually to students graduating from U.S. colleges who seek to become teachers. Tuition for a calendar year plus $2,400 for a single student, $2,950 if married, with dependency allowances for up to three children. Renewable for four years of study. Nomination in early fall by the student's undergraduate college to the Danforth Foundation, 222 South Central Avenue, St. Louis, Missouri 63105.

National Defense Education Act, Title IV

Fellowships granted by the U.S. Department of Health, Education, and Welfare for award by M.I.T. to graduate students in new, expanded, or ongoing programs of study. Twelve months' tuition plus $2,400–$2,800 and dependency allowances. Tenable for three years. Application on standard M.I.T. fellowship form to the student's prospective department at M.I.T. M.I.T. was allotted 22 new NDEA Fellowships for the academic year 1971–72.

National Institutes of Health

Grants of the National Institutes of Health provide traineeships for award by M.I.T. to U.S. graduate students in the medical sciences and health-related fields. Tuition plus a stipend determined by the department handling the grant. Application on standard M.I.T. fellowship form to the student's prospective department at M.I.T.

National Institute of Mental Health

Predoctoral Research Fellowships awarded annually to U.S. citizens for graduate study in various fields related to mental health, e.g., psychology, neurobiology, political science, psycholinguistics, urban studies, etc. Twelve months' tuition plus stipend of $2400 to $2800 and dependency allowances. Renewable. Application to the Research Fellowships Section, Behavioral Sciences Training Branch, Division of Manpower and Training Programs, National Institute of Mental Health, 5454 Wisconsin Avenue, Chevy Chase, Md. 20203

National Science Foundation

About 1,200 fellowships awarded annually to U.S. graduate students for study in the mathematical, physical, medical, biological, and engineering sciences, anthropology, economics, geography, the history and philosophy of science, linguistics, political science, psychology, and sociology. Twelve months' tuition plus $2,400 to $2,800 stipend and dependency allowances. Awarded for one or two years; renewable. Applications in the fall to the National Science Foundation, Washington, D.C. 20550. Watch for NSF announcements on dates.

Woodrow Wilson National Fellowship Foundation

One hundred-fifty fellowships to first-year graduate students, primarily to candidates in the humanities and social sciences but science and mathematics majors with a clear interest in teaching careers may be chosen. U.S. and Canadian citizens only. Payment of $1,000 tuition award plus stipend of $2,000 and dependency allowance for an academic year. Not renewable. Nomination in early fall by a faculty member to the Chairman of the appropriate Regional Committee. For information, write the Woodrow Wilson National Fellowship Foundation, Box 642, Princeton, New Jersey.

Other

Numerous other programs exist. These include the Barker Fellowship in Engineering, the Federal Housing and Urban Development National Fellowship Program, and the Hertz Foundation Fellowship Program for support in specific fields of graduate study, based on M.I.T. nominations. See Graduate School Office for details. Also consult the Graduate School Office publication *Financial Support for Graduate Students*.

AID FOR FOREIGN STUDY

Churchill Scholarships

About 5–10 scholarships to U.S. male graduates for study at Churchill College in Cambridge University in natural sciences, engineering, or mathematics. M.I.T. may name two applicants to compete with other applicants from 19 institutions. Scholars may enroll in one-year program or three year Ph.D. program. See Foreign Study Advisor, Dean Hazen, Room 10–303 for details and applications.

Institute of International Education

Administers international scholarships in all fields of study; includes U.S. government Fulbright-Hays grants, travel grants and fellowships offered by foreign governments and foundations for foreign study. See Foreign Study Advisor, Dean Hazen, Room 10–303 for details and applications.

Marshall Scholarships

About 24 scholarships offered by the British government to U.S. graduates for two year study for a degree in any United Kingdom university. Field unrestricted. See Foreign Study Advisor, Dean Hazen, Room 10–303 for details and applications.

Rhodes Scholarships

For U.S. male graduates who exhibit scholarship, character, leadership and physical vigor to study at Oxford University. Fields generally unrestricted. See Dr. Tom Gerrity, tel. 492–1500.

Others

Numerous other fellowships exist for both graduate and post-doctoral study abroad. These include exclusively M.I.T. scholarships offered by the German government through DAAD and by ETH in Zurich. For the most inclusive international listing of fellowships see UNESCO's *Study Abroad XVIII*. Consult Dean Hazen, Foreign Study Advisor, for further information on opportunities for financial aid for foreign study.

VARIOUS FIELDS

Edward Austin

Bequest of $360,000, the income for needy, meritorious students and teachers to assist them in paying academic expenses.

William Sumner Bolles

Bequest of $25,000 by William P. Bolles in memory of his son, to support a fellowship, travelling scholarship, or resident scholarship, the recipient of which must have character, ability, or promise.

Helen Collamore

Bequest of $10,000, the income for aid to women students in post-graduate courses.

Alfred Willard French

Founded in memory of Alfred Willard French '89 by the French Oil Mill Machinery Company, for a graduate student in engineering (preferably mechanical) or business administration, with preference to a student from within a 100-mile radius of Piqua, Ohio.

Frank M. Greenlaw

Bequest of $74,000 by Frank M. Greenlaw '90 the income to establish a fellowship for research in physics or chemistry or related fields of learning.

International Business Machines Corporation

One fellowship for doctoral candidates in the fields of physics, chemistry, mathematics, electrical engineering, computer science, or materials science. Stipend of $3,000 plus dependency allowance; also tuition and department allowance.

Joint Center For Urban Studies

Doctoral fellowships to graduate students in any department of either Harvard or M.I.T. writing a doctoral dissertation in the broad area of housing; award including stipend up to $5,500.

John A. Lyons

Under the will of the late John A. Lyons, several fellowships are available for the support of graduates of Boston College, subject to the following provisions: the recipients must be of the Roman Catholic faith; they must have been born within a radius of 20 miles of the Massachusetts State House; preference will be given to applicants whose father and mother were of Irish descent; the fellowships are only for those who do not consume alcohol in any form; they must live at the Institute during the academic year. The fellowships will cover tuition and will provide a stipend to help meet living expenses. They will be renewable from year to year.

Financial Aids

GRADUATE

Henry Bromfield Rogers
Bequest of $20,000 by Anna Perkins Rogers, the income for a fellowship or scholarship for women graduates of M.I.T. or other colleges whose graduate work is carried on at M.I.T.

Henry Saltonstall
Bequest of $10,000, the income to aid one or more needy students.

James Savage
Bequest of $10,000, the income for scholarships in the institution "where my son-in-law, William B. Rogers, is President."

Susan H. Swett
Bequest of $10,000, the income to support a graduate scholarship.

Gerard Swope
Gift of $100,500 by Gerard Swope '95, the income to support fellowships for graduate students of exceptional ability and promise.

United States Steel Foundation
One fellowship for student who shows interest in graduate program relevant to a career in management based on a science or engineering background. Annual stipend of $5,000 plus tuition.

Thomas Upham
Bequest of $409,000 by Marcella B. Upham, the income for assisting poor and deserving students or graduates of the Institute.

Jonathan Whitney
Bequest of $525,000 by Mrs. Francis B. Green, the income to assist poor and deserving young men and women in obtaining an education at M.I.T.

AERONAUTICS AND ASTRONAUTICS

Donald W. Douglas
Gift of $73,725 in honor of Donald W. Douglas '14, Honorary Chairman of the Board of Directors of the McDonnell Douglas Corporation, the income to be used to support deserving graduate students in aerospace and related fields.

Richard C. du Pont
Memorial fellowship in aeronautics and astronautics, for a graduate student in any year of his work toward an advanced degree; tuition plus $2,100.

Lester D. Gardner
Fellowship in memory of Lester D. Gardner '98; tuition plus $2,100.

Sperry Rand Corporation
For graduate work in electronics; tuition plus $2,100 single; supplement if married.

ARCHITECTURE AND PLANNING

Avalon Foundation
Gift of $250,000, the income to support fellowships and scholarships for graduate students in the School of Architecture and Planning.

Francis Ward Chandler Memorial Fund
Bequest of $100,000; net income to be used to provide scholarship assistance to graduate or undergraduate students with first preference being given to undergraduate students in architecture.

W. Danforth Compton Memorial
Gift of $90,000 in memory of W. Danforth Compton '47, the income to support fellowships in the Department of Architecture.

William Emerson Fund
The income of the bequest of $29,000 of the late William Emerson, Dean of the School of Architecture, is used for fellowships in the Department of Architecture.

William Emerson
Gift of $5,000 by Dean William Emerson, the income to support graduate students in City Planning.

William and Frances Emerson
Gift of $100,000, the income to aid graduate and special students in the School of Architecture and Planning.

Ernest A. Grunsfeld Fund
To underwrite living expenses up to $2,000 per year for a black student admitted to one of the graduate professional programs in architecture.

William E. Hartmann Scholarships (1962)
This fund was established to assist students in architecture who hold baccalaureate degrees from an institution not offering professional architectural studies. Awards may be made for the first year at the Institute.

Samuel A. Marx
Established by gifts of $33,900 in memory of Samuel A. Marx '07, the income for an annual fellowship in the School of Architecture and Planning.

CHEMICAL ENGINEERING

American Cyanamid Company
For graduate students attending the School of Chemical Engineering Practice. Award is adjusted to pay pro-rate tuition and expenses while at the Bound Brook Station.

Esso Research and Engineering Company
For a graduate student in chemical engineering; tuition plus $1,075 per term.

Halcon International, Inc.
For a graduate student in chemical engineering; tuition plus $1,075 per term.

Arthur D. Little
Fellowship in memory of Arthur D. Little '85, for a candidate for a doctorate; tuition plus $1,075 per term.

Procter and Gamble Company
For a graduate student in chemical engineering; tuition plus $1,075 per term.

Union Carbide Chemicals Division
For a graduate student in chemical engineering; tuition plus $1,075 per term.

Union Oil Company of California Foundation
For graduate students attending the School of Chemical Engineering Practice. Award is adjusted to pay a portion of tuition and expenses.

CHEMISTRY

Lewis Paul Chapin
Bequest of $100,000 by Mrs. Mary Richardson Chapin in memory of her husband Lewis Paul Chapin, formerly Assistant in Inorganic Chemistry, the income to assist worthy postgraduate students in the Department of Chemistry.

Goodyear Tire and Rubber Company
Fellowship for a graduate student in chemistry; tuition plus $2,500.

Arthur D. Little
Fellowship in memory of Arthur D. Little '85, for a candidate for a doctorate in chemistry; tuition plus $3,125 for 12 months.

Forris Jewett Moore Memorial
Gift of $24,000 by Mrs. Forris Jewett Moore in memory of her husband, formerly Professor of Organic Chemistry, the income to assist a graduate in his studies at M.I.T. or elsewhere with preference given to a student in organic chemistry; tuition plus $2,500.

James Flack Norris
Bequest of $65,000 by James Flack Norris, formerly Professor of Organic Chemistry, the income to support a graduate fellowship; tuition plus $2,500.

Procter and Gamble Company
Tuition plus $2,340.

Texaco, Inc.
Fellowship for a graduate student in chemistry; tuition plus $3,000 for 12 months.

Uniroyal Foundation
For the support of graduate training in research; $3,400.

EARTH AND PLANETARY SCIENCES

Chevron (Standard Oil Company of California)
Tuition and stipend for a graduate student interested in geophysics, especially exploration geophysics.

ECONOMICS

Clarence J. Hicks Memorial
For a graduate of not more than five years (exclusive of military service) since his baccalaureate from a college or university in the U.S. or Canada, who is a candidate for a doctorate at M.I.T. in the field of industrial relations; tuition plus stipend.

Joseph N. Scanlon
In memory of Joseph N. Scanlon, formerly a Lecturer at M.I.T. in industrial relations; tuition plus stipend.

ELECTRICAL ENGINEERING

Grass Instrument Company

An endowment established by the Company and Dr. Albert M. Grass '34, the income for fellowships in electrical engineering, preferably for foreign students. Awards are made as often as sufficient income has accumulated to provide an appropriate grant to a student.

Schlumberger Foundation

For a graduate student in electrical engineering; tuition plus a stipend of not less than $3,000.

MANAGEMENT

Dresser Industries, Inc.

Some financial assistance is available for U.S. black and disadvantaged students in management.

Sloan School of Management

For college graduates seeking the doctor's degree who have demonstrated substantial academic competence and leadership promise. A number of fellowships and scholarships.

Roger P. Sonnabend

Some financial assistance is available for U.S. black students in management.

MECHANICAL ENGINEERING

Wilfred Lewis

Gift of $5,000 by Mrs. Emily Sargent Lewis in memory of Wilfred Lewis '75, the income to be applied for the support of a graduate student in Mechanical Engineering.

METALLURGY AND MATERIALS SCIENCE

Allegheny-Ludlum Steel Corporation

For a graduate student whose thesis research is on a topic of interest to the alloy steel industry; tuition plus stipend.

American Metal Climax Foundation

For a graduate student whose research is in the general area of high-temperature physical metallurgy; tuition plus stipend.

For a graduate student whose research is in the general area of nonferrous extractive metallurgy; tuition plus stipend.

American Optical Corporation

For a graduate student whose research is in the general area of glass science and technology; tuition plus stipend.

ASARCO Foundation

For a graduate student in metallurgy; tuition plus stipend.

Climax Molybdenum Company

For a graduate student in physical metallurgy; tuition plus stipend.

General Telephone and Electronics Laboratories, Inc.

For a graduate student in the field of electronic materials; tuition plus stipend.

International Nickel Company

For a graduate student in the field of materials science and engineering; tuition plus stipend.

Kennecott Copper Corporation

For a graduate student in metallurgy and materials science; tuition plus $2,250.

National Steel Corporation

For a graduate student whose research is in the general area of metallic corrosion; tuition plus stipend.

Owens-Illinois Incorporated

For a graduate student whose research is in the field of glass science; tuition plus stipend.

OCEAN ENGINEERING

General Dynamics Corporation

A fellowship for graduate study in Ocean Engineering; tuition plus $2,100 for two terms.

Gulf and South American Steamship Company

Fund established by Gulf and South American Steamship Company from which scholarship grants may be made upon initiative of the Department of Ocean Engineering. Preference is given to students in the fifth year in Shipping and Shipbuilding Management (Course XIII-B).

NUCLEAR ENGINEERING

General Electric Foundation

For a graduate student in nuclear engineering; tuition plus $2,250 for one academic year.

Sherman R. Knapp Fellowship in Nuclear Power Engineering

For a graduate student pianning a career in nuclear power engineering in the United States; tuition plus $2,700 for an unmarried student, $3,200 for a married student, for 9 months. At the end of the period, the Fellow is required to obtain three months of practical experience as a summer employee of Northeast Utilities.

NUTRITION AND FOOD SCIENCE

Bernard E. Proctor Memorial

Scholarship in memory of Professor Bernard E. Proctor '23, formerly head of the Department; tuition.

PHYSICS

Karl Taylor Compton Fellowships in Physics

For a graduate student in physics; tuition plus stipend of $3,000 for the academic year and $1,000 for summer study.

Fairchild Foundation Fellowship in Applied Physics

For a U.S. citizen or permanent resident in the field of applied physics; tuition plus $2,400 for nine months, and allowances.

Kennecott Copper Corporation

For a graduate student in physics; tuition plus not less than $1,800 single or married without children, $2,000 married with one or more children.

RESEARCH LABORATORY OF ELECTRONICS

Radio Corporation of America

For graduate work in electronics; tuition plus $2,100 single, $2,700 married.

Student Loan Funds

Loans are available to both graduate and undergraduate students at M.I.T. The amount of any loan granted by the Financial Aid Office is based on financial need.

Financial Aids

UNDERGRADUATE—GRADUATE

FEDERALLY-GUARANTEED LOAN PROGRAM

The Federal government's Guaranteed Loan Program is designed to aid students in meeting the expenses of their education. M.I.T. urges each applicant for aid to apply for loan assistance under the Program, which is administered by the several states. The loans are obtained through local banks and other lending agencies under certain conditions, and prospective students would be well advised to inquire at the earliest possible date about their eligibility for such assistance. The interest rates and repayment provisions are fixed by Federal and State legislation, but are by design more favorable than standard commercial terms.

TECHNOLOGY LOAN FUND (TLF)

M.I.T.'s Technology Loan Fund, established in 1931, was the first major loan fund established by a college; today it is the nation's largest. Since its founding, M.I.T. students have benefited from more than $10,000,000 in loans from this fund. Awards are made on the basis of financial need; and in the interest of its students, M.I.T. sets reasonable limits on the annual amounts borrowed from this fund, and on the total indebtedness accumulated by each borrower.

NATIONAL DEFENSE STUDENT LOAN (NDSL) FUND

M.I.T. also administers loan awards under the National Defense Student Loan Program, using need criteria established by the Financial Aid Office, and eligibility criteria established by the U.S. Department of Health, Education and Welfare. The maximum loan available to an undergraduate from this program for any one academic year is $1,000; no undergraduate may borrow more than a total of $5,000.

REPAYMENT TERMS FOR M.I.T. AND NDS LOANS

Repayment rates for loans acquired directly through the Institute will be established in each case by M.I.T. on graduation or termination of enrollment. (NDSL and GLP regulations established by the Federal government state a maximum repayment period of ten years on those notes. The regulations further outline a minimum annual repayment of $360 on these notes.)

Repayment commences six months after graduation. A student may apply for deferment of repayment if he enters a graduate school, military service, or the Peace Corps. (A maximum of three years' deferment is allowed in the latter two cases.)

OTHER LOAN FUNDS

The following funds have been established for special purposes at the Institute. Except where stated, these loans funds are administered under terms similar to those governing the Technology Loan Fund, and no separate application need be made.

Walter Phelps Bliss Memorial Fund
This fund is governed by the same conditions as the Technology Loan Fund and is available to students in financial need.

Boston Stein Club Freshman Loan Fund (1953)
Established by the M.I.T. Boston Stein Club, this fund is designed to assist needy students resident in the Greater Boston area. It is open only to first-year students who show good promise, and, in general, grants are for less than full tuition. Recipients are required to sign notes to repay amounts granted, without interest, after graduation.

Anna J. and Francesco Casaretta Loan Fund (1966)
Established in memory of Anna J. and Francesco Casaretto, to be operated as a loan fund for the benefit of needy and worthy students, regardless of race, creed or color.

Francis W. Chandler Loan Fund (1927)
This fund was established as a loan fund to assist worthy and needy students in the Department of Architecture.

Ruth Hornblower Churchill Memorial Loan Fund (1958)
Established by a gift in the name of Ruth Hornblower Churchill, this loan fund is used to help needy students at M.I.T.

Class of 1917 Loan Fund (1937)
The income and principal of this fund is used to assist deserving students, preference given to direct descendents of members of the Class of 1917. Beneficiaries are expected to issue notes agreeing to repay the face value, without interest, of amounts received.

Class of 1963 Loan Fund (1963)
This fund, established by the members of the M.I.T. Class of 1963, is used as a source of short-term emergency and special-use funds, without some of the restrictions associated with the Institute's educational loan funds. Repayment is expected before graduation in most cases; where appropriate the repayment period may be extended to one year beyond graduation. Preference is given to undergraduates.

Thomas F. and Lida Niles Connors Loan Fund (1962)
Established by the bequest of Lida Niles Connors, the principal and income of this fund is available to "qualified and deserving students who are undergraduates in Civil Engineering." Procedures of the Technology Loan Fund are followed in granting loans.

Ethel I. Fryer Scholarship Loan Fund (1951)
This fund was a gift of Herbert Fryer '11 to establish a loan fund for deserving students from the states of Washington, Oregon, and California. Grants are limited to $600 per student and are repayable within five years of graduation.

Nathan R. George Loan Fund (1943)
This bequest from Professor Nathan R. George of the Department of Mathematics is "to be loaned to undergraduates of M.I.T. who are either citizens or who intend to become citizens" and who are members of the third- or fourth-year classes.

Gerald L. Hartstein Memorial Loan Fund (1963)
The principal and income of this memorial fund, established at the request of Mr. Hartstein's mother, are available for loans to undergraduates.

John A. Herlihy Loan Fund (1962)
This commemorative fund was established by gift of the United Air Lines Foundation in honor of John A. Herlihy '27, Senior Vice President of United Air Lines. Grants from this fund, limited to undergraduates in the field of aeronautics and astronautics, are administered in the same manner as those from the Technology Loan Fund.

Jerome C. Hunsaker Loan Fund (1970)
This fund was established by Professor Jerome C. Hunsaker '12 for the purpose of making loans to students in the Department of Aeronautics and Astronautics, under the same terms as the Technology Loan Fund.

Rebecca R. Joslin Loan Fund (1924-36)
This fund is open to undergraduate and graduate students in chemical engineering and is restricted to students who are residents of Massachusetts and who abstain from using tobacco in any form.

Klock-Overton-Mills-Roberts-Longyear Loan Fund (1961)
This loan fund, established by Felix S. Klock '36, on the 25th anniversary of his graduation from M.I.T. in recognition of the people who significantly influenced and guided him in his education, functions on the same basis as the Technology Loan Fund. In granting awards, the Committee gives preference to needy and worthy students who are children of the employees of the Klock Corporation.

Lamson-Virgin Loan Fund (1946)
This bequest from Elizabeth H. Lamson is used in aiding a worthy student of excellent character who "must have shown not only respect for his parents but also proper consideration for the rights of others." Students thus aided shall repay if and when they find themselves able to do so.

Harry J. and Iolia R. Lohbiller Loan Fund (1962)
This fund was established by trusts created by Harry J. '01 and Iolia R. Lohbiller. Loans are restricted to juniors and seniors and in certain instances to sophomores.

Anthony P. Mathesius Loan Fund (1970)
This fund was established as a memorial to Anthony P. Mathesius '08 by members of his family. The principal and interest are used for loans in the same manner as are those of the Technology Loan Fund. First preference among recipients is given to students who are members of Phi Beta Epsilon.

George H. May Loan Fund (1914)
A gift from George H. May '92 provides a fund "to assist graduates of the Newton High Schools who are students at M.I.T. and who have been recommended as eligible by the Superintendent and Headmaster of the Newton High Schools." Beneficiaries under this fund are expected to issue notes agreeing to repay, without interest, the amounts received.

Helen and Leo Mayer Loan Fund (1967)
Established by a gift of the Helen and Leo Mayer Charitable Trust, the principal and interest of this fund are administered in the same manner as those from the Technology Loan Fund.

George J. Mead Loan Fund (1951)
This bequest of George J. Mead '16 is for loans to upperclassmen in aeronautics and astronautics and mechanical engineering.

Arthur T. Nelson, Jr. Memorial Loan Fund (1962)
Established by a gift of Mrs. Arthur T. Nelson and the Trustees of Arthur T. Nelson, Jr., this fund is used for loans administered under the regular procedures adopted by the Institute to students residing in certain states.

Michael Joseph Pollock Loan Fund (1962)
The income of this memorial fund, established by the parents, relatives, and friends of Michael Joseph Pollock '59, is available for loans to deserving students.

Ellen H. Richards Loan Fund (1964)
This fund, established by a gift from the Eastern Massachusetts Home Economics Association as a memorial to Ellen H. Richards, is used to provide loans, preference being given to women students in chemistry relating to food processing and food technology.

M. H. Rogers Loan Fund (1945)
This bequest of Minnie Hempel Rogers '90 is for loans to worthy students.

Lillie C. Smith Fund (1965)
Income from this fund in memorial of an early alumna is administered by the Association of M.I.T. Alumnae for aid to women students.

Technology Matrons Loan Fund (1960)
This gift of the Technology Matrons is used to assist needy and worthy students with loans.

Robert Kelley Thulman Loan Fund (1963)
The gift of the wife of Robert Kelley Thulman '22, this fund is designated for loans to students.

Timbie Memorial Fund (1954)
This fund was established by graduates of the Cooperative Course in Electrical Engineering (VI-A) in the name of William H. Timbie. It is used to provide loans for students in the Cooperative Course.

F. B. Tough Fund (1924)
Established by a gift of Mr. F. B. Tough, this fund is used to provide loans "for the purpose of extending financial assistance to worthy students while pursuing their courses."

Frank P. Wakefield Loan Fund (1955)
One-fourth of the income of this fund is available for loans to needy and worthy students majoring in chemistry, chemical engineering, and biology.

Prizes and Awards

To encourage and recognize high achievement by students at M.I.T., a number of prizes have been established by individuals and organizations. In general, these awards are made each year by the office of the Dean for Student Affairs or by the departments or organizations concerned.

Alpha Chi Sigma Prizes (1965)
Two prizes of $250 each are awarded annually to seniors in recognition of distinguished scholastic achievement, originality, and breadth of interest in chemistry and closely related fields.

American Institute of Chemists Award (1957)
The American Institute of Chemists offers annually two medals, one to a student in chemistry and one to a student in chemical engineering. The medals are given to students who show outstanding professional promise.

Association of M.I.T. Alumnae Award (1958)
This cash award is given to one or more outstanding women students in the junior class.

Avery Allen Ashdown Award
Awarded to a resident of the Ashdown House who carries on the tradition and spirit of service through participation in the affairs of the House.

Baton Society Awards (1960)
These awards are given to seniors for outstanding contributions to music at M.I.T.

Robert A. Boit Prizes (1921)
These annual prizes are made "to stimulate the interest in the best use of the English language." They are awarded to undergraduates on the basis of essays and imaginative works submitted by them. The prizes are made possible by a bequest of $5,000 from Robert A. Boit.

Karl Taylor Compton Prizes (1951)
These prizes are awarded in recognition and encouragement of outstanding contributions in promoting high standards of performance and good citizenship within the Institute community. They are awarded from the income of a fund composed of gifts by members and friends of the Boston Stein Club.

The Frederick Gardner Fassett, Jr. Award
Awarded to a member of the Interfraternity Conference, for qualities of spirit, dedication, and service in furthering the ideals of the M.I.T. fraternity brotherhood.

The Goodwin Medal
The Goodwin Medal together with a cash prize may be awarded in any year (but not necessarily in every year) to a graduate student who is also a member of the academic staff of the Massachusetts Institute of Technology, in recognition of conspicuously effective teaching. Candidates for this award are nominated through departmental channels or by the Student-Faculty Committee to the Dean of the Graduate School. The award is in memory of Dr. Harry Manley Goodwin, the first Dean of the Graduate School, through a fund given by Mary B. and Richard H. Goodwin.

Ellen King Prize (1950)
This prize is a collection of books valued at approximately $50, awarded for the best essay written by a freshman upon any topic suitable for treatment in literary form. Papers submitted in a regular subject, as well as extracurricular compositions, will be eligible for the prize. Specific topics must be registered and approved at the Headquarters of the Department of Humanities.

Military Prizes
A number of individual prizes are awarded to selected outstanding cadets in the Departments of Air, Military, and Naval Science on the basis of technical and professional proficiency.

Outstanding Freshman Award
This award is made to recognize distinguished scholarship, integrity, breadth of interests, adaptability, and high degree of unselfish activity toward the community at large. It is presented by the M.I.T. chapter of the Tau Beta Pi association, National Engineering honorary.

Phi Lambda Upsilon Award in Freshman Chemistry
This award is given yearly to the outstanding student in freshman chemistry. Taken into consideration are academic achievement for the two terms of freshman chemistry, over-all ability, interest, and promise.

Phi Lambda Upsilon Sophomore Award
This award is given annually to an outstanding sophomore who has demonstrated academic achievement and professional promise in pure and applied chemistry.

Scott Paper Foundation Leadership Award
This award of $1,500 is made annually to a student in the spring of his junior year for senior and first-year graduate study. It is presented in recognition of demonstrated high character, actions on behalf of the welfare of colleagues, and potential for making outstanding contributions to the professional aspects of engineering in business or industry.

William L. Stewart, Jr. Awards (1964)
These awards are given to individual students and student groups for outstanding contributions to extracurricular life. They are made from an annual gift by the W. L. Stewart, Jr. Foundation in memory of Mr. Stewart, member of the Class of 1923, member of the M.I.T. Corporation from 1952 to 1963, and long-time friend and benefactor of the Institute.

Stratton Prizes (1930)
Awards presented yearly for outstanding skill in organized debating. They are made possible by the income of a fund established by the late President Samuel W. Stratton.

AERONAUTICS AND ASTRONAUTICS

Luis de Florez Awards (1960)
The late Admiral Luis de Florez, distinguished engineer and alumnus of the Department of Mechanical Engineering, Class of 1911, endowed awards totaling $1,000 or more to recognize "original thinking or ingenuity" demonstrated by students in Aeronautics and Astronautics.

James Means Memorial Prize (1925)
A medal and monetary prize of $100 or more is offered annually to a senior for excellence in systems engineering.

Henry Webb Salisbury Memorial Award (1941)
Established by the family and friends of Henry Webb Salisbury '33, this award, consisting of books chosen by the recipient, is given for outstanding work in the Department of Aeronautics and Astronautics.

ARCHITECTURE AND PLANNING

Alpha Rho Chi Medal (1932)
This medal is given each year to a graduating senior in the Department of Architecture who has shown an ability for leadership, performed willing service for his School and Department, and given promise of real professional merit through his attitude and personality.

Student Medal of the American Institute of Architects (1914)
This medal is awarded on the recommendation of the Department to the member of the graduating Bachelor of Architecture class with the best record for the Course.

ATHLETICS

Athletic Awards

In addition to varsity letters and freshman numerals in 22 intercollegiate sports, a number of awards are given to undergraduates by student organizations for outstanding contributions to intramural and intercollegiate athletic activities.

Class of 1948 Award
Established by the Class of 1948, this award is given annually to the member of the graduating class who has best combined the traits of leadership and character with excellence in athletic performance.

Admiral Edward L. Cochrane Award
This award, made possible by Mrs. Cochrane in memory of her husband, is given to a member of the graduating class, participant in the intercollegiate athletic program, who has shown qualities of humility, leadership, and scholarship.

Eastern College Athletic Conference Merit Medal
This medal, established by the Conference to be awarded by its member institutions, gives recognition to an athlete for scholarship and athletic achievement.

Prizes and Awards

CHEMICAL ENGINEERING

Robert T. Haslam Cup (1959)
Established by Mr. and Mrs. Louis E. Seley in honor of Robert T. Haslam '11, this cup is awarded annually by the Department of Chemical Engineering to a senior who shows outstanding professional promise in chemical engineering.

Hunneman Prize (1927)
Established by William Cooper Hunneman in memory of his son Roger DeFriez Hunneman '23, this award of $100 is made to the most meritorious senior who has shown outstanding originality in his work in the regular Course in Chemical Engineering.

CIVIL ENGINEERING

A.S.C.E. Student Chapter Scholarship
Funds under this award are provided through the gift of Samuel Tapman as a scholarship given annually to an outstanding undergraduate who is a member of a Student Chapter of the American Society of Civil Engineers in A.S.C.E. Zone 1.

Tucker-Voss Award (1953)
Gift of the alumni and friends of the late Professors Ross F. Tucker and Walter C. Voss, former heads of the Course in Building Engineering and Construction, this prize is awarded annually to an undergraduate or a graduate student with high scholastic standing, leadership, and professional promise in the building field.

Richard Lee Russel Prize (1967)
This scholarship award of $500 for graduate study in civil engineering at M.I.T. is for an outstanding senior selected by the faculty of the Department. The award is supported by the Richard Lee Russel '89 Fund established in 1904 by Mr. Theodore E. Russel.

ELECTRICAL ENGINEERING

Morris J. Levin Award
Award to juniors in electrical engineering who have demonstrated excellent performance through independent work in an undergraduate laboratory project.

Supervised Investors' Services, Inc., Awards (1957)
Four prizes of $500 each are awarded to graduate students who are members of the teaching staff of the Department of Electrical Engineering. They are given to honor those who have demonstrated an interest and proficiency in the field of teaching and to help defray the expenses of graduate study for advanced degrees.

Carlton E. Tucker Awards for Excellence in Teaching (1962)
Two prizes of $500 each, awarded to graduate students who are members of the teaching staff of the Department of Electrical Engineering, are given to honor those who have demonstrated an interest and proficiency in the field of teaching and to help defray the expenses of graduate study for advanced degrees. The Awards honor Professor Carlton E. Tucker, the Department's Executive Officer for 24 years, for his dedication to and interest in high teaching standards; they are supported in part from funds given in memory of Professor Tucker and Professor William H. Radford.

David T. Schultz Award (1969)
An award made annually to an assistant professor in the Department of Electrical Engineering for outstanding accomplishment in teaching undergraduate students. The David T. Schultz Award for Excellence in Teaching in Electrical Engineering was established in 1969 by a gift from Baird-Atomic, Inc. of Cambridge of 1,000 shares of its common stock. The award honors Mr. David T. Schultz who is Chairman of the Executive Committee of the company.

MANAGEMENT

The Brooks Prize in Management
The E. P. Brooks Master's Thesis Prize of $100 is awarded each year for the thesis judged to be the best submitted for the Master of Science in Management. Nominations may be made by the chairman of any Master's Thesis Committee to the Sloan School of Management's Prize Committee.

Editorship of the Sloan Management Review
The editorship of the journal of the Sloan School of Management is awarded annually to selected graduate students in management who have achieved distinguished records of scholarship and leadership in the School.

Sloan School of Management Senior Prize
This annual award of $100, established through the generosity of Samuel Berke, '15, is made to an outstanding senior student in the field of management with high scholastic standing, leadership, and professional promise.

MECHANICAL ENGINEERING

American Society of Mechanical Engineers Student Paper Awards
This contest for outstanding professional papers by student members of A.S.M.E. is sponsored by the local chapter. Prizes totaling about $60 are awarded, and local winners are eligible for regional and national contests.

Luis de Florez Awards (1957)
The late Admiral Luis de Florez, distinguished engineer and alumnus of the Department of Mechanical Engineering, Class of 1911, endowed these awards to recognize "outstanding ingenuity" demonstrated by students in mechanical engineering. Prizes totaling $1,000 or more are awarded each year.

Silent Hoist and Crane Company Materials Handling Award (1950)
These annual prizes, totaling more than $500, are awarded for the best papers or theses submitted on subjects in the field of production, materials handling, or machine design related to materials handling equipment, on the basis of a competition held each year. The award is a gift of the Wunsch Foundation, Inc.

Ed Wellech — Corning Glass Works Award
This award is to be given to students in the Mechanical Engineering sophomore subject Engineering Design and Manufacturing. An aggregate of $250 is awarded for the best design project (or projects) and an equal aggregate for the best manufacturing project report (or reports) submitted during each year.

Engineering Projects Laboratory — Showcase Awards
Undergraduate and graduate students are encouraged to offer exhibits of their work at any time throughout the year. Prizes of about $25 to $50 are offered at the end of the year for exhibits judged most effective by a panel.

METEOROLOGY

The Carl-Gustav Rossby Award in Meteorology
This award was established, in part, by the gift of Julius Honig '53 in memory of Professor Carl G. Rossby who established the course in meteorology at M.I.T. The award of $100 is made in any year for the most outstanding graduate thesis submitted to the Department of Meteorology.

METALLURGY AND MATERIALS SCIENCE

Metallurgy and Materials Prize (1963)
The sum of $150 is awarded to an outstanding junior in the Department. The award was established by graduate students and associates of Professor Morris Cohen in recognition of his significant contributions to undergraduate education in materials. It is presently supported by the Boston Section, A.I.M.E.

American Metal Climax Foundation Prize (1969)
The sum of $300 is available for awards to students who perform outstanding laboratory projects.

OCEAN ENGINEERING

American Bureau of Shipping Prize (1924)
This award of $100 is provided by the Bureau to the American citizen who attains the highest average in scholarship for the third and fourth years in either the Course in Naval Architecture and Marine Engineering or the Course in Shipping and Shipbuilding Management.

Brand Award (1957)
This award, in memory of Rear Admiral Charles L. Brand, U.S. Navy Class of 1915, is made annually by the American Society of Naval Engineers to the student officer in the graduating class who attains the highest scholastic average in the Course in Naval Construction and Engineering (XIII-A).

Naval Ship Systems Command Award (1970)
This award, established by the Naval Ships Systems Command, is awarded annually for professionalism and scholarship to an Engineering Duty (Ship Engineering) officer in the graduating class of the Course in Naval Construction and Engineering (XIII-A).

CORPORATION STANDING, AUDITING, AND VISITING COMMITTEES

Standing Committees, 1971–72

EXECUTIVE COMMITTEE

JEROME B. WIESNER, *Ex officio*
HOWARD W. JOHNSON, *Ex officio*
PAUL E. GRAY, *Ex officio*
JOSEPH J. SNYDER, *Ex officio*
CONSTANTINE B. SIMONIDES, *Secretary*

EDWARD J. HANLEY	1972
JEPTHA H. WADE	1972
WILLIAM A. COOLIDGE	1973
WILLIAM B. MURPHY	1973
JAMES B. FISK	1974
CARL M. MUELLER	1975
GEORGE W. THORN	1976

DEVELOPMENT COMMITTEE

JAMES R. KILLIAN, JR., *Chairman*
HOWARD W. JOHNSON, *Ex officio*
JEROME B. WIESNER, *Ex officio*
PAUL E. GRAY, *Ex officio*
JOSEPH J. SNYDER, *Ex officio*
VINCENT A. FULMER, *Executive Officer*
ELIZABETH A. PIGOTT, *Administrative Assistant*

Terms Expiring in 1972

BENNETT ARCHAMBAULT
DAVID BAKALAR
LEO M. BECKWITH
SAMUEL BERKE
PHILIP L. COLEMAN
EMILIO G. COLLADO
PAUL M. COOK
WILLIAM E. P. DOELGER
HERBERT H. DOW
BRADFORD M. ENDICOTT
FRED C. FISCHER
W. H. KROME GEORGE
KENNETH J. GERMESHAUSEN
MORTON E. GOULDER
EDWIN W. HIAM
HALL L. HIBBARD
DONALD A. HOLDEN
CUTHBERT C. HURD
IRVING D. JAKOBSON
FRANKLIN M. JARMAN
ANDREW P. KELLOGG
RALPH LANDAU
CARL M. LOEB, JR.
JAMES MCCORMACK
DENMAN K. MCNEAR
THEODORE T. MILLER
MYLES MORGAN
THOMAS F. MORROW
JOHN W. NORRIS
FRANKLIN E. PENN
PAUL D. SHEELINE
DAVID W. SKINNER
S. JOSEPH TANKOOS, JR.
PAUL TISHMAN
THOMAS H. WEST

Terms Expiring in 1973

JONATHAN Y. BALLARD
W. GARDNER BARKER
WILLIAM B. BERGEN
EARL L. BIMSON
WILLIAM S. BREWSTER
BENJAMIN H. BRISTOL
HOMER A. BURNELL
DAYTON H. CLEWELL
RALPH E. CROSS
CHARLES DIEBOLD III
CARBON C. DUBBS
JAMES M. EWELL
DANIEL F. FLOWERS
WALTER H. GALE
CRAWFORD H. GREENEWALT
EARLE A. GRISWOLD
ARTHUR R. HARVEY
WAYNE J. HOLMAN, JR.
SHERIDAN C. F. ING
JOHN K. JAMIESON
GEORGE M. KELLER, JR.
I. AUSTIN KELLY III
PAUL V. KEYSER
JOHN R. KIMBERLY
DAVID I. KOSOWSKY
WILLIAM H. LANG
NORMAN B. LEVENTHAL
SAMUEL E. LUNDEN
HAROLD E. MACDONALD
WILFRED D. MACDONNELL
THEODORE A. MANGELSDORF
CHARLES B. MCCOY
THOMAS K. MELOY
WILLIAM C. MENTZER
ROBERT W. MILLER
ADOLF F. MONOSSON
DINO OLIVETTI
ALFRED E. PERLMAN
HERMON H. SCOTT
H. ROBERT SHARBAUGH
HERBERT L. SHUTTLEWORTH II
GOFF SMITH
RICHARD M. STEWART
JAMES E. TURNER
KARL R. VAN TASSEL
LAURENCE L. WAITE
WILLIAM J. WEISZ
THOMAS R. WILLIAMS
FRANK S. WYLE

Terms Expiring in 1974

WILLIAM L. ABRAMOWITZ
ARTHUR R. ANDERSON
OLIVER L. BARDES
CARL W. BLANCHARD
CHARLES P. BOWEN, JR.
JOSEPH S. BOWMAN
MARION W. BOYER
GEORGE M. BUNKER
W. VAN ALAN CLARK, JR.
THOMAS F. CREAMER
GEORGE P. EDMONDS
ELISHA GRAY II
RUDOLF E. GRUBER
ROBERT C. GUNNESS
JOHN F. HENNESSY
RUDOLPH HURWICH
HENRI P. JUNOD
BREENE M. KERR
SEMON E. KNUDSEN
ELLIS C. LITTMANN
LEO LOEB
ANGUS N. MACDONALD
JOSEPH R. MARES
WILLIAM J. MCCUNE, JR.
WILLIAM H. MILLS
CARL M. MUELLER
CLINT W. MURCHISON, JR.
GUY W. NICHOLS, JR.
JAN D. OTTEN
THORNTON W. OWEN
HOWARD L. RICHARDSON
JOHN L. RIEGEL
WILLARD F. ROCKWELL
CORNELIUS VAN S. ROOSEVELT
HOWARD J. SAMUELS
OLIVER H. SCHARNBERG
ARCH C. SCURLOCK
WILLIAM C. SESSIONS
WILLIAM J. SHERRY
LOUIS E. STAHL
HAROLD E. THAYER
L. G. LEE THOMAS
GEORGE R. VILA
TEDDY F. WALKOWICZ
HOWARD D. WILLIAMS

Terms Expiring in 1975

MARSHALL B. DALTON
PHILIP H. PETERS
D. REID WEEDON, JR.
THORNTON A. WILSON

Term Expiring in 1976

LUIS A. FERRÉ

INVESTMENT COMMITTEE

JOSEPH J. SNYDER, *Chairman*
HOWARD W. JOHNSON, *Ex officio*

EDWARD J. HANLEY	1972
DAVID A. SHEPARD	1972
GEORGE P. GARDNER, JR.	1973
GEORGE J. LENESS	1973
CARL M. MUELLER	1974
SEMON E. KNUDSON	1975
WILLIAM S. EDGERLY	1976

MEMBERSHIP COMMITTEE

HOWARD W. JOHNSON, *Chairman*
JEROME B. WIESNER, *Ex officio*

MARSHALL B. DALTON	1972
GEORGE P. GARDNER, JR.	1973
GILBERT M. RODDY	1974
WILLIAM S. BREWSTER	1975
DAVID A. SHEPARD	1975

Auditing Committee, 1970–71

DAVID A. SHEPARD, *Chairman*
FRANK R. MILLIKEN
GILBERT M. RODDY

JOINT ADVISORY COMMITTEE ON INSTITUTE-WIDE AFFAIRS, 1971-1972*

JAMES A. CHAMPY, *Chairman*
PAUL V. KEYSER, *Ex officio*
WILLIAM M. MACK, JR., *Ex officio*
HARTLEY ROGERS, JR., *Ex officio*
ROBERT N. SCHULTE, *Ex officio*

WILLIAM A. COOLIDGE	1972
HERMANN A. HAUS	1972
JOHN J. WILSON	1972
STEWART C. MYERS	1973
WILLIAM L. PORTER	1973
D. REID WEEDON, JR.	1973
DAVID BOTSTEIN	1974
GREGORY SMITH	1974

ROBERT D. BLAKE, *Secretary*

*Note: One additional faculty member, two additional undergraduate students, and two additional graduate students are to be elected to this Committee in the fall of 1971.

Visiting Committees, 1970–71[1]

DEPARTMENT OF AERONAUTICS AND ASTRONAUTICS

RUSSELL DE YOUNG, *Chairman*
J. RUSSELL CLARK*
GEORGE C. GROGAN, JR.*
WILLIS M. HAWKINS†
IRA G. HEDRICK†
SEMON E. KNUDSEN
WILLIAM P. LEAR†
ROBERT G. LOEWY†
JOHN R. WILEY*
THORNTON A. WILSON

SCHOOL OF ARCHITECTURE AND PLANNING

WILLIAM E. HARTMANN, *Chairman*
ANTHONY DOWNS†
IRÉNÉE DU PONT, JR.
HAROLD B. FINGER†
DAVID A. GROSSMAN*
JORDAN L. GRUZEN*
JOHN B. HIGHTOWER†
EUGENE MCDERMOTT
RAI Y. OKAMOTO*
JAMES W. ROUSE†
GEORGE H. TABER†

DEPARTMENT OF BIOLOGY

GEORGE W. THORN, *Chairman*
MAX DELBRÜCK†
HERMAN N. EISEN†
JEROME H. GROSSMAN*
MERVIN J. KELLY
KARL PFISTER*
ESMOND E. SNELL†
LEON A. SWEET*
UNCAS A. WHITAKER
ROBERT B. WOODWARD

CENTER FOR INTERNATIONAL STUDIES

CRAWFORD H. GREENEWALT, *Chairman*
VIRGILIO BARCO
KINGMAN BREWSTER, JR.†
EMILIO G. COLLADO†
JOHN COWLES†
HAROLD W. FISHER*
WILLIAM C. FOSTER*
CARL KAYSEN†
GEORGE J. LENESS
HENRY S. ROWEN*
CLIFTON R. WHARTON, JR.†

DEPARTMENT OF CHEMICAL ENGINEERING

JOHN K. JAMIESON, *Chairman*
WILLIAM L. ABRAMOWITZ†
PAUL M. COOK*
JOHN H. DESSAUER†
MAURICE F. GRANVILLE*
ROBERT C. GUNNESS
CHARLES G. KOCH†
RALPH LANDAU*
GORDON J. MACDONALD†
CHARLES A. THOMAS
MAX TISHLER†

DEPARTMENT OF CHEMISTRY

JOHN C. HAAS, *Chairman*
ROBERT T. ARMSTRONG*
JACK HALPERN†
GERALD D. LAUBACH*
BRUCE H. MAHAN†
HOWARD E. SIMMONS, JR.*
WALTER H. STOCKMAYER†
JOHN A. SWARTOUT†
GEORGE R. VILA
MARY F. WAGLEY
ROBERT B. WOODWARD

DEPARTMENT OF CIVIL ENGINEERING

BREENE M. KERR, *Chairman*
VIRGILIO BARCO
WALTER S. DOUGLAS†
RALPH E. FADUM†
LUIS A. FERRÉ
CHRISTIAN A. HERTER, JR.†
NORMAN B. LEVENTHAL*
WILLIAM H. MILLS*
RALPH M. PARSONS†
E. ALFRED PICARDI*
JEPTHA H. WADE
CHARLES J. ZWICK†

EARTH SCIENCES

CECIL H. GREEN, *Chairman*
PHILIP H. ABELSON†
EDWIN E. ALDRIN, JR.*
DAYTON H. CLEWELL*
THOMAS C. DESMOND
ROBERT A. FROSCH†
W. BARCLAY KAMB†
BREENE M. KERR
JOHN LAWRENCE
WALTER H. MUNK†
BERNARD VONNEGUT*
ROBERT M. WHITE†

DEPARTMENT OF ECONOMICS

VIRGILIO BARCO, *Chairman*
WILLIAM G. BOWEN†
JOHN R. COLEMAN†
THOMAS F. CREAMER*
ALAIN C. ENTHOVEN*
W. H. KROME GEORGE*
ELI GOLDSTON†
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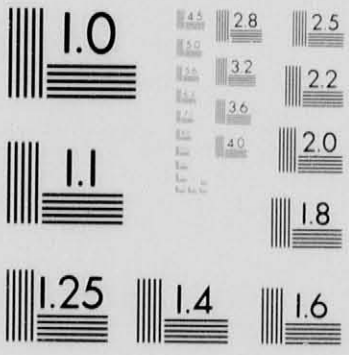
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CHARLES A. MYERS	1973
ALAR TOOMRE	1973
LOUIS D. BRAIDA	1974
JOHN W. DEVANNEY, III	1974
DANIEL J. KLEITMAN **	

Educational Policy

HARTLEY ROGERS, JR. (*Chairman*) *	
ROY KAPLOW (*Deputy Chairman*) *	
PROVOST *	
UNDERGRADUATE PLANNING PROFESSOR *	
STANLEY BACKER	1972
GEORGE B. FLINT	1972
ROBERT L. HALFMAN	1972
DANIEL M. HOLLAND	1972
DANIEL S. KEMP	1972
DANIEL J. KLEITMAN	1972
DOUGLAS S. LUTHER	1972
PETER A. MESSERI	1972
MICHAEL L. TELSON	1972
RAINER WEISS	1972
SUZANNE BERGER	1973
ALVIN W. DRAKE	1973
TRAVIS R. MERRITT	1973
LISA R. PEATTIE	1973
NORMAN C. RASMUSSEN	1973
STEVEN R. TANNENBAUM	1973

Graduate School Policy

DEAN OF THE GRADUATE SCHOOL (*Chairman*) *	
ASSOCIATE DEAN OF THE GRADUATE SCHOOL (*Secretary*) *	
ASSISTANT DEAN OF THE GRADUATE SCHOOL *	
EXECUTIVE OFFICER OF THE GRADUATE SCHOOL *	
DIRECTOR OF ADMISSIONS *	
ASSOCIATE CHAIRMAN OF THE FACULTY *	
JAMES M. AUSTIN	1972

[1] The dates to the right indicate the years in which the terms of appointment expire.
* *Ex officio*
** Appointed from the Committee on Educational Policy
# Presidential appointment

JUDSON R. BARON 1972
JULIAN BEINART 1972
SYLVAIN BROMBERGER 1972
PHILIP L. DE BRUYN 1972
DAVID J. EPSTEIN 1972
J. HARVEY EVANS 1972
MORRIS HALLE 1972
FRANCIS B. HILDEBRAND 1972
JOHN T. HOWARD 1972
GEORGE F. KOSTER 1972
CHARLES C. LADD 1972
RICHARD C. LORD 1972
SALVADOR E. LURIA 1972
THEODORE R. MADDEN 1972
DONALD G. MARQUIS 1972
LUCIAN W. PYE 1972
NORMAN C. RASMUSSEN 1972
WHITMAN A. RICHARDS 1972
WARREN M. ROHSENOW 1972
PETER TEMIN 1972
GLENN C. WILLIAMS 1972
GERALD N. WOGAN 1972

Industrial Liaison

GLENN C. WILLIAMS
(Chairman) 1973
JARROD M. WILCOX 1972
NICHOLAS P. NEGROPONTE 1972
SANFORD A. MILLER 1973
REGIS M. N. PELLOUX 1974
RICHARD D. THORNTON 1974

Libraries

Executive Board:

HENRY A. MILLON
(Chairman) 1975
DIRECTOR OF LIBRARIES*
ASSOCIATE DIRECTOR OF LIBRARIES*
BRUCE MAZLISH 1972
ROY KAPLOW# 1973
C. GARDNER SWAIN 1973
THOMAS J. ALLEN# 1975
RONALD F. PROBSTEIN 1975

Advisory Board:

MICHAEL B. BEVER
WILLIAM F. BOTTIGLIA
HERBERT S. BRIDGE
BORUCH A. BRODY
EVSEY D. DOMAR
RICHARD M. DUDLEY
JOHN D. FEDOR
MERRILL F. GARRETT
RAYMOND H. GRENIER
ALLAN F. HENRY
DANIEL M. HOLLAND
STANLEY H. HYMAN
NORMAN JONES
CHARLES KINGSLEY, JR.
WILLIAM H. PINSON, JR.
WILLIAM L. PORTER
RONALD F. PROBSTEIN
ROBERT C. REID
JOSE M. ROESSET
EUGENE B. SKOLNIKOFF
VICTOR P. STARR
HAROLD Y. WACHMAN

Nominations#

WILLIAM T. MARTIN
(Chairman) 1974
RICHARD L. CARTWRIGHT 1972
JOHN M. DEUTCH 1972
STEPHEN D. SENTURIA 1972
SHEILA WIDNALL 1973
ROBERT M. SOLOW 1974

Outside Professional Activities

THOMAS M. HILL
(Chairman) 1972
ROBLEY D. EVANS 1972
ROBERT W. MANN 1973
JOHN M. DEUTCH 1974
ROBERT J. HANSEN 1974

Staff — Administration

Staff:

DAVID C. WHITE
(Chairman) 1974
LYNN W. GELHAR 1973
JOHN B. HEYWOOD 1973
EDWARD H. BOWMAN 1974
WILLIAM M. RAND 1974

Administration:#

PAUL E. GRAY
ROBERT A. ALBERTY
ALFRED A. H. KEIL
ALBERT G. HILL
WILLIAM F. POUNDS
JOHN M. WYNNE

Student Environment

JOHN C. GRAVES 1973
(Chairman)
DEAN FOR STUDENT AFFAIRS*
ASSOCIATE DEAN FOR STUDENT AFFAIRS*
LOUIS L. BUCCIARELLI, JR. 1972
MARTIN DEUTSCH 1972
RUSSELL C. JONES 1973
JOEL A. HUBERMAN 1974
RICHARD C. TREMAGLIO 1974
STANLEY BACKER**

Undergraduate Admissions and Financial Aid

LEON TRILLING
(Chairman) 1972
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DIRECTOR OF STUDENT FINANCIAL AID*
CHAIRMAN OF THE FRESHMAN ADVISORY COUNCIL*
ARTHUR D. KALEDIN 1972
FRANK S. JONES 1973
MILTON L. LAVIN 1973
MILDRED S. DRESSELHAUS 1974
AUGUST F. WITT 1974
ALVIN W. DRAKE**

COUNCILS

ACADEMIC COUNCIL

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Chancellor (Vice-Chairman)
Provost (Chairman, Subcommittee on Educational Programs)
Vice President (Secretary)
Vice President and Treasurer
Vice President, Operations
Vice President and Secretary
Vice President, Administration and Personnel
Vice President
Vice President for Research
Vice President for Business and Fiscal Relations
Dean of the School of Architecture and Planning
Dean of the School of Engineering
Dean of the School of Humanities and Social Science
Dean of the Alfred P. Sloan School of Management
Dean of the School of Science
Dean of the Graduate School
Dean for Institute Relations
Dean for Student Affairs
Chairman of the Faculty
Director of Libraries
Comptroller

FACULTY COUNCIL

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Chancellor (Vice-Chairman)
Vice President (Secretary)
Chairman of the Corporation
Members of the Academic Council
Heads of Departments and Professional Courses
Associate Chairman of the Faculty
Secretary of the Faculty
Undergraduate Planning Professor
Director of Admissions
Director of Student Financial Aid
Director of Athletics
Director of the Center for Advanced Engineering Study
Director of the Center for Advanced Visual Studies
Director of the Center for International Studies
Director of the Center for Materials Science and Engineering
Director of the Center for Space Research
Director of the Education Research Center
Director of Information Processing Services
Director of the Joint Harvard-M.I.T. Program in Health Sciences and Technology
Director of the Francis Bitter National Magnet Laboratory
Director of Lincoln Laboratory
Director of the Laboratory for Nuclear Science
Director of the Operations Research Center
Director of the Research Laboratory of Electronics
Director of the Spectroscopy Laboratory
Director of the Urban Systems Laboratory
Director of the M. I. T. Press
Medical Director
Director of the Summer Session
Registrar
Associate Dean for Student Affairs
Associate Dean of the Graduate School
Associate Dean of the School of Engineering
Associate Dean of the Alfred P. Sloan School of Management
Administrative Director of the Division of Sponsored Research

ADMINISTRATIVE COUNCIL

President (Chairman)
Chancellor (Vice-Chairman)
Vice President (Secretary)
Members of the Academic Council
Director of Admissions
Director of Athletics
Director of the Industrial Liaison Office
Director of Information Processing Services
Director of Lincoln Laboratory
Medical Director
Director of the Office of Personnel Relations
Director of Career Planning and Placement
Director of Institute Information Services
Director of Student Financial Aid
Director of the Summer Session
Registrar
Planning Officer
President of the Alumni Association
Executive Vice President of the Alumni Association
Editor of *Technology Review*
Associate Dean for Student Affairs
Associate Dean for Administration of the Alfred P. Sloan School of Management
Assistant Dean of the School of Engineering
Administrative Director of the Division of Sponsored Research

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THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY DESCRIPTIONS OF SUBJECTS 1971-72

Send undeliverable copies and changes of address to Room 5-133, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139.

The Institute reserves the right to make changes in the regulations and courses announced in this Bulletin.

REGISTRAR'S ACADEMIC CALENDAR

1971

AUGUST 2	FIRST TERM REGISTRATION MATERIAL MAILED
AUGUST 16	LAST DAY TO PETITION FOR SEPTEMBER ADVANCED STANDING EXAM AND TO RETURN APPLICATION CARD FOR SEPTEMBER POSTPONED EXAM
AUGUST 30	REGISTRATION MATERIAL DUE IN REGISTRAR'S OFFICE
SEPTEMBER 3	FRESHMAN ORIENTATION WEEK BEGINS
SEPTEMBER 7, 8	ADVANCED STANDING EXAMS AND POSTPONED FINALS
SEPTEMBER 8	PAYMENT FOR FIRST TERM DUE IN BURSAR'S OFFICE
SEPTEMBER 13	REGISTRATION DAY
SEPTEMBER 14	FIRST DAY OF CLASSES
SEPTEMBER 24	LAST DAY TO PETITION FOR OCTOBER ADVANCED STANDING EXAM
OCTOBER 11	COLUMBUS DAY (*holiday*)
OCTOBER 16	ADVANCED STANDING EXAMS
OCTOBER 18	AUTOMATIC WITHDRAWAL DATE FOR STUDENTS NOT HAVING COMPLETED FOUR STEPS OF REGISTRATION
OCTOBER 25, 26	VACATION
OCTOBER 29	$5.00 PROCESSING CHARGE FOR ANY REGISTRATION CHANGE AFTER THIS DATE
	LAST DAY FOR SENIORS TO SPECIFY AN ELECTIVE FOR N/F GRADING
NOVEMBER 24	LAST DAY TO PETITION FOR DECEMBER ADVANCED STANDING EXAM AND TO TURN IN CONFLICT REPORT
NOVEMBER 25 *through* 28	THANKSGIVING VACATION
DECEMBER 1	DROP DATE. UNDERGRADUATES MUST PETITION TO COMMITTEE ON ACADEMIC PERFORMANCE TO CANCEL A SUBJECT AFTER THIS DATE
DECEMBER 2, 3	SECOND TERM REGISTRATION MATERIAL AVAILABLE IN LOBBY OF BUILDING 10
DECEMBER 8	BACHELOR'S THESES DUE FOR FIRST TERM
DECEMBER 10	LAST DAY FOR CHANGING THESIS TITLE
DECEMBER 13	REGISTRATION MATERIAL DUE IN REGISTRAR'S OFFICE
	LAST DAY OF CLASSES FOR SUBJECTS WITH FINAL EXAMS
DECEMBER 15	LAST DAY OF CLASSES FOR SUBJECTS WITH NO FINAL
DECEMBER 16 *through* 22	FINAL EXAM PERIOD
DECEMBER 23 *through* JANUARY 4	CHRISTMAS VACATION

1972

JANUARY 5	FIRST DAY OF INDEPENDENT ACTIVITIES PERIOD
JANUARY 7	FIRST TERM GRADE REPORTS MAILED TO HOME ADDRESS FOR U.S. AND CANADIAN STUDENTS, TERM ADDRESS FOR FOREIGN STUDENTS
JANUARY 14	DOCTOR'S THESES DUE FOR JANUARY
JANUARY 21	THESES, OTHER THAN DOCTOR'S, DUE FOR JANUARY
JANUARY 28	PAYMENT FOR SECOND TERM DUE IN BURSAR'S OFFICE
	LAST DAY OF INDEPENDENT ACTIVITIES PERIOD
JANUARY 29 *through* FEBRUARY 1	VACATION
FEBRUARY 2	REGISTRATION DAY
FEBRUARY 3	FIRST DAY OF CLASSES
FEBRUARY 7	GRADE REPORTS FOR JANUARY PERIOD MAILED
FEBRUARY 18	LAST DAY TO PETITION FOR MARCH ADVANCED STANDING EXAM AND TO RETURN APPLICATION CARD FOR MARCH POSTPONED EXAM
FEBRUARY 21, 22	VACATION
MARCH 11 *and* 18	ADVANCED STANDING EXAMS AND POSTPONED FINALS
MARCH 13	AUTOMATIC WITHDRAWAL DATE FOR STUDENTS NOT HAVING COMPLETED FOUR STEPS OF REGISTRATION
MARCH 24	$5.00 PROCESSING CHARGE FOR ANY REGISTRATION CHANGE AFTER THIS DATE
	LAST DAY FOR SENIORS TO SPECIFY AN ELECTIVE FOR N/F GRADING
MARCH 25 *through* APRIL 2	SPRING VACATION
APRIL 17, 18	VACATION
APRIL 19	SUMMER SESSION REGISTRATION MATERIAL AVAILABLE IN REGISTRAR'S OFFICE
APRIL 21	LAST DAY FOR CHANGING THESIS TITLE
APRIL 28	LAST DAY TO PETITION FOR MAY ADVANCED STANDING EXAM AND TO TURN IN CONFLICT REPORT
MAY 5	DROP DATE. UNDERGRADUATES MUST PETITION TO COMMITTEE ON ACADEMIC PERFORMANCE TO CANCEL A SUBJECT AFTER THIS DATE
	DOCTOR'S THESES DUE FOR SECOND TERM
MAY 10	SUMMER SESSION REGISTRATION MATERIAL DUE
MAY 12	THESES, OTHER THAN DOCTOR'S, DUE FOR SECOND TERM
MAY 17	LAST DAY OF CLASSES FOR SUBJECTS WITH FINAL EXAM
MAY 19	LAST DAY OF CLASSES FOR SUBJECTS WITH NO FINAL
	LAST DAY TO GO ON OR OFF DEGREE LIST
MAY 22 *through* 26	FINAL EXAM PERIOD
MAY 29	MEMORIAL DAY (*holiday*)
JUNE 2	COMMENCEMENT EXERCISES
	SECOND TERM GRADE REPORTS MAILED TO HOME ADDRESS
JUNE 12	FIRST DAY OF SUMMER SESSION

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1.	CIVIL ENGINEERING	2D
2.	MECHANICAL ENGINEERING	12D
3.	METALLURGY AND MATERIALS SCIENCE	25D
4.	ARCHITECTURE	30D
5.	CHEMISTRY	37D
6.	ELECTRICAL ENGINEERING	40D
7.	BIOLOGY	57D
8.	PHYSICS	60D
9.	PSYCHOLOGY	68D
10.	CHEMICAL ENGINEERING	71D
11.	URBAN STUDIES AND PLANNING	76D
12.	EARTH AND PLANETARY SCIENCES	82D
13.	OCEAN ENGINEERING	87D
14.	ECONOMICS	93D
15.	MANAGEMENT	98D
16.	AERONAUTICS AND ASTRONAUTICS	110D
17.	POLITICAL SCIENCE	118D
18.	MATHEMATICS	128D
19.	METEOROLOGY	138D
20.	NUTRITION AND FOOD SCIENCE	140D
21.	HUMANITIES	144D
22.	NUCLEAR ENGINEERING	160D
23.	FOREIGN LITERATURES AND LINGUISTICS	164D
24.	PHILOSOPHY	171D
	AEROSPACE STUDIES	175D
	MILITARY SCIENCE	176D
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DESCRIPTIONS OF SUBJECTS

The subjects and descriptions given in this Section are subject to change. The final list of subjects to be given in 1971–72 will be published with the class schedules booklet prior to the beginning of each term.

"(New)" below the subject title indicates a new offering.

"(Revised: Unit change)" or "(Revised: Content change)" below the subject title indicates a change from the previous catalogue.

A renumbered subject is so indicated in parenthesis below the current number.

"J" at the end of a subject number indicates that the subject is a joint offering of more than one department.

"(A)" following the name of a subject indicates that it is an approved subject for a graduate degree and is given primarily for graduate students.

All subjects open only to special groups are so noted at the end of the description of the subject.

The information given below the number and name of the subject is as follows:

1. The number(s) of prerequisite subjects, if any. Numbers in italics indicate subjects which may be taken simultaneously with the subject described. Prerequisites may be waived by the instructor in charge for particularly well qualified students.
2. The year classification (and term in which the subject is normally scheduled). "U" is an undergraduate subject; "G" is a subject given primarily for graduate students.
3. The time distribution of the subject, showing in sequence the units allotted to: recitation and lecture; laboratory, design, or field work; and preparation. Each unit represents 14 hours of work. The total unit credit for a subject is obtained by adding together all the units shown. One unit of recitation or lecture credit, and two units of laboratory or design credit, are each equivalent to one semester hour.

"*Arr.*" indicates that time units are specially arranged.

4. The name of the instructor(s) in charge, when known at press time.

1.

Civil Engineering

1.U.R. ***Research in Civil Engineering***
(1.998) *Prereq.:* ——
Year: U (1, 2) *Arr.*
Individual participation in an ongoing research project. (*For students in the Research Opportunities Program.*) *Staff*

1.00 ***Information Systems***
Prereq.: ——
Year: U (1, 2) 3–3–6
Introduction to computer-based systems for the acquisition, processing, storage, retrieval, display, and transmission of engineering information. Basic principles of programming systems and languages. Man-machine communications, input/output design, organization of computer systems. Introduction to the design and applications of problem-oriented languages and integrated systems. Real-time systems, computer-aided design, graphical data processing, and the role of information systems in engineering organizations. Extensive laboratory experience in computer programming. (*Limited enrollment.*) *J. M. Sussman, M. F. Nelson*

1.001 ***Civil Engineering Practice***
Prereq.: ——
Year: U (1) 1–0–2
Seminar on the use of theory and research to solve practical problems in civil engineering. Lectures by M.I.T. staff and guests, followed by class discussion. Topics treated: legal, business, and ethical aspects of civil engineering practice. *T. W. Lambe*

1.02 ***Engineering Materials***
Prereq.: 8.01
Year: U (1, 2) 3–3–6
Principles underlying the structure-properties interaction in materials important to civil engineers. Topics including atomic arrangements in crystalline and non-crystalline phases; thermodynamics of phase relationships and structural change; elasticity, microplasticity, viscoelasticity, and fracture; corrosion. Application of principles to structural metals, cementitious materials, structural-ceramics, wood, asphalt, and polymers. Mechanical properties of composite materials, including Portland cement concrete, asphalt-aggregate mixtures, and reinforced plastics. Laboratory work on the common techniques used in the study of microstructure and in the determination of mechanical properties.
J. N. Sultan, J. Soussou

1.03 ***Engineering Analysis***
Prereq.: *1.01*, 18.03
Year: U (2) 4–0–8
Mathematical formulation of engineering problems, solution and physical interpretation of results. Applications of ordinary differential equations in dynamics. Equations of motion for rigid bodies via vectors, Lagrange's equations, constraints and degrees of freedom. Free and forced vibrations, damping, superposition integral, unit impulse function, linear systems. Perturbation analysis of non-linear ordinary differential equations. Boundary value problems in structural theory with eigenfunctions introduced through vibration and buckling of beams and columns. Fourier series, Bessel functions, and an introduction to partial differential equations by separation of variables.
L. W. Gelhar

1.05 ***Fluid Dynamics***
Prereq.: 1.13 or 2.02
Year: U (1) 3–3–6
The fundamental principles and methods of fluid dynamics forming the analytical basis for the physical processes governing the distribution, movement, and quality of water in the environment. Fluid properties, statics, kinematics, and transport processes. Conservation equations for mass, energy, and momentum. Navier-Stokes equations of motion and solutions for laminar flow. Dynamic similitude, basic theory of models and correlation of experimental data. Laminar and turbulent boundary layers, uniform and nonuniform flow in conduits and open channels. Design of pipe line and fluid transport systems. Dynamic drag and lift forces on immersed objects. Turbulent diffusion and mass transport processes in water quality control. Lectures supplemented by laboratory experiments and student projects. *D. R. F. Harleman*

1.06 ***Soil Mechanics***
Prereq.: 1.01
Year: U (2) 3–3–6
The fundamental principles of soil behavior, with applications to retaining walls, foundations, and slope stability problems. Composition and structure of soils; phase relationships and unit weights; interactions between mineral particles and water; classification systems; transmission of forces between mineral particles. Influence of pore pressure on strength and compressibility; effective stress, effect of flowing water on stability. Drained and undrained strength. Theory of consolidation. Principles of limit analysis for soil masses. Methods for estimating soil deformations. Project-type laboratory exercises emphasizing applications of principles to practical problems. *R. V. Whitman*

1.07 ***Analysis of Uncertainty***
Prereq.: 1.10, 18.02
Year: U (1) 3–1–8
Introduction to probabilistic methods in civil engineering. Formulation and analysis of stochastic models of engineering systems and their environment, including estimation of the models' parameters and measures of the models' quality. Elementary notions of probability, including events, random variables, expectation, and derived distribution. Common distributions as models of physical phenomena. Simple time-dependent processes. Statistical treatment of experimental data. Elementary theory of decision making under uncertainty, including classical hypothesis testing. Examples and problems drawn from practice and literature in structures, transportation, materials, water resources, and soils. *C. A. Cornell*

1.071 ***Analysis of Uncertainty***
Prereq.: 1.10, 18.02
Year: G (1) 3–0–6
Same subject as 1.07, but without laboratory. (*Primarily for students who took undergraduate work in a department other than civil engineering at M.I.T., or in another school, who have had no exposure to this subject. Credit will not be given to the same student for both 1.07 and 1.071. Permission of instructor required.*) *C. A. Cornell*

1.08 ***Geotechnology***
Prereq.: ——
Year: U (1) 3–3–6
Basic principles of physical geology, with emphasis on topics pertinent to civil engineering. Minerals. Igneous, metamorphic and sedimentary rocks. Alluvial, glacial, eolian, lacustrine, marine, and colluvial sediments. Weathering. Rock defects. Earthquakes. Airphotos and geologic maps. Field trips. *R. C. Hirschfeld*

1.09 ***Civil Engineering***
Prereq.: 1.05, 1.06, 1.07, 1.08, 1.501
Year: U (2) 0–6–12
Fourth-year subject applying knowledge and methods from all undergraduate studies. Undertaking of a broadly based civil engineering project by students, typically working in two teams. Past projects: a parking garage, an offshore airport in outer Boston, a sports stadium for Boston. Lectures on organization of engineering firms and on the background for the pre-selected project during the early weeks of the term. Proposals for the specific terms of the project, followed by the teams' working with only general guidance from the faculty. Preparation of a written report and an oral presentation by each team. (*Primarily for fourth-year undergraduates in Course I; others by permission of instructor.*) *M. J. Holley, Jr.*

1.10 ***Civil Engineering Laboratory***
Prereq.: ——
Year: U (1, 2) 0–6–6
A program designed to introduce the student to the experimental solution of problems in the major disciplines of civil engineering. Work by students on two experimental projects, each in a different laboratory of the Department. (*Primarily for first- and second-year undergraduates or third-year undergraduates in Course I; others by permission of instructor.*) *R. J. Hansen*

1.11 ***Introduction to Systems Analysis***
Prereq.: *1.00* or *6.00*, 18.01
Year: U (1, 2) 3–3–6
Introduction to computer-based methods for the planning, design, and operation of transportation and communication networks, urban systems, water resources, building systems, and other facilities. First half — optimal combinations of inputs to achieve stated objectives: production functions, cost-effectiveness, fundamentals of linear and dynamic programming, sensitivity analysis. Second half — selection of optimal design objectives: decision analysis, utility theory, predictive models of choice. Emphasis on the application of the tools to actual planning and design problems. (*Fall term — recommended as a Science Distribution elective. Spring term — recommended for Course I juniors. Acceptable ability to use a computer will satisfy the 1.00 or 6.00 corequisite.*)
R. L. de Neufville, R. L. Keeney

1.12 ***Civil Engineering***
Prereq.: ——
Year: U (1) 4–0–8
An introduction to civil engineering. Case studies to illustrate the activities and issues faced by civil engineers. Case studies to consider social, political, economic, and technical factors which influenced the decision to initiate a project and guided its planning, design, construction, operation, and management. Extensive use will be made of various M.I.T. faculty and outside speakers.
T. W. Lambe

1.13 ***Behavior of Physical Systems***
Prereq.: 8.02, 18.02
Year: U (2) 3–3–6
An introduction to the mechanics of rigid and deformable bodies. Emphasis on basic principles of statics and dynamics; energy theorems and stability of equilibrium configurations. Particular attention devoted to the reduction of physical processes, in various fields of civil engineering, to simple mathematical models. The role of mechanics in engineering design. Applications in engineering materials and in structural, soil, and fluid mechanics. *J. M. Roesset*

1.131 ***Applications of Multivariate Statistical Analysis* (A)**
Prereq.: 1.07 or 6.28 or 14.371 or 18.303
Year: G (2) 3–0–6
Presentation of several statistical techniques useful in the analysis of engineering system performance. Emphasis on regression, analysis of variance, and the design of experiments. Approximate coverage: two-variable, least-squares regression; significance tests and confidence intervals (review of chi-square, t, F; simultaneous hypothesis tests); normality tests on residuals; transformations of data; types of models; interactions; experimental designs and their use and analysis (e.g., factorial, fractional factorial, hierarchical, randomized block, and Latin square); parameter estimation and interpretation of results; multivariate regression and correlation; the selection of variables for regression models. Examples drawn from a wide range of engineering applications.
M. B. Godfrey

1.132 ***Applied Random Processes***
(*New*)
Prereq.: 1.07 or 6.28 or 18.303
Year: G (1) 3–0–6
Introduction to random process theory and its application to phenomena and systems of interest in civil engineering. Poisson processes: maximum values and cumulative effects. Discrete state Markov processes and Markov decision analysis. General point processes in time and space: correlation structure, variance function. Spatial and temporal variability in random media. Frequency-domain analysis: characteristics of the power spectral density, statistical properties of Gaussian processes. Response of linear systems. Performance criteria. Estimation problems. Synthesis of systems in the face of uncertainty. Examples are drawn from technical literature in civil engineering: Representation of natural phenomena (hurricanes, floods, etc.). Hydrologic time series. Dam storage. Storm and earthquake damage. Bridge fatigue. Traffic flow. Spatial variability of soil properties and settlement prediction. Spectral representation of ocean waves, turbulence, and earthquake ground motion. *E. H. Vanmarcke, C. A. Cornell*

1.14 ***Economics for Engineers***
Prereq.: ——
Year: U (1) 3–0–9
Essentials of the price system, determination of the level of national income, project evaluation in the public and private sectors, and allied topics. *D. C. Major*

1.142 ***Numerical Methods of Engineering Analysis* (A)**
Prereq.: 18.03
Year: G (2) 3–0–6
Focus on formulation and numerical solution of problems arising in civil engineering, including topics from fluid mechanics, structural dynamics and soil mechanics. Interpolation, integration, finite difference solutions to

initial and boundary value problems, and an introduction to variational approaches for finite element methods. Emphasis on methods suitable for machine calculation. (*Ability to program a computer desirable, but not necessary. Alternate years. Not offered 1971–72.*) *J. T. Christian*

1.143 *Mathematical Optimization Techniques I* (A)
Prereq.: 1.00
Year: G (1) 3–0–6
Systematic survey of theory and application of mathematical optimization techniques to engineering problems. Emphasis on general problem formulation and application of techniques. Linear programming and network algorithms covered in depth. Survey material in various non-linear topics, such as, classical optimization methods, dynamic programming, integer programming, separable programming, and search methods. Term paper requiring the investigation of an engineering problem in order to devise optimization formulation and study of general solution techniques. *D. H. Marks*

1.146 *Engineering Systems Analysis I* (A)
Prereq.: 1.07 or 6.28, 1.14 or 14.02 or *15.012*
Year: G (1) 3–0–6
Synthesis of the computer-based analytic procedures for the identification and selection of optimal systems. Emphasis on the development of an engineering analysis and design process which will fully exploit the intellectual and mechanical innovations associated with the computer. Formulation of the design of complex systems as a multi-dimensional problem in resource allocation among the spectrum of technically acceptable alternatives defined by the production function. Search for optimal designs by use of marginal analysis, mathematical programming, and sensitivity analysis. Evaluation of systems with time-dependent benefits and costs. Selection of optimal design objectives based upon utility theory; demand functions as models of individual behavior; social welfare functions as models of collective choice. Inference of technical and behavioral forces governing the operation of a system through causal modeling and econometric analysis. *R. L. de Neufville*

1.148 *Decision Theories and Social Realities in Engineering and Planning* (A)
Prereq.: ——
Year: G (2) 3–0–6
Theories and techniques for relating technical studies to their social and institutional contexts. Examples drawn from urban highway location studies, metropolitan transportation planning, architecture, and other aspects of urban planning. Particular emphasis on the problem of evalauting and choosing among alternative actions which benefit some groups and hurt others. Development of a general theory and discussion of specific operational techniques: the PSP model, hierarchical structure, Alexander's methods for structuring complex problems, Bayesian decision theory; evaluation techniques such as cost-benefit, cost-effectiveness, goal fabric and differential impact analysis; community participation techniques, techniques for measuring community attitudes; the DODO computer system. (*Primarily for advanced students in political science, economics, planning, architecture, psychology, operations research, systems, civil engineering, or other selected areas.*) *M. L. Manheim*

1.151 *Computer Approaches to Engineering Problems*
Prereq.: ——
Year: G (1, 2) 3–2–4
Basic principles of man-machine communication, programming languages, and computer-based information systems. Particular emphasis on the planning and development of large-scale programs and systems for engineering and management applications. Basic internal and operating system concepts. Introduction to problem-oriented languages, integrated systems, computer organization, time sharing, computer-aided design, and the use of computers in an engineering organization. Extensive laboratory experience in computer programming and the application of information systems to engineering problems. *M. F. Nelson*

1.152 *Engineering Computer Systems Design* (A)
Prereq.: 1.00 or 1.151
Year: G (1) 3–2–4
Integration of engineering and computer considerations in the design of engineering computer systems. Engineering requirements on operating systems and programming languages; generation and processing of problem-oriented language; dynamic data and program structures; data management; memory management implications on application systems design; effective utilization of the Integrated Civil Engineering System (ICES). Laboratory experience with IBM System/360 assembler language and with planning and implementation of an engineering information system. (*Enrollment limited; undergraduates accepted only by permission of instructor.*) *R. D. Logcher*

1.153 *Engineering Computer System Management and Use* (A)
Prereq.: 1.00 or 1.151
Year: G (2) 4–0–5
Computer system organization, multiprogramming, multiprocessing and time sharing. How to choose and configure computer equipment. Remote computer use and its impact on engineering organizations. Implications of the use of computers in engineering problem solving and the design process. Implementation and use of computers by engineering organizations — hardware, software, operational, economic, and organizational considerations. Several seminars by qualified outside speakers. *D. Roos*

1.154 *Simulation Methods* (A)
Prereq.: 1.00 or 1.151 or 1.156;
1.07 or 6.28 or 6.579
Year: G (2) 3–0–6
Basic simulation methodology as applied to stochastic systems. Role of simulation in systems analysis. Comparison of various time-flow mechanisms. Use of several computer languages to program simulation models. Computer system requirements for simulation modeling. A survey of simulation applications including the study of several in depth. Random number generation and testing. Statistical aspects of simulation analysis including validation, variance reduction, experiment design, validity of results, run length considerations, model initialization, autocorrelated data. *J. M. Sussman*

1.156 *Computer Systems*
Prereq.: ——
Year: G (1) 2–1–6
Basic components of a computer system. Computer programming, including programming languages, organization and planning of programs. Man-machine communication, time sharing remote processing. Design and use of problem-oriented languages. Role of graphical input-output. Operating systems. Dynamic memory allocation. Comparisons between computer systems. Impact of the computer on the practice of engineering and management. (*Restricted to Fellows in the Center for Advanced Engineering Study.*) *J. M. Sussman*

1.16J *Special Studies in Systems Engineering* (A)
(Same subject as 2.191J, 6.604J, 13.47J)
Prereq.: ——
Year: G (2) 2–4–6
Development of basic techniques employed in planning and design of complex systems through involvement in

specific projects. Entire class works on a single project which changes each year. Specific background developed through lectures dealing with the selected project. Subgroups of class work on portions of problem and coordinate results through class meetings. Results presented formally at end of term. Recent projects included study of issues of vital importance to the long-range well being of New England, including electric power production, recreational opportunities, air and water pollution, and a study of the potential for expanding industrial and agricultural activity in Saudi Arabia based upon utilization of natural gas now being wasted.

W. W. Seifert, R. E. Stickney, E. G. Frankel

1.162 *Analytic Formulation of Engineering Systems Problems* (A)
Prereq.: 1.143 or 1.146
Year: G (2) 3–0–6
This subject designed to develop the student's understanding of how the techniques of mathematical optimization and systems analysis should be applied to engineering problems. Advanced topics extending the scope of 1.143 and 1.146 developed in the context of particular problems. Particular emphasis given to the examination of the significance of alternative formulations of problems and to the implications of the approximations that have to be made. The specific topics: (1) statistical definition of valid objective functions; (2) application of mathematical programming to the several alternative formulations of the generic location and scheduling problems; (3) use of optimization, with its usual single objective function, as a tool to search for regions of good design when multiple objective functions do, in fact, apply; and (4) inference of demands for the services provided by a system and how they may, by altering the constraints, change its optimal configuration. (*Previous experience in mathematical programming or systems analysis can be substituted for the prerequisites by permission of the instructors.*)

D. H. Marks, R. L. de Neufville

1.17 *Analysis of Public Systems* (A)
Prereq.: 1.07 or 6.28 or 18.303
Year: G (1) 3–0–6
Discussion and critical analysis of applications of operations research techniques in the public domain. Topics include air traffic control, hospitals, health, education, police systems, air pollution control, post offices, fire department operations, libraries, court systems, transportation facilities. Seminar presentations by Institute faculty and invited guests with experience in public systems. Term project for each student: critical summary of the relevant work in a public systems area in which he chooses to concentrate. Additional requirement: a written proposal to study a particular problem in that area (which may or may not be continued in following terms).

R. L. Keeney

1.18 *Building Design Systems* (A)
Prereq.: ——
Year: G (2) 3–0–6
Consideration of a building as an integrated system. Analysis of current building systems and proposals. Functional and preliminary planning of buildings, environmental design, and integrated design of engineered systems. Applications of computer systems to information processing in building design and data exchange among design disciplines. Use of mathematical optimization techniques, network theory, and decision analysis in subsystems design. CPM and resource allocation techniques. Survey of existing approaches to building systems evaluation and synthesis.

R. D. Logcher

1.20 *Transportation Laboratory*
Prereq.: ——
Year: U (1, 2) 2–6–4
Laboratory experience with the properties of transportation systems and their effects on urban and regional development. Students formulate experiments based upon readings and discussions of current transportation problems. Emphasis on formulation of hypotheses about properties and effects of different types of transportation systems; planning of experiments to test these hypotheses; analysis of results; and development of recommendations for changes in transport systems plans and policies. Experiments performed using computer programs developed by the Urban Systems Laboratory which simulate the behavior of transport systems. (*Prior experience with computers useful, but not required.*)

M. L. Manheim, E. R. Ruiter

1.201 *Analysis of Transportation Systems I* (A)
Prereq.: ——
Year: G (1) 3–0–6
Introduction to the transport systems problem: transportation innovations, changing patterns of demand, changing social values. Framework for analysis: decision makers and their options, social and economic impacts of transportation. Prediction problem: demand forecasting, modeling transportation technologies, network flow analysis. The decision problem: evaluation of impacts. Technology: basic physics of transportation, major technologies, the transportation production function. Basic transportation problems: urban, megalopolitan transportation, transportation and economic policy. Exercises; a major student case study. (*Primarily for incoming graduate students with diverse backgrounds.*)

M. L. Manheim, W. M. Pecknold

1.202 *Analysis of Transportation Systems II* (A)
Prereq.: 1.146 or 14.01; 1.201
Year: G (2) 3–0–6
Demand analysis and forecasting for multimode transportation systems. Theory of demand and demand prediction for urban and regional transportation cases. Demand models and the equilibrium approach of traditional urban transportation planning process. Supply-sensitive integrated and behavioral demand models. Information acquisition and model construction. Pricing policies of transport modes and other influences on demand. Urban land use and regional macroeconomic planning models. Freight demand models. Case studies on demand analysis of recent urban, regional, and developing country planning studies.

W. M. Pecknold

1.203 *Analysis of Transportation Systems III* (A)
Prereq.: 1.146 or 14.01; 1.201
Year: G (1) 3–0–6
Basic characteristics of transportation technologies. Determination of capacity for highways, air transport systems and terminals, railroads, ports and terminals. Analysis of network operations. Transfer and classification systems. Cost and performance models and generalized parametric analysis. Problems in system unreliability. Forecasting transportation technology and the synthesis of new modes and hybrid systems to meet selected transportation demands.

A. S. Lang

1.21 *Transportation Systems Planning and Design*
(*New*)
Prereq.: 1.20
Year: U (1) 4–0–8
Basic characteristics of transportation technologies. Analysis of cost and performance tradeoffs. Introduction to transportation demand and planning models. Discussion of issues in transportation planning. Case studies in innovative transportation technologies.

A. S. Lang, D. Roos

1.222J *Flight Transportation Seminar*
(Same subject as 16.752J)
Prereq.: ——
Year: G (1) 1–0–2
Economics of airline operation, problems of financing and of domestic and international route allocation. Subject developed around seminars presented by speakers from the regulatory agencies, national and international organizations, and industry on particular phases of flight transportation. Preparatory lecture preceding each seminar. Opportunity for students to conduct studies in their area of major specialization on a particular topic covered by the subject.
R. L. deNeufville, R. W. Simpson

1.23J *Planning and Design of Airports* (A)
(Same Subject as 16.78J)
Prereq.: 1.11 or 1.146; 1.20 or 1.201 or 16.751
Year: G (2) 3–0–6
The planning and design of airports, airport terminals, and airport access systems. Synthesis of current practice and advanced concepts. Airport site selection, airfield layout and design. Analysis of the effect of airport systems on the metropolitan and regional scale. Examination of demand models for the prediction of the loads on airport facilities. Multi-dimensional evaluation of benefits and costs to air travelers, airport operators, and local communities. Optimal strategies for terminal design. Planning of airport access systems. Special attention to the most advanced design concepts in the United States and Europe and the insight they provide for the design of airport systems of the future.
R. L. de Neufville, N. M. H. Wilson, R. Simpson

1.24 *Highway Network Engineering* (A)
(*New*)
Prereq.: 1.20 or 1.201
Year: G (1) 3–0–6
Integrated presentation of operational models for highway traffic networks, traffic engineering, highway geometrics, and highway location. Applications and examples, which involve term projects and field studies, drawn from the Boston area transportation network, both present and proposed. Approximate coverage: operational models of vehicular road traffic; network performance measures and their measurement; motor vehicle weights, lengths, and performance characteristics; freeway geometrics and their interaction with traffic operations and "accidents"; road location, alignment, and cost; urban street design; channelization and intersection design; single-intersection control and network traffic control; operational reliability and failure recovery techniques; network maintenance.
M. B. Godfrey

1.258 *Case Studies in Transportation Engineering* (A)
Prereq.: 1.201
Year: G (2) 3–0–6
Techniques for the planning and design of components of transportation systems. Measures of effectiveness of alternate schemes. Applications to specific projects in fields of highway, traffic control, public transit or airport engineering.
Staff

1.261 *Advanced Transportation Planning* (A)
Prereq.: 1.202 or 1.203
Year: G (1, 2) *Arr.*
Integration of technical tools in concerted attack on a specific major transportation problem, such as development of a transportation plan for a U. S. metropolitan area or for a major region in a developing country. Review of transportation planning techniques and related methodologies. Student work individually and in groups to resolve specific policy questions through technical analyses. Emphasis on the critical analysis of alternative solutions to the problem, and on the ability to adapt technical analyses to data limitations, political considerations, and other realities. (*Primarily for advanced students in transportation. Permission of instructor required.*)
M. L. Manheim

1.27 *Special Studies in Transportation Engineering* (A)
Prereq.: 1.201
Year: G (1 or 2) *Arr.*
Individual advanced study of a topic in transportation systems selected with the approval of the instructor.
Staff

1.311 *Theoretical Soil Mechanics I* (A)
Prereq.: 1.06
Year: G (1) 3–0–6
Discussion of elementary theories important in soil mechanics. Theories of elastic halfspace and elastic layers. Applications of elastic theories, especially to settlement problems. Use of limit analyses for active and passive stresses, bearing capacity, and slope stability. Theory of consolidation for one-dimensional problems and introduction to three-dimensional consolidation. Mathematics, construction, and interpretation of flow nets. Introduction to finite element methods and their use.
J. T. Christian

1.312 *Theoretical Soil Mechanics II* (A)
Prereq.: 1.311
Year: G (2) 3–0–6
Content variable from year to year. Such topics as advanced problems in three-dimensional consolidation; Kotter's equation; modern earth pressure theories of Brinch Hansen and Sokolovski; theories of plasticity applied to soil systems. Finite element methods in soil mechanics. (*Alternate years. Offered 1971–72.*)
J. T. Christian

1.321 *Soil Behavior* (A)
Prereq.: 1.361
Year: G (2) 3–0–6
Detailed study of soil properties with emphasis on methods of measuring properties in the field and laboratory and interpretation of experimental data for use in practice. Topics include: consolidation behavior of clays; basic strength principles; stress-strain behavior of saturated clays, emphasizing the influence of sampling, different types of stress systems, and environment; strength and compression of granular soils; engineering properties of compacted clays; permeability and capillarity.
C. C. Ladd

1.331 *Soil Dynamics* (A)
Prereq.: 1.06
Year: G (1) 3–0–6
Design of foundations for machinery; effects of earthquakes upon structures and earth dams, and ground motions caused by explosions. Stress-strain behavior of soil during transient and repeated loadings; relation of soil properties to wave velocity. Theory of wave propagation and dynamics of lumped systems as applied to problems in soil dynamics. (*Alternate years. Offered 1971–72.*)
R. V. Whitman

1.361 *Advanced Soil Mechanics* (A)
Prereq.: 1.06
Year: G (1) 3–0–6
Consideration of the following fundamentals of soil mechanics: the nature of soil, including a description of soil particles and stress transmission between particles, effective stress concept; fluid flow and its effect on soil behavior; stress-strain behavior of soil: lateral earth stresses and earth retaining structures; earth slopes; settlement and stability analyses of foundations and earth slopes.
C. C. Ladd

1.362 *Earth Dams* (A)
Prereq.: 1.361
Year: G (2) 3–0–6
Design and construction of earth and earth-rock dams. Seepage and stability problems; field measurements of deformations and stresses; construction problems. Materials in the book "Earth and Earth-Rock Dams" by Sherard, et al. covered by lectures and class discussion. *T. W. Lambe*

1.364 *Foundations* (A)
Prereq.: 1.361
Year: G (2) 3–0–6
Foundations and earth retaining structures including considerations of shallow foundations, deep foundations, and braced excavations. Subject built around case studies involving exploration, laboratory and field tests, analyses, and the measurement of field performance. *D. J. D'Appolonia*

1.365 *Improvement of Engineering Properties of Soils* (A)
Prereq.: 1.06 or 1.361
Year: G (2) 3–0–6
Presentation and evaluation of mechanical, physical, and chemical methods for altering engineering properties of soils. Discussion of construction specifications and control. Topics: compaction, mechanical stabilization, and chemical stabilization. (*Alternate years. Offered 1971–72.*) *A. E. Z. Wissa*

1.37 *Experimental Soil Mechanics* (A)
Prereq.: 1.06
Year: G (1) 2–4–3
Laboratory determination of soil properties emphasizing experimental techniques. Topics include: classification of soils; oedometer tests with measurements of pore pressure dissipation; undrained strength of clays from vane and unconfined tests; drained and undrained shear tests with pore-pressure measurements employing triaxial, simple shear, or plane strain equipment; strength-volume change-permeability characteristics of compacted clays; special topics of interest to students, such as frost heave, capillarity, stabilization, or thixotropy. *A. E. Z. Wissa*

1.38 *Engineering Geology* (A)
Prereq.: 1.06, 1.08
Year: G (2) 3–0–6
Geological aspects of subsurface exploration, dams, reservoirs, foundations, slopes, and tunnels, with emphasis on soil deposits. (Hard-rock engineering geology is covered as part of 1.381.) (*Alternate years. Not offered 1971–72.*) *R. C. Hirschfeld*

1.381 *Rock Mechanics I* (A)
Prereq.: 1.06, 1.08; or 12.01, 12.04
Year: G (1) 3–0–6
Principles of rock mechanics applicable to civil engineering. Engineering geology of rock masses. Rock classification. Stress distribution around openings. State of stress in the earth's crust. Permeability, deformability, and strength of intact rock and rock masses. (*Alternate years. Offered 1971–72.*) *R. C. Hirschfeld*

1.382 *Rock Mechanics II* (A)
Prereq.: 1.381
Year: G (2) 3–0–6
Applied rock mechanics. Rock excavation. Rock reinforcement. Design and construction of hard-rock tunnels and chambers, slopes, foundations of dams, and other heavy structures. Field instrumentation. (*Alternate years. Offered 1971–72.*) *R. C. Hirschfeld*

1.39 *Special Studies in Soil Engineering* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
For graduate students desiring further individual study of special topics. *Staff*

1.40 *Introduction to Electron Microscopy*
Prereq.: ——
Year: U (1) 1–3–2
Introduction to electron scattering and electron optics. Emphasis on student use of electron microscope for transmission and diffraction studies. Principles of operation. Preparation of specimens. Thin-film and replica techniques. Analysis and interpretation of micrographs and diffraction patterns. Supplementary use of optical microscopy. Application to study of structure of solid materials: metals, ceramics, glasses, polymers. Introduction to X-ray diffraction. *R. C. Jones*

1.401 *Introduction to Electron Microscopy and X-Ray Diffraction* (A)
Prereq.: ——
Year: G (1) 2–3–4
For graduate students desiring advanced study in the topics presented in 1.40. Laboratory projects involving the use of transmission and scanning electron microscopes, as well as other projects familiarizing students with other instruments available in the materials laboratory. *R. C. Jones*

1.41 *Strength of Structural Materials* (A)
Prereq.: 1.02
Year: G (1) 3–0–6
Analysis of criteria for crack initiation and propagation leading to structural failure. Study of fracture mechanics starting with Griffith theory for ideally brittle materials and through plane strain fracture toughness phenomena. Effects of geometry, rate, environment, fatigue, temperature, composition, and microstructure. Relation to dislocation mechanics. Significance of fracture surface morphology. Metals, cementitious materials, rock, polymers, fiber reinforced composites. Emphasis on current research in field. *F. J. McGarry*

1.42 *Structural Materials* (A)
Prereq.: 1.02
Year: G (2) 3–2–4
Mechanical behavior of important materials in civil engineering structures. Principles relating composition and structure to such behavior. Emphasis upon basic factors to facilitate understanding and use of new materials and combinations. Elastic, plastic, viscoelastic, and other time-dependent types of deformation. Influence of defects and imperfections. Consideration of creep and fracture phenomena, adhesion and corrosion, composites and multiphase systems. Reference to present and anticipated materials. Laboratory primarily concerned with structure-composition-mechanical property interactions. *R. C. Jones*

1.45 *Highway Technology* (A)
Prereq.: 1.02
Year: G (1) 3–0–6
Application of problem solving techniques to highway technology — design, construction, maintenance — with emphasis upon structural design. Systematic investigation of impact of overall transportation goals on highway performance evaluation, and user based approaches to this evaluation in terms of serviceability, reliability, and maintainability. Functional requirements of physical facilities as derived from performance evaluation. Formulation of alternative design actions and selection with economic and service quality criteria. Problems of construction and maintenance. Observation of actions as feedback to problem solving. Synthesis into overall framework for decision making. *F. Moavenzadeh*

1.46 *Portland Cement Concrete* (A)
(*Revised: Unit change*)
Prereq.: 1.02
Year: G (2) 2–3–4
Advanced study of Portland cement concrete. Emphasis on mechanical behavior and durability. Creep, fracture,

and fatigue. Lightweight concrete and technology of prefabricated structural elements; precasting, cast in place, prestressing, and past tensioning. *F. Moavenzadeh*

1.47 *Mechanics of Materials* (A)
Prereq: 1.02
Year: G (1) 3–0–6
Mechanical equation of state for engineering materials. Concepts of stress and strain. Isotropy, rate dependence, temperature effects. Elasticity, viscosity, plasticity, viscoelasticity. Applications to engineering analysis and design. (*Alternate years. Not offered 1971–72.*)
F. Moavenzadeh

1.471 *Mechanical Behavior of Plastics* (A)
Prereq.: 1.02
Year: G (1) 3–2–4
Relation between chemical composition, physical structure, and mechanical behavior of plastics or synthetic high polymers. Study of types of polymers; fundamentals of viscoelastic phenomena such as creep, stress relaxation, stress rupture, mechanical damping, impact; effects of chemical composition and structure on viscoelastic and strength properties; methods of mechanical property evaluation. Influences of plastics fabrication methods. Emphasis on recent research techniques and results. Laboratory on individual project basis investigating problems related to current research.
F. J. McGarry, J. N. Sultan

1.472 *Composite Materials* (A)
Prereq.: 1.42
Year: G (2) 3–2–4
Concepts underlying formation, characteristics and behavior of plastics-based composites such as fiberglass laminates, structural sandwiches, plywood, and load-bearing adhesive joints. Typical components such as metals, glass, synthetic and natural adhesives, plastics foams, wood, paper, fabrics, and rubber. Correlation between adhesion principles and physical behavior. Methods of design, analysis, fabrication, and testing. Discussion of failure mechanisms of chemical, electrical, and mechanical types. Laboratory on individual project basis investigating problems related to current research.
F. J. McGarry

1.473 *Viscoelasticity* (A)
Prereq.: 1.02
Year: G (2) 3–0–6
Methods of analysis of viscoelastic phenomena. Discrete element models, continuous distribution spectra. Constitutive equations for representation of viscoelastic behavior. Creep, relaxation, dynamic analyses. Principles of correspondence, interconversion, superposition. Treatment of non-linear systems. Applications to structural elements composed of metals, concrete, asphalt, soils. (*Alternate years. Not offered 1971–72.*) *F. Moavenzadeh*

1.48 *Special Studies in Materials* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Advanced study, research, and laboratory investigations in the field of materials engineering. Arrangement of individual and group study of topics by the instructor in charge. Special reading assignments, consultation, and original investigations in the Materials Research Laboratory. *Staff*

1.501 *Introduction to Structural Engineering*
(1.04) *Prereq.:* 1.13
Year: U (1) 3–3–6
Using statics and developing elementary mathematical techniques where appropriate, the principles and applications of structural engineering are developed by treating, in sequence, a series of questions. What kinds of loads must structures resist? What are the basic structural forms and how do they resist applied loads? What materials are structures made of and why? Why and how do structures fail? What structural arrangements are appropriate for floor systems, building frameworks, bridges, etc.? How are structures conceived, planned, financed, designed, and constructed? *W. A. Litle*

1.502 *Structural Analysis and Design*
(1.51) (*Revised: Unit change*)
Prereq.: 1.13; 1.501
Year: U (2) 3–2–7
Classical techniques for the analysis of structural members and member systems such as moment-area, slope-deflection, superposition, moment-distribution, reciprocal theorems. Formulation and application of the matrix displacement method to trusses and plane frames. Small deflection theory of plates. Elastic and inelastic stability of columns. Dynamic behavior of simple structural systems. Contemporary design criteria and practice for steel and reinforced concrete structures.
K. F. Reinschmidt

1.503 *Engineering Mechanics*
(1.01) *Prereq.:* 1.13
Year: U (2) 4–0–8
Statics and dynamics of deformable solids. Concepts of stress, strain, equilibrium, and energy. Elastic, inelastic and viscoelastic behavior. Solution of practical problems such as bending and twisting of beams, stress distribution under footings, stress concentrations. Dynamics of lumped mass and simple continuous systems. The nature of dynamic loads and their significance in engineering design. The concept of elastic stability. Introduction to probabilistic approaches.
E. H. Vanmarcke, F. Moavenzadeh

1.521 *Model Laboratory for Structural Design* (A)
Prereq.: 1.04
Year: G (1) 2–3–4
Lectures, assigned reading, and laboratory covering the theory and practice of model analysis to facilitate the analysis and design of structures and structural elements. Dimensional analysis, materials, fabrication, loading, instrumentation, and interpretation of results are considered. Illustration, by comprehensive laboratory problems, of the use of qualitative and quantitative models to study unusual structural behavior. (*Not offered 1971-72.*)
Staff

1.531 *Special Problems in Structural Engineering* (A)
Prereq.: ——
Year: G (1 or 2) *Arr.*
Individual study of advanced subjects under staff supervision. Arrangement of each program to suit the particular requirements of the student and interested members of the staff, subject to the approval of the instructor in charge. *Staff*

1.541 *Behavior of Concrete Structures* (A)
Prereq.: 1.502
Year: G (1) 3–0–6
Consideration of the mechanics of reinforced and prestressed concrete structural elements with emphasis on ultimate strength and time-dependent behavior. Systematic procedures for member checking and member design, with emphasis on design criteria. Detailing, formwork design, and construction procedures for *in situ* and precast reinforced and prestressed concrete.
M. J. Holley, Jr.

1.542 *Behavior of Metal Structures* (A)
Prereq.: 1.502
Year: G (2) 3–0–6
Consideration of properties of structural metals and the behavior of metal structures, including elasto-plastic behavior, buckling, fatigue and torsion. Procedures for the design of complete structures. *J. M. Biggs*

1.551 *Planning of Structural Systems* (A)
Prereq.: 1.502
Year: G (1) 3–0–6
Planning of a total structural system to meet given functions. The nature and range of functional requirements for structures. The nature of loadings, the relationship of deterministically vs. statistically based codes. The nature of constraints on structural arrangements brought about by fabrication and erection procedures, and the characteristics and installation procedures for other subsystems involved in the total structure. Emphasis on the conception and initial selection procedure of the structural system for a range of uses including low- and high-rise buildings, long span structures, bridges, and special structures. *J. M. Biggs*

1.552 *The Practice of Structural Engineering* (A)
Prereq.: 1.541, *1.542*, 1.551
Year: G (2) 2–3–4
Consideration of the preliminary design including structural concepts, selection of a system to engineer, and the proportioning of members and connections. Several case studies, given with lectures from practicing professionals and faculty members of the division.
R. J. Hansen

1.561 *Advanced Structural Mechanics* (A)
Prereq.: 1.571
Year: G (1) 3–0–6
Technical theory of beams: restrained torsion. Orthotropic plate theory: plate stretching, treatment of reinforced plates, analysis of cutouts; plate bending, consideration of transverse shear deformation, sandwich plates, plate-grid systems, application to orthotropic bridges. Axi-symmetric stress analysis. Three-dimensional stress analysis. Finite element methods treated extensively. (*Not offered 1971-72.*) *J. J. Connor*

1.571 *Advanced Structural Analysis* (A)
Prereq.: 1.502
Year: G (1) 3–0–6
Governing equations for a three-dimensional linear elastic solid; principle of virtual displacements; principle of virtual stresses; variational principles. Application to plane stress analysis. Flexure and torsion of prismatic members; shear center; technical theory of members. Matrix formulation for member systems; discussion of force and displacement solution procedures.
J. M. Roesset

1.572 *Advanced Structural Analysis* (A)
Prereq.: 1.571
Year: G (2) 3–0–6
Dynamics of discrete systems; single degree of freedom systems considered initially; extension to multi-degree of freedom systems; eigenvalue determination; numerical integration. Technical theory of plates and shells. Introduction to finite element methods for plane and axisymmetric stress analysis, plate bending, and thin shell analysis. *J. M. Roesset*

1.582 *Structural Reliability* (A)
Prereq.: 1.07, 1.502
Year: G (2) 2–0–4
Analysis and specification of structural performance and safety through probability. The description of uncertain live, wind, and earthquake loadings. The treatment of material properties' variability. Analysis of the reliability of the performance of structural systems. Optimum design accounting for uncertainty and failure consequences. New and developing code specifications with a probabilistic basis. *C. A. Cornell, E. H. Vanmarcke*

1.584 *Analysis and Design of Shell Structures* (A)
Prereq.: 1.571
Year: G (2) 3–0–6
Formulation of the governing equations of thin shells in orthogonal curvilinear coordinates. Membrane theory, inextensional bending, application to hyperboloids, cones and cylinders of revolution. Axisymmetric bending of shells of revolution. Shells with edge beams, design considerations, desirability of prestress, variable thickness. Application to various geometries. General theory of cylindrical shells. Design of cylindrical shell roofs. Shell theory in Cartesian coordinates, shallow shell theory, application to the design of elliptic and hyperbolic paraboloid shell roofs. Analysis of reinforced concrete nuclear containment structures. (*Not offered 1971–72.*)
J. J. Connor

1.586 *Structural Dynamics* (A)
Prereq.: 1.502
Year: G (1) 3–0–6
Analysis and design of structures subjected to dynamic loads. Modal analysis of multidegree systems. Numerical methods. Inelastic response. Continuous systems. Practical design methods. Applications to earthquake design, blast-resistant structures, machine supports, bridge vibration, etc. (*Alternate years. Offered 1971–72.*)
J. M. Roesset

1.588 *Structural Stability* (A)
Prereq.: 1.571
Year: G (2) 3–0–6
Detailed consideration of elastic and plastic buckling behavior of individual column and flexural elements. Buckling of plates considered and applied to local buckling of structural members. Buckling of shells, frames, trusses, and arches also discussed. (*Alternate years. Not offered 1971–72.*) *J. M. Roesset*

1.592 *Structural Information Systems* (A)
Prereq.: 1.00 or 1.151; 1.551
Year: G (2) 3–0–6
Identification of objectives, decision variables, processes and information flow in structural design. Interrelationships with participating disciplines in building design. Current building information systems and their technological problems. Study of information structure and processing techniques in current languages and computer systems for design, ICES: STRUDL, TABLE, information identification, hierarchial data structures.
R. D. Logcher

1.594 *Optimization of Structures* (A)
Prereq.: ——
Year: G (2) 3–0–6
Role of mathematical and computer techniques in the structural design process. Applications of optimization to the design of structural systems and nonstructural systems used in buildings. Formulation of problems and choice of decision variables, objectives, and constraints. Decomposition of large-scale systems, approximations, and simplifications in design. Techniques include linear, nonlinear, and integer programming and statistical decision analysis. (*Alternate years. Not offered 1971–72.*)
K. F. Reinschmidt

1.599 *The Dynamics of Real Estate Development* (A)
Prereq.: ——
Year: G (1) 2–0–4
Descriptive and analytic review of the dynamics of real estate development. Systematic examination of the en-

tire development process: personnel and organizations; scheduling and timetables; capital budgets and income projections; debt and equity financing; relationships of architects, engineers, contractors; management and brokerage; government controls; political, economic, and social constraints; various special problems. Extensive references made to existing apartment, office, and commercial real estate projects. Guest lectures by experts in pertinent fields. *A. Herrey*

1.60 *Introduction to Water Resources*
Prereq.: ——
Year: U (2) 3–0–6
Engineering, economic, and political aspects of water resources management. Designed as a multi-disciplinary introduction to the field for those who wish to consider further work in water resources and for students in engineering, economics, political science, and management who wish to use water resources as a case study of an important resource sector largely affected by government management. Topics include: pollution, ecological aspects of water development, water management institutions, engineering-economic design of water systems, formulation of objectives and criteria for water resource development, the role of the U.S. Congress and Federal agencies, water reuse systems, and global water problems. Group discussions, readings, some formal lectures, and invited speakers. *J. C. Schaake, D. C. Major*

1.612 *Fluid Mechanics*
Prereq.: 1.01, 18.03
Year: G (1) 3–0–6
Introduction to theoretical fluid mechanics. Development of general equations of motion, their significance in dimensionless form, and their application to the solution of problems involving pressure, gravitational, and viscous forces. Emphasis on dynamic similarity, laminar and turbulent flows, surface and form resistance, lift, propulsion, cavitation, and the use of turbomachinery in hydraulic systems. *R. H. Cross, III*

1.613 *Fluid Mechanics*
Prereq.: 1.01, 18.03
Year: G (1) 3–3–6
Introduction to theoretical fluid mechanics (same as subject 1.612). Lectures supplemented by laboratory experiments and projects. *R. H. Cross, III*

1.631 *Advanced Hydromechanics I* (A)
Prereq.: 1.05, 18.075, 18.076
Year: G (1) 3–0–6
Kinematics and dynamics of incompressible fluids. Stress and strain, Navier-Stokes' equations. Emphasis on inviscid theory remainder of the term. Vortex theorems. Applications of potential theory and complex variables. Motion of two and three dimensional bodies in fluid. Free streamline motions; examples taken from jets, cavities, and seepage flows. *C. C. Mei*

1.632 *Advanced Hydromechanics II* (A)
Prereq.: 1.631
Year: G (2) 3–0–6
Emphasis on dynamics of real fluids. Laminar motions. Low Reynolds number flows. Boundary layer theories. Steady and unsteady flows. Oscillatory flows and induced streaming. Thermal effects. Elementary features of hydromechanic instability. Mixing-length theories of turbulence, application to turbulent shear flows. Analysis for gross features of jets in various environments such as external current, bounded space. *C. C. Mei*

1.65 *Free Surface Flow* (A)
Prereq.: 1.05
Year: G (1) 3–0–6
Steady and unsteady flow in open channels, boundary resistance and boundary layer problems, surface curves, channel transitions and controls, standing waves, hydraulic jump, surges, and waves. Secondary flow, stratification, internal currents due to density variation, turbulent diffusion phenomena. *A. T. Ippen*

1.66 *Special Problems in Hydromechanics* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Advanced topics selected by students for individual study with staff approval. Choice of subjects from theoretical, experimental, and practical phases of hydromechanics, hydraulic engineering, and water resources. *Staff*

1.681 *Experimental Hydromechanics* (A)
(Revised: Unit change)
Prereq.: 1.05
Year: G (1) 2–3–4
The role of experimental studies in research and design. Theories of dynamic similarity and dimensional analysis with particular emphasis on their relation to fundamental hydromechanics, interpretation of experimental data and modeling. Criteria for modeling with geometric distortion and other conditions of incomplete dynamic similarity. Fundamentals of measurement and instrumentation. Analysis of the operating principles and performance characteristics of instruments for the measurement of physical quantities such as temperature, pressure, and flow. *F. E. Perkins*

1.69 *Waves and Coastal Processes* (A)
Prereq.: 1.65 or 1.681
Year: G (2) 3–0–6
Hydrodynamics of waves for deep and shallow water, wave generation refraction, energy transmission and dissipation; coastal phenomena, harbor and breakwater problems. Analysis of tides and tidal currents; saltwater-freshwater interaction and diffusion in estuaries; erosion and shoaling in tidal waters.
A. T. Ippen, R. H. Cross, III

1.70 *Mechanics of Sediment Transport* (A)
Prereq.: 1.65
Year: G (2) 2–0–4
General properties of the dynamics of fluid-solid flows. Measurement and description of sediment characteristics. Mechanics of entrainment, movement and deposition of granular and of cohesive sedimentary materials by moving fluids. Sediment suspensions in turbulent flow. Analysis of roughness, of bed stability and of sediment transport rate in alluvial channels. Ripples, dunes and antidunes. Similarity considerations. Design of earth-lined channels. Morphology of rivers.
C. C. Mei, A. T. Ippen

1.711 *Dynamic Hydrology* (A)
Prereq.: 1.05
Year: G (1) 3–0–6
Dynamics of the principal physical processes of interest to the engineering hydrologist. Transport processes in the atmosphere and oceans, energy balance of the earth, atmospheric and oceanic circulations. Emphasis upon the mechanics of evaporation and transpiration, precipitation and snowmelt, infiltration and groundwater flow, surface runoff. Structure of the drainage network. Synthesis of the general rainfall-streamflow process.
Staff

1.712 *Hydrologic Analysis and Synthesis* (A)
Prereq.: 1.07
Year: G (2) 3–0–6
Analysis and synthesis of hydrologic signals and systems. General structure of hydrologic time series. Correlation and spectral analysis of periodic and aperiodic signals. Sampling. Analysis of random signals including use of the extreme value distribution and order statistics, correlation and the variance spectrum. Decomposition

of mixed signals. Signal synthesis. Functional and parametric representation of stationary linear and nonlinear systems. System identification. Linear and nonlinear simulation of hydrologic processes. Time and space definition in hydrologic modeling. Criteria for instruments and networks. *Staff*

1.72 *Flow in Porous Media* (A)
(Revised: Unit change)
Prereq.: 1.05, 1.06
Year: G (1) 3–0–6
Dynamics of flow through porous media with emphasis on physical processes important in ground water hydrology and seepage. Continuum approach applied to conservation of mass and dynamics in porous media. Anisotropy and compressibility of media. Development of field equation and boundary conditions. Hydrodynamic dispersion and unsaturated flow phenomena. Analysis of flow in porous media via analytical method, the Dupuit approximation, model and analog methods, and numerical methods. Applications involving well analysis and aquifer management, seepage through dams, natural and artificial recharge, saline intrusion in coastal aquifers, and groundwater pollution. Includes recitation session with laboratory experiments, problem discussions, and term paper seminars. *L. W. Gelhar*

1.731 *Water Resource Systems I* (A)
Prereq: 1.00 or 1.151
Year: G (1) 3–0–6
Application of systems methodology to the analysis, design, and operation of surface and subsurface reservoirs, networks of pipes and channels, and multipurpose river basin developments. Identification of objectives and system definition. Synthesis of hydrologic inputs, operating rules, optimal design and operation, characteristics of systems performance. *J. C. Schaake*

1.732 *Water Resource Systems II* (A)
Prereq.: 1.711, 1.731
Year: G (2) 0–3–6
Organization for machine solution of comprehensive problems in hydraulics, hydrology and water resource systems. Analog or digital solution of such problems as flood forecasting, flood routing, transients in closed conduits, reservoir design and operation, water quality forecasting. (*A knowledge of computer programming at the* FORTRAN *level assumed.*) *F. E. Perkins, J. C. Schaake*

1.74 *Public Expenditure Theory* (A)
Prereq.: 1.143, 14.01
Year: G (2) 3–0–6
Presentation of the full range of benefit-cost criteria required for the optimal economic design of public expenditure projects. Emphasis upon water resource systems as specific examples. Provides necessary background in welfare economics and relevant material from political science dealing with the choice of objectives for public expenditure. Federal benefit-cost practices described and analyzed. Relates computer and mathematical programming techniques to public expenditure analysis. *D. C. Major*

1.77 *Water Quality Control* (A)
Prereq.: 1.05
Year: G (2) 2–2–4
Application of fluid mechanics to analysis of problems in water quality and water pollution control. Emphasis is on the mixing, and dispersion of pollutants discharged into lakes, rivers, estuaries, or oceans. Development of basic mass transfer equations. Analytical and finite difference computer methods for the determination of concentration distributions in rivers and estuaries. Biochemical oxygen demand and dissolved oxygen as water quality indicators. Offshore outfalls and diffusion in the ocean. Analysis of stratified flow systems, selective withdrawal, salinity intrusion in estuaries. Thermal pollution, recirculation and heat dissipation problems associated with fossil fuel and nuclear power plants. Thermal stratification in lakes and reservoirs and its effect on water quality. Optimal design for water quality control. Computation periods and laboratory experiments. *D. R. F. Harleman*

1.78 *Water Quality Management* (A)
Prereq.: —
Year: G (2) 3–0–6
Systematic approach to the management of water quality. Identification of major issues and problem areas. Type, sources, and stochastic nature of waste materials and their effect on water bodies. Ecosystem modeling. Identification and implications of control alternatives. Relationship of water use to water quality. Regional water quality management models. Application of optimization techniques to the problems of water quality management. Dynamic models of decision processes. Basis and implications of quality standards. Institutional arrangements for planning, implementing and operating water quality management plans. Economic aspects of quality management. Effluent charges and other economic alternatives as a method for quality control. Case studies of large scale systems. (*For graduate students and advanced undergraduates. Some knowledge of economics, statistics and optimization techniques assumed. Please see instructor if there are any questions about prerequisites.*) *D. H. Marks*

1.80 *Issues for Survival*
(1.101) *(Revised: Unit change)*
Prereq.: —
Year: G (1) 4–0–5
Exploration of the major threats to man's survival, e.g. population growth, pollution of the environment, resource depletion, devastating war. Objective examination of each threat; identification of what is factually known, and what ought to be determined. Definition, to the extent possible, of absolute bounds; calculation of time in which bounds will be reached if present trends persist with only minor modifications. Consideration of major changes, in the form of technological breakthroughs or altered social attitudes, or both, which may remove or alleviate the threats. (*For advanced undergraduate and graduate students.*) *W. A. Seifert, M. J. Holley, Jr.*

1.811 *Legal and Social Aspects of Environmental Quality I* (A)
(New)
Prereq.: —
Year: G (1) 3–0–6
Social values and legal doctrines relevant to environmental quality will be reviewed. Critical analysis of the legal system and other mechanisms of social control — public agencies, legislatures, citizens groups and Nader raiders, technological peer groups, professional and industrial associations. Recent proposals for technology assessment, scientific and industrial responsibility, and ecological action explored in this context. Discussion and readings focus on several specific environmental quality problems: e.g., water pollution, noise pollution, power plants, etc. Final paper. Readings include court cases, legislation and its background, journal and review articles from several disciplines, and readings from humanistic sources. Guests invited to ensure that a full spectrum of values and issues are presented. *M. S. Baram*

1.812 *Special Problems in Environmental Law and Regulation* (A)
(New)
Prereq.: 8.11
Year: G (2) *Arr.*
Class divided up into teams of 3 to 5 students, from different disciplines. Each team selects a specific en-

vironmental problem, such as the Charles River or the Ipswich Nuclear Power Plant, and fully develops a "case study" which includes legal, technical, socioeconomic and humanistic aspects of the problem. Progress reports presented by each team to the full class and invited guests in weekly sequence for ongoing review and education. Teams encouraged to explore the real-world context for their problem area and may work closely with citizens groups or public agencies. The term ends with the submission of team reports and an effort to share and synthesize the separate research experiences in order to discern fundamental principles for responsible social action on environmental problems. Readings include court cases, legislation and its background, journal and review articles from several disciplines, and readings from humanistic sources. Guests invited to ensure that a full spectrum of values and issues are presented. (*Permission of instructor required.*) *M. S. Baram*

1.82 *Engineering and Public Policy*
(*New*)
Prereq.: —
Year: G (2) 3–0–6
Introduction to the major issue areas encountered by engineers who assume an active professional role in national policymaking and planning as well as in the development and application of technology. Exploration of some of the non-technical factors involved in solving problems at the technology/society interface. Emphasis on the area of scientific-technical advice for the Congress and the Executive Branch; including discussion of the role of the adviser, the public interest, legitimacy, and limitations. Past and present Federal policies and allocation of resources for mission-oriented R&D reviewed. These issue areas examined in relation to the concepts of integrative planning, technology assessment, and environmental management. (*For advanced undergraduates and graduate students.*)
W. H. Matthews

1.83 *Law and the Social Control of Science and Technology* (A)
(*New*)
Prereq.: —
Year: G (2) 3–0–6
Exploration and analysis of social controls on science and technology. Public and private sector controls considered include the common law and the legal system, administrative agencies. Congress, peer groups, professional and industrial associations, insurance, citizens' groups and crusaders, and education. Critical review of diverse views on the role of science and technology; studies of the impact of technology on values and law; and recent proposals for technology assessment, professional responsibility, and citizen action. Focus on selected technological developments — e.g., in nuclear energy, pesticides, transportation. Term papers or project in selected areas. *M. S. Baram*

1.961-1.965 *Special Studies in Civil Engineering* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*

1.966-1.968 *Special Studies in Civil Engineering*
Prereq.: ——
Year: G (1, 2) *Arr.*
Graduate subjects taught experimentally with special subjects offered by visiting faculty; seminars on topics of current interest. Descriptions available shortly before, or on, registration day. *Staff*

1.969 *Special Studies in Civil Engineering* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Individual study, research, or laboratory investigations at the graduate level, under faculty supervision. *Staff*

1.971 *Research in Civil Engineering*
Prereq.: ——
Year: G (1) *Arr.*

1.972 *Research in Civil Engineering*
Prereq.: ——
Year: G (2) *Arr.*

1.973 *Research in Civil Engineering*
Prereq.: ——
Year: G (S) *Arr.*
For research assistants in civil engineering in cases where assigned research is not used for thesis but is approved for academic credit by the Department. Hours arranged with research supervisor. *Staff*

1.974 *Teaching Civil Engineering*
Prereq.: ——
Year: G (1, 2) *Arr.*
For qualified graduate students interested in teaching as a career. Laboratory, tutorial or classroom teaching under the supervision of a faculty member. Students selected by interview. Total enrollment limited by availability of suitable teaching assignments. *P. S. Eagleson*

1.991-1.998 *Special Studies in Civil Engineering*
Prereq.: ——
Year: U (1, 2) *Arr.*
Undergraduate subjects, taught experimentally with special subjects offered by visiting faculty; seminars on topics of current interest. Descriptions available shortly before, or on, registration day. *Staff*

1.999 *Special Studies in Civil Engineering*
Prereq.: ——
Year: U (1, 2) *Arr.*
Individual study, research, or laboratory investigations under faculty supervision. *Staff*

2.
Mechanical Engineering

2.00 *Introduction to Engineering Systems*
Prereq.: 8.02
Year: U (2) 3–3–6
Lectures and demonstrations concerning engineering activities, engineering problems, and representative techniques employed in their solution. Presentation of concepts basic to engineering including systems, models, fields, quantities, and units. Dimensional analysis and similitude with applications to design of engineering systems, planning of tests and experiments, and plotting of engineering data. Introduction to economic selections and proportions. Discussion of engineering materials and their properties. Brief treatment and use of modern computers. Examples and student projects on case studies of historical significance, as well as problems of current interest. (*Not offered 1971–72.*)
H. M. Paynter, I. Paul

2.01 *Mechanics of Solids*
Prereq.: 8.01, 18.02
Year: U (1, 2) 4–0–8
Extension of Newtonian particle mechanics to continuous bodies of finite size. Introduction to engineering applications of the mechanics of deformable continuous media with focus on the three-dimensional requirements of force equilibrium, geometric compatibility, and material behavior. Definition of the state of stress at a point in a continuum; properties of stress. Definition of the state of

strain and of rotation at a point in a continuum and development from the displacement field; properties of strain. Development of idealized constitutive relations for materials exhibiting elastic, plastic, and viscous behavior. Applications to stress distributions and deformations in rods, beams, plates, shafts, and other simple structures of engineering interest. Emphasis on the process of constructing idealized continuous and lumped-parameter analytical models to represent actual physical situations. Use of the computer for solutions to structural problems. Concepts of stability of deformable systems. *T. J. Lardner*

2.015 *Mechanics of Solids*
Prereq.: ——
Year: G (S) 2–0–4
Review for naval officers returning for graduate study; a shortened version of 2.01. (*Primarily for students in Course* XIII-A.) *T. J. Lardner*

2.02 *Introduction to System Dynamics*
Prereq.: 8.01, 18.02
Year: U(1, 2) 3–1–8
Dynamic modeling, by linear and nonlinear lumped multiport elements, of physical systems involving the transfer and storage of matter and energy. Unified treatment of active and passive mechanical, fluid, electrical, thermal and electronic devices and systems. Concept of state and state variables. Formulation and solution of state equations by direct analysis and by electronic analog and digital computer methods. Dynamic response and stability of linear systems. Exponential excitation, system functions, pole-zero configurations and their interpretation. Generalized impedance, source equivalents and transformations. Causal and acausal graphs. Extensive use of practical examples from the various fields of engineering and applied science.
H. H. Richardson, D. N. Wormley

2.023 *Dynamic Systems*
Prereq.: ——
Year: G (S) 3–0–6
Review for naval officers returning for graduate study; a shortened version of 2.02. (*Primarily for students in Course* XIII-A.) *H. H. Richardson*

2.03 *Dynamics*
Prereq.: 2.02, 18.03
Year: U (1, 2) 3–0–6
Formulation of dynamic equations of motion in mechanical, electrical, and fluid systems by direct and variational methods. Three-dimensional kinematics, inertia tensor, rigid body dynamics. Electrical networks and electromechanical transducers. Treatment of lumped-parameter and continuous systems. Applications to vibrations, wave motions, and frequency response of transducers. *S. H. Crandall*

2.032 *Advanced Mechanics* (A)
Prereq.: 2.03 or 2.06
Year: G (1) 3–0–9
The foundations of dynamics leading to Lagrange's equations and Hamilton's principle. Gyroscopic effects in mechanical systems. Analysis of the stability of steady motions. Self-excited vibrations and non-linear vibrations. *J. P. Den Hartog*

2.06 *Vibrations*
Prereq.: 2.03
Year: U (2) 3–0–6
Analysis of vibrations in multidegree-of-freedom systems. Characterization of physical systems by mathematical models using matrices or partial differential equations. Concept of resonance and its engineering implications. Free vibrations and natural mode theory. Response of such systems to steady-state single-frequency excitation, to transient pulses, and to random vibration. Implementation of numerical techniques using a digital computer. Case studies of vibration analysis in machine and instrument design and in noise reduction.
A. D. Pierce

2.060J *Principles of Acoustics* (A)
(Same subject as 13.81J, 16.081J)
Prereq.: 2.03 or 13.80 or 16.01
Year: G (1) 3–0–9
Derivation of acoustic equations: energy, intensity, speed of sound, acoustical impedance. Generation of sound: fundamental source terms, expansions in multipoles, interpretation of forces, stresses, as multipoles. Sound generation by solid bodies in contact with fluid; airfoils, vibrating surfaces, radiation impedance. Sound propagation: atmosphere acoustics, ray theory, refraction, absorption, scattering. Non-ideal behavior, finite amplitude effects. Sound in finite spaces, propagation in ducts and rooms. Sound attenuation in porous materials. Sound in rooms: wave and ray theory, reverberation and decay of energy. Transmission of sound between coupled spaces. Demonstrations of measuring and analysis techniques and basic phenomena.
R. H. Lyon, P. Leehey, S. E. Widnall

2.061 *Random Vibration* (A)
Prereq.: 2.03, 18.075
Year: G (1) 3–0–9
Introduction to mathematical description of stochastic processes. Impulse response and frequency response of linear time-invariant dynamic systems. Autocorrelation and spectral density of stationary response. Crossing rates and distributions of peaks and maxima. Markov processes and Fokker-Planck equation. Pulse processes triggered by Poisson random counters. Application to vibration problems in vehicles subject to wide-band random excitation. Measurement and simulation of random vibration. Failure under random loading due to fatigue and due to first crossing of a threshold.
S. H. Crandall

2.062 *Wave Propagation* (A)
Prereq.: 2.03, 18.075
Year: G (2) 3–0–9
Wave concepts in applied mechanics with examples chosen from elasticity, acoustics, magnetohydrodynamics, and related subjects. Phase and group velocities, dispersion, energy density and intensity. Transmission, absorption, refraction, diffraction, and scattering of waves. Waves in inhomogeneous media, the WKB and eikonal approximations, ray theory versus full wave theory. The Lamb-Cagniard-Pekeris method. Nonlinear waves, waves in moving or random media. Generation of waves during impact, surface waves, Rayleigh waves, Lamb's problem. Guided waves, normal modes, waves in stratified media. *A. D. Pierce*

2.063 *Sound and Structural Vibration* (A)
Prereq.: 2.03, 18.075
Year: G (2) 3–0–9
Derivation of acoustic wave equation, small-amplitude approximations. Acoustic intensity and energy density. Generation of sound. The statistical theory of room acoustics. Sound absorption and reverberation time. Direct and reverberant sound fields. Vibration of thin beams and plates. Radiation of sound from vibrating panels, fluid loading effects, critical frequency. Statistical theory of vibrations, response of many-degree-of-freedom systems. Coupling between sound fields and structural vibration; radiation resistance and generalized force. Modal coupling by liquid loading. Estimation of average response and variations. (*Alternate years. Not offered 1971–72.*) *R. H. Lyon*

2.065J ***Flow Noise*** **(A)**
(Same subject as 13.84J)
Prereq.: 1.05 or 2.201 or 16.02; *2.061* or *6.571*
Year: G (2) 3–0–9
Lighthill's theory of aerodynamic sound. Source, dipole and quadrupole radiation. Sound radiated from subsonic and supersonic jets. Curle's theory of the influence of solid boundaries. Aeolian tone, edge tone, feedback and resonator effects. Turbulent boundary layer noise: fluctuating wall pressure statistics, structural response and radiation, eddy Mach wave radiation. Comparison of theory with experimental results. Laboratory demonstrations. *P. Leehey*

2.066 ***Noise and Vibration in Transportation Systems***
Prereq.: 1.03 or 2.02 or 16.01; 1.05 or 2.201 or 16.02
Year: G (2) 3–0–9
Survey of noise and vibration associated with surface and aerospace transportation systems. Properties of vehicle and system construction, and those characteristics of the atmosphere and the earth affecting the transmission, spreading and absorption of noise. Effects of noise and vibration on individuals and community reaction. Discussion of noise from engines, propellers, boundary layers, shock waves, gears, impacts, wheels. Structural damage due to vibration and human reactions to noise. (*Alternate years. Offered 1971–72.*) *R. H. Lyon*

2.071 ***Introduction to Solid Mechanics***
Prereq.: 2.01, 2.30
Year: U (1) 3–0–6
Senior or graduate elective introduction to fundamentals of modern solid mechanics. Review of stress, equilibrium, displacement, strain, compatibility, theorem of virtual work. Laws of elasticity; applications of theorems of potential energy, complementary energy, Castigliano, and reciprocity. Introduction to plasticity, yield conditions, associated flow rule. Limit analysis; elements of plane deformation and slip line theory.
J. H. Williams, Jr.

2.072 ***Solid Mechanics — Introduction to Mechanics of Continuous Media*** **(A)**
Prereq.: ——
Year: G (1) 3–0–9
Geometric foundations; conservation laws of mechanics. Constitutive relations for finite elastic deformation, viscous flow, viscoelasticity, plasticity. Basic theorems governing each area of material behavior — e.g. potential and complementary energy theorems of elasticity, correspondence theorem of viscoelasticity, limit theorems of ideal plasticity. Studies of critical problems in each area. *W. J. Shack*

2.073 ***Solid Mechanics — Plasticity and Anelastic Deformation*** **(A)**
Prereq.: 2.071 or 2.072
Year: G (2) 3–0–9
Microscopic and macroscopic aspects of plastic deformation. Yield conditions, and associated flow rule. Studies in fully plastic deformation; limit theorems. Plane strain and slipline theory. Antiplane elasto-plastic strain. High temperature creep and deformation theory plasticity. Strain hardening in stability and uniqueness. Studies of role of plasticity in frictional contact, machining, fracture, geophysics. *T. J. Lardner*

2.074 ***Solid Mechanics — Elasticity***
Prereq.: 2.072, 18.076
Year: G (1) 3–0–9
Solution of elasticity problems with emphasis on analytical methods. Topics: review of basic field equations; solution of plane problems by complex potentials; application of integral transforms to boundary value problems in elasticity; application of singular integral equations, etc. (*Alternate years. Not offered 1971–72.*) *W. J. Shack*

2.075 ***Seminar in Applied Mechanics*** **(A)**
Prereq.: ——
Year: G (1 or 2) *Arr.*
Content varying from year to year depending upon current research activities in applied mechanics.
T. J. Lardner

2.083 ***Applied Elasticity*** **(A)**
Prereq.: 2.01
Year: G (2) 3–0–9
Review and development of equations of elasticity; clear distinction between linear and non-linear elasticity. Strain energy theorems, reciprocal theorems, stress functions. Two-dimensional problems, classical methods, complex variable techniques. Experimental methods. Finite element technique applied to two- and three-dimensional problems. Axisymmetric problems, torsion. Introduction to plate bending, axisymmetric linear, and non-linear shell theory, buckling. Survey of numerical methods for solution of elasticity and shell problems.
T. J. Lardner

2.092 ***Methods of Engineering Analysis*** **(A)**
Prereq.: 18.075
Year: G (2) 3–0–9
Study of the nature of complex problems in engineering analysis and of the means of obtaining practical solutions. Formulation of mathematical models for complex physical situations and the organization of computational programs for their solution. Examples chosen from mechanics, hydraulics, heat transfer, elasticity, compressible flow, etc. Numerical methods including iteration, relaxation, finite difference, and variational methods. *S. H. Crandall*

2.095 ***Special Problems in Applied Mechanics*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
Individual study of advanced subjects under staff supervision. Arrangement of each program to suit the particular requirements of the student and interested members of the staff, subject to the approval of the instructor in charge. *S. H. Crandall*

2.10 ***Elementary Programming and Machine Computation***
(*Revised: Unit change*)
Prereq.: ——
Year: U (1, 2) 2–2–5
Elements of automatic computation with emphasis on digital machines and use of FORTRAN programming language. Reduction of physical phenomena to mathematical models and solution of resulting equations by numerical methods using digital computers, particularly the Department's IBM 1130. Programming problems drawn from fields of current interest to students, including basic physics and mathematics. "Introduction to Analog Computation." *D. P. Adams, D. P. Garg*

2.101 ***Computer Models of Physical and Engineering Systems I***
Prereq.: ——
Year: U (1, 2) 3–3–6
Elements of automatic computation with emphasis on digital computers and FORTRAN as a programming language. Extensive laboratory experience using the 1130 computer. Aspects of the reduction of physical and engineering systems to simplified physical and mathematical models; representation using linear graphs, networks, logical operators, and reticular geometry. Manipulation of the resulting models using digital algorithms. Examples drawn from fields primarily of

interest to scientists and engineers, with some attention to styles of problem solving. (*Enrollment limited.*)

H. M. Paynter, R. Kaufman

2.11 *Elementary Programming and Machine Computation*
(*New*)
Prereq.: ——
Year: U (1, 2) 2–2–2
A shortened version of 2.10. The project hours at the end have been deleted. Otherwise the material is identical, class and laboratory hours are the same.

D. P. Adams, D. P. Garg

2.14 *Control System Principles*
Prereq.: 2.02, 2.201
Year: U (1) 3–1–8
Introduction to the analysis and synthesis of feedback systems. Functional description of linear and nonlinear systems. Block diagrams and signal flow graphs. State-space representation of dynamical systems. Transient response using convolution integral and computational techniques. Frequency response methods. Root locus and fluid flow analogy. Performance indices and error criteria. Controller realization. Examples of pneumatic, hydraulic, mechanical and electromechanical control systems. *H. M. Paynter, D. P. Garg*

2.141 *Modeling and Simulation of Dynamic Systems* (A)
Prereq.: 2.151
Year: G (2) 3–0–9
Modeling of complex linear and nonlinear energetic dynamic engineering systems. Emphasis on subdivision into simple multiport elements and representation by the bond graph language. Field lumping. Analytic and graphical reductions. Analog, digital and hybrid simulation with use of the IBM 1130-EAI 680 facility. Examples including mechanisms, electromechanical transducers, electric and fluid circuits, and thermal systems.

H. M. Paynter

2.151 *Advanced System Dynamics and Control* (A)
Prereq.: ——
Year: G (1) 3–0–9
Analytical and graphical descriptions of state-determined dynamic physical systems; time and frequency domain representation; system characteristics: controllability, observability, stability; linear and nonlinear system responses. Modification of system characteristics utilizing control techniques; feedback, feedforward and compensation techniques; optimization with respect to a quadratic performance index; Pontryagin's Maximum Principle. Emphasis on application of techniques to physical systems. (*Knowledge of undergraduate dynamics is a prerequisite.*)

D. N. Wormley

2.152 *Modern Control Theory and Applications* (A)
Prereq.: 2.151
Year: G (2) 3–0–9
Formulation of optimal control problems from engineering situations. Analytical and computational techniques for solving optimization problems; dynamic programming, calculus of variations, maximum principle. Characteristics of optimal systems; bang-bang systems, optimal linear systems. Control with some inaccessible state variables. Examples of engineering systems involving control of force and motion, thermal effects, and industrial processes. *D. E. Whitney*

2.154 *Dynamics and Control of Rotating Machine Systems* (A)
Prereq.: ——
Year: G (1) 3–0–9
Unified study of the dynamic behavior and control of systems of interconnected rotating machines, as typically used for power and propulsion, and for instrumentation and control. Modeling and simulation of *electromachines* (AC and DC motors and generators), *turbomachines* (pumps, compressors, fans, blowers, screws and steam, gas and hydraulic turbines) and *reciprocmachines* (i.e. engines, p.d. pumps, steam engines), together with their energy sources, power modulators and control equipment. Detailed investigations and case studies of a number of particular machine systems. Subject intended for qualified students concerned with plant utilities and services, test facilities, power and propulsion systems, as well as for those interested in automatic control applications. *H. M. Paynter*

2.155 *Analysis and Design of Nonlinear Control Systems* (A)
Prereq: 2.151 or 6.60 or 16.31
Year.: G (2) 3–0–9
Introduction to nonlinear characteristics. Analytical and numerical methods for the solution of nonlinear systems. Discussion of equilibrium states and equilibrium zones. State-plane portraits using graphical and computation techniques. Brief discussion of Krylov and Bogoliubov asymptotic methods. Discussion of theory and application of the describing function methods to nonlinear system design. Jump phenomenon and subharmonic generation. Analysis of system stability using Lyapunov methods. Concepts of stability in the large including Aizerman and Kalman conjectures. Presentation of Popov, circle and other frequency domain stability criteria and their use in system design using digital computers. Discussion of sensitivity analysis and stability of forced systems. Statistical concepts in nonlinear systems. *D. P. Garg*

2.161 *Analog/Digital Computation for Instrumentation and Control* (A)
Prereq.: ——
Year: G (2) 3–0–9
Use of analog, digital, and hybrid computer for processing experimental data. Digital data logging, signal conditioning, and on-line system identification. Effective use of graphic output devices. Functional approximation and synthesis. Computer hardware, including differential amplifiers, comparators, D/A switches, gates, flip flops, A/D and D/A converters. Use of simple analog hardware for direct instrumentation and control. Undergraduate background in mathematics, dynamics, control theory, elementary circuit theory and digital computer programming required.

H. M. Paynter, R. S. Sidell

2.171 *Fluid Power Controls and Fluidics* (A)
Prereq.: 2.14, 2.201
Year: G (1) 3–3–6
Theory and design of hydraulic and pneumatic control systems and components and their applications in aerospace, military, industrial, and other fields. Problems in the control and measurement of pressure, flow, speed, position, force, and other mechanical quantities. Application of basic principles to component and system design. Use of schematic and block diagrams. Solution of typical fluid power control system problems including non-linearities with aid of computers. Current development in the field of fluidics. Design and application of pure fluid amplifiers, logic elements and systems.

S. Y. Lee

2.173 ***Instruments for Measurement and Control*** **(A)**
Prereq.: 2.03
Year: G (2) 3–0–6
Presentation of basic concepts and principles important to the design and use of instruments for measuring various physical quantities. Analysis of dynamic behavior of instruments as elements in complex control systems. Detailed presentation of typical examples of digital as well as continuous types of instruments and control system components. Discussion of problems connected with signal amplification, remote indication, transmission and storage. *S. Y. Lee*

2.18 ***Man-Machine Systems*** **(A)**
Prereq.: ——
Year: G (1) 3–3–6
Models of man as a decision and control component in a physical system. Transmission and processing of information through the human organism. Quasi-linear models of the human operator in closed-loop control systems. Bayesian and other probabilistic models of human decision making and signal detection. Weekly laboratory experiments keyed to the theoretical presentations. Design of displays and controls for vehicles and man-computer interaction. Design exercises drawn from transportation, remote manipulation, computer-aided instruction and similar fields. (*Permission of instructor required.*) *T. B. Sheridan*

2.181J ***Life Support and Physiological Modeling in Manned Systems*** **(A)**
(Same subject as 16.43J)
Prereq.: ——
Year: G (2) 3–3–6
Environmental control and physiological characteristics of man as related to unusual acceleration, thermal, atmospheric, radiation or other stresses. Advanced models of sensory and neuromuscular systems. Lectures and student critique of current research. Design of systems involving man. Student projects in small groups throughout the term. (*Permission of instructor required.*) *T. B. Sheridan, L. R. Young*

2.191J ***Special Studies in Systems Engineering*** **(A)**
(Same subject as 1.16J, 6.604J, 13.47J)
Prereq.: ——
Year: G (2) 2–4–6
Development of the basic techniques employed in planning and design of complex systems through involvement in specific projects. Entire class works on a single project which changes each year. Specific background developed through lectures dealing with the selected project. Subgroups of class work on portions of problem and coordinate results through class meetings. Results presented formally at end of term. Recent projects included study of issues of vital importance to the long-range well being of New England, including electric power production, recreational opportunities, air and water pollution, and a study of the potential for expanding industrial and agricultural activity in Saudi Arabia based upon utilization of natural gas now being wasted. *R. E. Stickney, W. W. Seifert, E. G. Frankel*

2.201 ***Fluid Mechanics***
Prereq.: 8.01, 18.03
Year: U (1, 2) 4–0–8
Introduction to the dynamics of incompressible fluids. Equations of mass conservation and motion for inviscid and viscous flows. Bernoulli equation. Momentum theorems. Applications to engineering problems. Potential flow theory. Navier-Stokes equations. Poiseuille flows. Couette and Rayleigh problems. Laws of similitude. Pipe friction. Boundary layer theory. Elements of turbulent flows. Separation and drag. Open channel flows. *M. Y. Jaffrin*

2.203 ***Applications in Fluid Mechanics***
Prereq.: 2.201
Year: U (2) 3–0–6
Application of fluid mechanics to specific problems in areas of current interest, such as air and water pollution, biomedical flows, compressible flows and combustion, flows with suspended particles, fluid machinery, etc. Selection of some topics done with class participation.
A. A. Sonin

2.23 ***Environmental Pollution Seminar***
Prereq.: ——
Year: U (1) 3–0–6
A study of the problems of air and water pollution from many points of view: scientific, engineering, management, economic, and political. Selection of topics from the following: global pollution of air and water, urban air pollution, pollution from automobiles and power plants, politics and economics of pollution, solid and liquid waste disposal, pesticides, thermal pollution, eutrophication of lakes, noise. Content and format varying from year to year. Field trips and guest lecturers. An Undergraduate Policy Seminar for juniors and seniors. *J. B. Heywood, J. A. Fay*

2.25 ***Advanced Fluid Mechanics*** **(A)**
Prereq.: 2.201, *18.075*
Year: G (1) 3–0–9
Survey of principal concepts and methods of fluid dynamics. Statics. Fluid kinematics. Continuity momentum, and energy relations for continuous fluids. Vorticity dynamics. Circulation. Kelvin's and Helmholtz' theorems. Joukowsky and Schwarz-Christoffel transforms. Theory of lift. Navier-Stokes equations for viscous fluids and applications. Lubrication theory. Boundary layer theory. Introduction to turbulence. Drag.
C. F. Dewey, M. Y. Jaffrin

2.271 ***Compressible Fluid Mechanics*** **(A)**
Prereq.: 2.201, 2.403, 18.075
Year: G (2) 3–0–9
Survey of gas dynamics. Fundamentals of wave phenomena. One-dimensional steady flow, with effects of area change, friction, heat transfer, chemical reaction. Shock waves. Supersonic diffusers and wind tunnels. Subsonic high-speed flow. Supersonic flows. Unsteady flows and waves in ducts. *A. A. Sonin*

2.272 ***Viscous and Turbulent Flows*** **(A)**
Prereq.: 2.25
Year: G (2) 3–0–9
Viscosity and dissipative phenomena. Navier-Stokes and energy equations, their formulation, properties, and some exact solutions. Creeping flows at low Reynolds numbers; flows through porous media. Laminar boundary layers and their solution; compressibility effects. Laminar stability and transition to turbulence. Turbulent diffusivity, length scales, and transport of momentum by Reynolds stresses. Free and bounded turbulent shear flows including wakes, plumes, pipe flows and boundary layers. *R. F. Probstein*

2.273 ***Molecular Fluid Mechanics*** **(A)**
Prereq.: 2.201, *18.075*
Year: G (1) 3–0–9
Introduction to fluid flows from the molecular point of view, with emphasis on dilute gases. Molecular models and elementary kinetic theory of gases including pressure, mean free-path and transport phenomena. Gas-dynamic regimes. Equilibrium kinetic theory, Maxwellian velocity distribution, collisions and relaxation. Collisionless gas and interaction of a flowing gas with solid surfaces. Approach to thermodynamic equilibrium in fluid flows. Formulation of continuum conservation laws beginning with particle concepts. Transfer and model kinetic equations and their application to

low-density flows. Dense gases and liquids: equilibrium theory and elementary kinetic theory of transport phenomena. (*Not offered 1971–72.*)

R. F. Probstein, A. A. Sonin

2.275 *Turbomachinery Design* (A)
Prereq.: 2.202 or 2.25
Year: G (2) 3–0–9
Momentum transfer in turbomachines. Axial compressors and turbines: design considerations, cascade aerodynamics including effects of viscosity and compressibility, three-dimensional flow, performance limitations; radial machines; hydraulic pumps and turbines; cavitation. *D. G. Wilson*

2.277 *Biomedical Fluid Mechanics* (A)
Prereq.: 2.201
Year: G (2) 3–0–9
Fluid mechanics of the circulatory, pulmonary and urinary systems, with emphasis on engineering models and their utilization in describing in vivo observations. Analytic description of the analog models of the circulation, wave propagation in arteries, peristaltic pumping and diffusive transport across membrane walls. Fluid-mechanical description of diagnostic techniques and extracorporeal devices. Topics: hemodialysis (as related to artificial kidneys), heart-assist devices, extracorporeal oxygenators and flow and pressure measurements techniques for human applications.

C. F. Dewey, M. Y. Jaffrin

2.281 *Reacting Gas Dynamics* (A)
Prereq.: 2.201 or 16.02 or 16.03
Year: G (1) 3–0–9
Fundamental treatment of problems in non-equilibrium gas dynamics involving simultaneous occurrence of chemical reaction and transport of mass, momentum and energy. Applied chemical kinetics. Conservation equations considering chemical reaction and multispecies diffusion. Relaxation phenomena. Method of characteristics for non-equilibrium flows. Acoustic waves, shocks, flames, detonations; their propagation and structure. High-temperature gas flow in jets, nozzles, hypersonic boundary layers. Chemical effects on turbulence. Engineering applications. *T. Toong*

2.282 *Combustion* (A)
Prereq.: 2.201 or 16.02 or 16.03
Year: G (2) 3–0–9
Comprehensive treatment of combustion principles. Combustion instability, linear and non-linear mechanisms, interactions of acoustic waves with non-uniform and fluctuating reacting flows. Laminar and turbulent flames. Exothermic hypersonic flows. Supersonic combustion. Reacting boundary layers with ablation. Electromagnetic effects. Fire research. *T. Toong*

2.283 *Fluid Physics of Pollution* (A)
Prereq.: 2.201
Year: G (2) 3–0–9
Application of fluid physics to problems of air and water pollution. Properties and sources of air pollutants. Characteristics of atmospheric boundary layer. Turbulent mixing and diffusion of pollutants. Effects of thermal stratification on flow and mixing in air and water. Thermodynamics and kinetics of combustion processes. Oil pollution. *D. P. Hoult*

2.284 *Desalination and Water Purification* (A)
Prereq.: 2.201, 2.403
Year: G (1) 3–0–9
The water purification problem and its economics. Principal saline water conversion processes and industrial water purification methods including waste recovery. The fluid and thermodynamics, physics and chemistry of distillation including multistage flash and vapor compression; crystallization including vacuum freezing, secondary refrigerant freezing and hydrate formation; membrane processes including electrodialysis and reverse osmosis; chemical-physical processes including ion exchange, precipitation, and adsorption. Other methods. Some engineering and design considerations of selected saline water conversion plants and industrial purification units. *R. F. Probstein, A. A. Sonin*

2.29 *Advanced Topics in Fluid Mechanics* (A)
Prereq.: 2.25
Year: G (1 or 2) *Arr.*
Selected subjects relating to fluid mechanics. No formal lectures; assigned reading and special problems arranged on an individual basis in consultation with instructor.

J. A. Fay, R. F. Probstein, A. H. Shapiro, T. Toong

2.291 *Research in Combustion* (A)
Prereq.: 2.281 or 2.282 or 10.70 or 16.052
Year: G (1 or 2) *Arr.*
Selected theoretical or experimental problems in combustion and high-temperature gas dynamics, including radiative and electromagnetic effects. Work arranged on an individual basis in consultation with instructor.

T. Toong

2.30 *Mechanical Behavior of Materials*
Prereq.: 2.01, 3.141
Year: U (1, 2) 3–2–4
Subject planned to develop competence in materials behavior and application: materials selection, failure diagnosis and cure, and manufacturing limitations. Content includes: cost, availability and characteristics of engineering materials; elastic behavior; plastic behavior; thermoviscous behavior; fracture; corrosion and wear characteristics; and the effects of processing and environment. Laboratory projects emphasize materials applications. *N. P. Suh, A. P. L. Turner*

2.301 *Advanced Mechanical Behavior of Materials* (A)
Prereq.: 2.30
Year: G (1) 3–0–9
Emphasis on the quantitative prediction of mechanical behavior: plastic, viscous, and plastic deformation; crack formation and growth under monotonic and repeated loading; wear and friction; composite materials. McClintock and Argon, *Mechanical Behavior of Materials*, and selected readings from the current literature.

F. A. McClintock

2.304 *Physics of Strength and Plasticity* (A)
Prereq.: 2.30, 3.141
Year: G (2) 3–0–9
Molecular mechanisms of rubber-elasticity, viscosity, viscoelasticity and plasticity. Deformation mechanisms in crystalline materials; theories of yield stress, yield phenomena, strain hardening, transient and viscous creep. Types of fracture and theories of fracture; fatigue. *E. Orowan*

2.332 *Dislocation Theory* (A)
Prereq.: 2.01; 2.30 or 3.141
Year: G (1) 3–0–9
Derivation from elastic theory of the properties of dislocations in isotropic and anisotropic materials. Interactions between dislocations and other imperfections. Dislocations in particular crystal structures. Applications to theories of yield points, solution hardening, work hardening, creep and fracture. (*Not offered 1971–72.*)

A. S. Argon

2.34 ***Physics and Engineering Use of Adhesives*** **(A)**
Prereq.: ——
Year: G (2) 1–0–3
Peel strength and fracture strength; bond strength and joint strength. Mechanics of joint failure; chemical factors and bond strength. Structural adhesives; simultaneous use of adhesives and fasteners. Adhesives as matrix of composite materials. *E. Orowan*

2.398 ***Research in Materials***
Prereq.: 2.30
Year: U (1 or 2) *Arr.*
Experimental or theoretical research on mechanical behavior (fracture, plasticity, etc.) of metallic or nonmetallic materials. *Staff*

2.399 ***Research in Materials*** **(A)**
Prereq.: 2.30
Year: G (1 or 2) *Arr.*
Experimental or theoretical research on mechanical behavior (fracture, plasticity, etc.) of metallic or nonmetallic materials. *Staff*

2.402 ***Thermodynamics***
Prereq.: ——
Year: G (1) 4–0–8
Heat, work, the laws of thermodynamics. Entropy and absolute temperature. Properties of liquids, vapors, perfect gases and mixtures of gases and vapors. Applications to heat engine cycles. (*Primarily for selected officers of the U.S. Navy and Coast Guard.*) *J. L. Smith*

2.403 ***Thermodynamics***
Prereq.: 8.02, 18.03
Year: U (1, 2) 4–0–8
Classical thermodynamics with emphasis on the relation of abstract concepts to physical situations. Work and energy for pure conservative and pure dissipative systems. Heat, temperature, first law of thermodynamics. Pure thermal systems. Equilibrium and reversibility. Thermodynamically coupled systems, second law of thermodynamics, thermodynamic temperature, entropy. Bulk flow and open systems. The pure substance, solid, liquid and gaseous phases. Mixtures of gases. Applications to engineering systems. *J. L. Smith*

2.404 ***Introduction to Molecular Thermodynamics***
(*Revised: Unit change*)
Prereq.: 2.403 or 2.42
Year: U (2) 3–0–9
Elementary kinetic theory of gases: molecular velocity distribution; kinetic definitions of pressure and temperature; mean free path theory of transport of mass, momentum and energy. Elementary quantum mechanics: development of the Schrodinger equation; wave functions and their properties; quantum mechanics of simple particles, harmonic oscillator, and rigid rotator; formulation of energy states of diatomic gases. Introductory statistical mechanics: population of energy states; Boltzmann, Bose-Einstein, and Fermi-Dirac statistics; equilibrium populations; partition functions; statistical mechanical interpretation of equilibrium thermodynamic properties and the first and second laws of thermodynamics; applications to monatomic and diatomic gases. *E. G. Cravalho, J. P. Appleton*

2.41J ***Thermodynamics of Power Systems***
(Same subject as 13.25J)
Prereq.: 2.403
Year: U (2) 3–0–9
Application of thermodynamics to power-generating systems. Thermodynamics of combustion and mixtures of gases. Analysis of Carnot, Rankine, Brayton, Otto, and Diesel cycles. Availability. Performance of modern steam plant, gas turbines, internal combustion engines, refrigeration plant, marine power plant. Economic and pollution aspects. New power generation concepts, such as fuel cells, MHD, vapor engines. The class will be split into several groups towards the end of the term to consider some of these topics in more detail. *J. B. Heywood, A. D. Carmichael*

2.412 ***Heat Engineering***
Prereq.: 2.402, 2.54
Year: G (2) 3–3–6
Applications of fundamental principles of thermodynamics, fluid mechanics, and heat transfer. Design of power and propulsion cycles and processes, and the associated fluid machinery and heat transfer equipment for nuclear and fossil fuels heat sources. Economic and logistic optimization, off-design performance, and control problems of power equipment. Laboratory projects on related topics. (*Primarily for selected officers of the U.S. Navy and Coast Guard.*) *J. L. Smith*

2.42 ***Elements of Classical and Statistical Thermodynamics***
Prereq.: 8.01, 18.02
Year: U (2) 4–0–8
First and second laws applied to simple systems through the classical concept of state: heat, work, energy, reversibility, entropy, availability, equilibrium, thermodynamic temperature, chemical reactions, chemical potential, chemical equilibrium. The system as an assembly of molecules behaving reversibly. Mechanical state, work of identification of mechanical state, ensemble representation of information, irreversibility and loss of information, entropy of a system represented by an ensemble, application of the criterion of equilibrium to microcanonical and canonical ensembles, a few examples. (*Not offered 1971–72.*) ——

2.451 ***Intermediate Thermodynamics*** **(A)**
Prereq.: 2.403 or 3.00 or 5.60 or 6.08 or 8.08 or 16.001
Year: G (1) 3–0–9
Development of fundamentals of classical thermodynamics, emphasizing physical significance of the first and second laws. Logical progression from the concepts of work and equilibrium to those of heat, available work, entropy, and temperature. Closed and open (flow) systems, single and multiphase systems, pure and multicomponent substances. Chemical equilibrium of multiphase, multicomponent systems: Gibbs and Helmholtz free energies, chemical potential, equilibrium constant or perfect gas mixtures. Fundamental equation of thermodynamics, equations of state, Maxwell relations. Problems relating to power generation and energy conversion, combustion and propulsion, chemical processes, and metallurgy. *R. E. Stickney*

2.452 ***Advanced Thermodynamics*** **(A)**
Prereq.: 2.451
Year: G (2) 3–0–9
Seminar on advanced topics in thermodynamics. Topics dependent on specific interests of class. Examples: thermodynamics of complex systems, such as surfaces and interfaces, plasmas, superfluids, electrolytes, or biological systems; thermodynamics of systems having negative temperatures (e.g., masers and lasers); thermodynamics and information theory; stability and fluctuations; thermodynamics of rate processes (irreversible processes). *R. E. Stickney, G. N. Hatsopoulos*

2.453 ***Advanced Projects in Heat and Thermodynamics*** **(A)**
Prereq.: 2.451
Year: G (1, 2) *Arr.*
Selected subjects of current interest in thermodynamics, mass transfer, and heat transfer. No formal lectures; assigned reading or experiment arranged on an individual basis in consultation with instructor. *W. M. Rohsenow, J. C. Keck*

2.461 ***Equilibrium Statistical Mechanics*** **(A)**
Prereq.: 2.403
Year: G (1) 3–0–9
Classical mechanics of systems of particles; the phase space description and Liouville's theorem. Quantum mechanics of simple systems; the energy states of atoms and molecules. Interatomic potentials and molecular forces. Gibbsian statistics and the canonical distribution. Bose-Einstein, Fermi-Dirac, and Boltzmann statistics. Quantum mechanical and classical partition functions. Perfect gases and perfect gas mixtures. Ortho and para hydrogen. Real gases and the Virial expansion. Chemical and phase equilibrium. Thermodynamic properties of crystals; Einstein and Debye theories. Thermionic emission. Thermal radiation. Magnetization. *J. P. Appleton, J. C. Keck*

2.462 ***Nonequilibrium Statistical Mechanics of Gases*** **(A)**
Prereq.: 2.461
Year: G (2) 3–0–9
Survey of transport properties and reaction kinetics of gases and plasmas. Diffusion, viscosity, heat transfer, and electrical conductivity. Translational and rotational relaxation. Master and diffusion equations for vibrational and electronic excitation. Generalized phase space theory of reaction rates; dissociation, ionization and exchange reactions. Emission and absorption of radiation. Theory of line broadening. Radiation transport. Applications to power generation and conversion, combustion, thermionics, lasers, gas surface interactions, atmospheric physics, and air pollution.
J. C. Keck, J. P. Appleton

2.47J ***Quantum Thermodynamics*** **(A)**
(Same subject as 22.58J)
Prereq.: 2.451, 2.461, 8.04
Year: G (2) 3–0–9
Theory of quantum thermodynamics derived from the general postulates of quantum mechanics and the second law. Definitions of state, changes of state described by unitary transformations in time, equilibrium state, stable state, and reversible processes. Definition and determination of available work and entropy for all systems and all states. Nature of irreversibility and its relation to field theory. Derivation of the general canonical distribution. Applications to bosons and fermions, and to ideal and perfect substances in stable states. Applications to general rate processes and to linear irreversible processes in gaseous, liquid, and solid phases.
G. N. Hatsopoulos, E. P. Gyftopoulos

2.50 ***Heat Transfer***
Prereq.: 2.201, 2.403
Year: U (1) 3–0–6
Heat and momentum transfer for laminar and turbulent boundary layer flow and fully developed flow of fluids. Conduction, radiation, heat exchanger design, boiling and condensation. *W. M. Rohsenow*

2.52 ***Biomedical Heat and Mass Transfer***
Prereq.: 2.50 or 2.51
Year: U (2) 3–0–9
Heat transfer in biological tissue. Determination of thermodynamic and transport properties of tissue. Metabolic heat removal; calorimetric measurements of living specimens. The role of heat transfer in cause and treatment of disease. Thermodynamic and heat transfer processes in implantable power sources for circulatory assist devices. Ultrasonic surgery; mechanism of lesion formation in nervous tissue. Cryobiology; effects of freezing and thawing processes on cell viability; organ, tissue, and blood storage. Thermography and its application as a diagnostic device. Mass transfer in biological systems and in various types of blood oxygenators. *E. G. Cravalho, B. B. Mikic*

2.53 ***Problems in Heat***
Prereq.: 2.403
Year: U (1 or 2) *Arr.*
Selected experiments with laboratory investigation of problems connected with the industrial application of heat, such as thermal conductivity, thermal expansion, specific heat, ceramics, etc. *W. M. Rohsenow*

2.54 ***Heat Transfer***
Prereq.: ——
Year: G (2) 3–0–3
Fundamentals of conduction, radiation of heat, and the effects of convection, with applications to problems arising in practice. *(Primarily for selected officers of the U.S. Navy and Coast Guard.)* *W. M. Rohsenow*

2.55 ***Advanced Heat Transfer*** **(A)**
Prereq.: 2.403, *18.075*
Year: G (1) 3–0–9
Review of analogies among heat, mass, and momentum transfer. Free and forced convection from theoretical and experimental viewpoint for laminar and turbulent flows in ducts and over flat plates and blunt bodies. Heat transfer coefficients at high velocities and in rarefied gases. Heat transfer-friction relationship in heat exchangers. Film and dropwise condensation. Boiling with forced and natural convection. Radiative heat transfer; heat transfer between surfaces, in absorbing media.
W. M. Rohsenow

2.56 ***Conduction Heat Transfer*** **(A)**
Prereq.: 2.403, *18.075*
Year: G (2) 3–0–9
Steady-state and transient-state heat conduction and mass diffusion for various constant and variable boundary conditions. Solution of differential equations in rectangular, cylindrical and spherical coordinate systems by formal mathematics. Various approximated methods, integral method, finite difference technique, analogies, fixed and floating random walk methods. Moving boundaries; problems in freezing and melting. Thermal stresses resulting from non-uniform temperature distribution. Thermal contact resistance. *B. B. Mikic*

2.57J ***Two-Phase Flow and Boiling Heat Transfer*** **(A)**
(Same subject as 22.36J)
Prereq.: 22.311, 22.312
Year: G (2) 3–0–9
Phase change in bulk stagnant systems. Kinematics and dynamics of adiabatic two-phase flow. Dynamics and thermodynamics of forced-convection two-phase flow with boiling and/or evaporation. Thermal and hydrodynamic stability of two-phase flows. Associated topics, such as condensation and atomization. Both water and liquid metal applications considered under each topic where data exists. *W. M. Rohsenow, N. Todreas*

2.58 ***Radiation Heat Transfer*** **(A)**
Prereq.: 2.42 or 2.403; *18.075*
Year: G (1) 3–0–9
Basic laws of thermal radiation. Radiation properties of solids; electromagnetic theory, dispersion, experimental results. Radiant interchange among surfaces separated by a transparent media; non-gray surfaces, specularly reflecting surfaces. Radiation properties of gases. Radiant interchange through absorbing, emitting and scattering media; radiative equilibrium, combined radiation and conduction; combined radiation and convection; approximate methods of solution.
E. G. Cravalho, L. R. Glicksman

2.60 ***Applied Thermodynamics and Heat Transfer***
Prereq.: 2.201, 2.403
Year: U (1, 2) 3–0–6
Applications of thermodynamics to engineering systems, examples of power and propulsion cycles and combustion. Heat and momentum transfer for laminar and turbulent flow of fluids. Conduction, radiation, boiling and conduction, heat exchanger design.
W. M. Rohsenow

2.601J ***Thermal Power Systems*** **(A)**
(Same subject as 13.26J)
Prereq.: 2.402 or 2.403; 2.201
Year: G (2) 3–0–9
Design of thermal power system components and system optimization. Review of thermodynamics, gas dynamics and heat transfer. Design of axial and centrifugal compressors and pumps, axial and radial inflow turbines, heat exchangers, evaporators, boilers and condensers. Problems and examples will be taken from the fields of space, electrical utility and marine power systems. Knowledge of elementary heat transfer and simple thermal power cycles will be assumed.
W. M. Rohsenow, A. D. Carmichael

2.615 ***Advanced Internal Combustion Engines*** **(A)**
Prereq.: 2.02, 2.403
Year: G (1) 3–0–9
Analytical approach to the engineering problems and performance estimation of diesel, spark ignition and mixed cycle engines. Study of fluid flow, thermodynamics, combustion, friction, heat transfer and other factors affecting power and efficiency. (*For graduate and selected undergraduate students interested in research development or design in this field.*) *A. R. Rogowski*

2.616 ***Advanced Internal Combustion Engines*** **(A)**
Prereq.: 2.615
Year: G (2) 3–0–9
Continuation of engine theory. Philosophy of design and design synthesis. Role of training, judgment, and experience. Choice of optimum thermodynamic cycle, fuel, engine geometry and cylinder size, to satisfy a given performance specification. Dimensional analysis, engine balance, stress concentration, fatigue, choice of materials. Individual engine design project with application and specifications selected by student.
A. R. Rogowski

2.618 ***Automotive Vehicles***
Prereq.: 2.03
Year: U (2) 3–0–6
Analytical approach to vehicle performance, handling, and riding qualities. Design of body, chassis, suspension, engine, and transmission to meet vehicle requirements. Individual study of a special problem related to automobile design. Demonstrations of vehicles and components. *E. E. Larrabee*

2.621 ***Gas Turbines*** **(A)**
Prereq.: 2.202; 2.403; 2.50 or 2.60
Year: G (1) 3–0–9
Application of engineering science to the design and development of gas turbines. Thermodynamics and fluid mechanics for flow phenomena in turbines and compressors. Problems of mechanical strength and vibrations encountered in rotating machinery and blading of turbines and compressors. Design of turbines, compressors, heat exchangers and combustion chambers. Operating characteristics of gas turbine power plants in various applications. *D. G. Wilson*

2.632 ***Research in Lubrication*** **(A)**
Prereq.: ——
Year: G (1 or 2) *Arr.*
Opportunity for the student to select a research problem (which may be independent of or closely related to the program in progress in the Surface Laboratory), such as lubrication proper, bearing design, surface finish, or fundamental studies of mechanism of friction from experimental and theoretical standpoints. *B. G. Rightmire*

2.641 ***Food Engineering***
Prereq.: 8.01
Year: U (1) 3–2–3
Primarily for students in nutrition and food science. Fundamental principles of thermodynamics including laboratory work. Development of basic refrigeration cycles and their application. *A. L. Hesselschwerdt*

2.642J ***Food Engineering***
(Same subject as 20.13J)
Prereq.: 2.641
Year: U (2) 4–0–5
Quantitative study of selected unit operations of the food industry with consideration of basic principles governing each operation, as well as of important applications. Emphasis on refrigeration and freezing, fluid flow, heat transfer, evaporation, dehydration, and filtration. *A. L. Hesselschwerdt, C. Cooney*

2.643 ***Air Conditioning***
Prereq.: 2.403
Year: U (1) 3–0–6
For students who have had a basic subject in thermodynamics. Physiological aspects of air conditioning. Air and water vapor mixtures, load estimates for heating, boilers, radiators, and heating systems. Complete and part air conditioning systems, including air handling equipment. *A. L. Hesselschwerdt*

2.644 ***Environmental Control — Air Conditioning***
Prereq.: —
Year: U (2) 3–0–5
Primarily for students in architecture. Physiological and functional aspects involved in producing and controlling a thermal environment. Relationship of space and enclosure to climate and weather. Development and analysis for heating, cooling, ventilation, and air distribution. Principles and techniques of cooling. Evaluation of allocation of space for equipment and systems in the building source and conveyance media. Lecture material supplemented with plant and site trips.
A. L. Hesselschwerdt

2.645 ***Advanced Air Conditioning*** **(A)**
Prereq.: 2.643
Year: G (2) 3–0–9
Psychrometry and its application to problems involving heat and mass transfer in spray equipment. Cooling load estimates and extended surface coils for cooling and dehumidification. Consideration of typical air conditioning equipment and control systems in relation to specific problems. *A. L. Hesselschwerdt*

2.646 ***Refrigeration***
Prereq.: 2.403
Year: U (2) 3–0–6
Discussion of refrigerating cycles. Refrigeration at more than one level. Operation and ratings of various types of compressors, evaporators, condensers, and automatic controls used in commercial refrigerating systems. Heat flow problems in condensers, evaporators, and cooling towers. *A. L. Hesselschwerd*

2.649 *Low Temperature Refrigeration* (A)
Prereq.: 2.403 or 2.42
Year: G (1 or 2) 3–3–6
Thermodynamic processes for producing low-temperature refrigeration. Problems of heat exchangers, insulation and rectification. Applications of low-level refrigeration to purification of oxygen and nitrogen. Laboratory projects on related topics according to individual interests.
J. L. Smith

2.652 *Experimental Stress Analysis*
Prereq.: 2.01
Year: U (1 or 2) 2–3–4
Common experimental methods of analyzing stress distributions. Photoelasticity, birefringent coatings, brittle lacquers, strain gage techniques and instrumentation, as applied to problems involving static, dynamic, and residual stress distributions. *W. M. Murray*

2.653 *Research in Experimental Stress Analysis* (A)
Prereq.: 2.652
Year: G (1 or 2) *Arr.*
Application of experimental methods to the solution of special problems; current development of theory and technique. *W. M. Murray*

2.654 *Physical Measurement and Analysis*
Prereq.: 8.02, 18.02
Year: U (1, 2) 2–6–4
Experimental techniques presented for observation and measurement of fundamental engineering quantities such as: displacement, force, torque, time, velocity, acceleration, temperature, pressure, and flow. Quantities for carrying out these measurements including the following: electrical (resistive, inductive, capacitive), mechanical, pneumatic, hydraulic, radio-tracer, and optical. Emphasis on a physical (and analytical) understanding of the static and dynamic behavior of measurement systems. Discussion includes statistical and dynamic analysis of data as well as dynamic analysis of the physical systems. Development in lectures of the background required for conducting the laboratory projects. Grading based primarily on laboratory reports.
N. H. Cook, E. Rabinowicz

2.67 *Urban Laboratory In Mechanical Engineering*
Prereq.: 8.02, 18.02
Year: U (1) 3–6–3
Attempt to solve a problem (e.g., control of pollution of wetlands; automatic ticketing for buses) usually in collaboration with a local city or state agency. Overall study and background lectures, followed by division of the class into groups, each of which tackles a research or design component of the overall problem in the laboratory or in the field. Subsequent assembling of the components with presentation in the form of a demonstration, trial, and report. (*Open to students from all schools. Limited to thirty students by arrangement with instructor.*) *D. G. Wilson*

2.672 *Experimental Engineering I*
(*Revised: Unit change*)
Prereq.: 2.01, 2.02, *2.201* or *2.403*
Year: U (2) 2–3–1
Engineering laboratory subject for mechanical engineering juniors. Major emphasis on the interplay between analytical and experimental methods in the solution of research and development problems. Groups of three students to work together on three problems for the term.
L. R. Glicksman, P. Griffith

2.673 *Projects in Mechanical Engineering*
(*Revised: Unit change*)
Prereq.: ——
Year: U (1, 2, S) *Arr.*
The Mechanical Engineering Laboratory requirement, which can be filled with this course, involves completing at least a six unit project and making an oral and written presentation. Also, any undergraduate wishing to do a project in Mechanical Engineering can secure a copy of the project list from the person in charge of projects for that term. Details on registration included with the project list. *P. Griffith, D. G. Wilson, A. H. Shapiro*

2.70 *Engineering Synthesis and Design*
Prereq.: ——
Year: U (2) 2–3–4
Introduction to the design process in engineering, stressing the creative approach. Problem definition and concept generation, visual thinking and graphical communication, design analysis and optimization, computer-aided design. Familiarization with standard machine elements, design specifications, production techniques and economic considerations. Instruction via case, project and independent resource methods to simulate professional engineering practice. *H. H. Richardson*

2.711 *Geometric Design*
Prereq.: ——
Year: U (1, 2) 0–4–2
Introduction to the design of structures, products, and mechanisms in which geometry is an intrinsic factor. Exploration and discovery of the features of exemplary current designs. Instruction in design procedures through the assignment of a variety of challenging problems providing real experience in the formulation and development of original ideas. Applications of the fundamentals of statics and kinematics to evaluate proposed designs. Techniques of problem definition, analysis, and solution. Methods of display and model making to animate and validate finished designs. Typical design problems: geodesic structures, developable hulls and fusilages, containers for appliances, contemporary furniture, sports vehicles, geometric sculpture, and special-purpose mechanisms and tools. (*Not offered 1971–72.*) *Staff*

2.724 *Nomography*
Prereq.: ——
Year: U (1, 2) 2–0–4
Graphical and computer-time-saving solutions of equations through using "alignment" diagram forms based upon determinants. Methods for more than three variables. The general projective transformation, cross-ratio, theory and use of central projection, determinant operators, dualities of point and line, point and plane, axis of homology. Quasi-alignment diagrams, near-canonical forms, empirical data. Answer-locus other than a straight line. Countable-bit representation of nomographic functional behavior. Nomographic solutions of non-linear differential equations, ordinary and partial, using Runge-Kutta methods. *D. P. Adams*

2.726 *Computer-Aided Design* (A)
Prereq.: 18.075
Year: G (1) 3–0–9
Survey of current applications and future possibilities. Taxonomy of the design process including conflicts between goals, leading to search and evaluation. Abstract representation of goals: utility theory, cost functions, goal hierarchies. Discovery in design: graphics, time-sharing, man-machine interaction. Simulation. Evaluation: decision theory and optimization methods. Artificial intelligence. (*Ability to program a computer desirable.*)
D. E. Whitney

2.73 ***Engineering Design***
Prereq.: 2.02; 2.70 or 2.861, 2.86
Year: U (1) 2–3–4
Instruction and experience in the integrated aspects of creative design and design analysis. Individual and group design projects stressing original concepts as well as thorough engineering analysis. Lectures devoted to background information, competitive approaches and pertinent disciplinary and theoretical material. Frequent student presentations and critiques culminate in a formal presentation. *I. Paul*

2.732 ***Design Concepts***
Prereq.: 2.73
Year: U (1) 2–2–5
The concept-development stage of engineering design, centered around the planning and critical analysis of engineering systems. Case studies, drawn from problems of current and anticipated technological significance, carried out by student groups in cooperation with participating industrial organizations and academic laboratories within the Institute. Such topics as automated production equipment; design and control of engineering systems; urban and societal systems; data processing and materials handling; and the control and design of transport systems. Objectives: development of ability to plan, organize, and lead engineering projects of broad scope, basing decision on fundamental physical laws, experimental data, experience, and engineering judgment.
H. H. Richardson, D. G. Wilson

2.733 ***Special Problems in Systems and Design***
Prereq.: ——
Year: U (1, 2) *Arr.*
For undergraduates desiring to carry on substantial projects of own choosing in the areas of engineering design, system analysis or automatic control. Special lectures and seminars to be arranged when appropriate. Projects arranged on individual basis in consultation with instructor. *R. W. Mann*

2.734 ***Advanced Projects in Systems and Design*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
For graduate students desiring to carry on substantial projects of own choosing in the areas of engineering design, system analysis or automatic control. Special lectures and seminars to be arranged when appropriate. Projects arranged on an individual basis in consultation with instructor. *H. H. Richardson*

2.737 ***Theory of Modern Kinematics*** **(A)**
Prereq.: 18.075
Year: G (1, 2) 3–0–9
Classical and modern methods of kinematic analysis and synthesis with applications to mechanism design. Properties of planar and spatial rigid-body motion, centrodes, inflection and return circles, Ball's point, Euler-Savary and Bobillier Laws. Mathematical and geometric theories for the synthesis of function, path and motion-generating mechanisms having prescribed first, second and higher-order kinematic characteristics. Digital computer techniques for planar and spatial linkage synthesis based upon recently developed stretch-rotation operators. Vector and matrix methods of analysis and synthesis using complex numbers, dual angles, dual vectors and dual quarternions; higher plane curves of synthesis; Dimentberg's screw calculus. Four-bar properties, coupler-curves, Roberts' theorem, cubic of constant curvature. Approximate straight-line techniques. Synthesis of mechanisms by Hain's point-position-reduction. Burmester theory, finitely and infinitely close points under a unified theory. Bottema's instantaneous invariants. Optimization with respect to design constraints and quality criteria. Error reduction by means of Chebychev polynomials and Freudenstein precision point respacing. Force balancing of linkages. Torque and force transmission. Review of recent developments and current research. *D. P. Adams, R. E. Kaufman*

2.74 ***Topics in Biomedical Engineering***
Prereq.: 8.02, 18.02
Year: U (2) 3–3–6
Examples, drawn from current research, of the application of engineering disciplines and techniques to significant problems in biology and medicine, e.g., fluid mechanical studies of the cardiovascular system, ultrasonic neurosurgery, neuromuscular-machine control integration in artificial limbs, engineering properties of biological materials. Treatment of both engineering and physiological aspects of topics.
R. W. Mann, C. F. Dewey, P. P. Lele, I. V. Yannas

2.75 ***Biomechanics*** **(A)**
Prereq.: ——
Year: G (1) 3–3–6
Treatment of the human neuromuscular-skeletal system, encompassing anatomy and physiology. Stress on the engineering systems aspects and utilizing conceptual, analytical and experimental approaches of physical science. Information transfer in the system, generation and control of forces and motion, volitional and reflex dynamics. Lectures and demonstrations by neurologic and orthopedic medical doctors. Individual or group laboratory projects. *R. W. Mann, I. Paul, E. Radin*

2.76 ***Biological Effects and Medical Application of Ultrasound*** **(A)**
(Revised: Unit change)
Prereq.: ——
Year: G (1) 3–3–6
Descriptive treatment of generation and propagation of compressional waves in ideal fluids, plane waves, pressure, intensity; propagation in biological media, nonlinear effects; attenuation, absorption-mechanisms, models, results in blood, soft tissues, bone, eye and lung, resonant bubbles; acoustic properties of biological materials; acoustic impedance, reflection from plane and curved surfaces, partial reflection, refraction, mode conversion, standing wave fields; streaming, stirring, wound healing; cavitation-mechanisms, results and effects, noise sonoluminiscence, chemical and biochemical reactions, emulsification, depolymerization, biological effects, surgery of cataract; mutations, cancer therapy; mechanisms of tissue alteration, Meniere's disease and its treatment; near field, far field, focused fields-energy distribution, gain, Surgical Applications and results; Diagnostic Applications-Pulse-Echo Techniques, methods of presentation, target characteristics, instrumentation limitations, clinical results; synthetic aperture, phased-array systems; Doppler Shift, single and double sources, continuous wave and pulsed Doppler applications, moving target indicator; image converter systems, holography. Laboratory demonstrations of some of the effects and current research. Visits to local hospitals to view clinical uses. Mathematical treatment of the physics of wave propagation and Piezo-electric Transduction available as optional seminars. Open to advanced undergraduates with permission of instructor. *(Alternate years. Not offered 1971–72.)* *P. P. Lele*

2.77 ***Biological Effects and Medical Applications of Non-Ionizing Radiations*** **(A)**
(New)
Prereq.: ——
Year: G (1) 3–3–6
Basic physics, biological effects, biomedical applications and hazards of Ultrasound, Laser, Microwaves and Magnetic fields suitable for graduates in engineering, physical sciences and life sciences. Ultrasoundwave propagation in Newtonian fluids and in biological materials; non-

linear effects; absorption and attenuation; bubble resonance; streaming, cavitation, mutations, biochemical effects; mechanisms of tissue alteration, surgical and diagnostic uses; Doppler effects and application; image converter systems. Laser-stimulated emission, pulsed and continuous wave systems, transmission through light guides, measuring devices; interaction with biological matter; absorption, stress, vaporization; safety; studies in tissue cultures, animals, man; clinical applications in ophthalmology, dermatology, cancer therapy, holography. Microwaves-physical characteristics; dosimetry, electrical properties of biological tissues in constant and varying fields, absorption, energy transfer and conversion, thermal effects, non-thermal effects; results and mechanisms in unicellular organisms, tissue cultures, blood, eye, testes, malignant tumors, neurohumoral regulation, behavior, growth; comparison with ionizing radiation and with ultrasound; applications in therapy, absorption spectroscopy, paramagnetic and magnetic resonance; health hazard-radar, microwave ovens. Magnetic fields-geomagnetic environment, techniques of astatisation and shielding, constant and varying fields; effects on enzyme systems, unicellular organisms, tissues, blood, organs, systems, behavior, fertility, lifespan of animals, tumors. Laboratory demonstration of some of the effects and visits to local hospitals and research centers. Open to advanced undergraduates with permission of instructor. (*Alternate years. Offered 1971–72.*)

P. P. Lele

2.86 ***Manufacturing Project Laboratory***
Prereq.: ——
Year: U (1, 2) 2–3–1

Discussion and laboratory experience covering modern methods of manufacture. First laboratory sessions directed towards development of the capabilities and limitations of manufacturing methods. Later laboratory sessions involving student selected projects investigating particular manufacturing operations with emphasis on the effects of material properties, friction and wear, and cost. *P. A. Smith, N. H. Cook*

2.861 ***Engineering Design and Manufacture***
Prereq.: ——
Year: U (2) 4–4–4

Design principles applied to machine components. Philosophy of design stressing the creative approach to engineering problems. Comprehensive design project integrating functional requirements, proportions of elements and methods of production. Description and mechanics of manufacturing processes. Determination and application of materials test data to process analysis. Application of economic principles to manufacturing. (*Not offered 1971–72.*) *N. H. Cook*

2.862 ***Machine Tool Fundamentals***
Prereq.: 2.86
Year: U (1) 2–1–2

Analysis of manufacturing processes with emphasis on manufacturing economics. Tool life studies, optimization of material removal rates, process and equipment selection based upon capabilities and minimum cost. Principles of quality control. Discussion of industrial organization and personnel problems associated with manufacturing. *P. A. Smith*

2.865 ***Theory of Material Interface Phenomena*** **(A)**
Prereq.: ——
Year: G (1) 3–0–9

Theory of surfaces and interfaces, and influence of surface geometry and surface chemistry. Transmission of force, heat, electricity, mass. Phenomena of friction, wear, lubrication and adhesion. Characteristics of materials particularly suitable for interface action. Experimental investigation of interface phenomena.

E. Rabinowicz, B. G. Rightmire

2.866 ***Application of Material Interface Phenomena*** **(A)**
Prereq.: ——
Year: G (2) 3–0–9

Theories of metal processing including new electrical methods. Sliding systems including hydrodynamics, hydrostatics, gases, rolling contacts, and gears. Instrumentation applicable to this field. Statistical analysis of interface phenomena, and deduction of events occurring at the interface. *N. H. Cook, N. P. Suh*

2.869 ***Research in the Mechanical Processing of Materials*** **(A)**
Prereq.: ——
Year: G (1 or 2) *Arr.*

Opportunity for the student to work on a special problem of his choice in the general area of mechanical processing, including: material removal, displacement or addition; the alteration of surface properties; or the measurement of processed parts. *N. H. Cook, N. P. Suh*

2.900J ***Biomedical Materials***
(Same subject as 3.101J)
Prereq.: 2.901 or 3.091 or 7.01
Year: U (2) 2–1–3

Introduction to the science and engineering of materials used in a variety of medical applications such as sutures, orthopedic implants, artificial joints, blood vessel replacements and artificial organs. Elements of structure and properties of polymers, ceramics and metals with emphasis on interaction with the human body. Histological analysis of connective tissue with emphasis on aspects related to materials science and engineering. Fracture, structure and healing of normal and abnormal bone. Implantation problems: inflammation, thrombogenesis, rejection, resorption, corrosion, structural failure. Case histories. Laboratory time spent in surgical amphitheatres at nearby hospitals. (*Basic background in descriptive biology is desirable.*) *E. L. Radin, I. V. Yannas, R. M. Rose, W. Putschar, A. Schiller*

2.901 ***Polymer Materials Science***
Prereq.: 5.01, 8.01; or 3.091
Year: U (2) 3–0–9

Principles of macromolecular structure, their relation to properties of polymers and application to the design of engineering materials. Statistics of macromolecules and experimental determination of their sizes and shapes. Model structures: helices, extended chains, folded-chains and random coils. Theories of rubber elasticity, glass transitions and crystalline melting transitions. Survey of engineering properties of rubbers, proteins, glasses, plastics, and fibers. *I. V. Yannas*

2.902 ***Mechanochemistry***
Prereq.: 5.01, 8.01; or 2.901
Year: U (1) 3–0–6

Systematization of relationships between the generation of mechanical stress and the rearrangement of molecular structure. Open and closed mechanochemical systems: isometric stress generation and isotonic length relaxation. Mechanochemical cycles: isothermal conversion of chemical energy to mechanical energy. Specification of stress-induced molecular motions by infrared spectroscopy (dichroism), photoviscoelasticity and X-ray diffraction. Application to (a) the thermodynamics of polymer engines, (b) the heat setting of textile fibres, (c) the physical chemistry of polymer deformation, and (d) the mechanism of muscle contraction. (*Not offered 1971–72.*) *I. V. Yannas*

2.903 *Elements of Textile Materials and Processes*
Prereq.: ——
Year: U (1) 3–0–6
Characteristics of fibers as affecting processing and performance of textile intermediate and end products. Principles of textile manufacturing: treating operations such as blending, carding, combing, drafting, twisting, etc., and their combination into processes for natural and man-made fibrous materials. Principles of structural design of twisted, woven, knitted, braided, and felted materials. *S. Backer*

2.904 *Fiber Processing Dynamics*
Prereq.: 2.03
Year: U (2) 3–0–6
The mechanical interaction between fiber process manufacturing operations and the fiber, yarn, or fabric in process. Dynamics of fiber process operations, including analysis of ring spinning mechanics, balloon dynamics, traveller ring interactions, spindle vibration, shuttle dynamics, tension control, and fabric guiding and winding control. Process theory relating to product irregularity, blending statistics, drafting mechanics, and breakage probabilities. *S. Backer*

2.905 *Polymer Viscoelasticity* (A)
Prereq.: 2.30; or 2.901; or 5.01, 8.01
Year: G (1) 3–0–6
Theory of linear viscoelasticity and its systematic application to the mechanical behavior of amorphous and semicrystalline polymers. Use of the Boltzmann superposition principle and of the principles of Gross to define and to connect material functions with corresponding mechanical spectra. The transition from linear to nonlinear viscoelastic behavior. Systematic exposition of polymer physics in terms of the five regions of viscoelastic behavior. Empirical superposition rules relating effects of timescale, temperature and diluent concentration. Introduction to the study of molecular motions accompanying deformation in polymers. Study of cold drawing and fracture phenomena in polymers.
I. V. Yannas

2.906 *Physical Chemistry of Macromolecular Systems* (A)
Prereq.: 2.901; or 5.41, 5.61
Year: G (2) 3–0–6
Elements of theory of probability and their systematic application to the analysis of macromolecular structure. Gaussian macromolecules, freely rotating chains and the rotational isomeric state model. Statistical thermodynamic theories of the glass transition, the helix-coil transition, crystalline melting and of rubber elasticity. Analysis of macromolecular structure by spectroscopic and classical optical methods. (*Not offered 1971–72.*)
I. V. Yannas

2.907J *Science and Engineering of Biological Membranes and Structural Tissue*
(*New*)
(Same subject as 3.79J, 7.62J, 8.531J)
Prereq.: —
Year: G (1) 3–0–6
Biophysical, biochemical and engineering aspects of various biological membranes and of structural tissue. Molecular biology and biochemistry of cell membranes; membranes of cancer cells. Introduction to the nonequilibrium thermodynamics of transport across membranes. Cooperative phenomena involving biological macromolecules and membranes. Capillary structure and analysis of water flux across the capillary wall. Molecular structure of collagen, elastin and of various mucopolysaccharides; the native and the denatured biological solid state. Introduction to linear relaxation mechanics with application to the function of articular cartilage. Topics in the structure and function of skin. Structure and physiology of bone; introduction to quantitative stereology with application to calcified tissue.
I. V. Yannas, B. W. Burge, J. F. Burke, R. M. Rose, H. E. Stanley

2.911 *Polymer Physics Laboratory* (A)
Prereq.: ——
Year: G (1) 3–6–3
Determination of viscoelastic and physicochemical constants of synthetic polymers and biopolymers. Application to current research problems in the relation of molecular structure to the macroscopic properties of fibers, plastics, glasses, rubbers and proteins. Design of novel instruments for polymer research. (*Limited enrollment. Open to advanced undergraduates by permission of instructor.*)
I. V. Yannas

2.912 *Fiber Research Laboratory* (A)
Prereq.: 2.913
Year: G (2) 3–3–2
Application of the research group method to solution of experimental problems. Exercise in analysis of material and structural properties affecting intermediate or end product behavior and in design of apparatus and/or experiments in fiber mechanics. *S. Backer*

2.913 *Fibers and Polymers Seminar* (A)
Prereq.: 2.30
Year: G (1) 2–0–2
Discussions of current problems in applied mechanics of fibrous assemblies. Differential geometry of twisted structures; translation of fiber properties into yarn behavior; role of fiber variability; mechanics of paper and other fibrous sheet materials; interaction of yarn and fabric structures. Analysis of woven, knitted, laminate, and composite materials used in engineering and apparel applications. *S. Backer*

2.914 *Fibers and Polymers Seminar* (A)
Prereq.: 2.913
Year: G (2) 2–0–2
Student and staff participation in critical discussions of important problems in fiber and polymer rheology, applied mechanics of fiber structures, and dynamic interactions between fibrous structures and manufacturing processes, together with reviews of the current literature and the results of researches in these fields at the Institute.
S. Backer

2.951 *Industrial Practice*
Prereq.: ——
Year: U (S) 40 h.p.w.

2.952 *Industrial Practice*
Prereq.: ——
Year: U (1, 2) 0–8–0
Approximately six months of practical work carried out by the Cooperative students in manufacturing, engineering, research, and development at the plants of the organizations which are participating in the Cooperative program. *W. M. Murray*

2.97 *Independent Activities*
(*New*)
Prereq.: —
Year: U (J) *Arr.*
For undergraduates desiring to carry on independent studies during the (January) period between terms. Each student will carry on a program of his own choosing, either as an independent worker, or as a member of a team, or class. Special lectures, seminars, and laboratory projects arranged when appropriate. Programs arranged on an individual basis in consultation with the instructor. Credit arranged with the instructor. *Staff*

2.981–2.987 *Undergraduate Research in Mechanical Engineering*
(New)
Prereq.: —
Year: U (1, 2, S) *Arr.*
Individual study, research, or laboratory investigations under faculty supervision, including individual participation in an ongoing research project.
P. Griffith, D. G. Wilson

3.
Metallurgy and Materials Science

3.U.R. *Undergraduate Research*
(3.71) *Prereq.:* —
Year: U (1, 2) *Arr.*
Extended participation in the work of a research group, which includes such activities as independent study of the literature, direct involvement in the group's research commensurate with the student skills and preparation, or project work under an individual faculty member extending over more than one term. (*Admission by arrangement with individual faculty member.*) *Staff*

3.00 *Thermodynamics of Materials*
Prereq.: 3.091 or 5.01
Year: U (2) 4–0–8
Essential concepts of thermodynamics and their application to the behavior of metals and materials. The first law of thermodynamics; thermochemistry; enthalpies of reaction, transformation, and solution. Introduction to the second law, entropy, the third law, work functions, chemical potential, and the phase rule. An introductory treatment of statistical thermodynamics.
J. B. See

3.01 *Thermodynamics and Statistical Mechanics*
Prereq.: 3.00, 18.03
Year: U (1) 3–0–9
Intermediate thermodynamics and elementary statistical approaches. State properties and Jacobians; the first and second laws, heterogeneous and homogeneous equilibrium. Solutions. Electrochemistry. Surfaces and fields. Phase space; ergodicity; Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics. Equipartition; specific heats of classical and degenerate systems. Boltzmann transport equation; irreversible thermodynamics.
R. M. Rose, K. C. Russell

3.02 *Chemistry of Materials*
Prereq.: 3.00, 3.091 or 5.01
Year: U (2) 3–3–6
Chemical characteristics of useful materials, elemental and compound. Relation of chemical properties to atomic structure and bonding. Quantitative measures of reactivity. Preparation of pure materials. Reaction of materials with environment, including protection.
T. B. King

3.03 *Chemical Metallurgy*
Prereq.: 3.01, 3.02
Year: U (1) 3–0–6
Application of principles of 3.02 to treatment of important metallurgical processes according to stoichiometric, thermodynamic, and kinetic viewpoints. Gas-solid reactions such as reduction of oxides. Slag-metal reactions in smelting. Gas-liquid processes such as distillation. Refining processes such as precipitation, segregation, vacuum melting and degassing. *T. B. King*

3.05 *Materials Research Laboratory*
Prereq.: 8.01
Year: U (1, 2) 2–6–4
Laboratory work on structure-property relations in materials. Introduction for all students to structure analysis techniques such as metallography (examination by light microscope) and X-ray crystallography, followed by assignment of each student to an individual faculty member and research project in one area, such as: mechanical properties, crystal growth, surface chemistry, electronic materials, superconductivity, electron microscopy, ceramics, chemical processing, electron diffraction, magnetic properties, high-temperature alloys, crystal imperfections. Periodic classroom discussion of laboratory project. (*Limited enrollment.*) *H. C. Gatos*

3.06 *Ceramics*
Prereq.: 3.00, 5.01, 18.03
Year: U (2) 3–0–6
Introduction to ceramics as a class of materials, emphasizing both advantages and disadvantages for selected uses. Application of structural knowledge, thermodynamics, and theories of deformation and transport processes to the analysis and understanding of selected ceramic processes, including fabrication of glasses and glass-ceramic materials, slip casting, plastic forming and sintering. *D. R. Uhlmann*

3.07 *Physical Ceramics I*
Prereq.: 3.13 or 3.141
Year: U (1) 3–0–6
Characteristics of vitreous and crystalline non-metals. Relationships of atom arrangements and interactions to thermal, mechanical, and electrical properties. Application of phase equilibria, surface properties, atomic mobility, nucleation, and crystal growth to development of structure during fabrication, shaping, heat treatment, and use. Relationship of structures to thermal, electrical, and mechanical properties.
W. D. Kingery, B. J. Wuensch

3.091 *Introduction to Solid-State Chemistry*
Prereq.: ——
Year: U (1, 2) 5–0–7
Chemical and physical properties of solids as related to bonding, crystal structure, and structural imperfections. Mechanisms and energy changes in chemical reactions and phase transformations.
J. Wulff, A. F. Witt, K. C. Russell

3.10 *Electrons and Atoms in Solids*
Prereq.: ——
Year: U (2) 4–0–8
Crystals and chemical bonding. Electrons and waves in molecules and crystals. Electrical and magnetic fields in solids and liquids. Semiconductors, semiconductor devices and materials. Thermoelectricity. Magnetism. Dielectric and optical materials. Lasers and quantum electronics. Superconductivity. (*Not offered 1971–72.*)
R. M. Rose

3.101J *Biomedical Materials*
(Same subject as 2.900J)
Prereq.: 2.901 or 3.091 or 7.01
Year: U (2) 2–1–3
Introduction to the science and engineering of materials used in a variety of medical applications such as sutures, orthopedic implants, artificial joints, blood vessel replacements and artificial organs. Elements of structure and properties of polymers, ceramics and metals with emphasis on interaction with the human body. Histological analysis of connective tissue with emphasis on aspects related to materials science and engineering. Fracture, structure and healing of normal and abnormal bone. Implantation problems: inflammation, thrombogenesis, rejection, resorption, corrosion, structural

failure. Case histories. Laboratory time to be spent in surgical amphitheatres at nearby hospitals. (*Basic background in descriptive biology desirable.*)
W. G. J. Putschar, E. L. Radin, R. M. Rose, A. L. Schiller, I. V. Yannas

3.11 *Mechanics of Materials*
Prereq.: 8.01, 18.02
Year: U (1) 4–0–8
Response of materials and devices to applied forces interpreted on different structural bases, from the idealized continuum to the imperfections in natural crystals and molecular arrays. The transition from particle to continuum mechanics. Problems in statics. Structure of crystals. Elasticity: states of stress and strain; problems in rod- and sheet-like sections. Plasticity: behavior of crystals; combined-stress yielding in isotropic and anisotropic materials; strain hardening. Fluidity and viscosity. Fracture: theory and control in real materials.
W. A. Backofen

3.12 *Principles of Crystallography and X-ray Diffraction*
Prereq.: 8.02, 18.02
Year: U (1) 4–3–5
Introduction to the nature of the solid state. Crystal geometry; space lattices, crystal systems, symmetry classes, and space groups. Atomic arrangements in crystals and their determination by X-ray diffraction. Application of the reciprocal lattice in the solution of X-ray diffraction problems. The use of X-ray diffraction in the study of crystals by the Laue, rotating crystal, and powder methods. The role of atomic arrangements in polymorphism, order-disorder, phase transformations, deformation, and crystal growth.
R. E. Ogilvie, B. J. Wuensch

3.13 *Materials Science I*
Prereq.: 3.01, 3.11, 3.12
Year: U (2) 4–3–5
Principles underlying the physical, mechanical and chemical properties of metals, ceramics, and polymers. Equilibrium and non-equilibrium phase relationships in one-, two-, and three-component systems; relation of symmetry to physical properties of crystals; mechanisms and kinetics of diffusion; structural imperfections and their influence upon mechanical properties; oxidation and corrosion. Emphasis upon correlation of properties with crystal structure and microstructure, including quantitative metallography. Use of laboratory experiments on some of the basic techniques to evaluate the structure and properties of materials. *M. Cohen*

3.14 *Physical Metallurgy I*
Prereq.: 3.13 or 3.141
Year: U (1) 4–3–5
Extension of the principles of materials science to the metallic state; nucleation and growth; diffusion-controlled and diffusionless transformations; heat treatment and hardenability; thermal and transformation stresses; relaxation processes; continuous and discontinuous yielding; shear and cleavage fracture; quench aging and strain aging; engineering alloy systems. Laboratory experiments planned and conducted by the students in small groups; providing introduction to research in physical metallurgy; emphasis on report writing, in cooperation with the Department of Humanities. *M. B. Bever, M. Cohen*

3.141 *Science of Materials*
Prereq.: 8.01
Year: U (1, 2) 4–3–5
Principles underlying the structure and properties of materials. Lecture and laboratory work in atomic, molecular, crystal, and phase structure of solids. Emphasis on equilibrium and non-equilibrium transformations in multicomponent systems. Study of the kinetics of nucleation and diffusion in relation to recovery, recrystallization, and grain growth. Correlation of structure in metals, ceramics, and polymers with chemical and mechanical behavior. Laboratory experiments concerned with structure and properties of materials.
M. C. Flemings, R. M. N. Pelloux

3.144 *Physical Metallurgy I*
Prereq.: 3.13 or 3.141
Year: U (1) 4–0–4
Same as 3.14 but without laboratory.
M. B. Bever, M. Cohen

3.15 *Materials Science II*
Prereq.: 3.13, 8.03, 18.03
Year: U (2) 4–3–5
Introduction to the physics of solid materials from a phenomenological or experimental point of view. A brief discussion of the quantum theory of atomic structure, followed by a treatment of solids invoking free electron and nearly free electron concepts. Topics discussed: electrical and thermal properties of metals, semiconductors and insulators; optical properties; magnetic properties, including the simpler theories of dia-, para- and ferromagnetism. Treatment centered on the effect of structure, both atomic and microscopic, on physical properties. Selected experiments performed in the laboratory; a time-sharing computer used for problem solving, employing the MAP system, and requiring no prior computing experience. *R. Kaplow*

3.16 *Physical Metallurgy II*
Prereq.: 3.14 or 3.144
Year: U (2) 2–4–4
Factors affecting mechanical, chemical, and physical behavior of materials in service. Property, processing, and economic considerations in materials selection. Laboratory on commercial metals and alloys, with emphasis on microstructures and their interpretation. Classes of alloys; examination of normal and defective materials. *C. F. Floe, R. M. N. Pelloux*

3.17 *Case Histories in Engineering Science*
Prereq.: ——
Year: U (2) 3–0–3
Study of actual processes leading to induction of generalizations and their subsequent application in science and engineering. Discussion in depth of a few case histories of recent and current investigations in which M.I.T. metallurgy and materials science faculty have played an active role. Participation by the students in evaluating key factors leading to scientific and engineering success on the basis of these detailed case histories. (*Not offered 1971–72.*) *W. D. Kingery*

3.18 *Materials Processing*
Prereq.: 3.13 or 3.141
Year: U (1) 4–3–5
Fundamentals of heat flow, diffusion, and fluid flow applied to: heating and cooling solids, glass melting and pressing, mixing theory, powder preparation, powder fabrication, sintering and hot pressing, foundry molds, casting and solidification. Emphasis on microstructure development. Laboratory on heat flow measurements, powder processing, and foundry experiments. *R. L. Coble*

3.188 *Materials Processing*
Prereq.: 3.13 or 3.141
Year: U (1) 4–0–4
Same as 3.18 but without laboratory. *R. L. Coble*

3.19 *Techniques of Metal Sculpture*
Prereq.: ——
Year: U (1, 2) 0–4–2
Workshop devoted to learning techniques for the translation of design to modern metal sculpture: brazing, welding, forming, cutting; mechanical and chemical finishing, and patinas. Basic materials involved: steels, aluminum, brass, copper, and stainless steel, in the simple forms: tubing, rod, sheet, strip and bar. Complex industrial shapes will also be utilized, as well as junk sculpture. (*Limited enrollment.*) *R. M. Rose*

3.20 *Thermodynamics in Metallurgy* (A)
Prereq.: 3.01
Year: G (1) 4–0–8
Advanced treatment of the thermodynamic properties of inorganic materials. Introductory statistical thermodynamics and surface thermodynamics. Application of the laws of thermodynamics to the chemical behavior of elements, compounds and solutions. Discussion of heterogeneous equilibria, chemical reactions, effect of different potential fields and the thermodynamics of structural defects. *J. B. See*

3.21 *Kinetics in Metallurgy and Materials Science* (A)
Prereq.: 3.01, 3.13
Year: G (1) 4–0–8
Unified treatment of kinetics from phenomenological and atomistic viewpoints. Diffusion in metals and nonmetals, including boundary value problems in growth, coarsening, and homogenization; mechanisms, high diffusivity paths, and diffusional instabilities. Rate laws, consecutive and competing reactions, absolute rate theory. Homogeneous and heterogeneous nucleation kinetics including condensation, film deposition, solidification, precipitation and diffusionless transformations. Frequent introduction of examples to illustrate principles discussed. *H. K. Bowen, J. F. Elliott*

3.22 *Defects in Solids* (A)
(*Revised: Unit change*)
Prereq.: 3.01, 3.13
Year: G (2) 3–0–9
Point, line, and surface defects considered primarily from a theoretical viewpoint. Tensor elasticity treated as prelude to dislocation theory. Theory of perfect and dissociated dislocations and their interactions with surroundings. Surface thermodynamics with regard to equilibrium forms, kinetics, and stability. Equilibrium configuration, formation, and removal of point defects in metallic and non-metallic materials. *K. C. Russell*

3.24 *Structure and Properties of Metals* (A)
Prereq.: 3.12; 3.14 or 3.144
Year: G (2) 3–0–6
Systematic treatment of the relations between the structure of metals and their properties. The elements of structure, especially grain structure; substructure, preferred orientation and the morphology of multiphase systems, with emphasis on quantitative aspects. The structural features of order phenomena, coherency and cold worked metals. Analysis of the effects of structural variables on mechanical, electrical, magnetic and other selected properties. *M. B. Bever*

3.30 *Strengthening Mechanisms in Metals* (A)
Prereq.: 2.332 or 3.22
Year: G (1) 2–0–4
Theories of strength of perfect and imperfect crystals, solid-solution hardening, strain hardening, crystal-size effects and precipitation hardening. Emphasis upon both the fundamental and applied aspects of achieving high strengths in metals through control of composition and structure. Frequent reference to current literature. *J. F. Breedis*

3.31 *Phase Transformations in Metals* (A)
Prereq.: 3.20, 3.21
Year: G (2) 3–0–9
Advanced treatment of phase transformations, including solidification, crystal growth, precipitation, eutectoids, recrystallization and grain growth, order-disorder and martensite. Emphasis on phenomenological understanding of kinetics and resultant morphology in terms of thermodynamics, transport processes and interface structure. *J. W. Cahn*

3.32 *Introduction to Electron Optics and Electron Microscopy* (A)
Prereq.: 3.12, 3.13
Year: G (2) 2–4–6
Detailed treatment of the design, construction, and application of electron optical instruments such as the electron microanalyzer, scanning electron microscope, and the transmission electron microscope; principles of electron interaction with matter, and in particular the study of diffraction contrast effects in foils containing lattice defects or precipitates. Emphasis on the use and reliability of methods employed in the study of materials. Laboratory work stressing use of the instruments and specimen preparation. *R. E. Ogilvie*

3.35 *Solidification Processing* (A)
Prereq.: 3.13 or 3.141
Year: G (1) 2–0–4
Principles of control of structure, properties, and shape in processes involving liquid-solid and vapor-solid transformations. Heat flow, solute redistribution, nucleation, growth kinetics. Resultant structures and properties. Examples drawn from commercial processes, including metal casting, zone refining, electrodeposition, and crystal growth from the melt, vapor, and solution.
M. C. Flemings

3.36J *Welding Engineering* (A)
(Same subject as 13.151J)
Prereq.: 3.13 or 3.141
Year: G (1) 3–0–6
Detailed study of processing variables involved in joining materials by welding, brazing, and adhesive bonding. Synthesis of elementary physical phenomena such as transient heat flow, phase transformations, and dimensional changes into the complex over-all reactions associated with joining. Testing, inspection, and properties of finished joints. Laboratory demonstrations of arc, electron beam, resistance, and other electric welding processes. *T. B. King, K. Masubuchi*

3.37 *Deformation Processing* (A)
Prereq.: 3.11; 3.13 or 3.141
Year: G (2) 2–0–4
Processing for shape change and property control by plastic deformation and fracture. Analyses of processing systems in terms of underlying problem areas: continuum plasticity; friction and lubrication in tool-metal interfaces; mechanical behavior under processing conditions; final structures and properties. Examples for discussion from a wide range of industrial operations.
W. A. Backofen

3.38 *Behavior of Metals at Elevated Temperatures* (A)
(*Revised: Unit change*)
Prereq.: 3.13 or 3.141
Year: G (1) 3–0–6
Study of metal and alloy behavior above the minimum recrystallization temperature. Creep, stress rupture and fatigue interpretation. Relationships between structure and properties in terms of strength and ductility. Strengthening mechanisms. Nature of high-temperature deformation and fracture. *N. J. Grant, R. M. N. Pelloux*

3.39 ***Fracture Mechanisms in Metals*** **(A)**
(Revised: Unit change)
Prereq.: 2.30 or 3.11
Year: G (2) 3–0–6
Advanced treatment of the mechanisms of brittle and ductile fracture in metals. Relation of fracture toughness to microstructure, environment, and time-dependent factors. Application to fracture of engineering structures and fracture in processing. Emphasis on recent research.
R. M. N. Pelloux

3.40J ***Laboratory in Physics of Solids*** **(A)**
(Same subject as 6.641J)
Prereq: 3.15 or 6.08; 8.04 or 8.211
Year: G (1, 2) 0–8–4
Experimental investigations on the physical properties of materials closely related to current research; brief lectures on the basic theories and experimental methods. Experiments in areas of X-ray diffraction, galvanomagnetic effects, superconductivity, ferroelectricity, crystal growth, infrared absorption, Mössbauer effect, thermal properties, magnetic resonance, dielectric properties, carriers in semiconductors, elastic constants, defect structures. *D. J. Sellmyer, A. C. Smith*

3.41 ***Introduction to Theoretical Methods in Physics of Solids***
Prereq.: ——
Year: G (1) 4–0–8
Unified treatment of fundamental physical and mathematical concepts prerequisite to developing an understanding of the quantitative theories of solid-state phenomena. Lectures on basic topics in classical electrodynamics, quantum mechanics, and statistical physics. Special topics: the semiclassical theories of the interaction of electromagnetic radiation with matter; the application of quantum statistics to the electron and photon gases.
K. H. Johnson

3.42J ***Physics of Solids*** **(A)**
(Revised: Unit change)
(Same subject as 6.651J)
Prereq.: 3.41; or 6.03, 8.211
Year: G (1) 4–0–8
First term of a two-term sequence presenting the basic concepts of the quantum theory of crystalline materials. Emphasis on mathematical methods and physical models which have proven to be generally useful in obtaining quantitative descriptions of physical quantities. Topics include: diffraction of X-rays, electrons, and neutrons by solids; periodic structures and reciprocal space; lattice dynamics, normal modes and phonons; quantum statistics; electron states in solids, Bloch waves and energy bands; perturbation theory; classification of solids.
D. J. Sellmyer, A. C. Smith

3.43J ***Physics of Solids*** **(A)**
(Revised: Unit change)
(Same subject as 6.652J)
Prereq.: 3.42J or 6.651J
Year: G (2) 4–0–8
Second term of a two-term sequence presenting the basic concepts of the quantum theory of crystalline materials. Topics: dynamics of electrons in solids, effective mass theorem; transport phenomena, electrical conductivity; magnetic phenomena, angular momentum and spin; paramagnetism, diamagnetism, ferromagnetism; interaction of radiation with solids, optical properties, resonance phenomena. *K. H. Johnson, A. C. Smith*

3.44 ***X-ray and Crystal Physics*** **(A)**
Prereq.: 3.41 or 8.04; 18.06
Year: G (1) 3–0–9
Theory and application of X-ray techniques for the determination of atomic and molecular arrangements in crystals, liquids, and amorphous solids. General review of the structure of matter as determined by X-ray diffraction analysis. X-ray spectra, atomic scattering factors. Elements of space groups.
B. L. Averbach

3.45 ***X-ray Diffraction*** **(A)**
(New)
Prereq.: 3.44
Year: G (2) 3–0–9
Selected advanced topics in the application of X-ray diffraction to problems in solid state physics. The elastic spectrum of crystals from the temperature diffuse scattering. Measurements of long range and short range order parameters in binary alloys. Randomness in structures and cold work distortion in metals. Fourier analysis of imperfect crystals. Small angle scattering from biological and organic materials. *B. L. Averbach*

3.50 ***Thermodynamics in Process Metallurgy*** **(A)**
Prereq.: 3.03, 3.20
Year: G (2) 3–0–6
Advanced treatment of the thermodynamic properties of metallurgical systems with emphasis on molten metals, slags, and mattes. Reactions of molten iron, steel, and other metals with slags and gases. Problems in the refining and solidification of metals, and other selected topics. Use of computer time sharing in metallurgical problems. *(Alternate years. Offered 1971–72.)* *J. F. Elliott*

3.51 ***Process Metallurgy*** **(A)**
Prereq.: 3.03
Year: G (2) 3–0–6
Study of integrated metallurgical processes. Application of the fundamental treatment of 3.03 to the extractive metallurgy of the more common metals, such as iron, copper, zinc and aluminum, and of less common metals such as titanium, molybdenum, and chromium. *(Offered occasionally. Consult instructor.)* *J. B. See*

3.52 ***Dynamic Behavior of Metallurgical Systems*** **(A)**
Prereq.: 3.01, 18.03
Year: G (2) 3–0–6
Interpretation of the behavior of metallurgical systems by application of the methods of process analysis and control theory. Modeling of systems and exploration of their characteristics with digital and analog computers. *(Alternate years. Not offered 1971–72.)* *J. F. Elliott*

3.53 ***Electrochemistry*** **(A)**
Prereq.: 3.01
Year: G (1) 2–0–4
Development of principles underlying galvanic cells, conductance, electrode kinetics, double layers; with assignment of typical numerical problems. Discussions of application to practice, including electro-analysis, electroplating, electro-winning, primary and secondary cells, electrophoresis. *H. H. Uhlig*

3.54 ***Corrosion*** **(A)**
Prereq.: 3.01
Year: G (2) 3–0–5
Quantitative application of electrochemical principles to corrosion reactions. Effect of metallurgical factors; atmospheric, soil, or aqueous environments; oxidation and tarnish; stray currents; cathodic and anodic protection; metallic, inorganic and organic coatings; inhibitors; treatment of water and steam systems; selection of materials. *H. H. Uhlig*

3.60 ***Physical Ceramics II*** **(A)**
Prereq.: 3.07
Year: G (2) 3–0–6
Effects of composition and structure on properties of crystalline ceramics. Anisotropy, tensor representation

of properties, and effect of crystal symmetry. Application to piezoelectricity and elastic properties of ceramics. Propagation of elastic waves in crystals. Discussion of thermal conductivity, heat capacity, magnetic and ferroelectric behavior, with emphasis on real materials and influences of microstructure. *B. J. Wuensch*

3.61 *Physical Ceramics III* (A)
Prereq.: 3.60
Year: G (1) 3–0–6
Structure of amorphous solids. Effects of composition and thermal history on properties of glasses, including discussions of recent publications. *D. R. Uhlmann*

3.62 *Electrical and Optical Properties of Ceramics* (A)
(New)
Prereq.: 3.07, 3.60
Year: G (1) 3–0–6
Discussion of the electrical and optical properties of ceramics in terms of defect chemistry, band theory, and transport theory. Readings in the current literature to emphasize the effects of material processing, composition and microstructure on the properties of real materials. *H. K. Bowen*

3.63 *Ceramic Processes* (A)
Prereq.: 3.06 or 3.07; 3.20; 3.21
Year: G (2) 3–0–6
Critical aspects of powder processing — powder preparation, fabrication, and firing. Glass processing — homogenization during melting: relationship to mixing theory — glass forming. Vapor growth of crystals and coatings — thermodynamics, transport processes and kinetics in relation to structures developed. *R. L. Coble*

3.64 *Special Problems in Ceramics* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Advanced work in this field. Lectures, conferences, assigned readings, and laboratory work. *W. D. Kingery*

3.65 *Ceramics Seminar* (A)
Prereq.: 3.06 or 3.07
Year: G (1, 2) 1–0–2
Individual talks followed by group discussion on current research and developments in ceramics by staff, students, and invited speakers. *D. R. Uhlmann*

3.66 *Materials Science of Polymers* (A)
Prereq.: ——
Year: G (2) 3–0–6
Consideration of the structure and properties of polymers from the viewpoint of materials science. Specific attention to polymerization processes, melt and crystal structures, crystallization from the melt and dilute solutions, rheology and relaxation behavior, rubber elasticity, mechanical properties, and effects of orientation and fillers on various properties. Strong emphasis on student participation in class discussion. *D. R. Uhlmann*

3.70 *Special Problems in Metallurgy* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Minor investigation in one of the special branches of metallurgy. *(Open only to students properly qualified in the special field.)* *Staff*

3.701J *Materials for Ocean Engineering*
(Same subject as 13.161J)
Prereq.: ——
Year: G (2) 4–1–6
Properties of metals used for the construction of ship and ocean engineering structures. Fracture characteristics, microstructures, processing, heat treatment and corrosion resistance of non-ferrous and ferrous metals. *C. F. Floe, K. Masubuchi*

3.72J *Nuclear Fuels* (A)
(Same subject as 22.72J)
Prereq.: 3.13 or 3.14 or 22.71
Year: G (2) 3–0–9
Behavior of nuclear fuels and fuel element cladding materials in reactor cores. Experimental observations and theory of radiation damage to metals and ceramics of practical interest. Processes for fabricating fuel elements and fuel assemblies; fuel fabrication costs. Recent developments of advanced reactor core materials. *A. L. Bement*

3.721J *Radiation Effects in Crystalline Solids* (A)
(Same subject as 22.73J)
Prereq.: 3.13 or 3.14 or 22.71
Year: G (2) 3–0–9
Theory of atomic displacements, cascades, and spike phenomena produced in metals and ceramics by high-energy radiation bombardment. Recovery of damage related to mobility and structure of crystalline imperfections. Discussion of radiation damage experiments of technological importance and basic experiments designed to test the theory of damage production and recovery. Consideration of special problems associated with damage in fissionable materials. Brief outline of the role of materials in nuclear reactor design. *A. L. Bement*

3.73 *Applications of Digital Computers* (A)
Prereq.: ——
Year: G (1) 3–1–4
The theory and practice of computer programming and digital computation techniques with examples of analysis useful in research. Series expansion, integration, table look-up and interpolation, iterative solutions, matrix operations, least-square fitting, Fourier transforms, differential equations, relaxation procedures, policy improvement, Monte Carlo methods. IBM 360/65 computer used. *R. Kaplow*

3.74 *Thermodynamics of Solids* (A)
Prereq.: 3.20
Year: G (2) 2–0–4
Statistical thermodynamics; effects of strain on thermodynamic functions; constrained equilibrium: Thermodynamic and kinetic consequences of lattice coherency; fluctuations, including introduction to nucleation, and some irreversible thermodynamics. *(Offered occasionally. Consult instructor.)* *K. C. Russell*

3.75 *Structure and Properties of Interfaces* (A)
Prereq.: 3.01
Year: G (1) 3–0–6
Examination of the salient physical and chemical characteristics of surfaces from a macroscopic and atomistic viewpoint. Emphasis on the thermodynamic description of systems with plane and curved surfaces, the kinetics of surface processes, atomic and electronic configuration of interfaces and the electrochemical nature of phase boundaries. Application of principles to wetting and spreading, adhesion, electrode processes, measurement of surface tension of solids. Discussion of the role of surfaces in nucleation, crystal growth, catalysis. *P. L. de Bruyn*

3.76J *Electronic Materials* (A)
(Same subject as 6.64J)
Prereq.: 3.15; or 6.02, 6.13; or 6.02, 6.341
Year: G (2) 2–0–6
Various aspects of electronic materials such as preparation, purification, crystal growth, crystal structure, characterization, electronic properties, band structure and device applications. Special emphasis on relationships between structural characteristics, atomic bonding and physical properties in classes of materials such as elemental and compound semiconductors, thermoelectrics and superconductors. Extensive rather than intensive coverage. *H. C. Gatos, A. F. Witt*

3.77 *Laboratory Measurement and Control*
Prereq.: ——
Year: G (1 or 2) 2–1–3
Discussion of laboratory techniques. Instrument characteristics. Basic electrical circuits. Transducers for force, stress, pressure, displacement, flow, and temperature input. Vacuum techniques. Special methods such as radio tracers, ultrasonic, laser. Control and recording systems. Analysis of experimental data. *J. T. Blucher*

3.78J *History of Materials*
(Same subject as 21.414J)
Prereq.: One first-year Humanities sequence
Year: U (2) 2–0–7
Study of man's knowledge of materials and attitude toward them in all ages from the discovery of ceramics to modern materials science. Materials as a bridge between art, science and engineering. Emphasis on use of original sources and artifacts. *(Not offered 1971–72.)*
C. S. Smith

3.79J *Science and Engineering of Biological Membranes and Structural Tissue*
(New)
(Same subject as 2.907J, 7.62J, 8.531J)
Prereq.: ——
Year: G (1) 3–0–6
Biophysical, biochemical and engineering aspects of various biological membranes and of structural tissue. Molecular biology and biochemistry of cell membranes; membranes of cancer cells. Introduction to the non-equilibrium thermodynamics of transport across membranes. Cooperative phenomena involving biological macromolecules and membranes. Capillary structure and analysis of water flux across the capillary wall. Molecular structure of collagen, elastin and of various mucopolysaccharides; the native and the denatured biological solid state. Introduction to linear relaxation mechanics with application to the function of articular cartilage. Topics in the structure and function of skin. Structure and physiology of bone, introduction to quantitative stereology with application to calcified tissue.
R. M. Rose, B. W. Burge, J. F. Burke, H. E. Stanley, I. V. Yannas

4.
Architecture

4.011 *Graphics Laboratory I*
Prereq.: ——
Year U (1) 0–3–2
Freehand drawing exercises to develop accurate observation and skill in graphic representation. Linear, light and shadow, detail and perspective renderings of varied subject matter. Control of line, value, color, texture and form using pencil, pen, and brush. *Staff*

4.012 *Graphics Laboratory II*
Prereq.: ——
Year: U (2) 0–3–2
Continuation of practice in representational techniques. Exercises employing graphic devices useful in all types of freehand drawing. Use of charcoal pencil, pen and ink, and water color as effective means to create the graphic equivalent of what is observed or visualized.
R. O. Preusser

4.013 *Graphic Composition*
Prereq.: 4.032
Year: U (1) 2–4–6
Study of visual abstraction based on graphic images. Study projects centering on aesthetics of surfaces, visual counterpoint, optical illusions, pictorial motion, compositions of positive and negative area relationships, the concrete and the amorphous, analogous and complementary, exploration of symbolic images. Objective: realization of visual meaning and composition through synthesis of graphic imagery. *Staff*

4.021 *Visual Design Problems I*
Prereq.: ——
Year: U (1, 2) 1–4–4
Studio participation in problems of visual invention, organization, and expression. Development of visual awareness, imagination, and creative insight focused upon subjective qualitative values. Experimentation in application of materials, tools, and processes unique to each student's professional field encouraged as means of gaining confidence and ability to create visual form.
R. O. Preusser

4.022 *Visual Design Problems II*
Prereq.: 4.021 or 4.051 or 4.071
Year: U (2) 1–4–4
Visual design experiments with emphasis on inventive use of media. Studio procedures individually directed enabling students to formulate and execute independent projects. Opportunity to explore industrial materials, tools and techniques, physical processes, natural forces, mathematical ideas and scientific instruments as means for innovating visual art forms. *R. O. Preusser*

4.023 *Visual Design Projects*
Prereq.: 4.032
Year: U (2) 2–4–6
Investigation of visual potential inherent in science and technology. Inventive manipulation of materials, tools, and techniques as means for broadening basis of visual thinking and clarifying interaction between concept, media, and design principles. Specific problems of visual form with special attention given to relationship of art to architecture and urban environment. *Staff*

4.031 *Form and Design I*
Prereq.: ——
Year: U (1) 2–4–6
Study of the visual elements of form to understand the processes of form synthesis. Studio experiments and lectures on proportion, shape, rhythm, visual quality of materials and three-dimensional composition. Emphasis on imagination and visual sensitivity directed to enlarge the individual's ability to create an aesthetic form.
R. Filipowski

4.032 *Form and Design II*
Prereq.: 4.031
Year: U (2) 2–4–6
Three-dimensional experiments and lectures on the organization of quantities, unit to volume relationships, modularity and form, volume and structure, surface structure of volume, space composition, point, line, plane composition, and sculptural composition. Emphasis on architectonic and sculptural aesthetic of form.
R. Filipowski

4.033 *Form and Color I*
Prereq.: 4.031
Year: U (1, 2) 2–0–4
Examination of color in natural form followed by experiments involving the color and form relationship to proportions, percentages, repetition, directions, quantity organization, structural order, angle position, and volume composition. A study to gain knowledge of color for the refinement of architectural form. *R. Filipowski*

4.034 *Form and Color II*
Prereq.: 4.032
Year: U (1, 2) 2–4–6
Study of color in relation to visual refinements of form — hue, value and chroma relationship from the general to the particular. Sequence of study projects involving color and area, texture, periodic patterns, random configurations, color depth, black and white, visual vibrations, color and natural form, volume, structure, motion, object and the color environment, and the visual influence of color on spaces. *R. Filipowski*

4.041 *Light and Color I* (A)
Prereq.: 4.032
Year: G (1) 2–4–6
Study of psychological and physiological phenomena of light and color. Lectures, demonstrations and exercises to determine the vocabulary of these elements, their relevance to communication and use in creating visual form. Utilization of photography to analyze light as a form-giving element and creative tool. Advances in techniques for generating light and producing color investigated and utilized in studio work. *R. O. Preusser*

4.042 *Light and Color II* (A)
Prereq.: 4.032
Year: G (2) 0–9–11
Study of light and color in all aspects relevant to their creative manipulation in art and architecture. Studio work supplementing a survey of the physical, physiological, and psychological phenomena of light and color. Analysis of the historical use of these elements and exploration of new tools and media. *R. O. Preusser*

4.051 *Creative Photography I*
Prereq.: ——
Year: U (1, 2) 2–6–1
Exposure of the beginning student to photographic technique involving camera, light, film, chemicals and paper. Development of a sense for composition through visual exercises and analysis of photographic images. Development of the student's awareness of his own way of seeing through exposure to many photographic images — his own, his instructors', exhibited gallery prints, and those of our mass media. (*Limited enrollment.*)
G. C. Thomas, J. Green

4.052 *Creative Photography II*
Prereq.: 4.051
Year: U (1, 2) 2–6–1
Expansion of fundamentals of technique and vision by exploration of the negative, direct contact with subject matter, and photographic metaphor. Photography based on conscious concentration for purposes of communication and evocation. (*Limited enrollment.*) *J. Green*

4.053 *Documentary Photography*
Prereq.: 4.051
Year: U (1, 2) 2–6–1
Examination of the photograph as a visual statement about the human condition, in which moments related to time are converted into images related in space. Lectures and class discussion on technical, psychological, and graphic-layout problems followed by ten weeks of individual photographic projects resulting in completed visual or audio-visual presentations. (*Limited enrollment.*)
J. Green

4.054 *Photo-Graphics I*
Prereq.: 4.051
Year: U (1) 2–6–1
A research, experiment, and print-production subject using working materials and processes made available by contemporary technology such as silk screen, photo relief, and dye processes as well as classical, gum bichromate, and photogravure methods. Personal expression through production of photo-originated graphic images. (*Limited enrollment.*) *R. MacNeil*

4.055 *Photo-Graphics II*
Prereq.: 4.054
Year: U (2) 2–6–1
Continuation of 4.054 with emphasis on individual work.
R. MacNeil

4.056 *Evaluating Photography*
Prereq.: ——
Year: U (1, 2) 3–0–6
Introduction to an existential basis of criticism for photography. Evaluations based on confrontations with images in states of heightened awareness and investigations of many individual responses to a single image are used to reveal to the student the essential tendencies of his own thought and vision and the uniqueness of the perceived image. (*Limited enrollment.*) *J. Green*

4.057 *Creative Audience*
Prereq.: ——
Year: U (1, 2) 4–0–5
Group dynamics based on photographic images. Attempts to generate responses equivalent to the image stimulus. Emphasis on group experience and involvement as a way of personal growth and as a means of communication between the viewer and the photographer. The photographer's audience as creative as he is in matters of perception. (*Limited enrollment.*) *M. White*

4.058 *Special Projects and Selected Topics in Photography*
Prereq.: ——
Year: U (1, 2) *Arr.*
Photographic projects on individual basis with minimum project length one month. Registration subject to prior arrangement for subject matter and supervision. Work in various fields of photography not covered by regular subjects of instruction such as photographic design, intensive study of individual photographers, creative writing and photography, and architectural photography. (*May be repeated for credit. Limited enrollment.*)
Staff

4.059 *Special Projects and Selected Topics in Photography*
Prereq.: ——
Year: G (1, 2) *Arr.*
Individual projects of short or long duration. Registration subject to prior arrangement for subject matter and supervision. Work in various advanced fields of photography such as creative editing, curatorial practices and exhibition techniques, light and luminance, and various topics in the history of photography such as the Photo-Secession. Students have the opportunity to work closely on a master-apprentice basis with a well-known photographer. (*May be repeated for credit. Limited enrollment.*) *Staff*

4.06 *Advanced Visual Design* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Studio projects in the visual arts as elements in an architectural setting; visual communication through exhibition design, posters, and architectural use of lettering and signs; visual documentation, or the graphic presentation of environmental situations and ideas. *Staff*

4.061 *Visual Design, Special Problems*
Prereq.: ——
Year: U (1) *Arr.*

4.062 *Visual Design, Special Problems*
Prereq.: ——
Year: U (2) *Arr.*
Supplementary work on individual or group basis. Registration subject to prior arrangement for subject matter and supervision by staff. *Staff*

4.063 ***Projects in Environmental Art*** **(A)**
(New)
Prereq.: ——
Year: G (1, 2) *Arr.*
Individual or specially scheduled topics in advanced visual design. Enrollment and credit by arrangement.
G. Kepes, C. A. V. S. Staff

4.071 ***Painting***
Prereq.: ——
Year: U (1) 1–4–4
Practice in the art of painting coordinated with theory related to contemporary concepts in the light of historical development. Language of art with emphasis on structure and content advanced by lectures and demonstrations as framework for studio activity. Creative capacity and analytical ability challenged by studio and seminar participation. Manipulation of the visual elements in painting utilizing principles of organization to realize individual expression through pictorial means. Primary goal: experiencing the artist's process and understanding visual values and meaning of art in culture. *(Not offered 1971–72.)* *R. O. Preusser*

4.081 ***Plastic Composition***
Prereq : 4.032
Year: U (1, 2) 2–4–6
Study of plastic sculptural form based on continuity of surfaces, synthesis of diverse geometries, group form relationships, object and the landscape, and the optimum three-dimensional relationship of the object. Studies directed toward inventiveness and meaning of sculptural form. *(Permission of instructor required.)* *R. Filipowski*

4.091 ***Introduction to Film Making***
Prereq.: ——
Year: U (1, 2) 4–6–2
Workshop exploration of the potentialities of the motion picture as documentary and as a means of personal and political expression. Series of exercises combining filming, editing, and sound. Viewing and discussion of many films. Ample opportunity for students to experiment with various film techniques. *(Limited enrollment.)*
E. Pincus

4.092 ***Advanced Film Making***
Prereq.: 4.091
Year: U (1, 2) 2–5–5
Practical experience in filming and editing with modern synchronous sound equipment. Individuals to take full responsibility for sequences in films that are expected to be used and useful. *(Limited enrollment.)*
R. Leacock, E. Pincus

4.093 ***Special Topics in Motion Picture Production***
(New)
Prereq.: 4.091 or 4.092
Year: G (1, 2) *Arr.*
Individual projects of short or long duration. Registration subject to prior arrangement for subject matter and supervision. *Staff*

4.094 ***Seminar on Film and Television Technology*** **(A)**
(New)
Prereq.: ——
Year: G (2) *Arr.*
To develop research projects on: (1) The simplification and sophistication of sync sound film making techniques for both 16mm and 8mm; (2) Complex computer controlled projection systems. *R. Leacock*

4.096 ***Movies: An Introduction I***
Prereq.: ——
Year: U (1) 3–5–1

4.097 ***Movies: An Introduction II***
Prereq.: ——
Year: U (2) 3–5–1
Analysis of the various components of the film experience. Such problems as point-of-view, editing, acting and the creation of film time and space taken up as they relate to various historical and genre traditions. Viewing of many films as well as multiple viewings of the same film. Film clips and other visual material accompanying lectures. *E. Pincus, R. Leacock*

4.098 ***Special Topics in Film History and Criticism*** **(A)**
(New)
Prereq.: 4.096, 4.097
Year: G (1, 2) *Arr.*
Individual projects in film history and criticism. Prior arrangement and approval of instructor necessary. *Staff*

4.099J ***Workshop in Critical and Creative Experience***
(New)
(Same subject as 21.954J)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Inquiry into the social and cultural basis of perception and into the connection between aesthetic experience and the emotions. Emphasis on encountering visual images, especially photographic ones, as a mode of self expression. Development of a critical approach grounded in experience of the image rather than opinions about it. Application of gestalt and encounter group techniques to discover the feelings, preconceptions and roles that block openness to the interpersonal and cultural environment. *(Limited enrollment.)* *M. White, M. Miller*

4.121 ***Architectural Design***[1]
Prereq.: ——
Year: U (1) 0–12–8

4.122 ***Architectural Design***[1]
Prereq.: 4.121
Year: U (2) 0–12–8
Establishment of basic attitudes to architectural organization and its reflection in form. Small-scale projects whose imposed conditions of site, program, and building system emphasize the interrelationship of fundamental elements in the pattern of decision making that constitutes design. Presentations developed through drawings and models. *M. K. Smith, R. Tremaglio*

4.131 ***Architectural Design***[1]
(Revised: Unit change)
Prereq.: 4.122
Year: U (1) 0–12–8

4.132 ***Architectural Design***[1]
(Revised: Unit change)
Prereq.: 4.131
Year: U (2) 0–12–8
Projects selected to develop awareness of the principal issues facing the contemporary architectural designer and the range of possibilities available for effective satisfaction of common environmental needs. *Staff*

[1] ***Note about the subjects in Architectural Design***
The sequence in Architectural Design is a cumulative program. Its successful completion by the student is subject to the evaluation of the staff independently of formal grades accumulated.

4.143 ***Architectural Design*** **(A)**
Prereq.: 4.132, 4.32
Year: G (1) 0–12–8

4.144 ***Architectural Design*** **(A)**
Prereq.: 4.143
Year: G (2) 0–12–8

Design for intensive and extended space uses, the grouping of buildings, buildings of multi-story construction, mass circulation movements, and areas requiring specialized space forms or equipment or having multiple uses. Consideration of the thermal problems of buildings, the distribution of daylight and artificial light, and the control of sound in buildings as they influence the design concepts and study of the installations associated with them. *Staff*

4.155 ***Architectural Design*** **(A)**
Prereq.: 4.144
Year: G (1) 0–12–8

Emphasis on the setting of architectural work as part of an organized community in projects having to do with built-up areas as well as those on new sites. Study of plans for long-range development giving students increasing experience in the analysis of real-life situations requiring program research. *Staff*

4.160 ***Urban Settlement Design in Developing Countries*** **(A)**
(New)
Prereq.: 4.155
Year: G (1) 0–15–20

Advanced projects on Urban Settlement Environments for low income groups in developing countries. Aims: to prepare designers to participate effectively in the process of shaping the environment; to develop tools to define and evaluate design determinants; and to make these tools available to those concerned and responsible for action at the policy making level. *H. Caminos*

4.161 ***Urban Settlement Design in Developing Countries***
(New)
Prereq.: 4.160
Year: G (2) 0–15–20

Continuation of 4.160 with emphasis on independent projects. *H. Caminos*

4.162J ***Collaborative Design*** **(A)**
(Same subject as 11.37J)
Prereq.: 11.711
Year: G (2) *Arr.*

Project work on design problems which will benefit from collaboration between architects and city planners or between these groups and other disciplines. *J. R. Myer, J. Beinart, W. L. Porter*

4.163 ***Urban Design II*** **(A)**
Prereq.: 4.162
Year: G (1) *Arr.*

Advanced projects in urban design such as the design of new towns, universities, urban renewal, and integrated urban transportation systems. Emphasis on the method, prediction, and evaluation of the design. *J. Beinart*

4.164 ***Systems and Industrialization*** **(A)**
(New)
Prereq.: 4.155
Year: G (1) 0–15–20

4.165 ***Systems and Industrialization*** **(A)**
(New)
Prereq.: 4.164
Year: G (2) 0–15–20

Special projects on urban and building systems responding to laws of human behavior, organization and construction. Emphasis on high density community design; interpretation of systems and subsystems. Minimum requirement: two terms. *E. Catalano, W. Zalewski*

4.17, 4.171 ***Architectural Design, Special Problems***
Prereq.: ——
Year: U (1, 2) *Arr.*

Supplementary work on individual or group basis. Registration subject to prior arrangement for subject matter and supervision by staff. *Staff*

4.19 ***Special Problems in Architectural Design*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*

4.191 ***Special Problems in Architectural Design*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*

Supplementary design work for graduate students. Registration subject to prior arrangement for subject matter and supervision by staff. *Staff*

4.20 ***Introduction to Information Processing*** **(A)**
Prereq.: ——
Year: G (1, 2) 3–0–3

Basic principles of computer hardware organization, programming systems, languages and problem solving with digital computers. Laboratory experience in computer programming, computer operation, and the application of computers to problems of architectural interest. Different man-machine communication modes exemplified with exercises and demonstrations in computer graphics, information-retrieval systems, and time-sharing. *T. Johnson*

4.21 ***Design Information: Structures and Models*** **(A)**
Prereq.: 1.00 or 4.20 or 6.00
Year: G (2) 3–3–3

Basic principles of data structures and organization, exemplified by computer based and traditional structures that have applications in architectural design. Computer simulation and modeling techniques for studying time dependent problems. Exercises in converting architectural programs to an explicit set of requirements. *T. Johnson*

4.23J ***Analysis of Urban Design*** **(A)**
(Revised: Unit change)
(Same subject as 11.34J)
Prereq.: 4.20, 11.30 or 11.31
Year: G (2) 3–0–6

Analysis of the processes and the products of urban design. Discussion of descriptions of environments and of transformations and tests of the descriptions. Examination of techniques, especially computer-based, which can be used to aid the designer. Development of criteria by which to evaluate the adequacy of computer languages to represent design ideas, accommodate design processes and to aid the designer. An independent project required. *W. L. Porter*

4.24 ***Computer-Aided Urban Design*** **(A)**
Prereq.: ——
Year: G (1) 3–0–6

Workshop with students pursuing research projects of their choosing within the context of architect-machine communication as an aid to the design of urban environments. Special emphasis on machine-partnership and programs of evolution. *(Programming experience necessary. Master's candidates can take 1.00 or 4.20, or 6.00 simultaneously.)* *L. B. Groisser, N. P. Negroponte*

4.25 ***Machine Intelligence in Design*** **(A)**
Prereq.: 4.24
Year: G (2) 3–0–6
Experimentation with machines that learn about their users, in particular, their users' needs, desires and attitudes. Application of machines which directly view physical environments; applying studies in pattern recognition, linguistics, and self-organizing systems. The subject relies on student initiated research and visiting specialists. *L. B. Groisser, N. P. Negroponte*

4.27 ***Special Topics in Design Aids***
Prereq.: ——
Year: U (1, 2) *Arr.*
Supplementary work in the area of design aids as independent study. *Staff*

4.29 ***Special Topics in Design Aids*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
Supplementary work in the area of design aids as independent study. *Staff*

4.30 ***Basic Structural Theory***
Prereq.: 8.02, 18.02
Year: U (2) 3–3–6
Introduction to the static behavior of structures. Determination of loads, deformations of determinate and indeterminate structures. Definitions of stress and strain at a point with an introduction to material behavior. Applications to stress distributions and deflections of slender elements in twisting and bending. Considerations of stability of structures in both elastic and plastic situations. The qualitative use of models to illustrate basic concepts as well as for solution of complex problems. Laboratory work giving students opportunity to produce creative designs for solving structural problems, with execution of these designs by building models and testing them. *L. B. Groisser*

4.311 ***Framed Structures I***
Prereq.: 4.30
Year: U (1) 4–0–4
4.312 ***Framed Structures II***
Prereq.: 4.311
Year: U (2) 4–0–4
Study of structural configurations and systems viewed as a response to loads. Investigation of the effects of scale on structural design. Application of framed structural systems in wood, steel, concrete, masonry, etc.
L. B. Groisser, E. Traum

4.313 ***Funicular and Membrane Structures***
Prereq.: 4.30
Year: U (1) 4–0–4
Study of structural systems which derive their strength from their geometry: arches, domes, shells, folded plates. Space frames. Suspended and tension structures. Membrane structures. *Staff*

4.321 ***Structural Design and Application I*** **(A)**
Prereq.: 4.30
Year: G (1) 2–2–4
4.322 ***Structural Design and Application II*** **(A)**
Prereq.: 4.30
Year: G (2) 2–2–4
Integrated architectural-mechanical-structural design. Nature and range of functional requirements for structures. Study of interrelationship between structures and building methods and architectural and mechanical design. Emphasis on conception and initial selection procedure of the structural system. *P. Morreau*

4.331 ***Synthesis of the Behavior of Structural Systems*** **(A)**
Prereq.: 4.30
Year: G (2) 2–2–4
Classification of the most characteristic patterns of the behavior of basic structural materials, structural systems, and their components. Catenary, Arch, and Shell Structures. Flow of internal forces in Deep Walls and Beams; Trusses; Frames and Plates. Study of basic relationship between shape of structure and its technological and mechanical efficiency as a way to general optimization. Study of methods of quantitative estimate of structural behavior for typical cases. Mastery of simplified procedures-graphical and numerical-applied to the design of structural systems. *W. Zalewski*

4.332 ***Industrialization of Structural Systems*** **(A)**
Prereq.: 4.30
Year: G (1) 2–4–4
Examination of the application of industrialized processes to building construction. Industrialized building components and systems; design, fabrication and erection. Implications of industrialized construction for architecture and engineering design. *W. Zalewski*

4.39 ***Special Problems in Structural Design*** **(A)**
Prereq.: 4.30
Year: G (1, 2) *Arr.*
Supplementary structural design on individual or group basis. Registration subject to prior arrangement for subject matter and supervision by staff. *Staff*

4.402 ***Building Process***
Prereq.: ——
Year: U (1) 3–3–6
Principal building systems as affected by environmental and legal conditions, materials, and industrial constraints. Interrelationships among the parts of the system. Fundamental systems of enclosure, load distribution and environmental control; air, heat, light, sound. Assembly processes and principles of project control. Problems, projects, and field trips to illustrate principles. *A. G. H. Dietz, E. B. Allen, W. H. Brown*

4.42 ***Materials***
Prereq.: 1.02
Year: U (2) 3–2–3
Emphasis on newer materials and combinations. Development of properties and applications from fundamental structure of materials. Plastics and other polymeric materials. Engineering adhesives and principles of bonding. Wood derivatives and bonded structures. Ceramics. Glass. High-performance masonry. Metals and alloys. Composites of several materials: fiber-reinforced, laminates, and sandwiches. Principles of combined behavior. Deterioration of materials, protection against attack. *A. G. H. Dietz*

4.43 ***Environmental Control — Acoustics***
Prereq.: 8.02
Year: U (1) 3–0–5
Principles of acoustical design for good hearing conditions and control of noise in rooms and buildings; design criteria; analysis of sound absorption and transmission; acoustical properties of room shapes, structures, and surface materials; laboratory demonstrations.
R. B. Newman

4.431 ***Special Problems in Architectural Acoustics*** **(A)**
Prereq.: 4.43
Year: G (1 or 2) *Arr.*
Broad study of functional acoustic design in architecture (based on project work in actual buildings where possible), sound distribution and diffusion in rooms, and sound transmission through building structures.
R. B. Newman

4.49 *Environmental Controls, Special Problems* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Supplementary work on individual or group basis. Registration subject to prior arrangement for subject matter and supervision by staff. *Staff*

4.52 *Industrialized Building Seminar* (A)
(*Revised: Unit change*)
Prereq.: 4.402
Year: G (1) 3–0–6
Trends toward offsite fabrication of buildings. Principles of industrialized production. Implications for design and construction. Principal types of industrialized systems, materials, and components. Problems of the module. Major emphasis on housing with consideration of industrialized building in general. Invited participants from industry and the professions. Field trips as opportunities arise. *A. G. H. Dietz*

4.53 *Project Organization and Control* (A)
Prereq.: 4.402
Year: G (2) 3–0–6
Organization for building design and construction. Analysis of projects. Use of networks and other systems for control of projects including CPM, PERT and similar logic diagrams for timing, acceleration, trade-offs, and resource control. Elements of linear programming related to the field. Invited participants from industry and the professions. *A. G. H. Dietz*

4.54 *The Industrialized Building Industries* (A)
(*New*)
Prereq.: —
Year: G (1, 2) 3–0–6
Structure, operation and performance of the manufactured building industry and the mobile home industry, and their roles within the building industry. Supply functions, product development, manufacturing, marketing, financing and public regulation. Development trends of the industries, exploratory forecasts. Problems and potentials, especially from an architectural and planning perspective. Normative forecasts. A case study in radical industrialization: strategies for the comprehensive development of both industries. Industry speakers, field trips. *A. D. Bernhardt*

4.55 *Selected Topics in Industrialization of the Building Industry* (A)
(*New*)
Prereq.: —
Year: G (1, 2) *Arr.*
Special topics in the industrialization of the building industry, with particular emphasis on political, socio-economic and technological problems. Research-oriented seminar, topics varying with student interest. (*Limited enrollment.*) *A. D. Bernhardt*

4.601 *Topical Studies in the History and Theory of Art*
Prereq.: ——
Year: U (1, 2) 3–0–6
Painting, sculpture, and architecture from pre-history to the present. The different motivations for visual art, its cultural implications, the various forms it has assumed, and the means of its production investigated relative to time and place. Theories of art and art history and methods of criticism presented and analyzed in lectures and discussions, and on visits to Boston area museums. (*Limited enrollment.*) *W. V. Andersen, N. Arghyros*

4.602 *Introduction to Modern Art*
Prereq.: ——
Year: U (1, 2) 3–0–6
Painting and sculpture from the late eighteenth century to the present. An investigation of the theoretical basis for such different styles as neoclassicism, romanticism, impressionism, cubism, constructivism, surrealism, etc., and including the recent events of abstract expressionism and its aftermath. Presented both historically and topically. Problems of interpretation and criticism. (*Limited enrollment.*) *J. G. Wechsler*

4.603 *Painting and Sculpture in the Middle of the Nineteenth Century*
Prereq.: ——
Year: U (1) 3–0–6
Art and artists in Paris around 1850, preceding the formulation of Impressionism in the late sixties and seventies. Manet, Degas, Pissarro, Monet, Renoir, the early Cézanne — their background and their achievements, their continuity into the eighties and importance for later phases of modern art. Special emphasis on nineteenth century color theory. *J. G. Wechsler*

4.604 *Modern Art from Post-Impressionism to Cubism*
Prereq.: ——
Year: U (2) 3–0–6
Cézanne, Gauguin, Van Gogh, and Seurat presented against a background of Impressionism and other nineteenth century styles. Their relationship to the Synthetist, Nabis, and Symbolist groups. Required readings from letters and other writings by the artists, their artist and writer friends, and their critics. *W. Andersen*

4.605 *Painting in the Twentieth Century*
Prereq.: ——
Year: U (1, 2) 3–0–6
Cubism, Futurism, Constructivism and other phases of early twentieth-century art during which the theories, styles, and attitudes of contemporary art were formulated. Dadaism, Surrealism, and other intermediate phases leading to Abstract Expressionism in New York. Post-Painterly Abstraction styles, Pop Art, and the recent Optical Art Movement, considered both historically and critically. *J. G. Wechsler*

4.606 *Sculpture in the Twentieth Century*
Prereq.: ——
Year: U (2) 3–0–6
Development, against a background of Rodin and late nineteenth century sculpture, of the trends leading to the present-day situation. Special emphasis on Maillol and the "large-figure" style, Brancusi and direct carving; cubist, futurist, and constructivist sculpture. One-third of the subject devoted to American sculpture since 1930. (*Not offered 1971–72.*) *R. E. Krauss*

4.607 *Twentieth-Century Art Theories*
Prereq.: ——
Year: G (1 or 2) 3–0–6
Seminar on the origin and interaction of the movements which established the formal vocabulary of most twentieth-century art. (*Open also to advanced undergraduates with consent of instructor. Not offered 1971–72.*) *R. E. Krauss*

4.608 *Symbolism in Modern Art*
Prereq.: ——
Year: G (1 or 2) 3–0–6
Seminar on selected topics in the analysis of the content and meaning of modern art. (*Open to qualified students with consent of instructor.*) *W. V. Andersen*

4.609 *Advanced Study in Symbolic Imagery* (A)
(*New*)
Prereq.: 4.608
Year: G (1 or 2) 3–0–6
Seminar on visual symbolism involving critical uses of modern psychoanalytical, structuralist, contextual and non-directional modes of pictorial conception and analysis. Independent research on topics chosen by students. (*Limited enrollment.*) *Staff*

Descriptions

4.61 ***Studies: Architecture in the Ancient World***
Prereq.: ——
Year: U (1) 3–0–6
Analysis of role of mass, space, structure, light, surface, and related social, political, and economic factors in architecture and urban design from prehistory through Roman times. *(Not offered 1971–72.)* *H. A. Millon*

4.62 ***Studies: Architecture 1400-1750***
Prereq.: ——
Year: U (2) 3–0–6
Same as 4.61, but covering the period from the beginning of the Renaissance to the end of the Rococo. *(Not offered 1971–72.)* *H. A. Millon*

4.621 ***Origins of Contemporary Architecture in the Eighteenth Century* (A)**
Prereq.: 4.62 or 4.64; 4.651, 4.652
Year: G (1) 3–0–6
Seminar surveying the principal works of architecture and major theoretical statements of eighteenth-century architects and writers in order to define, understand, and examine the origins of contemporary theoretical positions. *(Not offered 1971–72.)* *H. A. Millon, S. Anderson*

4.63 ***Studies: Architecture in the Middle Ages***
Prereq.: ——
Year: U (1) 3–0–6
Selected buildings and urban complexes from the time of Rome's conversion to Christianity to the beginning of the Renaissance. Special attention given to the influence on the builders of architectural traditions as well as significant religious, social, political and economic factors. *(Not offered 1971–72.)* *S. Anderson*

4.64 ***Studies: Architecture from 1750 to the Present***
Prereq.: ——
Year: U (2) 3–0–6
Study of selected designs as research programs (architectural form and its intellectual, social, and technical context.) Emphasis on the twentieth century. *(Not offered 1971–72.)* *S. Anderson*

4.641 ***Modern Architecture in Europe from 1895 to the Bauhaus* (A)**
Prereq.: 4.64 or 4.652
Year: G (1) 3–0–6
Art and architecture in Europe from the late nineteenth century to the time of the Nazi repression of modern art. Intensive study of the men, the works, and the controversies from which the European "modern movement" emerged, leading in turn to the transformation of American architecture. *(Not offered 1971–72.)* *S. Anderson*

4.651 ***Introduction to History of Architecture I***
(New)
Prereq.: —
Year: U (1) 3–0–6
Selected aspects of architecture and urban planning in Europe and the mid-east from pre-history through Roman times, and the fifteenth through eighteenth centuries in Europe and the new world. *H. A. Millon*

4.652 ***Introduction to History of Architecture II***
(New)
Prereq.: —
Year: U (2) 3–0–6
Selected aspects of architecture and urban planning in medieval and modern times. *S. Anderson*

4.653 ***Meaning in Architecture* (A)**
(New)
Prereq.: 4.601, 4.651, 4.652
Year: G (2) 3–0–6
Theories of the origin of building and architecture; theories of the significance of materials and use (see also 4.655); distinctions between artifacts and objects of design; contextual issues of patronage, society, culture. In general, an examination of theoretical and formal models (see also 4.654) as they are revealed in the built environment. *S. Anderson*

4.654 ***Form in Architecture* (A)**
(New)
Prereq.: 4.601, 4.651, 4.652
Year: G (1) 3–0–6
An examination of intrinsic formal qualities of architecture, formal vocabularies, and innovation in architectural form. The subject will also consider the relationship between built forms and (1) intent, (2) theoretical models, and (3) theories of form perception, as well as, secondarily, (4) meaning (see 4.653), and (5) construction methods (see 4.655). *H. A. Millon*

4.655 ***Physical Considerations in Architecture* (A)**
(New)
Prereq.: 4.601, 4.651, 4.652
Year: G (1 or 2) 3–0–6
Materials, construction and structure; activity and use in architecture as well as the theories of form (see also 4.654) and of function (see also 4.653) which have been based on such physical considerations. *S. Anderson*

4.661 ***Criticism of Architecture* (A)**
(New)
Prereq.: 4.601, 4.651, 4.652
Year: G (2) 3–0–6
Seminar surveying the various approaches (social, environmental, economic, compositional, structural, functional, etc.) and bases for the criticism of architecture. Principal emphasis on formal bases of criticism. History of criticism, relation of criticism and history, value of criticism to the profession, criticism as a means of achieving quality in architecture, and criticism as a rational and emotional response to architecture. *(Not offered 1971–72.)* *S. Anderson, H. A. Millon*

4.662 ***Studies Toward a Theory of Architecture* (A)**
(New)
Prereq.: 4.601, 4.651, 4.652
Year: G (1) 3–0–6
Seminar about contemporary theoretical positions. Reports by seminar members either in the context of, or in criticism of, the thesis of the seminar.
S. Anderson, H. A. Millon

4.664 ***Studies Toward a Theory of Environmental Design and Form* (A)**
(New)
Prereq.: —
Year: G (1) *Arr.*
Seminar with intent to stimulate thought about our contemporary theoretical positions. Studies to be carried out by seminar members may be either in criticism or in support of the thesis of the seminar.
J. R. Myer, W. Southworth

4.67 ***History of Urban Form* (A)**
Prereq.: ——
Year: G (2) 3–0–6
History of the city as an architectural form. Study of the physical growth of cities as an expression of a developing social structure, as well as with reference to artistic ideals. *Staff*

4.671 ***Elements of Urban Evolution***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Consideration of the forces, in different periods, determining the character and principal functions of cities — military, religious, commercial, political, industrial and

utopian. Readings in literary, artistic, and historical sources. Independent individual student projects with a wide range of choice for production of term papers dealing with a particular city over a manageable time span, usually less than a century. Lectures and seminars. (*Limited enrollment. Not offered 1971–72.*) *Staff*

4.681 *Theory and Method in the History of Art and Architecture*
Prereq.: ——
Year: U (1, 2) 3–0–6
Selected research with written report. Intended primarily to prepare the student for graduate studies. (*Open only to advanced students.*) *Staff*

4.691-4.695 *Selected Topics in the History of Art and Architecture* (A)
Prereq.: 4.601, 4.602; or 4.61, 4.62, 4.63, 4.64
Year: G (1, 2) *Arr.*
Special topics in the history of art and architecture, varying at the discretion of the instructor. *Staff*

4.70 *User and Community Involvement in Housing*
Prereq.: 4.122
Year: U (1, 2) 4–0–4
Study of different types of user-involvement in housing and the impact on the environment and the users. Comparison of case projects and development of design criteria for experimental projects. *H. Harms*

4.701 *Architectural Communication*
Prereq.: ——
Year: U (1) 4–2–2
Introduction to techniques of communication with self (visualization), with others (presentation), and with machines (manipulation). Techniques of projective geometry, photography, and state of the art media. In parallel, a series of introductory lectures from members of the Architecture Department faculty giving both an overview of the Department offerings and an introduction to principles of architecture, visual design, building technology, and design methods. (*Recommended as a freshman/sophomore introduction to Course IV.*) *Staff*

5.
Chemistry

5.01 *Chemistry*
Prereq.: ——
Year: U (2) 5–0–7
Structure of individual molecules, based on quantum theory of atomic energy levels. Methods of determining their structures through the use of spectroscopy. Dynamics of molecular collisions, and how these affect gas and liquid properties and the kinetics of chemical reactions. *J. I. Steinfeld*

5.03 *Principles of Inorganic Chemistry I*
Prereq.: 5.41; 5.61 or 8.04
Year: U (2) 3–0–9
Presentation of the theoretical principles of chemical bonding and molecular structure, and their application in a survey of the chemistry of all the elements of the periodic system. Emphasis on the lighter non-transition elements. *A. Davison, R. J. Lagow*

5.04 *Principles of Inorganic Chemistry II*
Prereq.: 5.03
Year: U (1) 3–0–6
Theory and descriptive material relating to the heavier elements and the transition elements. Special emphasis on ligand field theory. *A. Davison*

5.065 *Advanced Inorganic Chemistry* (A)
Prereq.: 5.03
Year: G (2) 3–0–6
Extended treatment of some special topics of current interest in modern inorganic chemistry, organometallic compounds, and hydrides; treatment in terms of modern electronic and structural theory. (*Not offered 1971–72.*) *A. Davison*

5.066 *Special Topics in Inorganic Chemistry* (A)
(*New*)
Prereq.: 5.04
Year: G (2) 2–0–4
Lectures and discussions on subjects of current research interest in inorganic chemistry with emphasis on stereochemistry, dynamics, and reactivity of transition metal systems, including some of possible biochemical relevance. *R. H. Holm*

5.067 *Chemical Applications of Group Theory* (A)
Prereq.: 5.04
Year: G (1) 2–0–4
Elements of group theory and its application to problems of molecular structure; treatment of vibrational spectra of inorganic compounds; introduction to ligand field theory and its use in the interpretation of spectral and magnetic properties of compounds of the transition elements; other current problems in theoretical inorganic chemistry, as time permits. *F. A. Cotton*

5.121J *Planetary Physics and Chemistry I*
(Same subject as 8.291J, 12.131J)
Prereq.: 8.02, 18.02
Year: U (1) 3–0–9

5.122J *Planetary Physics and Chemistry II*
(Same subject as 8.292J, 12.132J)
Prereq.: 8.02, 18.02
Year: U (2) 3–0–9
Study of the planetary system: evolution, composition, present configuration, dynamics, interiors, surfaces, atmospheres, and magnetospheres of the planets and, where appropriate, similar aspects of the satellites, asteroids, and comets. Theoretical interpretations of the existing data will be stressed. First term: a general description of the solar system and its origin and a comprehensive discussion of the outer planets. Second term: solar system dynamics, the interplanetary medium, and the interiors, surfaces, and atmospheres of the inner planets. *J. S. Lewis, I. I. Shapiro*

5.125J *Planetary Atmospheres* (A)
(Same subject as 12.631J)
Prereq.: ——
Year: G (1) 3–0–6
Discussion in light of recent spectroscopic and space probe data of compositions, structures, and origins of the atmospheres of the planets. Thermodynamics of atmospheric structure, cloud precipitation, and mineral buffers of pressures of reactive gases. Photolysis; escape rates, mineralogy of surface rocks. Chemical behavior of a solar-composition atmosphere; the solar nebula, the interiors of the major planets. Models for the origin and development of planetary atmospheres. (*Permission of instructor required. Not offered 1971–72.*) *J. S. Lewis*

5.129J ***Current Research in Meteoritics*** **(A)**
(Same subject as 12.636J)
Prereq.: ——
Year: G (2) *Arr.*
Discussion of current research and special problems in meteoritics. Composition and structure of important classes of meteorites; meteorite dating methods and their results; thermodynamics of meteoritic minerals. Geochemistry and isotopic chemistry of meteoritic and lunar surface material. Evidence concerning the origin of meteorite classes and proposed genetic relationships. Conditions in the solar nebular. *J. S. Lewis*

5.194 ***Design and Analysis of Experiments*** **(A)**
Prereq.: ——
Year: G (2) 2–0–4
Principles and applications of statistical design and analysis in chemistry and related fields. Significance testing, analysis of variance, correlation and regression. Sampling, sequential analysis, block designs, factorial design, fractional replication and determination of optimum conditions. *D. N. Hume*

5.195 ***Interpretive Spectroscopy*** **(A)**
Prereq.: 5.42, 5.61
Year: G (1) 3–0–6
Discussion of spectrometric techniques and their application to the identification of chemical compounds. Major emphasis on complementary use of infrared, nuclear magnetic resonance and mass spectrometry. Discussion of other techniques including ultraviolet spectrometry and molecular emission spectra. *K. Biemann*

5.20 ***Laboratory Problems in Chemistry***
Prereq.: ——
Year: U (1, 2) 1–3–2

5.21 ***Laboratory Problems in Chemistry***
Prereq.: ——
Year: U (1, 2) 1–6–5
Laboratory work with guidance of the chemistry department staff. Projects of chemical nature involving the determination of properties of a system or the reactivity of combinations of systems. Available topics: ΔS of a reaction by temperature dependence of e.m.f., ΔH's by calorimetry, colligative properties of liquids, mass spectrometry, chemical kinetics, X-ray interpretation and model building, construction and use of a photoelectric calorimeter and adaptation for optical rotation experiments, simple harmonic oscillator model, dipole moment by heterodyne beat method, chromatography, gas diffusion, construction of a simple NMR detector, quantum yield and actinometry of a photochemical reaction, organic and inorganic syntheses, radiochemical studies and investigation of the accuracy of analytical methods. Topics for organic-biochemical specialization: synthesis, enzyme kinetics and chromatography. (*Enrollment limited. Third- and fourth-year students must consult instructor before registering.*) *Staff*

5.22J ***Environmental Measurements Projects Laboratory***
(*New*)
(Same subject as 8.16J, 20.03J)
Prereq.: ——
Year: U (1) *Arr.*

5.23J ***Environmental Measurements Projects Laboratory***
(*New*)
(Same subject as 8.17J, 20.04J)
Prereq.: ——
Year: U (2) *Arr.*
An interdisciplinary project laboratory with faculty guidance but emphasizing independent work on measurements related to environmental problems.
Chemistry Staff, J. G. King, C. Cooney

5.31 ***Introduction to Chemical Experimentation***
Prereq.: 5.41
Year: U (1) 2–8–2
Introduction to the methods of experimental chemistry which emphasizes modern procedures for the preparation, isolation, purification, analysis, and characterization of substances, solid and liquid. *Staff*

5.32 ***Intermediate Chemical Experimentation***
Prereq.: 5.31, *5.42, 5.60*
Year: U (2) 2–8–2
More advanced experimental work with emphasis on equilibria, thermochemical measurements, and measurements of properties of gases. Introduction to the construction of simple apparatus, to simple electrical measurements, to the measurement and interpretation of infrared, visible, and ultraviolet spectra, and to chromatographic separations. (*Enrollment limited to 120 students.*) *Staff*

5.33 ***Advanced Chemical Experimentation***
Prereq.: 5.32, *5.61*
Year: U (1) 2–12–4
Advanced experimentation with particular attention to the syntheses of compounds, the measurement of kinetic phenomena, and the use of modern instrumentation. Some of the topics to be included: interpretation of nuclear magnetic resonance spectra and mass spectra, use of electronic equipment, application of computers to the solution of chemical problems, and use of the chemical literature. *C. C. Stephenson, C. G. Swain*

5.34 ***Introduction to Chemical Research***
Prereq.: 5.03, 5.33, 5.62
Year: U (2) 2–12–4
Project-oriented laboratory in which the student may select a program of experimentation from among projects that illustrate contemporary research methods in synthesis and in physicochemical measurement. Areas to be represented: atomic and molecular spectroscopy, transport properties of gases, molecular dynamics and interactions, electric and magnetic properties, properties of macromolecules, solid-state structure and properties, surface phenomena, and the preparation of relatively complex inorganic, organic and organometallic substances, etc. Full use of the techniques and instrumentation employed in the modern research laboratory including the application of computers to the solution of chemical problems. *C. C. Stephenson*

5.41 ***Introduction to Structure, Bonding and Mechanism***
(*Revised: Unit change*)
Prereq.: ——
Year: U (1, 2) 5–0–7
Correlation of chemical properties with a minimal set of empirical observations and theoretical principles. Electronic structures of atoms and molecules, structural chemistry, elementary concepts of energetics and kinetics. Description and prediction of acid-base behavior. Concept of mechanism with examples drawn from organic and inorganic chemistry. Generalized substitution reactions. Chemistry of the carbonyl grouping.
J. E. Baldwin

5.42 ***Organic Chemistry***
Prereq.: 5.41
Year: U (2) 4–0–8
Study reaction mechanisms with emphasis on reactive intermediates, structure-reactivity relationships, and reactions of synthetic value. *D. S. Kemp, F. D. Greene*

5.43 *Organic Chemistry*
Prereq.: 5.42
Year: U (1) 3–0–6
Study of reaction mechanisms with emphasis on reactive intermediates, structure-reactivity relationships, and reactions of synthetic value. *F. D. Greene*

5.51 *Advanced Organic Chemistry: Synthesis* (A)
Prereq.: 5.53
Year: G (1) 3–0–6
Organic reactions and the methods by which they are applied to synthetic problems in organic chemistry.
K. B. Sharpless

5.53 *Molecular Structure and Reactivity* (A)
Prereq.: 5.32, 5.42
Year: G (1) 3–0–6
Introduction to the theoretical interpretation of reactivity, reaction mechanisms, and molecular structure of organic compounds. Applications of spectroscopy to the determination of structure. *G. M. Whitesides*

5.54 *Physical Organic Chemistry* (A)
Prereq.: 5.53
Year: G (2) 2–0–4
Mechanisms of representative organic reactions in homogeneous liquid systems. Kinetic and other physical methods useful in studying organic reactions. Types of experimental evidence upon which current theoretical interpretations of reactivity are based. *C. G. Swain*

5.55 *Organic Chemistry: Natural Products* (A)
Prereq.: 5.51
Year: G (2) 2–0–4
The chemistry and physiological action of natural products. Methods of isolation; determination of structures and synthesis. *G. H. Buchi*

5.56 *Special Topics in Organic Chemistry* (A)
Prereq.: 5.51, 5.53
Year: G (2) 3–0–6
Advanced topics of special current interest.
K. Biemann, G. M. Whitesides, K. B. Sharpless

5.60 *Chemical Equilibrium*
Prereq.: 18.02
Year: U (1, 2) 4–0–8
Equilibrium properties of macroscopic systems. Basic thermodynamics — system, state of system, state variables. Work, heat, first law of thermodynamics, thermochemistry. Second and third law of thermodynamics — entropy, Gibbs function. Equilibrium phase rule, colligative properties of solutions, homogeneous and heterogeneous chemical equilibrium of reactions in the gas phase and solutions. *Term 1: J. Ross, R. J. Silbey*
Term 2: C. W. Garland, J. S. Waugh

5.61 *Physical Chemistry*
Prereq.: 8.02, 18.02
Year: U (1) 4–0–8
Introductory quantum chemistry: elementary atomic spectra; particles and waves; wave mechanics; atomic structure and the Periodic Table; valence theory; experimental methods of determining molecular structure; structure of crystals and liquids; photochemistry.
J. L. Kinsey, R. C. Lord

5.62 *Physical Chemistry*
Prereq.: 5.60
Year: U (2) 4–0–8
Elementary kinetic theory and statistical mechanics; transport properties of gases and liquids; rates of chemical reactions. *J. W. Dubrin, R. J. Silbey*

5.64J *Biophysical Chemistry*
(Same subject as 7.07J)
Prereq.: 5.60
Year: U (2) 3–0–9
Equilibrium and kinetic behavior of systems of biological interest. Solution equilibria, coupled reactions, theory of multiple equilibria, allosteric systems, enzyme catalysis and kinetics, chemical relaxation spectrometry, protein and polypeptide structures and conformations, helix-coil transformations, protein denaturation, polymer statistics, hydrodynamics of macromolecules, nucleic acid physical chemistry, special topics.
R. A. Alberty, P. R. Schimmel

5.68 *Kinetics of Chemical Reactions* (A)
Prereq.: 5.62
Year: G (2) 3–0–6
Experimental and theoretical aspects of advanced topics including: collision and transition state theories, homogeneous reactions in gas and liquid phases, enzymatic reactions, very fast reactions in solution, gas phase reactions in shock tubes and in molecular beams. (*Not offered 1971–72.*) *J. W. Dubrin*

5.70 *Introduction to Statistical Thermodynamics* (A)
Prereq.: 5.62
Year: G (1) 3–0–6
Review of classical thermodynamics and an introduction to elementary statistical mechanics, with applications to simple physical and chemical systems. *I. Oppenheim*

5.71 *Chemical Thermodynamics I* (A)
Prereq.: 5.62
Year: G (1) 2–0–4
Fundamental definitions and concepts; first and second laws of thermodynamics with applications to chemical systems, ideal and real gases, ideal and real solutions; partial molar quantities, chemical equilibrium; third law of thermodynamics and applications to chemical systems; free energy calculations. *C. C. Stephenson*

5.72 *Statistical Mechanics* (A)
Prereq.: 5.70, 5.73, 18.075
Year: G (2) 3–0–6
Principles and methods of statistical mechanics. Classical and quantum statistics, grand ensembles, fluctuations, molecular distribution functions, and other topics in equilibrium statistical mechanics. Advanced topics in thermodynamics, including irreversible processes.
I. Oppenheim

5.73 *Introductory Quantum Mechanics I* (A)
Prereq.: 5.61, 8.03
Year: G (1) 3–0–6
Fundamental concepts of quantum mechanics: wave properties, uncertainty principle, Schrödinger equation. Basic applications to: harmonic oscillator, hydrogen atom, WKB method. Perturbation theory and variation method. Pauli principle and spin. Introduction and use of operator and matrix methods. *J. S. Waugh*

5.74 *Introductory Quantum Mechanics II* (A)
Prereq.: 5.73, 18.075
Year: G (2) 3–0–6
Continuation of 5.73. Permutation symmetry and angular momentum. Molecular dynamics. Time-dependent problems, radiation and matter. Scattering by a central field. Many-electron systems, approximate molecular and atomic wave functions. *J. L. Kinsey*

5.76 *Molecular Spectra and Molecular Structure* (A)
Prereq.: 5.61, 18.075
Year: G (2) 3–0–6
Rotational, vibrational and electronic spectra of molecules; use of spectra to find dissociation energies, force constants, inter-atomic distances, molecular symmetry

and related quantities; other techniques for study of molecular structure such as dipole moments, magnetic susceptibilities, and nuclear magnetic resonance.
R. C. Lord

5.80 *Special Topics in Chemical Physics* (A)
Prereq.: 5.70, 5.73
Year: G (1, 2) *Arr.*
Advanced topics of special or current interest. The specific areas announced in advance of each term.
J. Ross

5.81 *Advanced Topics in Chemical Biophysics* (A)
Prereq.: 5.70, 18.075
Year: G (1 or 2) *Arr.*
Structures and properties of biopolymers. Statistical mechanics of biopolymers; matrix methods; conformational energies and configurational statistics; cooperative phenomena. Dynamics of biological processes; rates of enzymatic reactions; theory of chemical relaxation spectrometry with applications to biological reactions; rates of configurational changes in biopolymers. (*Offered occasionally. Consult instructor.*) *P. R. Schimmel*

5.82 *Advanced Topics in Solid State Chemistry* (A)
Prereq.: 5.70, 5.73
Year: G (1 or 2) *Arr.*
Selected topics from areas such as: structure of crystals, surface structure, symmetry groups, diffraction methods, lattice dynamics, order-disorder and magnetic phenomena, molecular motions in solids, relaxation phenomena, optical properties and exciton theory. (*Offered occasionally. Consult instructor.*) *C. W. Garland, R. J. Silbey, C. C. Stephenson*

5.83 *Advanced Topics in Statistical Mechanics and Kinetic Theory* (A)
Prereq.: 5.70, 5.73
Year: G (1 or 2) *Arr.*
Fundamental concepts of the statistical mechanics of irreversible processes, and the kinetic theory of gases in relation to molecular interactions and collision dynamics. (*Offered occasionally. Consult instructor.*) *I. Oppenheim*

5.84 *Advanced Topics in Spectroscopy and Quantum Mechanics* (A)
Prereq.: 5.74
Year: G (1 or 2) *Arr.*
Topics varying from year to year, including magnetic resonance, beam spectroscopy, non-linear optics, kinetic applications, and quantum field theory. (*Offered occasionally. Consult instructor.*) *J. S. Waugh*

5.89 *Special Problems in Chemistry for Undergraduates*
Prereq.: ——
Year: U (1, 2) *Arr.*
Program of study, either experimental or theoretical, to be arranged by the student and a departmental faculty member. Research for an undergraduate thesis may be arranged in this subject. *Staff*

5.90 *Special Problems in Chemistry* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Directed research and study of special chemical problems. (*For graduate students only.*) *R. C. Lord*

5.913 *Seminar in Organic Chemistry* (A)
Prereq.: ——
Year: G (1) 1–0–2

5.914 *Seminar in Organic Chemistry* (A)
Prereq.: ——
Year: G (2) 1–0–2
Discussion of current journal publications in organic chemistry by graduate students and staff members.
Term 1: K. B. Sharpless
Term 2: F. D. Greene

5.915 *Seminar in Analytical Chemistry* (A)
Prereq.: ——
Year: G (1) 1–0–2

5.916 *Seminar in Analytical Chemistry* (A)
Prereq.: ——
Year: G (2) 1–0–2
Discussion of topics of current interest in analytical chemistry by graduate students and staff members.
D. N. Hume

5.931 *Seminar in Physical Chemistry* (A)
Prereq.: ——
Year: G (1) 1–0–2

5.932 *Seminar in Physical Chemistry* (A)
Prereq.: ——
Year: G (2) 1–0–2
Discussion of topics of current interest in physical chemistry by staff members and students. *J. I. Steinfeld*

5.941 *Seminar in Inorganic Chemistry* (A)
Prereq.: ——
Year: G (1) 1–0–2

5.942 *Seminar in Inorganic Chemistry* (A)
Prereq.: ——
Year: G (2) 1–0–2
Discussion of current research in inorganic and nuclear chemistry by graduate students and staff. *R. J. Lagow*

5.981J *Seminar in Biochemistry* (A)
(Same subject as 7.74J)
Prereq.: ——
Year: G (1, 2) 1–0–2
Presentation by graduate students of critical reviews of recent publications in chemistry and biochemistry with application to selected biochemical problems. Discussions by staff and students.
Chemistry and Biochemistry Staff

6.
Electrical Engineering

6.00 *Introduction to Computation*
(*Revised: Unit change*)
Prereq.: —
Year: U (1, 2) 4–3–5
Study of computational processes as algorithms. Formal and informal techniques for the representation of algorithms and their implementation on digital computers. Selected lectures on topics of current interest in computer science. Introduction to computer programming. Experience with an algebraic language in the writing and running of programs to solve elementary problems.
F. J. Corbato

6.01 *Introductory Network Theory*
(*Revised: Content change*)
Prereq.: 8.02, 18.03
Year: U (1, 2, S) 4–0–8
Fundamentals of network theory with emphasis on types of networks important in many areas of engineering. The lumped network model: Kirchhoff's laws, energy, power, Tellegen's theorem. Network elements for a variety of types of networks; formulating network equations. State description of logic-gate networks and elementary finite-state machines; Karnaugh maps, state diagrams, and Boolean algebra. Time-domain state description of RLC networks with dependent sources. Natural response of linear networks; impulse response and convolution. Frequency-domain response of linear networks and relation to natural frequencies.
P. L. Penfield, Jr.

6.02 ***Electronic Devices and Circuits***
Prereq.: 6.01
Year: U (1, 2, S) 4–0–8
Modeling of electronic devices and analysis of nonlinear circuits. Physical electronics of semiconductor junction devices and the development of circuit descriptions for these devices; relation of electrical behavior to internal physical behavior, and limitations of circuit models. Development of incremental and large-signal techniques for analyzing circuits containing nonlinear devices. Analysis of signal-processing circuits which employ these devices, with examples chosen from switching circuits, single-ended and differential amplifiers, and integrated-circuit amplifiers. *R. B. Adler*

6.03 ***Electromagnetic Fields and Energy***
Prereq.: 6.01; 8.03
Year: U (1, 2, S) 4–0–8
Maxwell's equations and the Lorentz force law. Simple quasistatic electric fields and sources, electrical energy and its relation to forces. Integral and differential static electric field laws; Poisson's and Laplace's equations; boundary value problems in Cartesian and polar coordinates. Quasistatic magnetic fields; the law of magnetic induction. Integral and differential magnetic field laws and their solution; vector potential and vector Poisson's equation. Polarizable and magnetizable matter, non-linear media and magnetic circuits. Magnetic diffusion and charge relaxation.
H. A. Haus, J. R. Melcher

6.04 ***Electrodynamics***
Prereq.: 6.03, 6.05
Year: U (1, 2, S) 4–0–8
Basic subject in electrodynamics, with emphasis on phenomena associated with wave propagation and radiation. Plane waves in three dimensions, field solutions of an elementary electric dipole, radiation from current distributions and arrays, diffraction and interference. Guided electromagnetic waves on continuous transmission lines, periodic structures, and metallic waveguides; propagation and evanescence; energy flow and impedance matching. Pulse propagation in dispersive systems; energy and group velocity. Natural frequencies and modes of closed electromagnetic structures; coupling to resonant structures, loaded and unloaded Q's. Examples throughout taken from the fields of optics and microwaves. *R. J. Briggs, R. R. Parker*

6.05 ***Signals and Systems***
Prereq.: 6.01, 18.03 or 18.031
Year: U (1, 2, S) 4–0–8
Basic subject in system theory for electrical engineering students. System input-output in terms of impulse response and convolution integral. Signal representation in terms of Fourier series and Fourier integrals; applications to filtering, modulation and sampling. Laplace transform analysis; applications to feedback systems. Discrete time systems, Z transforms. State variable description of system operations. *A. B. Baggeroer*

6.08 ***Statistical Mechanics and Thermodynamics***
Prereq.: 8.04 or 8.211
Year: U (1, 2, S) 4–0–8
The statistical description of physical systems: phase space and ensembles; temperature and entropy. The laws of thermodynamics developed from statistical mechanics: work and heat; free energies and Maxwell relations; equations of state; heat engines and refrigerators; quantum statistics: Maxwell-Boltzmann, Bose-Einstein, and Fermi-Dirac gases; statistics of electrons in metals and semiconductors; Bose condensation; electronic and lattice specific heats; thermal noise. *D. Adler*

6.11 ***Project Seminar***
Prereq.: ——
Year: U (1) 2–0–4

6.12 ***Project Seminar***
Prereq.: ——
Year: U (2) 2–0–4
Study and evaluation of professional literature, oral presentation and active open discussion of topics drawn from and extending beyond those treated in the regular curriculum. Flexible organization, comprising a few students under guidance of a staff member. *L. D. Smullin*

6.13 ***Electric and Magnetic Properties of Solids***
Prereq.: 6.03, 8.04
Year: U (1) 3–0–9
Introduction to the physics of solids. Crystal structure, lattices and reciprocal lattices. Binding energies. Wave propagation in periodic lattices. Free electron and nearly free electron theory. Energy bands. Statistics of electrons and holes. Wave packets, charge carrier motion, the Boltzmann transport equation. Conductivity and Hall effect. Lattice vibrations. The dielectric and magnetic properties of solids. *(Not offered 1971–72.)*
D. J. Epstein

6.14 ***Introduction to Electronics***
Prereq.: 8.02, 18.02
Year: U (1, 2) 4–2–6
An introductory subject suitable for students with little or no previous background in electronics. Elementary network theory, diode and transistor circuits, analysis and design of analog and digital circuits using integrated circuits. Examples emphasizing the uses of electronics in experimental science. Alternate week laboratory.
S. D. Senturia

6.20 ***Electronics in Instrumentation***
Prereq.: 6.05
Year: U (1, 2) 3–0–6
Analysis and design principles of electronic systems for measurement, instrumentation and control. Review of basic devices, circuits, and concepts employed in electronic instrumentation, including analog and digital electronics. Functional elements such as d-c, a-c, and operational amplifiers; regulators; modulators; demodulators; wave and pulse generators, shapers, and detectors; analog and digital gates; basic logic elements. Emphasis on feedback operational amplifiers in instrumentation. *(Not offered 1971–72; see 6.632)* *T. S. Gray*

6.212 ***Systems, Networks, and Computation***
(New)
Prereq.: 6.01, 18.031 or 18.700
Year: U (2) 3–0–9
An undergraduate elective directed primarily to sophomores and juniors who are interested in the quantitative analysis of multivariable systems, and the use of the computer as a simulation and algorithmic tool. Modeling of electric networks, transportation systems, ecological systems, and socio-economic systems using the state variable concept through vector difference and differential equations. Analytic and algorithmic techniques for static and dynamic, linear, and nonlinear systems. Iterative solutions of vector equations; the Picard and Newton methods. Numerical integration of differential equations. Relationships between state and input-output representations. Introduction to feedback systems and stability considerations. Basic intent of this subject to present a unified approach to the mathematical description of diverse physical processes using a modern system theory approach. *M. Athans, L. A. Gould*

6.213 ***Dynamic Systems, Control and Optimization***
Prereq.: 6.05 or 6.212; 18.031 or 18.700
Year: U (1) 4–0–8

6.214 ***Dynamic Systems, Control and Optimization***
Prereq.: 6.213
Year: U (2) 4–0–8

A two-term elective sequence aimed at introducing the principal ideas of modern system theory and its applications. Emphasis on problem formulation and synthesis methods. Modeling of systems and signals. State-space description of linear dynamic systems; controllability, observability; input-output description. Optimal control of linear systems with respect to quadratic performance criteria. Estimation and filtering: the Kalman filter. Optimal control in the presence of noise; combined estimation and control; the separation theorem. Static optimization and mathematical programming. Dynamic programming and the principle of optimality. The Pontryagin maximum principle. *L. A. Gould*

6.215 ***Feedback Control Laboratory***
Prereq.: 6.05 or 6.212
Year: U (1, 2) *Arr.*

Supervised investigation of special projects in control system analysis and design; experimental and computer studies. Program and hours to be arranged with interested staff member, subject to approval of instructor.
L. A. Gould

6.231 ***Programming Linguistics***
Prereq.: ——
Year: U (1, 2) 4–1–7

Study of linguistic constructs for the specification of algorithms, and practice in using them to build large semantic structures out of small ones. Initial introduction to and familiarization with a particular general purpose language; detailed analysis of the language and its relation to mathematical logic. Bound and free variables, substitution rules, recursion, structures, generalized jumps and labels; contrast and comparison with certain linguistic features of LISP, FORTRAN, ALGOL, PL/I. (*An introductory subject intended primarily for students whose major interest is computer science. Note: students are strongly recommended to have had programming experience with an algebraic language such as* PL/I *or* FORTRAN.) (*Not offered 1971–72.*) *J. M. Wozencraft*

6.232 ***Computation Structures***
Prereq.: 6.01, 6.231 or 6.251 or 6.252
Year: U (1) 4–0–8

Study of hardware and software concepts for realizing computer systems. Design of combinational and sequential logic circuits. Schemata that model concurrency in computation. Sufficient and necessary conditions for determinacy of computations. Implementation of computation schemata as asynchronous modular systems. Location addressed and associative memory systems. Typical architecture of monosequence processing units. Machine language representation of programs expressed as program graphs. Use of cooperating processes in multiprocess computer systems. Implementation of systems of program graph procedures; recursion. Representation of computations on structured information; dynamic storage allocation. *J. B. Dennis*

6.233 ***Information Systems***
Prereq.: 6.232
Year: U (2) 4–0–8

Sources of complexity in information systems, with emphasis on problems arising when a single information system serves a community of users. Contrast of problems intrinsic to purposes of use with those related to technical limitations. Multilevel memory systems; content-related storage organization; privacy of information. State-of-the-art implementations of process synchronization and multiprocess scheduling algorithms. Limitations on information systems arising from the laws of physics, from logical complexity, and from economics; reliability. Techniques of controlling complexity. A model information system, case studies of working systems, and outside reading in the current literature provide comparisons and contrasts between general purpose community computing facilities and information systems dedicated to a special task such as telephone line switching or air traffic control. *J. H. Saltzer*

6.239 ***Seminar in Current Computer Science***
Prereq.: —
Year: U (1) 2–0–4

Weekly lectures on state-of-the-art topics in computer science by members of the M.I.T. faculty and others as available. Lectures will cover such topics as artificial intelligence, time-sharing systems, operating systems, automata theory, machine design, graphics, information retrieval, and programming theory. Each student prepares a report criticizing a recent paper in one of the areas treated. Enrollment is limited and grading is Pass/Fail. (*Permission of the instructor required.*)
P. H. Winston

6.243 ***Inventions and Patents***
Prereq.: 14.01, 21.012
Year: U (1) 3–0–6

History of private and public rights in scientific discoveries and applied engineering leading to the development of worldwide patent systems. The classes of invention protectable under the patent laws of the United States, including the procedures in protecting inventions in the Patent Office and in the courts. Review of past cases involving various electrical and electronic and other inventions, including the Bell Telephone cases and key radio, solid-state, and computer inventions.
R. H. Rines

6.251 ***Digital Computer Programming Systems***
Prereq.: —
Year: U (1, 2) 3–2–7

Basic principles of programming systems. Techniques for translation from problem-oriented languages to machine languages. Computer organization, programming, program planning and organization. Construction of assemblers, interpreters, compilers, monitor, multiprocessed, multiprogrammed systems. The use and manipulation of data structures. Laboratory work in the preparation and testing of programs for the IBM 360 computer. (*Note: Students are strongly recommended to have had programming experience with an algebraic language such as* PL/I *or* FORTRAN.) *J. J. Donovan*

6.252 ***Structure and Translation of Computer Languages***
(*New*)
Prereq.: —
Year: U (1, 2) 4–1–7

Study of the basic concepts associated with the representation and implementation of computer languages. Elementary techniques for the interpretation and translation of algorithms, including parsing of expressions and code generation. Implications of features commonly found in machine, algebraic, and list processing languages; the role of procedures, recursion, assignments, pointers, conditionals, and labels. Elementary data structures; problems of data access and garbage collection. Abstraction of ideas such as binding and binding time, scope, sharing, naming, and linking. The use of lambda expressions as representations of functions. (*Primarily intended for students whose major interest is computer science. Students are expected to have had programming experience with an algebraic language such as* PL/I. *Limited enrollment 1971–72. Permission of instructor required.*)
M. L. Dertouzos, J. Weizenbaum

6.253 *Theoretical Models for Computation*
Prereq.: 6.261
Year: U (1) 3–0–9
Study of the theoretical models with widest application to computer systems and programming, stressing equivalence between abstract machines and corresponding formal grammars. Specific topics include: Formal languages and grammars. Operations on sets of sentences. Finite-state machines. State diagrams and linear grammars. Kleene's theorem on regular expressions and finite-state accepters. Limitations of the finite-state model. Pushdown automata and context free languages. Ambiguity. Recognition procedures. Turing machines. Unsolvable decision problems with applications to formal linguistics. *J. B. Dennis*

6.256 *Applications of Combinatorial Mathematics*
Prereq.: 6.261 or 18.075
Year: U (2) 3–0–9
Topics in combinatorial mathematics that find frequent application in electrical engineering. Discussion of enumeration techniques will include: permutations and combinations, generating functions, recurrence relations, the principle of inclusion and exclusion, and Pólya's theory of counting. Graph theory and its applications to be covered: Euler paths and Hamiltonian paths, planar and dual graphs, domination, independence, chromatic numbers, network flow and the theory of matching. Other topics to be discussed: linear programming, block design, and projective geometry. *C. L. Liu*

6.258 *Introduction to Artificial Intelligence*
Prereq.: —
Year: U (1) 4–0–8
Study of the ideas and techniques that enable machines to behave intelligently. Case studies of classic programs that play chess, solve geometric analogy problems, integrate symbolically, understand the visual environment, and engage in English discourse. The role of learning, planning, simplification, analogy, description matching, goal formation and heuristic search. Comparison with human methods. Discussion of some philosophical and social implications. *P. H. Winston*

6.261 *Introduction to Modern Algebra*
Prereq.: 18.03 or 18.031
Year: U (1) 4–0–8
Introduction to modern algebra for students interested in computer and information sciences. Emphasis on finite algebraic systems and their applications. Fundamentals of set theory. Natural numbers and induction. Elementary notions of cardinality. General features of algebraic systems: subsystems, isomorphism, homomorphism, quotient systems. The structure of finite Boolean algebras. Basic properties of groups. Fields as generalized arithmetic systems. Polynomial rings, congruences, and the construction of Galois fields.
F. C. Hennie

6.262 *Computability, Formal Systems, and Logic*
Prereq.: 6.261 or 18.701
Year: U (2) 4–0–8
Study of the basic concepts underlying mathematical theories of computation. General purpose algorithm schemes and their properties. Recursive derivations, Turing machines, and idealized computers. Universal algorithms and the design of universal machines. Computable and non-computable functions. Semantic and syntactic properties of formal systems. The undecidability of various syntactic problems, such as Post's correspondence problem and the tag problem. Logical systems, models, and valuation. Gödel's completeness and incompleteness theorems and their implications.
F. C. Hennie

6.271 *Switching Theory and Logic Design*
Prereq.: 6.01
Year: U (1, 2) 4–3–5
Introduction to characteristics, specification, and design of digital systems. Boolean algebra, combinational logic, NAND — NOR synthesis and iterative arrays. Elementary properties of finite-state machines. Analysis and synthesis of sequential circuits with pulse and level inputs. Design examples including arithmetic elements, counters and shift registers. Related laboratory treats integrated circuits, static and dynamic properties of gates and flip-flops, synthesis of small digital systems.
R. N. Spann, D. E. Troxel

6.272 *Digital Systems Project Laboratory*
Prereq.: 6.271
Year: U (1, 2) 2–8–2
Introduction to some of the basic techniques used in the design of digital computing and control systems. Preliminary work by a combination of classes, homework, and associated laboratory experiments. Study of comparators, operational amplifiers, analog-digital interfaces, memory systems, and the transmission of digital signals. Implementation of all projects with integrated circuits. Oral presentation and written report on completion of project. Initial classroom material more advanced than that of 6.711 with accordingly higher standards in the character and scope of projects. (*Credit will not be given for both 6.272 and 6.711.*)
R. N. Spann, D. E. Troxel

6.273 *Programming of Small Scale Computers*
Prereq.: 6.00
Year: U (1, 2) 3–3–6
Introduction to the organization of modern small scale digital computers. Assembly language programming. Interaction and tradeoff between hardware, programming and processing time. Input-output, data channels, interrupt system and real-time consideration. Special topics include: data structures, buffering techniques, assemblers and loaders, signal generation, display processors, and case studies of engineering and research application of small scale computers in real-time environment. *F. F. Lee*

6.274 *Advanced Digital Systems Project Laboratory*
Prereq.: 6.272, 6.273
Year: U (2) 2–8–2
Logical design and construction of digital subsystems and their interface to digital computer for efficient and economical performance of specialized tasks. Projects implemented with integrated circuit digital modules and by programming in assembly language on a digital computer. Individual oral presentation and project report required. (*Enrollment limited. Permission of instructor required.*) *F. F. Lee*

6.28 *Probabilistic Systems Analysis*
Prereq.: 18.02
Year: U (1, 2) 4–0–8
Serves as a self-contained development of the theory and application of probabilistic concepts and provides the foundation for graduate subjects in engineering, management, and science. Presentation of the theory of probability on an axiomatic basis. Emphasis on sample space concept. Discussion of algebra of events, operations on random variables, discrete and continuous transform techniques, common distributions and stochastic processes, limit theorems, classical and Bayesian statistics. Consideration of implications of probability theory for decision making, data analysis, and system modeling. Presentation of applications concurrently with the development of the theory. *A. W. Drake*

Descriptions

6.31 *Pattern Recognition*
Prereq.: 6.05
Year: U (1) 3–0–9
Introduction to normative and generative theories of pattern recognition. Algebraic characterization of patterns. Techniques of statistical classification. Evaluation procedures using classical statistics. Feature choice, feature extraction, analysis-by-synthesis, and cluster analysis. Linear discrimination and adaptive "learning." Syntactic properties of conventional symbol systems. Equivalence relations on ideal and "noisy" patterns. Pattern recognition schema as models for animal and human perceptual tasks. Discussion of specific pattern recognition tasks; printed characters, hand-writing, speech, biological cells, particle tracks, optical illusions.
M. F. Eden, I. T. Young

6.341 *Solid State Circuits I*
Prereq.: 6.02
Year: U (1) 3–3–6
Analysis and design of transistor circuits, based directly on the semiconductor physics and transistor circuit models developed in 6.02. Physics, models, and circuit applications of field-effect transistors. High-frequency and low-frequency design calculations of multistage transistor and FET circuits using a computer. The charge-control model. Computer-aided analysis of switching transients. Regenerative switching circuits. *C. L. Searle*

6.342 *Solid State Circuits II*
Prereq.: 6.341
Year: U (2) 3–2–7
Computer-aided analysis and design of feedback amplifiers. Stability and transient response. Bipolar-transistor d-c amplifiers. Design and application of operational amplifiers with particular emphasis on available integrated-circuit units. Analog signal switching techniques and applications. *J. K. Roberge*

6.345 *Advanced Circuit Techniques*
Prereq.: 6.05, 6.342
Year: U (1) 3–2–7
Following a brief classroom discussion of relevant principles, each student completes the paper design of several advanced circuits such as multiplexers, sample-and-holds, gain-controlled amplifiers, analog multipliers, digital-to-analog or analog-to-digital converters, and power amplifiers. One or two of each student's designs are presented to the class, and one is built and evaluated. (*Enrollment limited. Permission of instructor required.*) *J. K. Roberge*

6.35 *Acoustics*
Prereq.: 6.01, 18.075
Year: U (1) 3–1–6
General discussion of sound generation and propagation in elastic media. Conversion between acoustical, electrical, and mechanical energy. Lumped-parameter approximations. Sound in rooms, microphones, loudspeakers, and audio communications systems. Interaction of sound and man. *A. G. Bose*

6.39 *Image Transmission Systems*
Prereq.: 6.05
Year: U (1) 3–0–6
Efficient design of image transmission systems, which differ from other information systems both in the multidimensional nature of the inputs and the destination of the output, and therefore depend on a study of the properties of pictures, the properties of observers, and the effect of the parameters of the system on the quality of the transmission. Topics including historical developments, mathematical description of images, objective measures of picture quality, scanning and quantizing, picture processing and coding, color systems, and relevant properties of human vision. Term paper or project required. (*Not offered 1971–72.*) *W. F. Schreiber*

6.40 *Animal Communication Systems*
Prereq.: ——
Year: U (2) 3–0–6
Introductory study of communication systems in a variety of animals, including ants, bees, spiders, frogs, birds, bats, dolphins, humans, etc. Analysis and characterization of such systems in terms of formal communication structures, functional significance, signal properties, behavioral response patterns, and physiological mechanisms. Discussion of research strategies, experimental techniques, empirical results, and theoretical models.
H. S. Colburn, N. I. Durlach, L. S. Frishkopf

6.41 *Sound, Speech, and Hearing*
Prereq.: 6.05
Year: U (2) 3–0–9
Introduction to the physical, physiological and psychological bases of auditory communication. Physical acoustics, properties of neural and muscular elements, the vocal tract and speech generation, signal transmission in the auditory system, perception of attributes of speech and speechlike sounds, and the linguistic units that underlie speech events. Disorders of human communication.
D. H. Klatt, W. T. Peake, K. N. Stevens, T. F. Weiss

6.42 *Electrocardiography*
Prereq.: ——
Year: U (1) 2–0–4
An introduction to cardiovascular anatomy and physiology for students interested in biomedical engineering. Particular attention to the electrical activity of the heart including electrophysiology of cells, and the physical basis of scalar and vector electrocardiography. Survey of diagnostic electrocardiography including normal and pathological waveforms and arrhythmias. Discussion of EKG instrumentation such as electrocardiographs, monitors, and computational techniques of waveform representation and analysis. *R. G. Mark, S. K. Burns*

6.43 *Biophysics of Neuroelectric Potentials*
Prereq.: 6.01, 8.02, 18.03
Year: U (1) 3–3–6
Introduction to basic phenomena of generation, transmission and interaction of signals in nervous systems. Discussion of the excitation and conduction of the nerve impulse along nerve fibers, synaptic transmission and transduction processes in receptors. Use of mathematical models — particularly electric circuit models — in describing the electro-chemical behavior of cell membranes. Specific topics include: Nernst equilibrium potentials, resting potential of cells, cable equations, Hodgkin-Huxley model, saltatory conduction, probabilistic properties of nerve membrane, chemical and electrical transmission at synapses, quantal transmission, post-synaptic potentials, spike initiation, dendritic function, receptor potentials. Laboratory experiments illustrating the relations between theoretical formulations and experimental data in this field and introducing some techniques of recording electric activity from nerve tissue.
W. T. Peake, T. F. Weiss

6.431 *Biophysics of Neuroelectric Potentials*
(*New*)
Prereq.: 6.01, 18.03
Year: U (1) 3–0–6
Identical to 6.43 except no laboratory is required.
W. T. Peake, T. F. Weiss

6.46 *Fields, Forces, and Motion*
Prereq.: 6.03
Year: U (2) 3–0–9
Basic subject dealing with electromechanical interactions in lumped-parameter and continuum systems. Review of integral and differential electromagnetic laws, including motion. Lumped electrical and me-

chanical elements: thermodynamics of discrete electromechanical coupling, equations of motion. Energy conversion exemplified by synchronous and induction rotating machines. Linear incremental and nonlinear potential-well transducers, transient and steady-state dynamics; electromechanical time constants, constant flux, and constant potential dynamics. Field transformations, electrical conduction, magnetic diffusion and charge relaxation in moving conductors, electric and magnetic Reynolds numbers, dc rotating machines. Electromagnetic force densities and stress tensors. Coupling to thin rods, strings and membranes: Delay lines and acoustic systems. Non-dispersive mechanical and electromechanical waves: characteristics and eigenmodes. Electromechanical dispersive waves with material convection to exemplify interactions with electron beams, plasmas and solids: absolute and convective instability, wave evanescence and amplification. *J. R. Melcher*

6.47 *Statistical Physics of Noise Fluctuations and Flows*
(New)
Prereq.: 6.05; *6.28* or *18.171*
Year: U (2) 3–0–9
The statistical description of physical systems. Principle of detailed balance, Markov processes and the master equation. Entropy and the tendency toward equilibrium. Equilibrium situations including Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics. Steady flows and the Boltzmann transport equation, fluctuation theory, power density spectra, and the fluctuation dissipation theorem. Examples include electronic conduction processes, density distributions in fully ionized plasmas, thermal noise and optical pumping and scattering. Note: A familiarity with joint probability densities and average values will satisfy the 6.28 or 18.171 corequisite. *(Not offered 1971–72.)* *R. S. Kennedy*

6.48 *Problem Solving*
(New)
Prereq.: —
Year: U (1, 2) 3–3–6
General and systematic approach to the understanding and solving of problems outside the range of the students' formal training. Special attention given to the relationship of the students' capabilities and attitudes with respect to the problems under consideration. Problems from many fields including physics, engineering, politics, business, digital logic design and electronics. Topics include the evaluation, selection or rejection of problems, economic use of resources, heuristic methods, use of the CRC handbook, dimensional analysis and the elements of problem solving. Student use of portable digital logic laboratories to build and debug complex computer type logic projects. *E. Fredkin*

6.501 *Principles of Environmental Sensing* (A)
(New)
Prereq.: 6.03, 6.08
Year: G (2) 3–0–9
Physical and physical chemical principles underlying detection of atmospheric pollutants. Types of pollutant, their origin, stability and toxicity: gases, aerosols, and particulates. Optical absorption methods: electronic, vibrational and rotational molecular states; laser sources; tuneable infrared lasers; detectors; light scattering techniques; Raman scattering. Principles and applications of chromatography. Discussion of existing and proposed detection systems. *D. J. Epstein*

6.508J *The Nuclear Arms Race and Arms Control — Technology, Management and Government Policy* (A)
(New)
(Same subject as 17.841J)
Prereq.: —
Year: G (1) 3–0–6
The decision making process relating to national security based on the interaction of technological assessments with political and economic judgments. Both the development of nuclear weapons systems and disarmament considerations take into account existing and projected technology. Includes a critical examination of the decisions to develop ballistic missiles, ABM, MIRVs, etc. Also reviews the Nuclear Test Ban Treaty and SALT. To the extent possible experts who have played key roles in the topics covered invited to give guest lectures. *J. P. Ruina, G. W. Rathjens*

6.509J *Seminar in Technological Assessment and Public Policy: Selected Topics* (A)
(New)
(Same subject as 17.856J)
Prereq.: —
Year: G (2) 3–0–6
Examination of several cases of the interaction of technological judgment and expertise with political and economic policy questions. The cases to be examined chosen at the beginning of the course taking into account the interests of the class and include some of the following: Communication Satellites; Electric Power Sources and the Environment; Air Traffic Control; Manned Space Flight; and Supersonic Transport. Focus of the seminar discussion on how these issues were, or are being, affected by the nature and use of technical knowledge, extrapolations and projections and on the interaction of technical experts with the executive and legislative branches of government. Also consideration of the nature of "objectivity" in rendering technical advice and counsel. Some of the leading "actors", technical and political, as guest lecturers.
J. P. Ruina, G. W. Rathjens

6.512 *Development of Inventions and Creative Ideas* (A)
Prereq.: 14.01, 21.02
Year: G (2) 3–0–9
The role of the engineer as patent expert and as technical witness in court and patent interference and related proceedings, with emphasis on actual experiences in the field of electrical and electronic engineering. Rights and obligations of engineers in connection with various types of employment contracts and employers, including educational institutions, government, and large and small businesses. Various manners of transplanting inventions into business operations, including the development of the New England electronics industry and its different types of institutions. American systems of incentive to creativity apart from the patent laws, including provisions relating to inventions and ideas in the atomic energy and space fields. *(For graduate students only; others see 6.243.)* *R. H. Rines*

6.515J *Analysis of Urban Service Systems* (A)
(Same subject as 11.915J and 16.76J)
Prereq.: 1.07 or 6.28 or 18.303
Year: G (2) *Arr.*
Quantitative techniques useful in the analysis of large scale, urban service systems (e.g., fire and police departments, emergency ambulance services, airports, mass transit systems). Unified study of geometrical probability, multi-server queueing theory, spatial location theory, scheduling and sequencing techniques and relevant methods of simulation. Validation of models and parameter estimation. Cost structures and utility theory. Applications: geometrical configuration of

service areas; response time to high priority situations; stacking and delays at airports. Emphasis on development of policy-relevant models of system operation. Promising areas for future research are outlined.
R. C. Larson, A. Fleischer, A. R. Odoni

6.527 *Continuum Electromechanics I* (A)
Prereq.: 6.46, *6.58*
Year: G (1) 3–0–9
Dynamics of continuous media coupled to electric and magnetic fields. Electromagnetic macroscopic forces, force densities and stress tensors, including polarization and magnetization. Electromechanical energy conversion processes from a field theory point of view, exemplified by practical devices including rotating machines. Classification of magnetic and electric converters and their general limitations in terms of electromagnetic stress, material velocity, frequency and conversion density. Magnetic diffusion and charge relaxation, and the effects of material motion on electric and magnetic fields. Electromechanics of Newtonian fluids: static equilibria and inviscid flows, stability and dynamics including electromechanical forms of Rayleigh-Taylor and Kelvin-Helmholtz instability, stability of hydromagnetic equilibria and charged drops. Acoustic and magnetoacoustic dynamics of compressible fluids, Alfvén waves, nonlinear wave phenomena and the method of characteristics, quasi-one-dimensional flows, magnetohydrodynamic and electrohydrodynamic energy conversion. Continuum transfer networks for electromagnetic fields, mechanical media and electromechanical coupling used as a unifying theme throughout. (*Not offered 1971–72.*) *J. R. Melcher*

6.528 *Continuum Electromechanics II* (A)
Prereq.: 6.527
Year: G (2) 3–0–9
Electromechanics of viscous fluids: peristaltic pumping, Hartmann flow, and electrokinetic phenomena. Double-layer transduction and topics from physicochemical hydrodynamics with reference to biological systems. Internal dynamics and stability of inhomogeneous systems of fluids, with reference to field-controlled image display systems. Electrothermal coupling; Bénard instability and convection in the presence of electromagnetic fields. Electromechanics of elastic solids; piezoelectric and piezomagnetic coupling, Rayleigh surface waves and quasi-one-dimensional models for electroelastic structures as signal processing devices. Hybrid electromechanical systems; two-fluid and fluid-elastic models, continuum feedback control. (*Not offered 1971–72.*) *J. R. Melcher*

6.531 *Programming Language Processors* (A)
Prereq.: 6.251
Year: G (1) 3–0–9
A study of the basic problems in the design and implementation of programming language processors; discussion and evaluation of current implementation techniques and exploration of applicable theory. Specific topics covered include: formal definition of the syntax and semantics of programming languages, parsing and code generation techniques, optimization of register use, data structure representation and accessing, and compiler-compilers. Implementation problems of several specific languages such as PL/I and SNOBOL will be examined. A representative compiler will be studied in depth as a case study. A working compiler-compiler will be available for class use. *R. M. Graham*

6.534 *Semantics of Parallel Computation* (A)
Prereq.: 6.232, 6.261
Year: G (2) 3–0–9
Consideration of various abstract models for representing parallelism or data-dependence in computation. Extensions of basic models to computations over structured information. Comparison with other formal semantic theories and consideration of applications to language definition. Content based on papers selected from the technical literature. Term papers and/or presentation of material by students. *J. B. Dennis*

6.535 *Structure of Computing Systems* (A)
Prereq.: 6.232
Year: G (2) 3–0–9
Study of the design of general-purpose digital computer systems in relation to the devices and technology employed in fabrication, and in relation to basic properties of procedures, interaction of procedures with the system environment, and efficient utilization of resources. Contemporary representation techniques are developed and used to describe the structure of modular hardware and multi-process systems. Trends in processor and memory organization of computer systems are explored together with the technology of scheduling, storage allocation and resource sharing. *S. S. Patil*

6.536 *Probabilistic Models in Systems Engineering and Operations Research* (A)
Prereq.: 1.07 or 6.28 or 18.171 or 18.303; 15.062 or 18.075
Year: G (2) 3–0–9
Analysis of linear probabilistic systems. Application of linear system theory to the study of finite- and infinite-state, discrete- and continuous-time, stationary and non-stationary, Markov and semi-Markov processes. Optimization of probabilistic systems over short and long time periods by means of dynamic programming. Concurrent presentation of examples in the areas of system reliability, congestion processes, automatic control, maintenance and replacement policies, search procedures, inventory control, and other operating problems of systems. Discussion of unsolved problems and promising areas of research. *A. W. Drake*

6.537 *Introduction to Operations Research* (A)
(*New*)
Prereq.: 6.579
Year: G (1) 3–0–9
6.538 *Introduction to Operations Research* (A)
(*New*)
Prereq.: 6.537
Year: G (2) 3–0–9
A two-term introduction to some important techniques of operations research, including linear programming, network analysis, dynamic programming, statistical inference and decision theory, Markov models, queueing theory, inventory theory, and simulation. Emphasis on decision-making applications. Several recently published studies critically reviewed. Oral and written presentation of a course project required. (*Restricted to practicing engineers of the Center for Advanced Engineering Study.*) *R. C. Larson*

6.539 *Algebraic Manipulation* (A)
Prereq.: 6.261 or 18.701, 6.231
Year: G (2) 3–0–9
Algorithms for manipulating algebraic expressions and theoretical results about such algorithms. Manipulation of polynomials and rational functions: representation, the greatest-common-divisor algorithm, factorization, integration. Manipulation of general expressions: simplification, equivalence matching, integration. Computation of group-theoretic structures. Additional topics related to the design of an algebraic manipulation system. *J. Moses*

6.541 ***Special Topics in the Computer Sciences*** **(A)**
Prereq.: ——
Year: G (1) *Arr.*

6.542 ***Special Topics in the Computer Sciences*** **(A)**
Prereq.: ——
Year: G (2) *Arr.*

A seminar-type discussion of special topics in the computer sciences. Opportunity for graduate students and instructors to investigate a topic of common interest. Topic and staff announced each term. These subjects given independently or sequentially, as circumstances require. (*Consent of instructor required.*) *R. M. Fano*

6.544J ***Heuristic Programming and Artificial Intelligence*** **(A)**
(Same subject as 18.436J)
Prereq.: ——
Year: G (2) 3–0–9

The problem of making machines behave intelligently. Application of machines to problems of learning, induction, pattern-recognition, game-playing, theorem-proving, neural nets, self-organizing systems, and other areas where problems have been solved by heuristic programming. Problems in administration and allocation of effort within programs. Models of cognitive processes. Machine aids for human problem solving. (*Ability to program a computer required.*)
M. L. Minsky, S. A. Papert

6.545 ***Topics in Artificial Intelligence*** **(A)**
Prereq.: ——
Year: G (2) 3–0–9

Seminar on selected, currently active, research topics in artificial intelligence. One or two topics to be covered in depth each term. Subject intended primarily for advanced students in artificial intelligence but also open to students with backgrounds in areas related to the topics discussed. (*Permission of the instructor is required.*)
M. L. Minsky

6.546J ***Algorithms*** **(A)**
(*Same subject as 18.426J*)
Prereq.: 18.03 or 18.031
Year: G (1) 3–0–9

Basic algorithms of computer science. Parsing, sorting, searching, shortest-path methods, multiplication of matrices and integers, and evaluation of polynomials. Emphasis will be placed on theoretical and experimental methods for the evaluation and comparison of alternative methods. Some algorithms studied will be implemented on a computer. (*Ability to program a computer required.*) *A. R. Meyer, M. J. Fischer*

6.548 ***Computation by Automata*** **(A)**
Prereq.: 6.253 or 6.262 or 18.420
Year: G (2) 3–0–9

Time and space-bounded computation by automata including Turing machines, counter machines, random access models. Crossing sequence arguments and time-space tradeoff theorems. Equivalence of stack automata to space-bounded Turing machines. Equivalence of time-bounded Turing machines and space-bounded push-down automata. Theorems relating machine structure and efficiency: simulation of multi-tape, multi-dimensional storage by simpler devices, "real-time" computation by automata. Time and space requirements for multiplying integers, recognizing primes, calculating roots (with application to constructing transcendental numbers). Complexity of circuits for finite functions. *A. R. Meyer*

6.551 ***Power System Engineering I*** **(A)**
Prereq.: 2.03 or 6.46; 2.062 or 6.04
Year: G (1) 3–0–9

Primarily for first-year graduate students. Introduction to power system engineering. Definition of an electric power system in terms of its principal functions and major components. Modeling of the following components — generating units, transformers, transmission lines, and circuit breakers using the concepts and techniques of field theory, circuit theory, thermodynamics, etc. Use of these models to study those problems in which electrical behavior is quasi-steady-state, for example, load flow, overvoltage conditions, fault currents, and transient stability. *G. L. Wilson*

6.552 ***Power System Engineering II*** **(A)**
Prereq.: 6.551
Year: G (2) 3–0–9

Continuation of 6.551, Power System Engineering I. Nonlinear behavior of transmission systems; digital computer modeling. Refinement of component models to represent transient electrical phenomena such as switching surges and lightning impulses; surge control and protection; control systems for generators, turbines, and synchronous condensers; effect of excitation on system stability; corona radio interference, and audible noise from transmission lines; direct current transmission.
G. L. Wilson

6.553 ***Special Topics in Power System Engineering*** **(A)**
Prereq.: 6.552
Year: G (2) 3–0–9

Treatment in depth of special topics in power system technology by notable experts in the field. *G. L. Wilson*

6.556 ***Dynamics of Electric Machines*** **(A)**
Prereq.: 2.02 or 6.46
Year: G (2) 3–0–9

Treatment of transformers, electromechanical transducers, and rotating electric machines with emphasis on their dynamic performance in systems. Equivalent-circuit models and block diagrams for synchronous, induction, and d-c machines. Problems chosen to illustrate engineering applications. Discussion of new developments and current research. *C. Kingsley*

6.56 ***Electronic Circuits*** **(A)**
Prereq.: 6.00, 6.02, 6.05
Year: G (1) 3–0–9

Theory and analysis of non-linear and active circuits with particular emphasis on the use of numerical methods. Matrix operations and transformations; realizability conditions; numerical methods for iteration, integration, and optimization; computer simulation in the frequency domain; sensitivity, noise, and tolerance considerations. Extensive use of digital computers. *R. D. Thornton*

6.568 ***Principles of Communication*** **(A)**
Prereq.: 6.05; 6.28 or 18.171
Year: G (1, 2) 3–0–9

Probabilistic formulation of the communications problem. Mathematical description of signals and noise. Decision regions and optimum receivers. Discrete modulation and signal design. Introduction to channel capacity and error-free communication over noisy channels. Performance and limitations of continuous modulation systems (AM, FM, PPM). Interchange of bandwidth and signal-to-noise ratio; threshold effects.
E. V. Hoversten

6.569J ***Space Communications*** **(A)**
(Same subject as 16.45J)
Prereq.: ——
Year: G (1) 3–0–9

Study involving the important interaction between the orbital and dynamical characteristics of spacecraft, the

transmission of electromagnetic signals over long distances and the concepts of modern communication theory. Stress on interplay between these diverse topics in practical space communication systems. Discussions of spacecraft dynamics, stabilization, attitude control, propagation effects and pertinent modulation and coding methods. (*Some background in space dynamics or in communications assumed. Permission of instructor required. Not offered 1971–72.*) *J. V. Harrington*

6.57 *Probability and Random Processes* (A)
(*Revised: Content change*)
Prereq.: 18.075
Year: G (1) 3–0–9
The first half of the subject: elementary probability theory, random variables, expectations, the law of large numbers, the central limit theorem, and statistical inference. Applications to reliability decision theory and communication discussed. Use of filmed lectures and a self-study approach. The second half of the subject: development of elementary random process theory. Specific topics to be covered include: complete and partial characterization of processes, second moment theory, series expansions, and Gaussian processes.
H. L. Van Trees

6.573 *Introduction to Random Processes* (A)
(*Revised: Unit change*)
Prereq.: 6.05, 6.28 or 18.171
Year: G (1) 4–0–8
Random processes: partial and complete characterization, stationarity and ergodicity. Calculus of random processes: continuity, integration, and differentiation. Functions of random processes. Characterization of linear systems using impulse responses and state-variables. Input-output relations for random processes in linear systems. Differential equations driven by random processes. Process measurements and statistics: mean, distribution function, spectrum, and correlation function. Representation of processes: sampling theorem, orthogonal series, spectral decomposition. Poisson processes. Renewal processes. Gaussian processes. Markov processes: discrete time-continuous state and introduction to continuous time-continuous state. Emphasis on developing an ability to reduce engineering problems to a mathematical model, to solve the resulting probabilistic problem, and to appreciate the significance and limitations of the results. *H. L. Van Trees, E. V. Hoversten*

6.574 *Transmission of Information* (A)
Prereq.: 6.28 or 6.57 or 6.573 or 18.171
Year: G (2) 3–0–9
Introduction to the quantitative study of communication processes, with emphasis on the concepts fundamental to the engineering of accurate, efficient communication systems. Definition of a measure of information and study of its properties; efficient representation of discrete message sources; communication channels and their capacity; encoding and decoding of data for transmission over noisy channels and evaluation of bounds to the probability of decoding errors. *R. G. Gallager*

6.575 *Advanced Topics in Information Theory* (A)
Prereq.: 6.574
Year: G (2) 3–0–9
Further work on information processing based on 6.574. Varying content. *P. Elias*

6.576 *Detection, Estimation, and Modulation Theory* (A)
Prereq.: 6.57, *6.573;* or 6.573
Year: G (2) 3–0–9
A unified approach to the areas of detection, estimation, and modulation theory. Classical detection and estimation theory: Bayes, Neyman-Pearson tests; Bayes estimation, maximum likelihood estimation. Process representations. Detection of signals in Gaussian noise. Fredholm integral equation theory. Signals with unwanted parameters, composite hypotheses. Estimation of continuous waveforms. Linear estimation. Wiener filters. Closed-form error expressions. Differential equation representation of linear systems. Kalman-Bucy filters. Non-linear modulation theory: phase-lock loops, optimum angle modulation, rate distortion theory. Comparison of various communication systems. Gaussian signals in Gaussian noise: detection and parameter estimation. *H. L. Van Trees*

6.577 *Communication Systems and Optical Channels* (A)
Prereq.: 6.568 or 6.573
Year: G (2) 3–0–9
Application of information and detection theory to important physical channels such as additive noise, filtered, and fading dispersive channels. Discussion of appropriate channel models, their fundamental performance limitations, and communication systems which approach these limits. Illustration of ideas in terms of the channels which are important at optical frequencies, followed by study of channels in which the fading may be non-Gaussian, in which the spatial variations of the received signal may be important, and in which the noise may be signal dependent. Emphasis on the coupling between the physical channel characteristics and the communication system. (*Alternate years. Offered 1971–72.*) *E. V. Hoversten, R. S. Kennedy*

6.578 *Advanced Topics in Random Processes* (A)
Prereq.: 6.573
Year: G (2) 3–0–9
Additional study of the theory of random processes introduced in 6.573. Topics change from year to year at the discretion of the instructor in charge.
H. L. Van Trees

6.579 *Probability Theory and Random Processes* (A)
Prereq.: 18.03
Year: G (1) 3–0–9
An introduction to the theory of probability and random processes with engineering applications. Probability as a model for empirical averages. Random variables and probability distribution functions. Statistical averages. Elements of estimation and sampling theory. Correlation and characteristic functions. Passage of random processes through linear systems, definition of spectra. Basic properties of the simple random walk and the Poisson and Gaussian random processes. Various additional applications at the discretion of the instructor. (*Restricted to Practicing Engineers in the Center for Advanced Engineering Study.*) *W. B. Davenport*

6.58 *Electrodynamics of Waves, Media, and Interactions* (A)
Prereq.: 6.04 or 6.07
Year: G (1) 3–0–9
Intended for first-year graduate students and seniors whose interest is in the interaction of electric and magnetic fields with charged particles and continuous media. Wave propagation and dispersion relations; linear response functions in time and space; temporal and spatial dispersion in media. Energy, momentum and their flow associated with small-amplitude wave propagation in passive and active media. Linear and parametric coupling of modes in stable and unstable systems. General stability criteria and techniques for identifying and classifying wave-type instabilities. Examples treated are: Plasma waves; spin waves in ferrites; acoustic waves in solids, and their interactions with electrons; electron-beam waves and their interactions with plasmas and plasma and slow-wave structures; dispersion in dielectrics; laser media. *A. Bers*

6.581 ***Advanced Electromagnetic Theory*** **(A)**
(New)
Prereq.: 6.04 or 6.584
Year: G (1) 3–0–9
A first year graduate course on electromagnetic field problems with emphasis on mathematical approaches, problem solving, and interpretation. Intended both for students wanting to relate the analytical methods to physically meaningful field solutions, and for students requiring deeper understanding of fields from an engineering point of view. Can serve as a transition to courses on antennas, microwave circuits, particles in fields, etc. Topics include most of the following: static and quasi-static boundary value problems in free space and material media. Use of field expansions from solutions to partial differential equations. General construction of propagating field solutions in rectangular, cylindrical, and spherical geometry. Guided wave systems, resonators, and radiating structures to serve as examples. Field theorems and their use in problem solving. Field equivalences, the induction theorem, image theory, duality, reciprocity. Model expansions and field solutions at discontinuities like irises and posts. Variational techniques, perturbation methods in resonators and waveguides. The Ritz procedure and Slater perturbation formula. Scattering of fields by objects — Rayleigh scattering. *K. I. Thomassen*

6.583 ***Advanced Topics in Continuum Electrodynamics*** **(A)**
Prereq.: 6.04 or 6.584 or 8.311
Year: G (1) 3–0–9
Material covered and prerequisites differ from year to year according to interest of the instructor in charge. Typical topics: electromagnetism of moving media, continuum electrohydrodynamics, antennas and propagation, waves in dispersive media. In 1971–72: electromagnetic wave propagation and radiation in stratified media and moving media. Plane wave propagation, spectrum analysis, mode theory, ray tracing, guided waves, antenna radiation, optical interference coating. The media include simple dielectric, uniaxial and biaxial crystals, plasmas, gyrotropic media, magnetoelectrics, and laser media. *J. A. Kong, P. L. Penfield, Jr.*

6.584 ***Electromagnetic Theory*** **(A)**
Prereq.: 6.02, 18.075
Year: G (1) 3–0–9
Selected topics from fields, energy and forces, energy transmission and radiation, treated from an advanced viewpoint. *(For first-year graduate students.)* *L. J. Chu*

6.585 ***Electromagnetic Theory and Particles*** **(A)**
Prereq.: 6.04 or 6.07 or 6.584, 8.04
Year: G (2) 3–0–9
Electromagnetic theory from particle point of view, including relativistic and non-relativistic interactions of charged particles and photons. Specific topics include the special theory of relativity, kinematics and dynamics of single and colliding relativistic particles, Lienard-Wiechert potentials, cyclotron and synchrotron radiation, relativistic bremsstrahlung, Cherenkov radiation, radiation damping, review of quantum theory and its application to interactions between photons and particles.
D. H. Staelin, J. Kong

6.59 ***Bioelectric Signals*** **(A)**
Prereq.: 6.43
Year: G (2) 3–0–9
For graduate students in the communication sciences. Neuroelectric activity in relation to complex behavioral processes, including learning, perception, sleep and movement. Emphasis on the study of neuroelectric signals from behaving organisms, including man. Analysis of cortical potentials and other neuroelectric events pertinent to major topics. Sensory processes as they apply to the control of behavior. *(Admission only by permission of instructor.)* *W. A. Rosenblith, R. D. Hall*

6.591 ***Signal Processing by the Auditory System: Physiology*** **(A)**
Prereq.: 6.05, 6.43
Year: G (1) 3–0–9
Intended for graduate students with a serious interest in sensory physiology. Discussion centering on responses of the auditory system to acoustic stimuli. Presentation aimed at understanding of the physiological mechanisms involved in transmission and processing of signals. When possible, discussion of the physiological process underlying normal behavior of organisms and hearing pathologies. Major emphasis on the more peripheral parts of the system: signal transmission in the external ear, middle ear, cochlea, auditory nerve, cochlear nucleus, superior olivary complex. Some discussion of the anatomy and physiology of higher levels. *(Alternate years. Not offered 1971–72. Appropriate background other than the listed prerequisites may be accepted by the instructor.)*
N. Y. Kiang, W. T. Peake, T. F. Weiss

6.592 ***Signal Processing by the Auditory System: Perception*** **(A)**
Prereq.: 6.05, 6.28; or 6.57
Year: G (2) 3–0–9
Study of behavioral aspects of human hearing in relation to current physiological knowledge. Examination of performance in detecting, discriminating, localizing, identifying and scaling acoustic stimuli. Brief presentation of necessary physiological background. Correlations between behavior and physiology that reflect the tonotopic organization and stochastic responses of the auditory system. Modern research methods for dealing with stochastic nature of behavioral responses. Mathematical models of psychophysical relations that incorporate quantitative knowledge of physiological transformations by the peripheral auditory system. Applications to problems in music perception, audio transmission, diagnosis and aids for partially deaf, and noise pollution.
H. S. Colburn, J. L. Goldstein

6.593 ***Sensory-Neural Systems*** **(A)**
Prereq.: ——
Year: G (1) 3–0–9
Detailed consideration of a number of sensory-neural systems with respect to anatomy, physiology, and mode of operation. Reading of relevant papers and critical discussion of the methods and results described. Topics selected on the basis of their current research interest with emphasis on systems containing relatively few elements for which simple models relate physical input to sensory cell/neuron output. Examples from vertebrate and invertebrate species including mechanical, visual, and other modalities. *(Permission of instructor required.)*
L. S. Frishkopf

6.595 ***Communication Sciences Seminar*** **(A)**
Prereq.: 6.05
Year: G (1) 3–0–9

6.596 ***Communication Sciences Seminar*** **(A)**
Prereq.: 6.05
Year: G (2) 3–0–9
Selected topics relevant to research areas in which the theory and techniques of communications, information, and control engineering bear upon problems in the life sciences. Intended mainly for electrical engineering graduate students interested in communications science, but also open to students in fields such as linguistics, psychology, and physiology. Reading, discussion, and the preparation of individual term papers. Material varying from term to term and year to year.
M. Eden, S. J. Mason

6.604J ***Special Studies in Systems Engineering*** **(A)**
(Same subject as 1.16J, 2.191J, 13.47J)
Prereq.: ——
Year: G (2) 2–4–6
Development of basic techniques employed in planning and design of complex systems through involvement in specific projects. Entire class works on a single project which changes each year. Specific background developed through lectures dealing with the selected project. Subgroups of class work on portions of problem and coordinate results through class meetings. Formal presentation of results at end of term. Recent projects included study of issues of vital importance to the long-range well-being of New England, including electric power production, recreational opportunities, air and water pollution and a study of the potential for expanding industrial and agricultural activity in Saudi Arabia based upon utilization of natural gas now being wasted.
W. W. Seifert, R. E. Stickney, E. G. Frankel

6.611 ***Digital Processing of Signals*** **(A)**
Prereq.: 6.05
Year: G (1) 3–0–9
Representation, analysis and design of discrete signals and systems. Z-transforms and the discrete Fourier transform. Difference equation and transform representation of recursive and non-recursive systems. Discrete linear networks. Frequency-domain design techniques and examples for recursive and non-recursive systems. Implementation of discrete linear systems. Computation of the discrete Fourier transform: Goertzel's algorithm, the fast Fourier transform (FFT) algorithms. The chirp z-transform. Implementation of non-recursive systems using the FFT. Homomorphic filtering and cepstral analysis with applications. Effects of quantization, truncation and parameter inaccuracies in implementation of digital filters and the FFT.
A. V. Oppenheim

6.612 ***Advanced Topics in Digital Signal Processing*** **(A)**
Prereq.: 6.611
Year: G (2) 3–0–9
Spectral analysis and spectral estimation using digital signal processing techniques. Discrete representations of analog signals. Discrete Hilbert transforms. Algorithmic design of digital filters. Considerations in digital signal processing hardware. Multi-dimensional signal processing. Applications of digital signal processing. A term paper required. (*Enrollment limited.*)
A. V. Oppenheim

6.613 ***Image Processing*** **(A)**
Prereq.: 6.05
Year: G (1) 3–0–9
Basic digital computer, optical, and electro-optical image processing techniques with applications to image quality enhancement, pattern recognition, and efficient coding of pictures for storage or transmission. Two-dimensional Fourier analysis. Nature of light — coherence and polarization. Geometrical optics and projective transformations. Diffraction theory. Optical Fourier transform and spatial filtering. Holography. Computer generation of optical spatial filters and holograms. Film scanners. Image digitizing — sampling and quantization. Digital computer Fourier transform and linear filtering. Nonlinear operations and techniques pertaining to pattern recognition. Applications.
T. S. Huang, O. J. Tretiak

6.621 ***Microwave Circuits*** **(A)**
Prereq.: 6.04
Year: G (2) 3–2–7
Electromagnetic wave propagation on uniform and periodic structures; apertures and obstacles; equivalent circuit representations; non-reciprocal ferrite devices Cavity and confocal resonators; perturbation theory Multiport junctions. Solution of boundary value problems and orthogonal mode expansions plus qualitative discussion of more complex structures. Laboratory experiments.
R. L. Kyhl

6.622 ***Antennas*** **(A)**
Prereq.: 6.04
Year: G (2) 3–0–9
General theory of radiation and its application to the analysis of representative types of antennas; emphasis placed on the design of antenna arrays, microwave reflectors, and lenses. (*Not offered 1971–72.*)
L. J. Chu

6.624 ***Detection and Measurement of Radio Astronomical Signals*** **(A)**
Prereq.: 6.04
Year: G (1) 3–0–9
Detection and measurement of radiation typical of signals encountered in radio astronomy. Characterization and measurement of random electromagnetic fields, including their spatial, angular, time, and polarization correlation properties. Holograms. Angular filtering properties of antennas, including interferometers and aperture synthesis systems. Antenna temperature and gain. Statistical analysis of signal processors, including basic radiometers, spectrometers, interferometers, and certain digital systems. Noise characterization and analysis for n-port networks. The equations of radiative transfer and their inversion. Applications of parameter estimation theory. (*Alternate years. Not offered 1971–72.*)
D. H. Staelin

6.625J ***Fundamentals of Radio Astronomy*** **(A)**
(Same subject as 8.951J)
Prereq.: 6.624 or 8.05 or 8.211
Year: G (2) 3–0–9
Emission and absorption of radio energy in stellar and planetary atmospheres, gaseous nebulae, and the interstellar medium. Detailed development of emission mechanisms, including free-free transitions, spectral line radiation from H, OH, and other atoms and molecules, synchrotron radiation using classical relativistic electrodynamics. Theory and results of radio observations of the moon, planets, sun, discrete galactic sources, galactic background radiation, extra-galactic sources. Impact of radio astronomy on galactic structure, physics of the interstellar medium, origin of cosmic rays, cosmology. Radio astronomical observations and experiments from space vehicles. (*No prior knowledge of astronomy or astrophysics required. Students who wish to do thesis work in this area are advised to take 6.624 and 6.625J.*)
D. H. Staelin, A. H. Barrett

6.628 ***Solid-State Diode Detectors, Frequency Changers, Amplifiers and Oscillators*** **(A)**
Prereq.: ——
Year: G (1) 3–0–9
Principles, applications and fundamental limitations of solid-state diodes in non-digital applications. Primarily for those interested in research involving very high frequencies. Topics include theory and fundamental performance limitations of mixers, switches and detectors, parametric amplifiers and frequency multipliers, and avalanche transit-time amplifiers and oscillators. Emphasis on noise theory and dynamic range.
D. H. Steinbrecher

6.631J ***Introduction to Plasma Physics*** **(A)**
(Same subject as 8.613J)
Prereq.: ——
Year: G (1) 3–0–9
Introduction to plasma phenomena. The occurrence and generation of plasmas with applications to such problems as gas lasers, thermonuclear fusion and space.

Basic collisional processes, ionization, diffusion, electrical conductivity. Motion of charged particles in uniform and nonuniform electric and magnetic fields, adiabatic invariants, drifts, confinement in magnetic mirrors and tori. Boltzmann and Vlasov descriptions of a plasma, fluid equations. Collective phenomena: Debye length, sheaths and plasma oscillations. Simple equilibria and unstable behavior. Elementary theory of wave propagation: Alfven waves, electron- and ion-acoustic waves, transverse electromagnetic waves, Landau damping. *K. I. Thomassen, G. Bekefi*

6.632 *Electronic Instrumentation and Control* (A)
Prereq.: 6.05
Year: G (1, 2) 3–0–9
Transistors, other solid-state devices, and electron tubes in electronic instrumentation for control and measurement. Electronic conversion transducers; direct-coupled, pulse, and signal-processing amplifiers; modulators and demodulators; monostable and bistable switching circuits; gates; coincidence circuits; random-event counting and count-rate circuits. Illustrations from such applications as time-interval and frequency measurements, high-speed counting and recording instruments, computer components, strain gages, tachometers, and nuclear-reactor control. *T. S. Gray*

6.633 *Special Topics in Plasma Research*
(New)
Prereq.: 6.631J or 8.613J
Year: G (2) 3–0–9
Selected topics of current interest in plasma research with application to the controlled release of nuclear fusion energy. Topics and staff to be announced each year. *A. Bers, R. J. Briggs, R. R. Parker, K. I. Thomassen*

6.635 *Semiconductor Electronics* (A)
Prereq.: 6.08, 6.341
Year: G (1) 3–0–9
Principles and applications of some of the electronic properties of semiconductors important for devices: use of quasi-fermi levels in the description of p-n junctions and transistors; review of diode and transistor performance at high injection levels; statistics of recombination and trapping, and effect on diode and transistor characteristics; avalanche processes in p-n junctions and transistors; four-layer diodes and controlled rectifiers. *R. B. Adler*

6.636 *Microelectronics* (A)
Prereq.: 6.341
Year: G (2) 3–0–9
Fabrication, design, and applications of microcircuits with particular emphasis on silicon monolithic integrated circuits. Physical and electrical description of integrated components: transistors, diodes, capacitors, and resistors. Introduction to the theory and technology of epitaxial growth, oxidation, and diffusion. Circuit design philosophy for linear and digital integrated circuits. The operational amplifier and the digital gate — basic integrated circuit building blocks. Discussion of recent designs to illustrate the design and application of integrated circuits, particularly linear circuits. Additional topics such as the use of computeraided design, active filter design, MSI and LSI as time allows. Possible requirement of a laboratory project or a term paper. *R. B. Adler*

6.64J *Electronic Materials* (A)
(Same subject as 3.76J)
Prereq.: 3.15; or 6.02, 6.341
Year: G (2) 2–0–6
Various aspects of electronic materials such as preparation, purification, crystal growth, crystal structure, characterization, electronic properties, band structure and device applications. Special emphasis on relationships between structural characteristics, atomic bonding and physical properties in classes of materials such as elemental and compound semiconductors, thermoelectrics and superconductors. Extensive rather than intensive coverage. *H. C. Gatos, A. F. Witt*

6.641J *Laboratory in Physics of Solids* (A)
(Same subject as 3.40J)
Prereq.: 3.15 or 6.08; 8.04 or 8.211
Year: G (1, 2) 0–8–4
Experimental investigations on the physical properties of materials closely related to current research; brief lectures on the basic theories and experimental methods. Experiments in areas of: X-ray diffraction, galvanomagnetic effects, superconductivity, ferroelectricity, crystal growth, infrared absorption, Mössbauer effect, thermal properties, magnetic resonance, dielectric properties, carriers in semiconductors, elastic constants, defect structures. *A. C. Smith, D. J. Sellmyer*

6.642 *Special Topics in the Solid State and Its Application* (A)
Prereq.: 8.321
Year: G (1) 3–0–9

6.643 *Special Topics in the Solid State and Its Application* (A)
Prereq.: 8.321
Year: G (2) 3–0–9
Primarily for those interested in research on solid-state materials and devices for electrical and electronic applications. Topics and staff to be announced each term. Given independently or sequentially as circumstances require. *(Permission of instructor required.)* *D. J. Epstein*

6.644 *Microwave Magnetics* (A)
Prereq.: 6.04 or 6.46
Year: G (2) 3–0–9
Introduction to the propagation and mutual interaction of microwave photons, magnons, and phonons in ferro-, antiferro- and ferrimagnetic crystals. Molecular field theory of ferrimagnetism. Quantum mechanical and semi-classical treatments of magnons including dipolar interactions; harmonic oscillator approximation of spin waves and Holstein-Primakoff transformations. Elementary domain theory. Linear and non-linear effects associated with magnetic resonance. Propagation of electromagnetic waves in ferrite-loaded waveguides; reciprocal and non-reciprocal microwave circuit elements such as rotators, isolators and circulators. Magnetoelastic wave propagation in exchange-coupled gyromagnetic media when magnetostriction is present. Detailed study of the electromagnetic, exchange, and elastic channels of power flow. Linear and non-linear mechanisms of magnon/photon and magnon/phonon conversion; applications to fundamental spectroscopy and to the field of microwave devices. *F. R. Morgenthaler*

6.645 *Topics in Semiconductor Device Research* (A)
Prereq.: 6.08, 6.341; 6.651J or 8.511
Year: G (2) 3–0–9
Relationship of the electrical properties and band-structure of semiconductor materials to device performance. Device applications of the following phenomena: tunneling, heterojunctions and Schottky barriers, impurity- and impurity-band-conduction, hot electron effects including the Gunn effect, avalanche including avalanche transit time oscillators, optical properties including luminescence, laser action and photo-detection. *R. H. Rediker, J. N. Walpole*

6.646 ***Conduction Processes in Solids*** **(A)**
Prereq.: 6.08; 6.651J or 8.511
Year: G (1) 3–0–9
Topics in transport theory, including irreversible thermodynamics, Onsager relations, crystal symmetry, energy band theory, effective mass approximation, Boltzmann transport theory, electrical and thermal conductivity, thermoelectric, thermomagnetic, and galvanomagnetic effects. *(Not offered 1971–72.)* *D. Adler*

6.647 ***Electronic Properties of Solids*** **(A)**
Prereq.: 6.651J or 8.511
Year: G (1) 3–0–9

6.648 ***Electronic Properties of Solids*** **(A)**
Prereq.: 6.647 or 8.511
Year: G (2) 3–0–9
Development of empty lattice, weak binding and tight binding approximations for energy bands, group theory with applications to solid-state problems, symmetry methods for energy band models, spin-orbit coupling. Survey of techniques for energy band calculations. Discussion of effective mass theory, Bloch electron in a magnetic field, deformation potentials. Illustrative discussion of the relationship of the above to transport properties, to optical and magneto-optical properties, and to the study of the Fermi surface. *G. W. Pratt*

6.649 ***Quantum Electronics*** **(A)**
Prereq.: 6.651J or 8.05
Year: G (1) 3–0–9
Quantum states and energy levels. Time-dependent perturbation theory and relations to line broadening. The density matrix and its time evolution. Quantization of the electromagnetic field. Spontaneous and stimulated emission of radiation. Negative temperatures and population inversion as a driving source of an electromagnetic field. Lamb's theory of optical lasers. Coherence of optical fields, fluctuations, photon statistics and noise. Gas and semiconductor lasers. Electro-optic effects and non-linear optics. *G. W. Pratt*

6.65 ***Quantum Theory of Magnetism*** **(A)**
Prereq.: 6.651J or 8.511
Year: G (2) 3–0–9
Magnetic properties of isolated atoms and ions. Crystal field theory. The spin Hamiltonian. Optical properties of paramagnetic crystals. Spin paramagnetism of metals. Diamagnetism of solids. The de Haas-van Alphen effect. Ferromagnetic exchange interactions. The Weiss and Heisenberg theories of ferromagnetism. The Bethe-Peierls-Weiss theory. Energy band theory of ferromagnetism. Superexchange coupling in antiferromagnetism. Ferrimagnetism. *G. W. Pratt*

6.651J ***Physics of Solids*** **(A)**
(Revised: Unit change)
(Same subject as 3.42J)
Prereq.: 3.41; or 6.03, 8.05; or 6.03, 8.211
Year: G (1) 4–0–8
First term of a two-term sequence presenting the basic concepts of the quantum theory of crystalline materials. Emphasis on mathematical methods and physical models which have proven to be generally useful in obtaining quantitative descriptions of physical quantities. Topics: diffraction of X rays, electrons, and neutrons by solids; periodic structures and reciprocal space; lattice dynamics, normal modes and phonons; quantum statistics; electron states in solids, Bloch waves and energy bands; perturbation theory; classification of solids.
A. C. Smith, D. J. Sellmyer

6.652J ***Physics of Solids*** **(A)**
(Revised: Unit change)
(Same subject as 3.43J)
Prereq.: 3.42J or 6.651J
Year: G (2) 4–0–8
Second term of a two-term sequence presenting the basic concepts of the quantum theory of crystalline materials. Topics: dynamics of electrons in solids, effective mass theorem; transport phenomena, electrical conductivity; magnetic phenomena, angular momentum and spin; paramagnetism, diamagnetism, ferromagnetism; interaction of radiation with solids, optical properties, resonance phenomena. *A. C. Smith, K. H. Johnson*

6.653 ***Dielectric, Optical and Magnetic Materials and Devices*** **(A)**
(New)
Prereq.: 6.03
Year: G (1) 3–0–9
Introduction to solid state devices primarily dependent on polarization and magnetization processes. Physical models for the dielectric, optical and magnetic properties of solids. Tensor properties and relation to crystal symmetry. Coupled effects: piezoelectricity, pyroelectric, magnetoelastic and acoustoelectric properties and applications. Optical properties: wave propagation in anisotropic crystals, the indicatrix, electro-optical and photoelastic effects; optical switches, modulators and signal processors, beam deflectors. Non-linear optical materials: frequency doubling, parametric amplifiers and oscillators, phase matching. Laser crystals: three and four level lasers, rate equations, threshold condition. Magnetic domains and their application; domain structure, mobility, magnetic bubbles. Magnetic resonance; non-reciprocal microwave devices. *D. J. Epstein*

6.661 ***Dynamical Systems and Control I*** **(A)**
(New)
Prereq.: 6.05, 6.212 or 6.214 or 18.031 or 18.700
Year: G (1) 3–0–9

6.662 ***Dynamical Systems and Control II*** **(A)**
(New)
Prereq.: 6.661
Year: G (2) 3–0–9
An integrated and unified approach to the overall design problem for nonlinear, multivariable, uncertain dynamic systems using state-variable techniques, optimal control, and stochastic estimation methods. Simultaneous treatment of continuous and discrete-time problems. Provides the motivation for the advanced specialized subjects in modern system and control theory. Subdivision of design process into modeling, deterministic optimal open-loop control, on-line stochastic state estimation, and on-line feedback stochastic control. State variable modeling of dynamic systems. Vector differential and difference equations; existence and uniqueness of solutions. Static and dynamic linearization. Linear dynamic systems and the transition matrix. The response of linear systems to deterministic and stochastic inputs, algorithmic solutions. Relation of state variable and transfer function descriptions. Qualitative properties; controllability, observability, and stability. Sampled-data systems. Introduction to deterministic optimal control theory, the Pontryagin minimum principle, the discrete minimum principle, the matrix minimum principle. Dynamic programming. The linear-quadratic optimal regulator and tracking problems; the matrix Riccati equation; time-invariant designs. Computational methods in optimal control; steepest descent and Newton's method; penalty functions. Introduction to stochastic estimation and prediction. The Kalman-Bucy filter and its derivation using the minimum principle. State estimation algorithms for nonlinear systems and their real-time computational requirements. Introduction to simultaneous estimation and control; design of feedback compensators

using linearized dynamics and stochastic quadratic criteria; the separation theorem. Simultaneous parameter estimation and control; adaptive stochastic system philosophy and design. Applications to aerospace, transportation, defense, process control, air traffic control, and economic systems. Computer subroutines provided for computer-aided design and simulation of realistic systems. *J. Willems, M. Athans*

6.663 *Control System Theory* (A)
(New)
Prereq.: 6.05
Year: G (1) 3–0–9
Introduction to basic theory for analysis and design of control systems. Emphasis on linear, infinite time interval problems. Mathematical models for dynamic systems. Review of transforms and stability criteria. Analyses for transient and steady-state response. Root loci. Trial and error design techniques using frequency response methods. Optimization theory for stochastic and deterministic signals. Selected topics from: sampled-data theory, sensitivity analysis, and control system components. *G. C. Newton*

6.664J *Nonlinear Programming and Discrete Optimal Control* (A)
(New)
(Same subject as 15.084J)
Prereq.: ——
Year: G (1) 3–0–9
Review of linear programming. Unconstrained optimization and convex analysis. Generalized Lagrange multipliers, duality theory and the Kuhn-Tucker theorem. Non-linear programming algorithms including quadratic programming, method of feasible directions, cutting plane and penalty function methods. Discrete maximum principle. Computational methods and discretization of continuous optimal control problems. Dynamic programming and control of Markov chains. (*Knowledge of 18.100 and 18.700 are useful but not required.*) *S. K. Mitter, J. F. Shapiro*

6.665J *Optimization in Finite and Infinite Dimensions* (A)
(New)
(Same subject as 15.094J)
Prereq.: 6.664J or 15.084J
Year: G (2) 3–0–9
Constructive fixed point theory. Contraction mappings and dynamic programming. Elementary Hilbert space theory. Convex programming and duality theory in Hilbert space. Optimal control problems and the maximum principle. Approximation and iterative methods in function space. *S. K. Mitter, J. F. Shapiro*

6.666 *Advanced System Theory* (A)
(New)
Prereq.: 6.261, 6.661
Year: G (2) 3–0–9
Unified presentation of aspects of system theory, automata theory and languages. Systems as an input-output relation. Concept of state; Nerode and Myhill equivalence relations. Linear systems and their state space; module structure; controllability, observability and transfer functions; realization theory and algorithms for realizations. Algebraic decomposition theory for finite automata; decomposition of group and semigroup machines. Some algebraic aspects of languages. Structure theory of linear systems; pole assignment, decoupling, inverse systems. Representation of multilinear systems. Realization theory of stochastic linear systems. Identification of finite-state Markov systems.
S. K. Mitter

6.667 *Non-Linear Dynamical Systems* (A)
(New)
Prereq.: 6.213 or 6.661
Year: G (2) 3–0–9
Introduction to basic non-linear phenomena and methods. Fixed-point theorems and implicit function theorems. Solution of non-linear equations using recursive algorithms. Applications to non-linear differential equations. Perturbation theory and the method of averaging. Passivity in linear and non-linear systems. Wellposedness of non-linear feedback systems. Stability concepts for dynamical systems including input-output stability and Lyapunov stability. Stability criteria based on the small gain theorem, passivity conditions, and conic operators. Study of time-varying and non-linear feedback systems including free and forced responses, jump-phenomena, and subharmonic generation. Circle criterion, Popov's criterion and other frequency-domain stability criteria. Lyapunov stability theory. Foundations of state space descriptions for dynamical systems. Construction of Lyapunov functions using variational methods and path integrals. Applications drawn from mechanics, electronics, and automatic control.
J. C. Willems

6.668 *Advanced Optimal Control Theory* (A)
(New)
Prereq.: 6.662
Year: G (1) 3–0–9
Rigorous treatment of the main theoretical tools in deterministic optimal control. Definition of the optimal control problem with control, state variable constraints, and kinks. Derivation of the Pontryagin minimum principle using the reachable sets approach. Existence and uniqueness theorems. The Hamilton-Jacobi-Bellman theory and the dynamic programming algorithm. Singular problems. Average-optimal control problems using limited state variable feedback and subject to compensator constraints. Optimal control of systems with time-delays. Advanced computational algorithms; modified gradient methods, differential dynamic programming, special algorithms for time-optimal and fuel-optimal problems. Differential games; minimax problems, zero sum and non-zero sum problems, Nash equilibrium strategies. Limited information pattern problems, non-scalar valued criteria and conditions for optimality using partial ordering. (*Not offered 1971–72.*) *M. Athans*

6.671 *Modeling, Estimation and Identification* (A)
(New)
Prereq.: 6.05, 6.28 or 18.171, 6.212 or 18.031 or 18.700
Year: G (1) 3–0–9
Modeling and analysis of linear, time varying dynamic systems with uncertainty in input, output (observations) and nature of system itself. Bayesian (probabilistic), Fisher (unknown-probabilistic), and unknown but bounded models considered along with weighted least squares concepts. Estimation (filtering) theory including Kalman-Bucy filter. Decision making (hypothesis testing) and its role in general system problems. Maximum likelihood system identification and special cases. Development based on use of state space concepts to go from static models to discrete time dynamic systems and then to continuous time systems as a limit process. Emphasis on techniques suitable for digital computer implementation and on actual applications.
F. C. Schweppe

6.672 *Simulation Methods for Analysis and Control* (A)
(New)
Prereq.: 6.213 or 6.663
Year: G (2) 3–0–9
Introduction to simulation methods for analysis of complex dynamical systems and their controls. Assumption of background of elementary control theory. Treatment of analog, hybrid, and digital methods for simulation by means of case studies. Use of one or more special languages useful in digital simulations. Speed and cost of alternative computing procedures. Emphasis on analytical checking methods and pertinent questions of numerical analysis. Illustration of modern simulation methods by project-type problems using both analog and digital facilities. *G. C. Newton*

6.673 *Process Control* (A)
(New)
Prereq.: 6.661 or 6.663 or 10.35
Year: G (2) 3–0–9
Control of industrial processes with emphasis on applications in the chemical industries. Development of lumped and distributed models of processing units. Partial differential equations of linear convective processes and approximate methods of solution. Conventional regulation theory; cascade, feedforward, and non-interacting control. Modal analysis and state space representation of lumped and distributed systems; modal control.
L. A. Gould

6.674 *Seminar in Control Research* (A)
(New)
Prereq.: ——
Year: G (1, 2) 3–0–9
A seminar dealing with advanced topics in the theory and applications of decision and control systems. Selected topics according to student and instructor interest. Preference given to topics that will bridge gaps between system science, computer science and operations research. *(See instructor for specific topics to be offered in a particular semester.)* *G. C. Newton*

6.675 *Special Problems in Control* (A)
(New)
Prereq.: 6.213 or 6.663 or 6.672
Year: G (1, 2) *Arr.*
Supervised investigation of special topics in feedback control system analysis and synthesis, laboratory investigations supported by library research and analytical work utilizing the facilities of the feedback control laboratory. *(Program and hours to be arranged with interested staff member, subject to approval of instructor.)* *G. C. Newton*

6.681 *Introduction to Electrical Engineering Research*
Prereq.: ——
Year: G (1, 2) *Arr.*
Lectures on research currently under way in Department of Electrical Engineering. Opportunity for individual study, under a staff member, of advanced subjects related to electrical engineering not otherwise included in the curriculum. Program to suit individual requirements by the student and staff members interested, subject to approval of the professor in charge. *(Restricted to entering graduate students in the Department of Electrical Engineering.)* *D. J. Epstein*

6.682, 6.683 *Special Studies in Electrical Engineering*
Prereq.: ——
Year: G (1, 2) *Arr.*
Opportunity for individual study, under a staff member, of advanced subjects related to electrical engineering not otherwise included in the curriculum. Program to suit individual requirement by the student and staff members interested, subject to approval of the professor in charge. *(Registration of non-Course* VI *students subject to approval of professor in charge.)* *D. J. Epstein*

6.684-6.689 *Special Subjects in Electrical Engineering* (A)
Prereq.: ——
Year: G (1 or 2) *Arr.*
Opportunity for group study of advanced subjects related to electrical engineering not otherwise included in curriculum. *(Programs subject to approval of professor in charge.)* *D. J. Epstein*

6.691J *Speech Communication* (A)
(Same subject as 23.768J)
Prereq.: ——
Year: G (2) 3–0–9
Survey of structural properties of natural languages with special emphasis on the sound pattern. Survey of physiology of speech production, articulatory phonetics. Acoustical theory of speech production: the vocal tract as a generator of acoustical signals; acoustical correlates of vocal-tract configurations, both stationary and dynamic; acoustical and articulatory descriptions of phonetic features. Perception of speech: the auditory capabilities of man; evidence for perceptual correlates of phonetic categories. Mechanical recognition and generation of speech. *(Recommended prerequisites: engineering and science students, 6.41; linguistics students, mathematical background equivalent to 6.05 or 18.05. Others admitted by permission of instructor.)* *K. N. Stevens, M. Halle*

6.694J *Laboratory on the Physiology, Acoustics, and Perception of Speech* (A)
(Same subject as 23.766J)
Prereq.: ——
Year: G (1) 0–6–6
Experimental investigations of speech processes. Topics include (a) interpretation of X-ray motion pictures, (b) measurement of pressure and volume velocity, (c) computer-aided waveform analysis and spectral analysis of speech, (d) synthesis of speech with an articulatory model and with a terminal analog model, (e) identification and discrimination of speech-like sounds, (f) the perceptual reality of phonetic features, and other topics. *(Recommended prerequisites: engineering and science students, 6.41; linguistics students, mathematical background equivalent to 6.01 or 18.03. Others admitted by permission of instructor.)*
D. H. Klatt, M. Halle

6.695 *Engineering Applications of Linguistics* (A)
(New)
Prereq.: ——
Year: G (1) 3–0–9
Mathematical models and computational techniques for the linguistic analysis of English. Study of dictionary representation (morphological analysis), parts of speech determination, syntactic models (a transformational rule tester will be available), parsing, phonological models, letter-to-sound rules, and statistical techniques. Applications to linguistic research and engineering problems including text-to-speech conversion and speech recognition. *J. Allen*

6.70 *Electronic Components and Measurements*
Prereq.: 6.01
Year: U (1, 2, S) 1–4–1
Introductory laboratory for electrical engineering students. Laboratory work concerned with meters, components, oscilloscopes and other equipment necessary to make common measurements of electrical parameters.
C. K. Crawford

6.702 *Bioelectronics Project Laboratory*
Prereq.: ——
Year: U (2) 2–8–2
Project laboratory in the design of electronic instrumentation with biomedical applications. Classroom and laboratory work on the specification, design, construction, and evaluation of an electronic system including several interrelated subsystems employing both analog and digital techniques. Extensive use of integrated circuits and discrete components. No prior knowledge of electronics assumed. Discussion of operation of commonly used laboratory instruments as optional laboratory exercises. Development of circuit models for active and passive devices and terminal models for more complex functional components with evaluation in the laboratory in the context of a project. Written report and oral presentation after completion of project. (*Permission of instructor required.*) *S. K. Burns, R. G. Mark*

6.71 *Electronic Circuits and Signals Laboratory*
Prereq.: 6.70
Year: U (1, 2, S) 1–4–1
Experiments on electric and electronic circuits and systems. *C. K. Crawford*

6.711 *Digital Systems Project Laboratory*
Prereq.: 6.01, 6.70
Year: U (1, 2) 3–7–2
Introduction to some of the basic techniques and devices used in the design and implementation of digital computing and control systems. Preliminary work by a combination of classes, homework, and associated laboratory experiments with digital integrated circuits. Detailed study of logic design, including Boolean algebra, synthesis of combinational logic, iterative logic realizations, and techniques for description and syntheses of sequential circuits; other topics, such as memory devices, if time permits. Implementation of all projects with microcircuit logic elements. Oral presentation and written report on completion of project. (*Students who have previously taken 6.271 should register for 6.272. Registration limited to 40 students.*) *I. T. Young*

6.712 *Advanced Bioelectronics Project Laboratory*
Prereq.: 6.702
Year: U (1) 2–8–2
Individual projects emphasizing the design, construction, and evaluation of electronic systems useful in medicine, biology, or psychology. Systems may include on-line use of small digital computer. The first few weeks of the term will be spent in developing project proposal in consultation with instructor. Remainder of term will be spent in laboratory working on individual projects. Weekly class meeting to discuss individual student's projects. Oral presentation and written project report required upon completion of project. Opportunity for collaboration at a Boston area hospital. (*Permission of the instructor required.*) *S. K. Burns, R. G. Mark*

6.714 *Strobe Project Laboratory*
Prereq.: ——
Year: U (1, 2) 2–8–2
A project laboratory for experiments, involved mainly with the characteristics of electronic flash sources of light and their applications to photography and to measurement problems. A program of experimentation concerned with electronic flash will be organized with each group of students, at the start of the term. (*Permission of instructor required.*) *H. E. Edgerton*

6.715 *Power Systems Project Laboratory*
Prereq.: 6.01, *6.03*, 6.70
Year: U (1, 2) 2–8–2
Introduction to the concepts and techniques used in power systems engineering. Student's choice (either alone or with lab partners) of a project; independent work involving linear and non-linear circuits both passive and active, electromagnetic phenomena, electromechanical phenomena, etc., all in a power system context. (*Limited enrollment.*) *G. L. Wilson*

6.716 *Particle Optics Project Laboratory*
Prereq.: 6.03
Year: U (2) 2–8–2
Special projects involving low energy electrons and ions and their interactions with fields and surfaces. Typical projects: design and testing of mass spectrometers, low magnification electron microscopes, high power beams, electron multipliers, and special cathode ray tubes. Other studies concern secondary emission, electron diffraction, microminiaturization of computer components using electron-induced chemistry, thin films, or other areas of interest. *C. K. Crawford*

6.717 *Audio Frequency Communications Project Laboratory*
Prereq.: *6.05*, 6.70
Year: U (2) 2–8–2
Introduction to some of the more common techniques and methods for the transmission or storage of information carrying signals. Application of systems analysis, information theory, and circuit design to the development of communications systems. Emphasis on the interrelationship between bandwidth, noise, energy, cost, size, reliability, effectiveness, etc. Illustrative examples, including RF transmitters and receivers, tape recorders, companders, vocoders, compressers, human speech, to be discussed in seminar-like recitations. Laboratory experiments related to classroom discussions with oral and written presentations of the projects. *B. A. Blesser*

6.718 *Psychoacoustics Project Laboratory*
(*New*)
Prereq.: 6.70
Year: U (1) 3–4–5
Introduction to the problems and methods involved in the measurement of human auditory abilities. Application of on-line computation to the control and analysis of experiments involving the measurement of hearing. Classroom discussion of auditory function, principles of psychoacoustic measurement, models for psychoacoustic performance, experimental apparatus, and computer control techniques. Project topics: absolute and differential auditory sensitivity, operating characteristics of human observers, span of absolute judgment, adaptive measurement procedures, scaling sensory magnitudes, etc. Oral presentation and written report.
L. D. Braida, N. I. Durlach

6.719 *Microelectronics Project Laboratory*
Prereq.: 6.02, 6.70
Year: U (1, 2) 2–8–2
Introduction to some of the basic techniques and processes used in the fabrication of microcircuits with particular emphasis on monolithic silicon integrated circuits. Classes, homework, and preliminary laboratory projects on the theory and techniques of oxide masking, diffusion, and thin-film deposition. Individual project in one of the above areas, or in the fabrication of such semiconductor devices as integrated capacitors or resistors, bipolar transistors, JFETS, MOSFETS, Schottky-barrier diodes, or delay lines. *F. O. Arntz, C. G. Fonstad*

6.721 ***Optical Semiconductor Devices Project Laboratory***
(New)
Prereq.: 6.02, 8.03
Year: U (1) 2–8–2
The fabrication and operation of semiconductor optical sources and sensors. Lectures on techniques of device fabrication and principles of device operation, and on their applications in such areas as spectroscopy, pollution monitoring, infrared detection, imaging, display and communications. Preliminary laboratory projects on fabrication and measurement techniques of semiconductor devices, including luminescent diodes, lasers, tunable sources, photodiodes, and photoconductors. Major individual project to include the fabrication and testing of a device in simple prototype version. (*Permission of instructor required; limited enrollment.*)
J. N. Walpole

6.722 ***Modern Optics Project Laboratory***
Prereq.: 6.03, 6.05
Year: U (1, 2) 2–8–2
Emphasis on coherent optical systems, quantum electronics, and optical information processing and transmission. Lectures and demonstrations preliminary to projects: properties of light, imaging and transforming properties of a lens, practical optical systems, optical measurements, lasers, optical detectors, holography, optical modulation and communication. Project areas: optical filtering, holography, optical communication, lasers, and quantum noise. Oral presentation and written report. (*Limited enrollment.*) *E. V. Hoversten*

6.723 ***Image Transmission Systems Project Laboratory***
Prereq.: 6.02
Year: U (2) 0–12–0
Student use of facilities of the Image Processing Laboratory of the Cognitive Information Processing Group in R.L.E. for projects related to picture transmission or reproduction systems. Facilities available for computer simulation studies as well as hardware projects. Possible topics: enhancement of images, such as X-rays, by analog or digital filtering; production of a series of standard images for use in image quality evaluation studies; computer generation of images for study of optical illusions; character recognition; picture noise suppression; study of optimum filtering of sampled images, etc. (*Not offered 1971–72.*) *W. F. Schreiber*

6.724 ***Control Systems Project Laboratory***
Prereq.: 6.05
Year: U (1) 2–8–2
Lectures on classical feedback system design methods. Experimental verification and illustration of the techniques via analog simulation and bench-type experiment. Supervised independent projects on a wide variety of applications including development of computer-aided design methods, simulation of economic and social systems, transportation problems, distributed parameter systems and other topics. Oral and written reports.
L. A. Gould

6.74 ***Advanced Electrical Energy Processing Laboratory* (A)**
Prereq.: 6.46
Year: G (1 or 2) *Arr.*
Graduate subject planned for the individual student; special problems on electrical energy conversion, control, and utilization. *G. L. Wilson*

6.79 ***Special Problems in Computation***
Prereq.: ——
Year: U (1, 2) *Arr.*
Individual work in computer science at the undergraduate level. (*Permission of instructor required.*) *J. H. Saltzer*

6.80 ***Special Studies in Electrical Engineering***
Prereq.: ——
Year: U (1, 2) *Arr.*
Opportunity for individual study at the undergraduate level related to electrical engineering not covered by other subjects offered by the Department. Responsibility of students for initiation of arrangements.
W. B. Davenport

6.801-6.809 ***Special Subjects in Electrical Engineering***
Prereq.: ——
Year: U (1, 2) *Arr.*
Opportunity for group study of undergraduate subjects related to electrical engineering not otherwise included in curriculum. (*Programs subject to approval of professor in charge.*) *W. B. Davenport*

6.81 ***Electrical Engineering Laboratory***
Prereq.: ——
Year: U (1, 2) *Arr.*
Opportunity for individual experimental work at the undergraduate level related to electrical engineering not covered by other subjects offered by the Department. Responsibility of students for initiation of arrangements. (*Permission of instructor required.*) *C. K. Crawford*

6.82 ***Undergraduate Thesis Presentation***
Prereq.: ——
Year: U (1, 2) *Arr.*
Registration for written and oral presentation of the undergraduate thesis when the thesis work is an extension of a project laboratory. *R. L. Kyhl*

6.831-6.839 ***Teaching Electrical Engineering***
Prereq.: ——
Year: G (1, 2) *Arr.*
For qualified graduate students interested in teaching as a career. Laboratory, tutorial, or classroom teaching under the supervision of a faculty member. Students selected by interview. (*Total enrollment limited by availability of suitable teaching assignments.*) *J. D. Bruce*

6.841-6.849 ***Research in Electrical Engineering***
Prereq.: ——
Year: G (1, 2) *Arr.*
For Research Assistants in electrical engineering in cases where the assigned research is approved for academic credit by the Department. (*Hours arranged with research supervisor.*) *C. L. Searle*

6.852-6.858 ***Project Study***
Prereq.: ——
Year: U (1, 2) 0–12–0
Extended participation in the work of a research group, including activities such as independent study of the literature, direct involvement in the group's research commensurate with the student's skills and preparation, or project work under an individual faculty member extending over more than one term. (*Admission by arrangement with individual electrical engineering faculty member.*)
R. S. Kennedy

6.951-6.953 ***Industrial Practice***
(New)
Prereq.: ——
Year: U (1, 2, S) 0–9–0

6.954 ***Industrial Practice***
(New)
Prereq.: ——
Year: G (1, 2, S) 0–9–0
Enrollment restricted to students registered in Course VI-A. Provides academic credit for work assignments of VI-A students at companies affiliated with the Department's VI-A Program. Students register for these subjects in sequence, i. e. first work assignment, 6.951; second, 6.952; etc. Credit given for these subjects upon

satisfactory completion of the work assignment and receipt of a favorable evaluation of the student by his company and VI-A Faculty Advisor. *J. A. Tucker*

7.
Biology

7.00 *Perspectives in Life Science*
Prereq.: ——
Year: U (2) 2–0–4
Lectures and readings presenting a general view of the broad area covered by the life sciences; emphasis on fundamental problems and current research from the molecular level to the place of man in the world of living organisms; summary of current work under way by general biologists, biochemists, biophysicists, microbiologists, and investigators in many other sciences. Treatment of subjects such as the origin of life; the chemistry of living things; the transfer of genetic information; growth and development; cellular, organismal, and environmental control mechanisms; and modern methods and techniques used in the life sciences. (*Planned for students electing the life sciences as a major field or as a survey for students planning to major in other fields.*)
B. S. Gould

7.01 *General Biology*
Prereq.: ——
Year: U (1, 2) 4–0–8
Introduction to biology — lectures and demonstrations. Part 1: Molecular biology using examples from work done with bacteria and viruses; introduction to synthesis of small molecules and macromolecules to enzymes and various aspects of cellular control systems, biochemical energetics, and genetics. Part 2: Evolution of more complicated processes in simple multicellular organisms; evolution and classification of plants and animals. Part 3: Higher organism physiology; interactions of organisms with their unfriendly environment. Emphasis on detectors and effectors which enable the organism to respond to both predictable and non-predictable changes in environment.
Term 1: S. E. Luria, P. R. Gross
Term 2: C. E. Holt, V. M. Simpson

7.011 *Introduction to Experimental Biology*
Prereq.: 7.01 or 7.05
Year: U (1, 2) 1–8–3
Basic techniques used in biochemistry, microbiology, and cell biology. *B. S. Gould*

7.02 *Experiments in Biology*
Prereq.: 7.01
Year: U (1) 1–8–3
Laboratory project to acquaint students interested in biology, but not following Course VII, with current problems of biological research. Student to carry out one of several projects offered for approximately first two-thirds of term, with last third used for discussion of results. (*Not offered 1971–72.*) *Staff*

7.03 *Genetics*
Prereq.: 7.21
Year: U (2) 3–0–9
Continuity and variation in the multiplication of living organisms. Mutation and selection as a mechanism for biological change. Principles of formal genetics. Physical and chemical basis of heredity. Structure and function of the hereditary material. Molecular basis for mutation, genetic function and recombination in micro-organisms. *M. S. Fox*

7.031 *Experimental Genetics and Microbiology*
Prereq.: 7.011, 7.21
Year: U (2) 2–16–6
Laboratory project in microbiology and genetics. (*Alternate years. Offered 1971–72.*) *D. Botstein*

7.04 *Developmental Biology*
Prereq.: 7.05
Year: U (1) 3–0–6
Mechanics and principles of development of selected invertebrate and vertebrate organisms. Biochemical and structural differentiation of cells, tissues, and organs. Review of experiments on metabolism, growth, movements, and interactions of cells and other components of developing systems. *E. Bell*

7.041 *Experimental Cell Biology*
Prereq.: 7.011
Year: U (1) 2–16–6
Laboratory investigation dealing with animal cells. (*Alternate years. Offered 1971–72.*)
D. Baltimore, B. W. Burge

7.05 *General Biochemistry*
(*Revised: Unit change*)
Prereq.: 5.41
Year: U (1) 5–0–7
Contributions of biochemistry toward an understanding of the structure and functioning of organisms, tissues and cells. Chemistry and functions of constituents of cells and tissues and the chemical and physical-chemical basis for the structures of nucleic acids, proteins, and carbohydrates. General metabolism of carbohydrates, fats, and nitrogen-containing materials such as amino acids, proteins, and related compounds.
G. M. Brown, U. L. RajBhandary

7.051 *Experimental Biochemistry*
Prereq.: 7.011, 7.05
Year: U (2) 2–16–6
Laboratory project in biochemistry. (*Alternate years. Not offered 1971–72.*) *P. W. Robbins*

7.06 *General and Cell Physiology*
Prereq.: 5.60, 7.01, 7.05
Year: U (2) 3–0–9
Physical and chemical basis for molecular structure and relationship between structure and function in living systems. General principles of cell maintenance, transport, irritability, contraction, and cellular interaction. Relation of form and function. Mechanisms by which the animal interrelates with its internal and external environment. *S. Penman, P. R. Gross*

7.061 *Experimental Physiology*
Prereq.: 7.011
Year: U (1) 2–16–6
Laboratory project in neurophysiology. Techniques of microelectrode recording and stimulating single nerve cells. (*Alternate years. Not offered 1971–72.*) *Staff*

7.07J *Biophysical Chemistry*
(Same subject as 5.64J)
Prereq.: 5.60
Year: U (2) 3–0–9
Equilibrium and kinetic behavior of systems of biological interest. Solution equilibria, coupled reactions, theory of multiple equilibria, allosteric systems, enzyme catalysis and kinetics, chemical relaxation spectrometry, protein and polypeptide structures and conformations, helix-coil transformations, protein denaturation, polymer statistics, hydrodynamics of macromolecules, nucleic acid physical chemistry, special topics. *P. R. Schimmel, R. A. Alberty*

7.08 *Introduction to Biophysics*
Prereq.: 7.00 or 7.01; 8.02
Year: U (2) 2–0–4
Application of the analytical methods of the physical sciences to biology. Emphasis on the molecular aspects of the control systems governing the growth, development and functioning of living organisms. *D. F. Waugh*

7.09J *Seminar in Technology and Society: Ethical and Social Issues in Bio-Medicine*
(New)
(Same subject as 21.941J)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–3–6
Examination, using case studies, of the ethical and social implications of the development and application of biomedical science and technology. Consideration of the following issues: experimentation with human subjects, death and organ transplantation, women and medicine, behavior control, mental health and illness, genetic engineering, allocation of resources. Laboratory work in psycho-socio research and clinical observation.
S. Leff, F. Ausubel, R. W. Wertz

7.21 *General Microbiology*
Prereq.: 7.05
Year: U (1) 3–0–9
Properties of unicellular organisms, especially bacteria: composition, metabolic activities, and structural organization. Micro-organisms as model systems for the study of cellular growth and its physiological basis. Variation, heredity, and the organization of the genetic system in bacteria. Comparative discussion of cellular organization in bacteria, in other microbes, and in multicellular organisms. *S. E. Luria*

7.23 *Microbial Physiology*
Prereq.: 7.21
Year: G (2) 3–0–9
Principal chemical processes responsible for the function and growth of microbial cells. Genetic and environmental control of cellular functions. Chemical activities of micro-organisms in a framework of comparative physiology and biochemistry. *B. Magasanik*

7.24 *Topics in Bacteriology* (A)
Prereq.: 7.23, 7.86
Year: G (1) 2–0–6
Recent developments in bacteriology: genetic, regulatory and macromolecular processes. *M. S. Fox, P. W. Robbins*

7.25 *Topics in Bacterial Viruses*
Prereq.: 7.21, 7.27
Year: G (2) 2–0–6
The biological and molecular properties of bacteriophages as model systems for the study of viruses and as prototypes of noncellular organisms are presented and discussed on the basis of specific examples from current literature. *Staff*

7.26 *Animal Virology*
(New)
Prereq.: 7.21
Year: G (1) 3–0–6
In odd years the course will be an intensive investigation of topics in the area of animal virology concentrating on tumor viruses. In even years the course will be a general survey of the animal viruses. In general, the course will concentrate on the unique aspects of those viruses which grow in animal cells. The virus as a probe of all macromolecular metabolism will be a continual concern. Some discussion of medical aspects of virology will be included.
D. Baltimore

7.27 *Molecular Biology of Bacteria and Bacterial Viruses*
(New)
Prereq.: 7.05
Year: G (1) 3–0–9
Detailed biochemical and genetic study of nucleic acid and protein synthesis in bacterial cells. The mechanism of protein and RNA synthesis, especially initiation and termination. Regulation of gene expression; replication, recombination and repair of DNA; physiology of bacteriophage development and its regulation. *H. F. Lodish*

7.31 *Eukaryotic Chromosomes*
(Revised: Unit change)
Prereq.: 7.27
Year: G (1) 3–0–6
Covers in detail the subject of eukaryotic chromosomes, with emphasis on areas of current interest. Subjects included: models of chromosome structure, histones, satellite DNA's and regulation of chromosomal transcription and replication. *J. A. Huberman*

7.32 *Analysis of Differentiation and Development*
Prereq.: 7.05
Year: G (2) 2–0–4
A graduate discussion seminar which examines in depth fundamental aspects of development and differentiation. In addition, particular attention paid to the critical appraisal of current published research in important areas of the field. *P. K. Gross, V. M. Ingram*

7.36 *Advanced Neurophysiology* (A)
Prereq.: 7.06
Year: G (1) 2–0–4
A series of lectures, with student participation, on some aspects of the nervous system. Foundation for work on the structure and function of the nervous system. *Staff*

7.41 *Biological Oceanography* (A)
Prereq.: 7.05
Year: G (2) 3–0–6
Subject deals with the special adaptations of organisms for life in the sea and the impact of biological processes on the non-living components of the marine environment. Ideas emphasized: the cycling of energy and matter through the marine ecosystem, the factors regulating the abundance, distribution, and community organization of marine micro-organisms and metazoans. Students introduced to the marine environment and the methods of studying the organisms and biological processes that occur in the sea through laboratory and shipboard work. (*Permission of instructor required.*)
J. W. Kanwisher, J. M. Teal
Woods Hole Staff

7.43 *Special Problems in Biological Oceanography* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Advanced problems in biological oceanography with assigned reading and consultation. *Woods Hole Staff*

7.491-7.493 *Research in Biological Oceanography* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Directed research in biological oceanography not leading to graduate thesis and generally done before the qualifying examination. Possible areas include: population dynamics, physiology and cytology of marine microorganisms, physiology, nutrition and productivity of phytoplankton, influence of organisms on the composition of sea water, systematics, physiology and ecology of pelagic larvae, zooplankton, benthos, and mesopelagic fishes, physiology and migration of large fishes, diving physiology and use of sound by marine mammals.
Woods Hole Staff

7.50 *Physical Chemistry of Macromolecules*
Prereq.: 5.60, 7.05
Year: G (2) 2–0–4
Emphasis on macromolecules of biological origin, particularly proteins and nucleic acids. Discussion of physical techniques (such as diffusion, ultracentrifugation, osmotic pressure, light scattering, electrophoresis, viscosity, spectrophotometry, optical rotatory dispersion) with respect to theory and contemporary developments in two major areas: (1) molecular size, shape and solvation and (2) internal structure, surface structure, intermolecular forces and specific and non-specific molecular interaction. *D. F. Waugh*

7.51 *Organ and System Physiology*
Prereq.: ——
Year: U (1) 3–0–6
Study of the mechanisms of cell-cell interaction and the physiology of organ systems, starting with a study of detectors of the state of the internal and external environment and continuing to examine chemical and mechanical effectors. Lectures on comparative functional anatomy, experimental methods, the sensory analysis of events, the generation of action patterns, and the normal and pathological behavior of whole systems. *J. Y. Lettvin*

7.61 *The Mammalian Cell-Selected Topics*
(New)
Prereq.: 7.05, 7.27
Year: G (2) 3–0–9
Lectures on certain aspects of mammalian biology at the cellular and molecular level. Emphasis on processes and structures which have little or no counterpart in microorganisms, and on mammalian cell culture systems. *H. Green, S. Penman, B. W. Burge*

7.62J *Science and Engineering of Biological Membranes and Structural Tissue*
(New)
(Same subject as 2.907J, 3.79J, 8.531J)
Prereq.: ——
Year: G (1) 3–0–6
Biophysical, biochemical and engineering aspects of various biological membranes and of structural tissue. Molecular biology and biochemistry of cell membranes; membranes of cancer cells. Introduction to the non-equilibrium thermodynamics of transport across membranes. Cooperative phenomena involving biological macromolecules and membranes. Capillary structure and analysis of water flux across the capillary wall. Molecular structure of collagen, elastin and of various mucopolysaccharides; the native and the denatured biological solid state. Introduction to linear relaxation mechanics with application to the function of articular cartilage. Topics in the structure and function of skin. Structure and physiology of bone; introduction to quantitative stereology with application to calcified tissue.
B. W. Burge, J. F. Burke, R. M. Rose, H. E. Stanley, I. V. Yannas

7.70 *Seminar in Protein and Nucleic Acid Structure* (A)
Prereq.: 7.05
Year: G (1) 2–0–4
Preparation and discussion of students' papers on topics in protein and nucleic acid chemistry. Emphasis on chemical evidence for the structure of these substances and on relationships between structure, function, and genetic control in selected instances.
U. L. RajBhandary, A. Rich

7.71 *Biophysical Chemistry* (A)
Prereq.: 7.05
Year: G (1) 2–0–4
Mechanism of enzyme action; steady-state enzyme kinetics and enzyme mechanisms and models; dynamics of enzyme catalysis from the viewpoint of fast reaction kinetics; regulation of enzyme activity and allosteric phenomena. Conformational analysis of polypeptides and proteins and relationship of conformation to biological activity; conformational energy estimates; folding of proteins, cooperative transitions in polypeptides and proteins; experimental approaches to the study of polypeptide and protein configurations, properties, and reactions. Physical chemistry of nucleic acids; conformational equilibria and configurations of synthetic polynucleotides and naturally occurring nucleic acids. Special topics. *P. R. Schimmel*

7.72 *Advanced Biochemistry* (A)
Prereq.: 7.05
Year: G (2) 4–0–8
Energy metabolism, the biochemistry of photosynthesis and photophosphorylation and the intermediary metabolism of carbohydrates. Discussion of electron transfer reactions and lipid metabolism from the point of view of the function of biological membranes. Major metabolic pathways involved in the synthesis and degradation of amino acids, purines, pyrimidines, porphyrins, and coenzymes with emphasis in the mechanisms of individual enzymatic reactions and problems of physiological control. *P. W. Robbins, G. M. Brown*

7.73 *Seminar in Immunology*
Prereq.: 7.05
Year: G (2) 2–0–4
Several lectures introducing basic concepts in immunology followed by student preparation of papers on topics of current research interest: antigens and immunogenicity, structure and heterogeneity of immunoglobulins, structural basis for antibody activity, ontogeny and phylogeny of the immune response, cellular and molecular events in antibody synthesis, tolerance, theories of antibody formation. *L. A. Steiner*

7.74J *Seminar in Biochemistry* (A)
(Same subject as 5.981J)
Prereq.: ——
Year: G (1, 2) 1–0–2
Presentation by graduate students of critical reviews of recent publications in chemistry and biochemistry with application to selected biochemical problems. Discussions by staff and students. *Biochemistry and Chemistry Staff*

7.86 *Molecular Genetics* (A)
Prereq.: 7.05, 7.27
Year: G (2) 3–0–9
Examination in depth of selected topics by study and discussion of the literature in seminar format. Special emphasis on experimental details supporting current ideas about replication of nucleic acids and control of gene expression as developed in microbial and applied to mammalian and other eukaryotic systems. Course designed to establish familiarity with literature and patterns of thought in the field and develop the ability of critically evaluating papers. Undergraduates who have taken 7.03 and 7.21 admitted with permission of the instructor. *E. R. Signer*

7.93 *Selected Topics in Biology* (A)
Prereq.: ——
Year: G (1 or 2) *Arr.*
Class work in various fields of biology not covered by the regular subjects of instruction. *Staff*

7.941 ***Research Problems*** **(A)**
Prereq.: ——
Year: G (1) *Arr.*

7.942 ***Research Problems*** **(A)**
Prereq.: ——
Year: G (2) *Arr.*

Directed research in a field of biological science, but not contributory to graduate thesis. *Staff*

7.95 ***Practical Electron Microscopy***
(Revised: Unit change)
Prereq.: 7.01 or 7.05
Year: G (1 or 2) *Arr.*

Two week intensive introduction to biological electron microscopy including both lectures and laboratory. Covers basic principles of image formation in the EM, sample preparation, negative staining and shadowing, Kleinschmidt technique for visualization of nucleic acids, operation of the electron microscope, and photographic techniques. Generally given at the beginning of each term. *(Enrollment limited to 16-20 students. See instructor for further information.)* *J. A. King*

7.97 ***Seminar in Neuroscience Research Topics*** **(A)**
Prereq.: 7.01 or 7.05
Year: G (1 or 2) 3–0–6

Graduate student participation in activities of the M.I.T. Neuroscience Research Program (NRP). Each student working with an assigned preceptor will critically review selected research topics. Topics approached through assigned reading, seminar presentations, and attendance at "work sessions" in which 15 to 20 invited scientists meet to discuss technical, methodological, and conceptual issues encountered at the frontiers of research. Each student prepares a written review article.
F. O. Schmitt, F. G. Worden

7.99 ***Molecular Configuration in Biological Systems Seminar*** **(A)**
Prereq.: 7.05
Year: G (2) 2–0–4

The properties conferred on biochemical substances by assumption of specific physical configurations. Optical methods (emphasizing X-ray diffraction) for determining configuration in macromolecular systems. Special emphasis on molecular structure of crystalline proteins and nucleic acids. *A. Rich*

8.
Physics

GENERAL UNDERGRADUATE SUBJECTS

8.01 ***Physics I***
Prereq.: ——
Year: U (1, 2) 5–0–7

An introduction to classical mechanics. Space and time: straight line kinematics; motion in a plane; forces and equilibrium; experimental basis of Newton's laws; particle dynamics; universal gravitation; collisions and conservation laws; work and potential energy; vibrational motion; conservative forces; inertial forces and noninertial frames; central force motions; rigid bodies and rotational dynamics. *Staff*

8.011 ***Physics I***
Prereq.: ——
Year: U (1) 5–0–7

Newtonian mechanics: motion and forces; frames of reference; momentum and energy; conservation principles; simple harmonic motion; orbital motion, angular momentum, rotating bodies. Electric fields and potentials. Special relativity. 8.011 may be followed by either 8.021 or 8.02. The combination of 8.011 and 8.021 is especially suited for those students who desire only one year of physics. *Staff*

8.012 ***Physics I***
(New)
Prereq.: ——
Year: U (1) 5–0–7

Covers much the same material as 8.01, but at a more advanced level. Particularly well-suited for students with a strong preparation either in mathematics or in physics. Elementary calculus used freely, and concurrent registration in 18.02 recommended. *Staff*

8.013 ***Physics I***
(New)
Prereq.: ——
Year: U (1) 5–0–7

Elementary kinematics and vector analysis. Newton's laws of motion. Statics; forces acting on the human body. Momentum conservation; application to ballistocardiography and to fracture and concussion during impacts. Conservation of energy; the first law of thermodynamics; applications to metabolism and work done by various organs of the body. Angular momentum and torque. Harmonic motion; damped and driven oscillators; resonance. Introduction to the principles of feedback and control systems, with examples in physiology. *F. M. H. Villars*

8.02 ***Physics II***
Prereq.: 8.01 or 8.011 or 8.012 or 8.013; 18.01
Year: U (1, 2) 5–0–7

Relativity: deviations from Newtonian dynamics; Lorentz-Einstein transformations; relativistic dynamics. Electromagnetism: electrostatics and field concepts; electric currents and magnetic fields; induction laws; field energies; Maxwell's equations; circuit electricity; electromagnetism and relativity. *Staff*

8.021 ***Physics II***
Prereq.: 8.01 or 8.011 or 8.012 or 8.013; 18.01
Year: U (2) 5–0–7

Electric currents, magnetism, magnetic fields and potentials, Maxwell's equations. Light, optics, quanta. Selected special topics in modern physics. 8.021 may be followed by 8.03 without too much difficulty. *Staff*

8.022 ***Physics II***
(New)
Prereq.: 8.012
Year: U (2) 5–0–7

Parallel to 8.02, but at a more advanced level. Some knowledge of vector calculus assumed. *Staff*

8.023 ***Physics II***
(New)
Prereq.: 8.01 or 8.011 or 8.012 or 8.013
Year: U (2) 5–0–7

Continuation of 8.013. Brownian motion and diffusion. Application to osmotic pressure and passage of substances through capillary walls. Poisson statistics with application to photoelectric detection and intensity discrimination by the eye. Molecular motion in gases: distribution functions and the Boltzmann Principle. Ideal gas law; two dimensional gas, with application to surface tension and lung surfactant. Intermolecular collisions and transport of mass, energy and momentum

in a gas. Equilibrium in external fields; the centrifuge and measurement of molecular weight. Information content in molecular structure, DNA. Entropy, free energy and the second law of thermodynamics.
F. M. H. Villars

8.03 *Physics III*
Prereq.: 8.02; 18.02
Year: U (1, 2) 5–0–7
Mechanical vibrations and waves: periodic motions and their superposition; free vibrations; forced vibrations and resonance; coupled oscillations and normal modes; vibrations of continuous systems; progressive waves; reflexion, refraction and diffraction (with Huygens' principle.) Electromagnetic waves and optics: plane wave solutions of Maxwell's equations; polarization; transparent media and refractive index; boundary conditions at conductors and dielectrics; cavity resonance and wave guides; fields of accelerated changes; examples of wave and ray optics.
Staff

8.033 *Physics III*
(New)
Prereq.: 8.023; 18.02
Year: U (1) 5–0–7
Electrostatics: Coulomb's law, electric fields, Gauss's law, the electrostatic potential. Laplace's equation, point charges, continuous charge distributions and dipoles. Capacitors, dielectrics and field energy. Quasi-static flow of charge, distribution of potential in volume conductors. Application to electrocardiography, and the conduction of electricity along nerve cells; the Hodgkin-Huxley equation. Magnetic fields, Ampere's law; the law of Biot and Savart; magnetic properties of matter. Faraday's law of induction. Electrical circuits, oscillators, feedback, with application to medical instrumentation; pacemakers. *G. B. Benedek*

8.04 *Principles of Quantum Physics*
Prereq.: 8.03
Year: U (1, 2) 5–0–7
Experimental basis of quantum physics. Bohr theory; optical and X-ray spectra. Wave properties of particles and the time-independent Schrödinger equation for one dimension. Eigenvalue problems. Interpretation of wave properties in terms of probability amplitudes. Polarization states and state vectors; superposition. Wave packets and the uncertainty principle. Time-dependent probability amplitudes. Superposed energy states; lifetimes and the uncertainty principle. Moving wave-packets, and scattering in one dimension. Barrier penetration problems and probability currents. Angular momentum. Quantum states in central fields. *Staff*

8.043 *Physics IV*
(New)
Prereq.: 8.033
Year: U (2) 5–0–7
Hydrostatics and hydrodynamics; viscous flow and the circulation of blood. Acoustic waves in gases and liquids; the wave equation. Reflexion, refraction and attenuation of sound. Ultrasonic diagnosis. The ear and hearing. Electromagnetic waves and physical optics; diffraction, interference and scattering of waves. Applications to optical spectroscopy, X-ray diffraction and macromolecular structure determination. Modern optical techniques in medical instrumentation. *G. B. Benedek*

8.05 *Physics of Atoms and Molecules*
Prereq.: 8.04
Year: U (1) 4–0–8
Hydrogen-like atoms, spin orbit splitting; Zeeman and Stark effects. Emission and absorption of radiation: microwave, infrared, optical and X-ray spectra. Selection rules and the correspondence principle — many — electron atoms. The Pauli exclusion principle; the periodic system of elements. Diatomic molecules. Rotational and vibrational spectra. Symmetry effects, para- and ortho-hydrogen. Qualitative theory of molecular binding, and the structure of solids. *Staff*

8.06 *Theoretical Physics I*
Prereq.: 8.04
Year: U (2) 4–0–8
Basic concepts of mechanics: Inertial frames of reference; space, time, mass, force. Types of forces. Equations of motion; non-inertial frames of reference. Conservation laws for closed systems. Planetary motion. Harmonic oscillator. Macroscopic objects: Constraints; Hamilton's principle and Lagrange's equations. Rigid body dynamics. Coupled oscillators, Green's functions. Normal modes; continuum limit: elastic strings, solids; fields. Canonical variables, Hamilton's equations. Survey of electrodynamics: Basic phenomena and systems of units. Maxwell's equations; simple applications: oscillating circuits, coaxial cables. Moving frames of reference, the Lorentz group. Energy momentum four-vectors, field tensors and relativistic equations of motion. *G. F. Koster*

8.07 *Theoretical Physics II*
Prereq.: 8.06
Year: U (1) 4–0–8
Electromagnetic waves: plane waves, polarization. Huygens' principle, Kirchhoff approximation, diffraction. Energy, momentum, angular momentum of wave packets. Spherical waves — Inhomogeneous wave equations. Green's function solution, Causality. Periodic charge-current distributions, $v/c \ll 1$ limit. Lienard-Wiechert potentials. Synchrotron radiation — Facts of quantum physics. Qualitative quantum mechanics. Classical limit; measurements and interpretation of Ψ. Systems with discrete spectra: harmonic oscillator, time-dependent solutions, classical limit. Angular momentum. The continuum: scattering of wave packets; scattering amplitude and cross sections. Photons, operators for E and B fields, classical limit. Emission, absorption and scattering of radiation: selection rules.
P. Morrison

8.08 *Theoretical Physics III*
Prereq.: 8.07
Year: U (2) 4–0–8
Quantum systems of identical particles. Pauli principle. Occupation number representation of Boson- and Fermion-states — Kinetic Theory: Phase space, Liouville theorem, Boltzmann equation. H-theorem. Ideal gas: work, heat, entropy. Transport phenomena. Thermodynamics: state variables, equations of state. First Law. Second Law; entropy maximum principle, reversible and irreversible processes. Thermodynamic temperature. Ideal gas and photon gas. Thermodynamic potentials, Maxwell relations. Simple and composite systems, phase transitions and chemical equilibrium. Statistical mechanics: ensembles and entropy. Canonical ensemble, partition function in classical and quantum mechanics. Bose and Fermi gas, Boltzmann limit. Specific heats, electric and magnetic susceptibilities. Fluctuations, noise, and Nyquist theorem. *Staff*

UNDERGRADUATE LABORATORY AND SPECIAL PROJECT SUBJECTS

8.11 *Physics Project Laboratory I*
Prereq.: ——
Year: U (1) 1–6–5

8.12 *Physics Project Laboratory II*
Prereq.: ——
Year: U (2) 1–6–5
Laboratory work with close faculty guidance but emphasizing independent work and a professional approach. Study of various physical systems and interpretation of

observed effects; construction of high-vacuum apparatus to study electrons, ions, and atoms; growing of single crystals and study of some of their properties. *Staff*

8.13 *Experimental Atomic Physics I*
Prereq.: 8.04
Year: U (1) 1–6–5
Laboratory experiments fundamental to the development of modern physics, illustrative of current experimental techniques and giving data challenging to analyze. About seven experiments, including: measurements of atomic and molecular spectra; thermionic and thermal emission; motional EMF in solids (Hall effect); optical coherence; speeds of cosmic rays and of light; scattering of alpha particles by nuclei (Rutherford); range-ionization curve for alphas (Bragg); Machine shop, vacuum and electronic practice as parts of the experiments. (*Limited primarily to juniors in Course VIII.*) *D. H. Frisch*

8.14 *Experimental Atomic Physics II*
Prereq.: 8.13
Year: U (2) 1–6–5
Continuation of 8.13. Experiments include: electron ionization (Franck-Hertz); and scattering (Ramsauer) in gases; optical rotation (Faraday); optical pumping; nuclear magnetic resonance; coherent scattering of gammas by nuclei (Mossbauer); scattering of gammas by electrons (Compton) and positron annihilation; lifetime of the μ meson; magnetic splitting of a molecular beam (Stern-Gerlach). *D. H. Frisch*

8.15 *Experimental Physics*
Prereq.: 8.14
Year: U (1) 2–0–2
Introduction to experimental research techniques by (1) lectures given by various members of the staff, and (2) individual presentation of research projects to whole group. Designed to bridge gap between elementary laboratory and research in modern physics. *Staff*

8.16J *Environmental Measurements Projects Laboratory I*
(*New*)
(Same subject as 5.22J and 20.03J)
Prereq.: ——
Year: U (1) *Arr.*

8.17J *Environmental Measurements Projects Laboratory II*
(*New*)
(Same subject as 5.23J and 20.04J)
Prereq.: ——
Year: U (2) *Arr.*
An interdisciplinary project laboratory with faculty guidance but emphasizing independent work on measurements related to environmental problems.
J. G. King, Chemistry Staff, C. Cooney

8.18 *Special Problems in Undergraduate Physics*
Prereq.: ——
Year: U (1, 2) *Arr.*
Opportunity for undergraduates to engage in experimental or theoretical research under the supervision of a staff member. *A. P. French*

8.19 *Readings in Physics*
Prereq.: ——
Year: U (1 or 2) *Arr.*
Supervised reading and library work. Choice of material and allotment of time according to individual needs. For students finding it desirable to do work not provided for in the regular subjects. Specific approval of Department Head required in each case. *A. P. French*

UNDERGRADUATE ELECTIVE SUBJECTS

8.211 *Introduction to Quantum Physics*
Prereq.: 8.03
Year: U (2, S) 4–0–8
Experimental foundations of quantum physics: matter waves, energy levels, photoelectric and Compton effects. Review of atomic models. Foundations of quantum mechanics: the Schroedinger equation; wave packets and uncertainty principle. Stationary states, eigenfunctions, energy eigenvalues, transmission through potential barrier. Three dimensional problems: angular momentum, the hydrogen atom. Many-electron atoms and the Pauli principle. Absorption and emission of radiation. *Staff*

8.222 *Group Theoretical Methods in Physics*
Prereq.: 8.05
Year: U (2) 3–0–9
Introduction to the theory of groups and group representations, physical applications. Finite groups: point and permutation groups. Continuous groups: rotation and Lorentz groups. Infinitesimal transformations. Angular momentum. Atomic structure and the vector model of the atom. Atoms and molecules in external fields. Evaluation of matrix elements. Wave functions of electrons in crystals. Electron spin. Dirac equation. Topics from high-energy physics, molecular structure and spectra, or nuclear physics. *Staff*

8.231 *Introduction to Solid-State Physics*
Prereq.: *8.05*, 18.075
Year: U (1) 3–0–9
Introduction to properties of solids, including structure and external symmetry properties of crystals; X-ray diffraction and microscopic crystal structure, binding energy in solids, elastic properties of continuous media; elastic waves in discrete lattices, temperature dependence of the physical properties of solids. Magnetic properties of solids, free electron theory of metals. *Staff*

8.232 *Topics in Quantum Theory of Matter*
Prereq.: 8.05
Year: U (2) 3–0–9
Elementary quantum mechanics applied to the study of real problems, largely from the field of solid-state physics. Review of exactly soluble problems. Approximation methods applied to many-electron atoms (Hartree-Fock), molecular binding, lattice structure of solids. Electronic states in solids: metals, semiconductors and insulators. Superconductivity: electron pairing, Meissner effect, flux quantization and Josephson junctions. Origin and nature of magnetism: ferro-magnets at low temperature; qualitative discussion of critical points. *Staff*

8.241 *Electron Physics*
Prereq.: 8.04
Year: U (1) 4–0–8
Electron ballistics, mass spectroscopy; high-energy accelerators; space charge theory; Fermi-Dirac statistics, thermionic emission, Schottky effect, high field and secondary emission, photoelectric effect in metals; conductors, insulators, and semiconductors. *G. G. Harvey*

8.242 *Quantum Electronics*
Prereq.: 8.04
Year: U (2) 3–0–9
Fundamental processes in lasers and masers. Classical dipole radiation; susceptibility, and bulk properties of matter. Interaction of a quantum-mechanical two-level system with electromagnetic radiation. Laser oscillators. Excitation mechanisms in gaseous and solid-state lasers. Raman effect and non-linear optics. Laboratory demonstrations. Familiarity with Maxwell's equations and the Schroedinger equation a requirement. *A. Javan*

8.251 ***Physics of Noise and Fluctuations***
Prereq.: 8.05
Year: U (2) 3–0–9
Mathematical description of random processes: joint probability distributions, correlation functions and power spectra. Fluctuations in discrete systems: shot noise, photon counting. Fluctuations about thermal equilibrium: space-time correlations of fluctuations of density, pressure, entropy, etc., and their relation to transport coefficients and dissipation constants. Discussion of modern experimental techniques for the study of thermal fluctuations. Quantum effects. Information theory. Fluctuations in living systems. *T. J. Greytak*

8.262 ***Plasma Physics of Gas Lasers***
Prereq.: 8.05
Year: U (2) 3–0–9
The basic physics of gas lasers. Discussion of low current glow discharges and high current arcs. Relevant plasma physics such as dc and rf breakdown theories, calculation of electron and ion mobilities and diffusion coefficients; ambipolar diffusion, the positive column, statistics of energy gained by free electrons and its transfer to the excitation and ionization of atoms; space charge sheaths, and anode and cathode phenomena. Various plasma instabilities and induced oscillations relevant to the experimental operating regimes of both the glow discharge and the arc discharge. Discussion of excitation and inversion mechanisms of He-Ne, Penning, ion, and molecular gas lasers. Various plasma diagnostic techniques including dc probes, microwave cavities, and radiometers. *E. V. George*

8.272 ***Introduction to Nuclear Physics***
Prereq.: 8.05 or 8.211
Year: U (2) 4–0–8
Elementary discussion of various topics of nuclear physics with description of selected experiments and discussion of results in light of current theories: two-nucleon systems, radioactive decay, nuclear reactions, and nuclear structure. *Staff*

8.285 ***Introduction to Astrophysics***
Prereq.: 8.03
Year: U (1) 3–0–9
Introduction to galactic structure, interstellar medium, cosmic rays, dimensional analysis and stellar models. Basic results of stellar evolution; supernovae, pulsars, neutron stars and nucleosynthesis. External galaxies, radio galaxies, quasars, cosmological theories, the 3° K background radiation and the big bang. *Staff*

8.291J ***Planetary Physics and Chemistry I***
(Same subject as 5.121J and 12.131J)
Prereq.: 8.02, 18.02
Year: U (1) 3–0–9

8.292J ***Planetary Physics and Chemistry II***
(Same subject as 5.122J and 12.132J)
Prereq.: 8.02, 18.02
Year: U (2) 3–0–9
Study of the planetary system: evolution, composition, present configuration, dynamics, interiors, surfaces, atmospheres, and magnetospheres of the planets and, where appropriate, similar aspects of the satellites, asteroids, and comets. Theoretical interpretations of the existing data will be stressed. First term: a general description of the solar system and its origin and a comprehensive discussion of the outer planets. Second term: solar system dynamics, the interplanetary medium; and the interiors, surfaces, and atmospheres of the inner planets. *I. I. Shapiro, J. S. Lewis*

8.293J ***Dynamical Astronomy*** **(A)**
(8.953J) (Same subject as 12.215, 16.441J)
Prereq.: 8.03, 18.075
Year: U (1) 3–0–9
Kepler's laws and the law of gravitation; one- and two-body motion: orbits in space and time; disturbed motion of two bodies as a special case of the general problem of n bodies: variation of orbital elements, planetary theory, expansion of the disturbing function, periodic and secular effects; resonance and stability; linear stability theory, periodic orbits and resonance in the three-body problem, examples involving planets, satellites, and asteroids; techniques of observation and computation: astronomical coordinate systems and time, optical, radio, and radar observations, numerical integration of orbits, orbit determination, maximum-likelihood estimation of orbit initial conditions and astronomical constants.
C. C. Counselman, I. I. Shapiro, W. Wrigley

GRADUATE SUBJECTS

General Interest and Mathematical Physics

8.311 ***Electromagnetic Theory I*** **(A)**
Prereq.: 8.04, 18.075
Year: G (1) 4–0–8

8.312 ***Electromagnetic Theory II*** **(A)**
Prereq.: 8.311
Year: G (2) 4–0–8
Maxwell's equations; static approximation; scalar potential, multipole expansion; boundary value problems; polarization; stress tensor. Vector potential; fields and forces of steady currents; magnetization. Induction and displacement current; conservation laws, energy-momentum tensor. Waves, polarization, and coherence. Reflection, refraction, and scattering of waves; Green's functions and causality; Huygens' principle, geometrical optics. Multipole radiation, radiation damping, "Bremsstrahlung." Special relativity. Covariant form of field equations and equations of motion. Potentials and gauge invariance. Classical electron theory. Vacuum field equations and equations of motion of electron. Lienard-Wiechert potentials. Self-energy and radiation damping. Derivation of macroscopic field equations; normal and anomalous dispersion. *Staff*

8.321 ***Quantum Theory I*** **(A)**
Prereq.: 8.07
Year: G (1) 4–0–8
Dynamics of particles and electromagnetic field in canonical form. Poisson brackets. Action and angle variables. Correspondence principle. Heisenberg matrices. Canonical commutation relations. Transformations of matrix representations and eigenvalue problems. Quantum states and superposition principle. Probabilistic interpretation. Uncertainty relations. Non-stationary states; equations of motion. Heisenberg and Schroedinger picture; transitions; the classical limit. Central field problems; angular momentum; elementary scattering theory. *Staff*

8.322 ***Quantum Theory II*** **(A)**
Prereq.: 8.321
Year: G (2) 4–0–8
Perturbation theory of stationary states. Symmetry and selection rules; rotations and tensor operators. Perturbation theory of non-stationary states. Adiabatic processes. Transition rates. Application to emission, absorption, and scattering of radiation and elastic and inelastic collisions. Systems of identical particles; method of "second quantization"; Hartree-Fock equations. General theory of scattering and reactions. T-matrix, variational, and other approximation methods. Unitarity conditions and S-matrix. *Staff*

Descriptions

8.323 ***Quantum Theory III*** **(A)**
Prereq.: 8.322
Year: G (1) 4–0–8
Relativistic kinematics; covariant equations of motion; dynamics of spin 0 particles; general concepts of relativistic quantum theory. Relativistic spin theory and Dirac equation. External field problems, scattering, polarization. Neutrinos and photons. Discussion of symmetry operations and symmetry properties of systems; CTP theorem. Quantum-, meso-, and electrodynamics. S matrix and Feynman rules. Chew-Low equation and elements of dispersion theory. *K. Huang*

8.333 ***Statistical Mechanics I*** **(A)**
Prereq.: 8.321
Year: G (1) 4–0–8
(i) Principles of thermodynamics: entropy, temperature and chemical potential. First, second and third laws. Thermodynamic potentials. (ii) Postulates of classical statistical mechanics. Microcanonical, canonical, and grand canonical ensembles. Quantum statistical mechanics: ensembles and the density matrix. Non-interacting Bose and Fermi systems; the ideal gas. (iii) Kinetic theory: Boltzmann transport equation. Transport phenomena in gases, liquids, and solids. Theory of fluctuations. Spectral decomposition of Brownian motion: Wiener-Khinchin theorem. Connection between transport coefficients and equilibrium statistics. Nyquist theorem. Kubo formalism, and Onsager relations. *H. E. Stanley*

8.334 ***Statistical Mechanics II*** **(A)**
Prereq.: 8.333
Year: G (2) 4–0–8
Cooperative phenomena and phase transitions, with emphasis on interplay of theory and experiment. (i) Magnetism: molecular field theory of spin interactions. Magnons in metals, ferro- and antiferro-magnets. Random phase approximation. Green's functions. Spin lattice relaxation — density matrix techniques. (ii) Superconductivity: Ginsberg-Landau and BCS theories. Quantum interference and the Josephson effects. Type II superconductors — fluxons and superconducting magnets. Diagram methods in superconductivity. (iii) Superfluidity: two fluid model. Quasiparticles in helium. Zeroth, first, second, third, and fourth sounds. Rotating helium. Interactions between ions and vortices. Macroscopic quantum effects. (iv) Phase transitions: critical point exponents. Landau theory. Scaling law theory. Similarities among phase in a wide variety of systems. Liquid crystals. "Phase transitions" in biological membranes and macromolecules. *H. E. Stanley*

8.341 ***Methods of Theoretical Physics I*** **(A)**
Prereq.: 8.06, 8.311
Year: G (1) 4–0–8

8.342 ***Methods of Theoretial Physics II*** **(A)**
Prereq.: 8.341
Year: G (2) 4–0–8
A course in the methods of mathematical physics for first year graduate students. Appeal to physical intuition for both motivation and understanding. Topics include: the equations of mathematical physics, linear spaces, electrostatics and complex variables, integral transforms, differential equations, separability and symmetry properties, orthogonal polynomials. Group theory with particular emphasis on the rotation group, Poincaré group and permutation groups. Green's functions and integral equations. Approximation methods. Scattering theory, including dispersion theory, the Mandelstam representation, and analytic properties of scattering amplitudes. *H. Feshbach*

8.351 ***Physical Applications of Group Theory*** **(A)**
Prereq.: 8.321
Year: G (1) 3–0–9
Theory of groups and their representations. Discussions of point, rotation, space, Lorentz and Lie Groups. Applications to various branches of physics. (*Alternate years. Not offered 1971–72.*) *Staff*

8.381, 8.382 ***Selected Topics in Theoretical Physics*** **(A)**
(New)
Prereq.: ——
Year: G (1 or 2) 3–0–9
Topics of current interest in theoretical physics, varying from year to year. *Staff*

8.391, 8.392 ***Special Problems in Theoretical Physics*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
Reading, consultation, and original investigation on a problem in theoretical physics. *Staff*

8.399 ***Special Problems in Physics*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
For graduate assistants in the Department of Physics where assigned research or teaching duties are approved for academic credit by the Department. *Staff*

Physics of Atoms, Radiation, Solids, Liquids and Plasma

8.411 ***Advanced Atomic Physics*** **(A)**
Prereq.: 8.321
Year: G (1) 3–0–9
Theory of spectroscopy, including atomic and solid-state spectroscopy in optical and microwave regions. Angular momentum through the use of the Racah formalism. One-electron and many-electron atoms. Atoms in crystal lattices; the Stark and Zeeman effects; the effects of strain on crystal spectra. Experimental methods and results. (*Alternate years. Offered 1971–72.*) *G. F. Koster*

8.421 ***Introduction to Optical, Microwave, and Radiofrequency Physics*** **(A)**
Prereq.: 8.321
Year: G (1) 3–0–9
Theory of radio frequency, microwave, and optical methods for determining magnetic and electric moments of nuclei and the charge and spin distributions of atoms. Topics include motion of spins in d-c and oscillating magnetic fields, electron-nuclear interactions, molecular beam methods, nuclear magnetic resonance, fluctuation phenomena and relaxation, masers, emission and absorption of light, optical pumping, and a brief introduction to lasers. (*Alternate years. Offered 1971–72.*) *D. Kleppner*

8.431 ***Physics of Quantum Electronics*** **(A)**
Prereq.: 8.321
Year: G (1) 3–0–9
Interaction of electromagnetic radiation with matter. Spontaneous and stimulated Raman and Brillouin scattering in solids. Scattering by phonons, plasmons and magnons. Non-linear optics, multiphoton processes, electro-optical and magneto-optical effects. Quantum description of lasers and magneto-Raman scattering in semi-conductors. *B. Lax*

8.442 ***Statistical Optics and Spectroscopy*** **(A)**
Prereq.: 8.05, *8.08*
Year: G (2) 3–0–9
Discussion of light as a statistical process and description of its spectrum by the modern concept of correlation functions. Interaction of light with photodetectors, modern techniques of spectral analysis: photon counting, self-beating, heterodyne beating. Brown-Twiss experi-

ment. Principles of interference and spatial coherence. Applications to Fabry-Perot interferometers and Fourier transform spectroscopy. Theory of diffraction, and grating spectrometers. Spectrum of light scattered by thermal fluctuations in transparent media.

T. J. Greytak

8.451 *Physics of Optical and Infrared Lasers* (A)
Prereq.: 8.311, 8.321
Year: G (1) 3–0–9
Course to develop the theoretical background of the physics of lasers and quantum electronics required for laboratory research with optical and infrared lasers: Classical treatment of the interaction of radiation with matter, with emphasis on radiation reaction and self-force, in free space and inside a resonant cavity. Optical resonators and normal modes. Quantum theory of dipolar interaction; density matrix representation of atomic states. Stimulated emission of radiation, Raman effect, non-linear optics and parametric interactions. (*Alternate years. Not offered 1971–72.*) *A. Javan*

8.452 *Seminar in Optical and Infrared Lasers* (A)
Prereq.: 8.311, 8.321
Year: G (1) 3–0–9
Seminar course dealing with current advanced topics in the physics' of quantum electronics and lasers. Subjects covered include gas laser theory, laser-induced line-narrowing effects, and short pulse propagation through optically thick media. (*Alternate years. Offered 1971–72.*)
M. S. Feld

8.481, 8.482 *Selected Topics in Physics of Atoms and Radiation* (A)
Prereq.: 8.321
Year: G (1, 2) 3–0–9
Presentation of subjects of current interest with topic varying from year to year. *Staff*

8.491, 8.492 *Special Problems in Physics of Atoms and Radiation* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Advanced problems in atomic, optical, microwave and radiofrequency physics, with assigned reading and consultation. *Staff*

8.511 *Theory of Solids I* (A)
Prereq.: 8.231 or 8.232; 18.075
Year: G(1) 4–0–8
Theory of phonons and lattice vibrations; X-ray and neutron scattering; band theory of solids. Electron theory of metals and Fermi-Dirac statistics. Boltzmann transport theory with applications to the flow of heat and electricity in metals and semiconductors. *T. J. Greytak*

8.512 *Theory of Solids II* (A)
Prereq.: 8.511
Year: G (2) 3–0–9
Formalism of many-body theory, applied to problems of solid-state physics. Theory of superconductivity and of superfluids. Theory of magnetism. Optical and magneto-optical properties of solids. Theory of semiconductors. *P. A. Wolff*

8.531J *Science and Engineering of Biological Membranes and Structural Tissue*
(*New*)
(Same subject as 2.907J, 3.79J, 7.62J)
Prereq.: —
Year: G (1) 3–0–6
Biophysical, biochemical and engineering aspects of various biological membranes and of structural tissue. Molecular biology and biochemistry of cell membranes; membranes of cancer cells. Introduction to the non-equilibrium thermodynamics of transport across membranes. Cooperative phenomena involving biological macromolecules and membranes. Capillary structure and analysis of water flux across the capillary wall. Molecular structure of collagen, elastin and of various mucopolysaccharides; the native and the denatured biological solid state. Introduction to linear relaxation mechanics with application to the function of articular cartilage. Topics in the structure and function of skin. Structure and physiology of bone; introduction to quantitative stereology with application to calcified tissue.
H. E. Stanley,
B. W. Burge, J. F. Burke, R. M. Rose, I. V. Yannas

8.541 *Neutron Diffraction* (A)
Prereq.: 3.12 or 8.551
Year: G (2) 3–1–8
Neutron properties, sources, and apparatus. Absorption and scattering of neutrons by isolated atoms. Transmission through and scattering by assemblages of atoms. Diffraction by single crystal and polycrystalline specimens. Crystallographic and magnetic structure analyses. Long wave-length methods and applications. Refractive index characteristics. Neutron polarization. Inelastic scattering. Laboratory experiments offered. (*Alternate years. Not offered 1971–72.*) *C. G. Shull*

8.551 *X-rays and Crystal Physics*
Prereq.: 8.05, 18.076
Year: G (1) 3–0–9
X-ray apparatus, production of X-rays, absorption, scattering, refraction, X-ray spectra. Theory and application of the diffraction of X-rays in matter to the determination of the structure of crystals, and the atomic and molecular arrangement in liquids and amorphous solids. General review of the structure of matter as determined by X-ray diffraction analysis. *B. E. Warren*

8.552 *X-ray Diffraction* (A)
Prereq.: 8.551
Year: G (2) 3–0–9
Selected advanced topics in the application of X-ray diffraction to problems of solid-state physics. The elastic spectrum of crystals from the temperature diffuse scattering of X-rays. Measurement of long-range and short-range order parameters in binary alloys. Measurement of randomness in structures and cold work distortion in metals by X-ray diffraction. Fourier analysis of imperfect crystals. Discussion of extinction effects in perfect crystals. *B. E. Warren*

8.581, 8.582 *Selected Topics in the Theory of Solids* (A)
Prereq.: 8.512
Year: G (1, 2) 3–0–9
Topics in solid-state theory varying from year to year. *Staff*

8.591, 8.592 *Special Problems in Solid-State Physics* (A)
Prereq.: ——
Year: G (1 or 2) *Arr.*
Advanced problems in the physics of the solid state, with assigned reading and consultation. *Staff*

8.611 *Introduction to Physics of Fluids and Plasmas* (A)
Prereq.: 8.08
Year: G (1) 3–0–9
Classification of fluids. Survey of physical properties of liquids, electrolytes, gases and plasmas. Thermodynamics and statistical mechanics of fluids. Quantum effects; solid state plasmas and liquid helium. Experimental techniques. Light and neutron scattering. — Collective motion and waves in liquids, gases and plasmas. Bulk and surface effects. The influence of applied electric and magnetic fields. Methods of generation and detection of waves. — Non-linear phenomena.

Wave interaction and turbulence. Turbulent diffusion. Wave-particle interaction. Radiation of sound and electromagnetic waves from turbulent gases and plasmas. — Survey of current research activities in fluid physics and discussion of one or more of these activities in depth. *K. U. Ingard*

8.613J *Introduction to Plasma Physics* (A)
(Same subject as 6.631J)
Prereq.: ——
Year: G (1) 3–0–9
Introduction to plasma phenomena. The occurrence and generation of plasmas with applications to such problems as gas lasers, thermonuclear fusion and space. Basic collisional processes, ionization, diffusion, electrical conductivity. Motion of charged particles in uniform and nonuniform electric and magnetic fields, adiabatic invariants, drifts, confinement in magnetic mirrors and tori. Boltzmann and Vlasov descriptions of a plasma; fluid equations. Collective phenomena: Debye length, sheaths and plasma oscillations. Simple equilibria and unstable behavior. Elementary theory of wave propagation: Alfven waves, electron- and ion-acoustic waves, transverse electromagnetic waves. Landau damping. *G. Bekefi, K. I. Thomassen*

8.621J *Plasma Kinetic Theory* (A)
(Same subject as 22.64J)
Prereq.: 8.611
Year: G (1) 3–0–9
Content varying from year to year. Typical subjects: the linearized Vlasov equation, Fokker-Planck and diffusion approximations for the average distribution function, autocorrelation functions, resonant and nonresonant diffusion, free energy, energy and momentum conservation, resonant wave coupling, non-linear Landau damping, strong turbulence theories. Selected applications to enhanced diffusion, stochastic acceleration, turbulent resistivity, shock waves, radio emission. *T. H. Dupree*

8.632 *Interactions of Plasmas with Electromagnetic Waves* (A)
Prereq.: 8.08
Year: G (2) 3–0–9
Propagation of transverse electromagnetic and longitudinal waves in infinite and bounded plasmas. Special emphasis on experimental methods and the interpretation of results insofar as these provide information about the physical behavior of the plasma medium. Discussion of the following topics: optical, laser, infrared and microwave interferometry; resonant cavity techniques; laser and microwave scattering from density fluctuations; bremsstrahlung, cyclotron and Cerenkov emission and absorption; longitudinal electron plasma and ion-acoustic waves in isotropic and magneto-active plasmas; beam-plasma interactions and instabilities. *W. P. Allis*

8.641 *Physics of High Temperature Plasmas I* (A)
(*New*)
Prereq.: 8.611 or 8.613J or 8.911
Year: G (1) 3–0–9

8.642 *Physics of High Temperature Plasmas II* (A)
(*New*)
Prereq.: 8.611 or 8.613J or 8.911
Year: G (1) 3–0–9
Basic physics of high temperature plasmas with application to problems in astrophysics and controlled thermonuclear fusion research. Specific significant problems treated in an inductive way to introduce basic theoretical concepts. Topics include: Use of the fluid, guiding-center, and drift kinetic approximations; full kinetic description. Local and non-local collisional transport theory (with and without trapped particle effects). Plasma confinement configurations; theory of equilibria. Collective modes in general; MHD instabilities, collisional and collisionless modes (non-local kinetic modes, integral equation representation, etc.). Anomolous transport coefficients. Nonlinear instabilities. Theory of radiation from inhomogeneous plasmas. (*8.641 — Alternate years. Offered 1971–72. 8.642 — Alternate years. Not offered 1971–72.*) *B. Coppi*

8.681, 8.682 *Selected Topics in Fluid and Plasma Physics* (A)
Prereq.: 8.611
Year: G (1, 2) 3–0–9
Presentation of subjects of current interest, with topic varying from year to year. *Staff*

8.691, 8.692 *Special Problems in Fluid and Plasma Physics* (A)
Prereq.: ——
Year: G (1 or 2) *Arr.*
Advanced problems in fluid or plasma physics with assigned reading and consultation. *Staff*

Nuclear and Particle Physics

8.711 *Nuclear Physics I* (A)
Prereq.: 8.05, 8.06
Year: G (1) 3–0–9
Introduction to nuclear physics, stressing experimental results and correlating the data with current theory and nuclear models. Static properties of nuclei, charge distributions from high energy electron scattering and μ-mesic X-rays. The nucleon-nucleon interaction from the deuteron, scattering experiments and theory. The Fermi gas model and the shell model. Shell structure in nuclei and atoms. The Hartree-Fock method. Near closed shell nuclei with emphasis on O^{17}. *A. M. Bernstein*

8.712 *Nuclear Physics II* (A)
Prereq.: 8.711
Year: G (2) 3–0–9
The study of nuclear structure through nuclear reactions. Optical model, resonance reactions, isobaric analog states, direct reactions such as nucleon transfer reactions, reactions at high energy. The shell model with residual interactions. Vibrational and rotational models. Single particle motion in deformed potentials. Collective states of nuclei and inelastic scattering. *A. M. Bernstein*

8.721 *High Energy Nuclear Physics* (A)
(*New*)
Prereq.: 8.712
Year: G (1) 3–0–9
Studies of nuclear structure using high energy probes: Elastic and inelastic scattering of high energy electrons, nucleons and mesons; photodisintegration. Compton scattering and coherent meson production. Born approximation, phase shift analyses and multiple scattering approximations. Distribution of charge, matter and magnetization. Transition densities. Sum rules. Mesonic atoms. Nuclear momentum distributions from (N, 2N) and (e, e'N) studies. Nucleon-nucleon correlations, (π, 2N), (γ, 2N) and other reactions. *W. Bertozzi*

8.751 *Theory of Nuclear Structure I* (A)
Prereq.: 8.322
Year: G (1) 3–0–9
Review of the current theories of the structure of atomic nuclei. Nature of internuclear forces as determined by two-body phenomena. The three-body problem. The nuclear many-body problem: Hartree-Fock approximation; Bruecker-Bethe Goldstone many-body theory, and its application to nuclear matter and finite nuclei. The nuclear shell model. (*Alternate years. Not offered 1971–72.*) *F. M. H. Villars*

8.752 ***Theory of Nuclear Structure II*** **(A)**
Prereq.: 8.751
Year: G (2) 3–0–9
Continuation of 8.751. Nuclear spectroscopy: collective and single particle excitations; the random phase approximation. Electromagnetic interaction, sum rules. Theory of nuclear reactions: resonance reactions and the Breit-Wigner formula; doorway and analog states. Theory of the optical potential. Interaction of nuclei with elementary particles. (*Alternate years. Not offered 1971–72.*) *F. M. H. Villars*

8.781, 8.782 ***Selected Topics in Nuclear Theory*** **(A)**
Prereq.: 8.751
Year: G (1 or 2) 3–0–9
Presentation of subjects of current interest in nuclear structure and reaction theory. Intended to be given once a year by Department members and (or) visiting professors. *Staff*

8.791, 8.792 ***Special Problems in Nuclear Physics*** **(A)**
Prereq.: ——
Year: G (1 or 2) *Arr.*
Research and reading with consultation in the general area of experimental or theoretical nuclear physics. *Staff*

8.811 ***Particle Physics I*** **(A)**
Prereq.: 8.05, *8.321*
Year: G (1) 3–0–9
Phenomenological approach to particles and their interactions. Classification, symmetry principles, conservation laws. Yukawa approach to mesons. Relativistic kinematics, elementary S-matrix theory, conservation of angular momentum, isotopic spin, etc. Characteristics of strong, electromagnetic, and weak interactions. Particle properties and their interpretation. *M. Deutsch*

8.812 ***Particle Physics II*** **(A)**
Prereq.: 8.811
Year: G (2) 3–0–9
Continuation in depth of 8.811 with particular emphasis on conservation laws, symmetries and their consequences. SU(3) and SU(6). Weak interactions and strong symmetries. *B. T. Feld*

8.822 ***Theoretical Particle Physics*** **(A)**
Prereq.: 8.323
Year: G (2) 3–0–9
Presentation of the basic techniques used in theoretical particle physics: static models; dispersion relations and the Mandelstam representation; helicity formalism. Complex angular momentum. Symmetries: current algebras and sum rules. *V. L. Teplitz*

8.871, 8.872 ***Topics in Relativistic Quantum Theory*** **(A)**
Prereq.: 8.323
Year: G (1 or 2) 3–0–9
Precise material to be covered to differ from year to year according to interest of the instructor. Typical subjects: quantum field theory, S-matrix theory, single and double dispersion relations, Regge-poles, approximate symmetries, and weak interactions. *Staff*

8.881, 8.882 ***Selected Topics in Particle Physics*** **(A)**
Prereq.: 8.811
Year: G (1, 2) 3–0–9
Topics in particle physics, varying from year to year. *Staff*

8.891, 8.892 ***Special Problems in Particle Physics*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
Research and reading with consultation in the general area of experimental or theoretical particle physics. Experimental work which may involve use of off-campus facilities such as the Cambridge Electron Accelerator, Brookhaven National Laboratory, Stanford Linear Accelerator Center, or cosmic ray stations. *Staff*

Space- and Astro-physics

8.911 ***Charged Particles in Space*** **(A)**
Prereq.: 8.07
Year: G (1) 3–0–9
Outline of properties of space beyond earth's atmosphere. Motion of charged particles in magnetic fields: Störmer's theory, Alfvén's approximation, adiabatic invariants. Geomagnetic effects on cosmic rays. Radiation belts. Collision cross sections and diffusion coefficients pertinent to physics of space. Physical quantities that characterize plasma; macroscopic versus microscopic description. Boltzmann equations for fully ionized gases; moments of Boltzmann equations; the generalized "Ohm's Law"; magnetohydrodynamic approximation. Elements of shock theory for dilute plasmas. (*Alternate years. Offered 1971–72.*) *V. M. Vasyliunas*

8.921 ***Physics of the Stars*** **(A)**
Prereq.: 8.05, 8.08
Year: G (1) 3–0–9
Observable stellar characteristics and a survey of star types. Interpretation of the observations as suggested by theoretical studies of stellar structure and evolution. An examination of physical processes in the stellar interior: matter and radiation under stellar interior conditions; nuclear transformations and modes of energy generation appropriate to quasi-static stages of evolution; photon absorption cross-sections and modes of energy transfer. Simple models describing gravitationally contracting, main sequence, and white dwarf stages. Stellar atmospheres and the determination of surface chemical composition. Final reexamination of the observations in the light of processes discussed.
I. Iben, Jr.

8.922 ***Stellar Evolution*** **(A)**
Prereq.: 8.921
Year: G (2) 3–0–9
Star formation, protostars, red giants, variable stars, planetary nebulae, novae, supernovae, pulsars, X-ray sources, nucleosynthesis, massive stars, stellar winds, white dwarfs, neutron stars, gravitational collapse.
W. K. Rose

8.932 ***Physics of the Galaxy*** **(A)**
Prereq.: 8.911 or 8.921
Year: G (2) 3–0–9
Stellar content of the galaxy; kinematical results and dynamical theory. Gas content: gravitational and optical methods; optical polarization and dust. Galactic radio astronomy: spectroscopy of H, OH; the continuum, thermal and non-thermal. Particles and radiation: the halo problem; cosmic rays; electrons and their history. The magnetic field. Relationships to external galaxies.
B. F. Burke

8.942 ***Cosmology*** **(A)**
Prereq.: ——
Year: G (2) 3–0–9
Cosmic ages, the Hubble law and Olbers paradoxes. Thermal backgrounds in space. The cosmological principle and its consequences: Newtonian cosmology and types of "universes"; survey of relativistic cosmology;

horizons. Overview of evolution in cosmology: radiation, and element synthesis; physical models of the "early stages." Radio sources and their statistics; quasars. Variability of physical laws. (*Consent of instructor required. Alternate years. Offered 1971–72.*) *P. Morrison, S. Weinberg*

8.951J ***Fundamentals of Radio Astronomy*** **(A)**
(Same subject as 6.625J)
Prereq.: 6.624 or 8.07
Year: G (2) 3–0–9
Emission and absorption of radio energy in stellar and planetary atmospheres, gaseous nebulae, and the interstellar medium. Detailed development of emission mechanisms, including free-free transitions, spectral line radiation from interstellar atoms and molecules, synchrotron radiation from relativistic electrons. Theory and results of radio observations of the moon, planets, sun, discrete galactic sources, galactic background radiation, extra-galactic sources. Impact of radio astronomy on galactic structure, physics of the interstellar medium, evolution of galactic sources.
A. H. Barrett, D. H. Staelin

8.954J ***Dynamical Problems of the Solar System*** **(A)**
(Same subject as 12.614J, 16.442J)
Prereq.: 8.293J
Year: G (2) 3–0–9
Introduction to current research in solar systems dynamics, tidal friction, evolution of spin and orbital resonances, and tests of gravitational theories.
I. I. Shapiro, C. C. Counselman, W. Wrigley

8.962 ***General Relativity*** **(A)**
Prereq.: 8.312
Year: G (1) 3–0–9
Review of special relativity: Lorentz transformations, relativistic mechanics, and electromagnetism. The equivalence principle. Linear gravitational theories. General covariance. Elements of tensor analysis. The gravitational field equations and some special solutions. Gravitational waves, Mach's principle, and cosmological models. *S. Weinberg*

8.981, 8.982 ***Selected Topics in Astrophysics*** **(A)**
Prereq.: ——
Year: G (1 or 2) 3–0–9
Topics of current interest, varying from year to year.
Staff

8.991, 8.992 ***Special Problems in Astrophysics*** **(A)**
Prereq.: ——
Year: G (1 or 2) *Arr.*
Advanced problems in astrophysics with assigned reading and consultation. (*Admission by permission of instructor only.*) *Staff*

9.
Psychology

9.00 ***Introduction to Psychology and Brain Science***
Prereq.: ——
Year: U (1, 2) 3–0–6
Survey of selected facts, principles, and theories in psychology. Historical origins, biological foundations, comparative and developmental studies, motivation, perception, learning, personality, and social processes.
A. Hein

9.001 ***Proseminar in Psychology*** **(A)**
Prereq.: 9.35, 9.40, 9.70
Year: G (1) 6–0–15
Intensive survey of psychology on the graduate level, covering historical origins, biological foundations, learning, and higher processes, perception, child development, personality, and social interaction. Lectures, group discussions, and guided reading. (*Restricted to graduate students in psychology.*) *Staff*

9.002 ***Tutorial in Psychology*** **(A)**
Prereq.: 9.001
Year: G (1, 2) *Arr.*
Continuation of 9.001 in selected problem areas, with assigned reading and consultation. *Staff*

9.01 ***Physiological Psychology***
Prereq.: 9.00
Year: U (1) 4–0–6
Explanations of behavior in neurological terms. General structure and physiology of central nervous system. Reflexes and motor systems. Sensory systems: anatomy, electrophysiology, ablation studies. Limbic system: exploring the bases of motivation, emotion, and visceral regulation. "Higher functions" and cerebral cortex. Introduction to neural processes in learning.
G. E. Schneider

9.011 ***Seminar in Psychophysiology of Memory*** **(A)**
Prereq.: 9.001 or 9.01 or 9.40
Year: G (2) 3–0–6
Discussion of physiological, biochemical and structural aspects of the mnemonic process. Mechanisms of information handling in biological systems with particular emphasis upon habituation, conditioning, and similar phenomena in animals. Consideration of models and theories concerning the biological basis of memory.
S. L. Chorover

9.012 ***Seminar in Physiological Psychology*** **(A)**
Prereq.: 9.001
Year: G (2) 3–0–6
Advanced treatment of topics in physiological psychology. (*Primarily for graduate students specializing in this field. Not offered 1971–72.*) *Staff*

9.013 ***Outline of Mammalian Neuroanatomy*** **(A)**
Prereq.: 9.001
Year: G (2) 3–0–6
An elementary survey of mammalian neuroanatomy based largely on the primate brain. Emphasis more on overall organization of the central nervous system than on cellular detail. *W. J. H. Nauta*

9.014 ***Practicum in Physiological Psychology I*** **(A)**
Prereq.: 9.001 or 9.01 or 9.013
Year: G (1) 2–4–3
Introduction to experimental techniques in psychophysiological research. Biophysical principles; control and measurement of electrophysiological and behavioral variables; care and treatment of laboratory animals; psychopharmacology, surgical and stereotaxic production of cortical and subcortical brain lesions, electrical and chemical brain stimulation techniques, recording and averaging of neuroelectrical activity. (*Limited enrollment. Permission of instructor required.*) *S. L. Chorover*

9.015 ***Practicum in Physiological Psychology II*** **(A)**
Prereq.: 9.001 or 9.013 or 9.014 or 9.02 or 9.03
Year: G (2) 2–4–3
Elementary neurohistology: fixation, blocking, embedding, cutting and staining techniques; interpreting and displaying the results. Special projects according to student interests. (*Limited enrollment. Permission of instructor required.*) *G. E. Schneider*

9.021 *Brain and Behavior* (A)
Prereq.: 9.001
Year: G (2) 3–0–6
Methods and results in neuropsychology — the correlation of neural structure with neural function (behavior). Analysis of cerebral structure in rodent, carnivore, and primate by methods drawn from macro- and micro-anatomy, by electrical stimulation and recording, and by chemical means. Analysis of function (behavior) proceeds by comparing effects of cerebral stimulation (or destruction) in the experimental animal, with corresponding effects of injury or disease in man. (*Not offered 1971–72.*) *H. L. Teuber*

9.022 *Light and Electron Microscope Techniques in Neurobiology* (A)
Prereq.: ——
Year: G (1) 2–6–2
Fixation and embedding of tissue for light and electron microscopy. Preparation of ultrathin sections. Fundamentals of light and electron microscopy techniques and their applications to the study of interneuronal connections. The ultrastructure of the nervous system. (*Enrollment limited to four students. Permission of instructor required.*) *H. Greenlaw, L. Heimer, H. J. Karten*

9.023 *Topics in Neurophysiology of Movement* (A)
Prereq.: ——
Year: G (2) 3–0–9
Regulation of movements at low and high levels of the nervous system. Spinal cord: the reflex effects from groups I, II, and III muscular afferents, joint and cutaneous afferents. Parallel operations of alpha and gamma mononeurons in the control of movement. Functional significance of vestibular, cerebellar, and cortical loops in the control of spinal neurons. (*Advanced undergraduates and graduates from any department, by permission of instructor.*) *E. Bizzi*

9.024 *Seminar on the Oculomotor System* (A)
(*New*)
Prereq.: ——
Year: G (1) 3–0–6
Eye muscle morphology and innervation. Comparative review of oculomotor circuitry with emphasis on the role and participation of the cerebellum and vestibular systems. Cortical control of eye and head movement. (*Advanced undergraduates from any department, by permission of instructors.*) *E. Bizzi, H. Karten*

9.03 *Neural Mechanisms of Learning and Motivation*
Prereq.: 9.01
Year: U (2) 3–0–6
Consideration of the evidence for physiological mechanisms of learning and of motivated behavior (e.g. eating, drinking, sleep, maternal and reproductive behavior) derived from neuropsychological, neurophysiological and neurochemical experiments. Reports, lectures and discussion. *S. L. Chorover*

9.30 *Animal Behavior*
Prereq.: 9.00
Year: U (1) 3–0–6
Review of basic concepts and methods in the study of behavior in animals ranging from amoeba to primate. Instinctive response patterns and their specific sensory releasers. Problems of maturation and learning in the analysis of these phenomena. Survey of parallels in the evolution of sensory-neural systems and the emergence of various behavior patterns. (*Not offered 1971–72.*) *A. Hein*

9.301 *Seminar in Comparative Psychology* (A)
Prereq.: 9.001 or 9.01 or 9.30 or 9.88
Year: G (1) 3–0–6
Topics for reports and discussion drawn from the following: evolution of sensory and motor systems, learning in invertebrates, animal navigation, animal communication, problems in interaction of genetic, maturational and experiential factors in the development of behavior, ethological theory, problems in the comparison of intellectual abilities within and between phyla, and similar topics. (*Not offered 1971–72.*) *A. Hein*

9.331 *Development of Vision* (A)
(*New*)
Prereq.: 9.013, 9.351
Year: G (1) 3–0–6
Critical consideration of the organic and environmental factors determining growth and function of the visual system. Evidence drawn from behavior, neurophysiology, neuroanatomy, and other relevant disciplines. *R. Held*

9.341 *Seminar in Sensorimotor Processes* (A)
Prereq.: 9.001; or 9.01, 9.35
Year: G (1) 3–0–6
Discussion of the systems which control spatially oriented movements of man and other vertebrates. Data from studies of spatial behavior, its modification by rearrangement, and its early development. Consideration of relevant neurology and neurophysiology as constraints on modeling these systems. Other topics: the relevance of sensorimotor systems to spatial perception, the dissociation of pattern analyzing from orienting behavior, and invertebrate systems of coordination. (*Not offered 1971–72.*) *R. M. Held, E. Bizzi*

9.35 *Psychology of Perception*
Prereq.: 9.00
Year: U (2) 3–0–6
Critical and historical survey of phenomena revealed in study of the senses and the problems they raise for the development of theories of perception. Information drawn from anatomy, neurophysiology, psychophysics, and other relevant disciplines.
R. M. Held, W. A. Richards

9.351 *Seminar on Sensation and Perception* (A)
Prereq.: 9.001 or 9.35
Year: G (2) 3–0–6
Reading, discussion, and criticism of current theory and experiments bearing on topics selected according to interests of participants. Topics may include perception of form, motion, and space; sensorimotor interaction; relevant neural processes; theoretical models, comparisons among species; and developmental approaches.
R. M. Held, W. A. Richards

9.355 *Visual Processes* (A)
Prereq.: 6.37 or 9.001 or 9.35
Year: G (1) 3–0–6
Fundamental visual processes, seen as major advances in the evolution of visual systems. Integration of these processes in the human visual system. Depending upon interest of participants, topics to be emphasized: image-formation, contrast, spatial-temporal interactions, adaptation phenomena, color, binocular vision, receptive fields and physiological correlates of form and movement perception. Visual mechanisms elucidated by psychophysical and neurophysiological evidence from primitive and complex visual systems. (*Not offered 1971–72.*) *W. A. Richards*

9.361 ***Electrophysiology of the Visual System*** **(A)**
Prereq.: 9.001
Year: G (1) 3–0–6
Survey of the electrophysiology of the mammalian visual system. Special attention given to the relationship between electrophysiological and psychophysical data. *P. H. Schiller, R. Kalil*

9.37 ***Color Science and Color Vision***
Prereq.: 9.35
Year: U (1) 3–0–6
Measurement and specification of color; colorimetry; color scales and color tolerances; chromatic adaptation; human color vision and its anomalies; theories of color vision. (*Consult instructor.*) *W. A. Richards*

9.381 ***Seminar on Binocular Vision*** **(A)**
(*New*)
Prereq.: 9.35
Year: G (1) 3–0–6
Stereopsis and stereoblindness. The role of eye movements in depth perception. Zoom mechanisms and convergence. The geometry of visual space. Interposition and the induced effect. Kinetic depth. Disparity receptive fields, surround inhibition and adaptation. Spatial and temporal response functions for disparity and their relation to vergence mechanisms. *W. A. Richards*

9.40 ***Learning***
Prereq.: 9.00
Year: U (2) 3–0–6
Theories and experimental findings on learning and memory in both humans and animals. Short-term and long-term memory for verbal and non-verbal materials, classical and instrumental conditioning, extinction, habituation, motivation and learning, discrimination learning, mathematical theories of learning and memory. *Staff*

9.401 ***Seminar in Learning*** **(A)**
Prereq.: 9.001 or 9.40
Year: G (2) 3–0–6
Reading, discussion and criticism of selected topics. Emphasis on one or more of the following themes in a particular term: conditioning and instrumental learning, multiple response learning, problem solving and concept formation, verbal learning, memory, systematic formulations of learning phenomena, mathematical learning theories, neural mechanisms of learning. *Staff*

9.45 ***Problem Solving***
Prereq.: 9.00
Year: U (2) 3–0–6
Theories, methods, and findings in human problem solving. Analysis of some heuristic problem solving methods applied to problems taken from mathematics, logic, games, puzzles, concept attainment, and practical situations. Use of these methods by humans. Learning of new methods. Transfer of methods from one problem to another. Language and problem solving. Development of problem solving ability in children. (*Not offered 1971–72.*) *Staff*

9.491 ***Seminar in Mathematical Psychology*** **(A)**
Prereq.: 9.00 or 9.001, 18.02
Year: G (2) 3–0–6
Reading and discussion of selected topics, and independent study. Applications of mathematical and computer techniques to psychological problems, particularly in the field of vision. Mathematical topics will be chosen primarily for their fruitfulness to psychology and physiology. (*Knowledge of mathematics or computer programming necessary. Not offered 1971–72.*) *Staff*

9.50 ***Research in Psychology***
Prereq.: 9.00 and one other subject in psychology
Year: U (1, 2, S) *Arr.*
Laboratory research in the areas of perception, learning and memory. Each student to carry out an original study in the area of interest to him. Survey of problems specific to research topics, design and conduct of experiments, written presentation of results. *P. H. Schiller*

9.59 ***Psychology of Language and Communication***
Prereq.: 9.00 or 23.751
Year: U (1) 3–0–6
Study of psychology of language processes in light of recent advances in structural linguistics; extensive critique of learning-theoretic accounts of verbal behavior; examination of problems of language acquisition and speech perception. Methodological implications of psycholinguistic experiments and theory will be stressed. *E. C. T. Walker, M. F. Garrett*

9.591 ***Seminar in Psychology of Language and Communication*** **(A)**
Prereq.: 9.001
Year: G (1) 3–0–6
Reading, discussion, and criticism of selected topics. Emphasis on one or more of the following themes in a particular term: theories of language, speech perception, communication in sub-human species, aphasia, language acquisition, language and thought, interaction between grammatical structure and verbal performance. *M. F. Garrett*

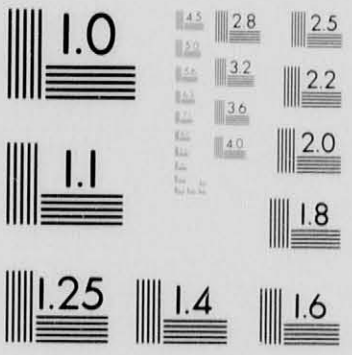
9.592 ***Seminar in Psychology of Language and Communication II*** **(A)**
Prereq.: 9.591
Year: G (2) 3–0–6
Advanced topics in psycholinguistics. (*A research paper is required as part of this course.*) *J. A. Fodor, M. F. Garrett*

9.60 ***Personality Structure and Development***
Prereq.: 9.00
Year: U (1) 3–0–6
Detailed study of basic personality phenomena and concepts, experimental and non-experimental methods and research findings. Phenomena discussed include: personality traits; the interrelations between motivation and memory, imagery, and thinking; anxiety, conflict, and defense; personality and beliefs; developmental changes in personality, especially in motives, modes of adaptation and morality. (*Limited enrollment. Not offered 1971–72.*) *Staff*

9.651 ***Cognitive Processes*** **(A)**
Prereq.: ——
Year: G (2) 3–0–6
Issues in the formation and exploitation of cognitive structures. Special attention to 'motor' theories of concepts, associationism, and the impact of recent psycholinguistic studies on general problems about thought and perception. (*Permission of instructor required for undergraduate students.*) *J. A. Fodor, M. F. Garrett*

9.70 ***Social Psychology***
Prereq.: 9.00
Year: U (2) 3–0–6
Examination of the basic processes by which people interact, perceive and make judgments of others, influence each other, and develop social beliefs and values, in the context of small and large groups and societies. *M. C. Potter*

9.80 ***Behavior in Groups***
Prereq.: 9.00
Year: U (2) 3–0–6
Psychological study of the behavior of individuals in group situations. Field studies and laboratory research, with emphasis on the latter. (*Not offered 1971–72.*) *Staff*



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9.851 ***Seminar in Social Development of Children*** **(A)**
Prereq.: ——
Year: G (2) 3–0–6
Description and comparison of children's social behavior at different stages of development. Selected topics concerned with moral development, communication and interaction, imitation and compliance, and group formation. (*Permission of the instructor required. Not offered 1971–72.*) *Staff*

9.881 ***Seminar in the Origins of Behavior*** **(A)**
(9.88) *Prereq.:* ——
Year: G (2) 3–0–6
Interaction of innate and experiential factors in the neonatal development of learning capacities, perception, cognition, social behavior, and motor patterns. Implications of evolution, genetics, embryology, and early experience for the ontogeny of behavior. (*Permission of instructor for undergraduate.*) *A. Hein, R. Diamond*

9.89 ***Developmental Psychology***
Prereq.: 9.00
Year: U (2) 3–0–6
Survey of major issues, problems, and theories of ontogenetic development. Developmental aspects of sensorimotor coordination, perception, learning and personality. *P. H. Schiller*

9.891 ***Seminar in Developmental Psychology*** **(A)**
Prereq.: 9.001
Year: G (2) 3–0–6
Advanced treatment of topics in developmental psychology. (*Not offered 1971–72.*) *A. Hein*

9.92 ***Advanced Psychology Seminar***
Prereq.: 9.00 and any two subjects in psychology
Year: U (2) 3–0–6
Critical survey of contemporary problems in psychology. *Staff*

9.921 ***Research in Psychology*** **(A)**
Prereq.: 9.001
Year: G (1) *Arr.*

9.922 ***Research in Psychology*** **(A)**
Prereq.: 9.001
Year: G (2) *Arr.*

9.923 ***Research in Psychology*** **(A)**
Prereq.: 9.001
Year: G (S) *Arr.*
Guided research under the sponsorship of individual members of the faculty. Ordinarily restricted to candidates for the doctor's degree in psychology. *Staff*

10.
Chemical Engineering

10.11 ***Chemical Process Analysis***
Prereq.: 10.12
Year: U (2) 2–0–4
Introduction to analysis of chemical processes, developing the techniques of taking an idea or laboratory result through preliminary analysis and design in order to evaluate alternatives and to determine economic attractiveness. Specific case studies made in areas such as pollution control, synthetic fuels, alternate energy sources for automobiles, proteins from petroleum and water demineralization. *E. R. Gilliland*

10.12 ***Staged Cascades in Chemical Processing***
Prereq.: ——
Year: U (1) 3–3–6
Cascade theory of staged separations processes such as washing of solids, solvent extraction, and distillation. Numerical iteration techniques and computer methods. Concepts of reflux. Algebraic solutions for linear systems. Graphical methods of analysis. Computer techniques for multicomponent distillation. Coupled cascade systems. Design and optimization of such systems. (*May be taken by freshmen.*) *P. L. T. Brian*

10.13 ***Chemical Engineering Thermodynamics***
Prereq.: 5.60
Year: U (2) 4–0–8
Engineering applications of thermodynamics. Concepts of equilibrium and reversibility. Properties of pure materials and of mixtures. The entropy, free energy, and availability functions and their use in the analysis of chemical reactors, power cycles, refrigeration cycles, and separation processes. Chemical equilibrium in homogeneous and heterogeneous systems. *P. S. Virk*

10.15 ***Thesis Reports***
Prereq.: ——
Year: U (1, 2) *Arr.*
Work done in conjunction with the S.B. thesis. Written and oral reports on literature survey and experimental work. Normally consists of three units in the fall term plus one unit in the spring term. *C. K. Colton*

10.17 ***Combustion and Air Pollution***
Prereq.: ——
Year: U (2) 2–0–4
Quantitative interpretation and application of the principles of combustion with examples and discussion centering on the analysis of current air pollution problems and methods of pollution abatement. Topics: chemical and thermodynamic aspects of combustion, laminar and turbulent flame structure, diffusion and premixed flames, flammability limits, generation and control of sulfur oxides, nitrogen oxides, carbon monoxide, hydrocarbons and particulates. *J. B. Howard*

10.18 ***Industrial Chemistry***
Prereq.: 5.60; 10.301
Year: U (2) 3–0–6
Study of processes for making industrial chemicals as systems. Exploration of those factors which determine the flow sheet and apparatus required for carrying out the reactions and associated operations. Extensive problem work on the influence of stoichiometry, energy requirements, equilibria, kinetics and the transfer processes on over-all design and operation. *H. P. Meissner*

10.21 ***Structures and Properties of Matter***
Prereq.: 5.41, 5.62
Year: U (1) 3–0–6
Atomic and molecular interactions and their importance in determining physical and chemical properties of matter. Bulk and interfacial properties of pure and mixed gases and solids, including synthetic and natural polymeric substances. Techniques for characterizing molecular structure and for predicting properties of matter. *R. F. Baddour*

10.24 ***Chemical Engineering Instrumentation Laboratory***
Prereq.: 5.60
Year: U (1, 2) 1–3–2
Combination of lectures, demonstrations, and laboratory exercises outlining principles and range of applicability of a number of instrumentational methods currently important in chemical engineering. Opportunities to work with specific instruments in association with research workers. Emphasis on gas chromatography,

infrared spectroscopy, and potentiometric measurements. Study of some of the following topics: flame photometry, ultra-violet and visible spectrophotometry, hot-wire anemometry, viscometry, microscopy, transient temperature measurements, pyrometry, pH measurements, and radiation counting techniques. *J. E. Vivian*

10.25 *Industrial Chemistry* (A)
Prereq.: 5.41, 5.62
Year: G (1) 3–0–6
Study of the factors determining the flow sheets, equipment design and interrelations in plants for producing industrial chemicals. Many examples drawn from the inorganic and organic industries both quantitatively and qualitatively. *H. P. Meissner*

10.26 *Chemical Engineering Laboratory*
Prereq.: 5.41, 10.13, 10.301
Year: U (1) 0–10–0
Laboratory projects in the areas of *applied* chemical research and unit operations. Emphasis on the applications of engineering concepts and fundamentals to the solution of practical and research problems. Training in planning research projects, execution of experimental work, and articulation (both oral and written) of the research plan and results in the areas of applied chemical technology and engineering operations related to mass, momentum, and heat transfer. *E. R. Gilliland*

10.28 *Industrial Chemical Synthesis* (A)
Prereq.: 5.41, 5.62
Year: G (1) 2–0–4
Study of the reactions and the large-scale processes for making selected petrochemicals, with particular reference to ethylene, acetylene, propylene, butadiene, and their derivatives. Exploration of current practice, including the state of the patent art. *H. P. Meissner*

10.301 *Modes of Heat and Mass Transfer*
Prereq.: 10.13
Year: U (1) 4–0–6
Diffusive transport of heat or mass in stationary media; additivity of resistances concept and transient analysis. Radiative transport of energy. Convective transport. Chemical engineering design of heat and mass exchangers. *K. A. Smith*

10.302 *Fluid Mechanics and Transport Processes*
Prereq.: 10.301
Year: U (2) 4–0–6
Introduction to fluid mechanics. Dynamics of fluids in motion; laminar and turbulent flow; Bernoulli's equation; friction in conduits, boundary layer theory; Navier-Stokes equations. Convective transport analysis. The analogies, boundary layers, condensation, natural convection. *K. A. Smith*

10.311 *Continuum Mechanics*
Prereq.: 10.301
Year: U (2) 4–0–6
A sound foundation for extensive work. Kinematics of continua; forces and stresses in continua; fluid statics; flow of an ideal fluid; rheology of real fluids; simple laminar flows. *K. A. Smith*

10.312 *Transport Phenomena*
Prereq.: 10.311
Year: U (1) 4–0–6
Convective heat and mass transfer. Boundary layer flows, turbulence, the analogies, flow past bluff bodies, condensation, natural convection. *K. A. Smith*

10.33 *Analytical Treatment of Chemical Engineering Processes* (A)
Prereq.: 10.301, 18.03
Year: G (2) 3–0–6
Mathematical techniques for handling rate problems such as diffusion, heat transfer, and chemical reactions basic to most chemical engineering operations. Formulation of problems corresponding to specific physical situations in terms of ordinary differential, partial differential, and finite-difference equations. Solution of these equations by appropriate analytical and numerical methods. *L. B. Evans*

10.34 *Numerical Solution of Problems in Chemical Engineering* (A)
Prereq.: 10.33
Year: G (2) 2–2–4
Advanced seminar in the numerical analysis associated with the solution of ordinary and especially partial differential equations by numerical methods. Lectures and problem assignments on the analysis of the stability and convergence of finite-difference methods of solving differential equations. Lectures and student seminar reports to cover recent advances and new techniques in the field. Each student will program and solve on a digital computer at least one problem from such fields as chemical reactor simulation, heat transfer, diffusion, and fluid mechanics, with the focus upon the relative effectiveness of various finite-difference methods of solving a particular type of problem. Some training in FORTRAN coding. (*Limited to ten students. Permission of instructor required.*) *P. L. T. Brian*

10.35 *Dynamics and Control of Chemical Engineering Processes* (A)
Prereq.: 10.301, 18.03
Year: G (1) 3–0–6
Description of the dynamic behavior of processes and equipment by ordinary and partial differential equations. State-space representation of dynamic systems. Introduction to feedback control concepts. Stability analysis. Optimal control theory. Use of digital simulation techniques. Design and analysis of conventional and computer control systems. *L. B. Evans*

10.36 *Process Design*
(10.361) *Prereq.:* 10.301
Year: U (1, 2) 3–0–6
Presentation and discussion of real process design problems, with case studies in chemical processing and petrochemicals. Emphasis on conception and invention of processes, as well as analysis and economic balances, to specify optimum design and operating conditions. Discussion of a variety of cases throughout the term. *J. E. Vivian*

10.37 *Chemical Kinetics and Reactor Design*
Prereq.: 5.60, 10.301
Year: U (1) 3–0–6
Fundamentals of chemical kinetics. Analysis of batch, plug flow, and continuous stirred tank reactors for single, multiple and series-type reactions. Introduction to concepts of residence time distribution and chain reactions. Consideration of some real reactors and typical reactor design problems. *C. N. Satterfield*

10.38 *Analysis and Simulation of Chemical Processing Systems* (A)
Prereq.: 10.301; 18.03
Year: G (2) 2–2–4
Introduction to techniques for computer-aided analysis of chemical processing systems. Development of mathematical models to describe dynamic and steady-state process behavior. Representation of the structure of complex, interconnected chemical processes with arbitrary recycle stream. Numerical methods for solving resulting systems of non-linear differential and algebraic equations. Application of various mathematical optimization techniques. Survey of recent developments in comprehensive problem-oriented computing systems to assist in chemical process design. A knowledge of FORTRAN programming will be assumed. *L. B. Evans*

10.39 ***Principles of Combustion and Pollution Control***
Prereq.: 5.62, 10.301
Year: U (1) 3–0–6
Application of chemical kinetics, transport phenomena and thermodynamics to combustion and other basic processes frequently encountered in pollution control. Chemistry and physics of combustion. Laminar, turbulent, diffusion and premixed flames. Combustion control by the use of additives and electric fields. Pyrolysis and combustion of solids, and combustion of clouds of particles and drops. Combustion in stationary, moving and fluidized beds. Nucleation, growth and agglomeration of small particles, and chemical and physical behavior of aerosols. Generation and control of sulfur oxides, hydrocarbons, nitrogen oxides, carbon monoxide and particulates. *J. B. Howard*

ENGINEERING OPERATIONS

10.40 ***Chemical Engineering Thermodynamics*** **(A)**
Prereq.: 10.13
Year: G (1, 2) 3–0–9
Basic postulates of classical thermodynamics. Application to transient open and closed systems. Criteria of stability and equilibria in homogeneous and complex heterogeneous systems including the effect of external force fields and chemical reaction. Thermodynamic properties of pure materials and mixtures with some discussion of estimation and correlating techniques. Applications emphasized through extensive problem work relating to practical cases. *R. C. Reid*

10.41 ***Distillation*** **(A)**
Prereq.: 10.13
Year: G (1) 3–0–6
General principles of staged contacting with major emphasis on the distillation of binary and multicomponent mixtures. Vapor-liquid equilibria of high pressure and non-ideal multicomponent systems. Cascade configurations. Graphical, analytical and computer techniques for binary and multicomponents systems. Tridiagonal matrix solutions for complex columns. Vapor-liquid contacting theory from transport fundamentals.
P. S. Virk

10.47 ***Ion Exchange*** **(A)**
Prereq.: 5.60, 10.301
Year: G (2) 2–0–4
Preparation and properties of synthetic organic exchangers. Industrial applications of the general ion exchange process; equilibrium and rate studies for fixed and moving beds; ion exchange chromatography. *R. F. Baddour*

10.50 ***Heat and Mass Transfer*** **(A)**
Prereq.: 10.302
Year: G (1) 3–0–6
Fundamentals of diffusive and convective transport of heat and mass. Analytical and numerical solutions to steady-state and transient diffusion problems. Superposition techniques. Forced convection of heat and mass in laminar flow. Turbulent diffusion. Mass, heat, and momentum transfer from a phase boundary to a turbulent fluid. Simultaneous heat and mass transfer.
G. Margolis

10.52 ***Mechanics of Fluids*** **(A)**
Prereq.: 10.302
Year: G (1) 3–0–6
Content varying from year to year with subject material drawn from topics such as boundary layer theory, turbulence, rheology, hydrodynamic stability, compressible flow, and continuum mechanics. *K. A. Smith*

10.53 ***Chemical Engineering Design*** **(A)**
Prereq.: 10.302
Year: G (1, 2) 3–0–6
Design of a complete plant. Plant size, location and selected process based on market analysis and technical and economic evaluation of alternate processes and of sources of raw material. *J. E. Vivian*

10.54 ***Advanced Topics in Mass Transfer*** **(A)**
Prereq.: 10.50
Year: G (2) 3–0–6
Advanced treatment of molecular and eddy diffusion and mass transfer between phases. Theories of mass transfer with simultaneous chemical reactions. Process design cases involving gas absorption. *K. A. Smith*

10.55 ***Advanced Topics in Heat Transfer*** **(A)**
Prereq.: 10.50
Year: G (2) 3–0–6
Advanced treatment of selected problems in heat transfer of current concern to the chemical engineer. Choice of problems in conduction, simultaneous heat transfer and chemical reaction, condensation, natural convection, and radiation. Emphasis on analytical methods such as superposition, perturbation, asymptotic methods, and integral equations. *A. F. Sarofim*

10.56 ***Chemical Engineering in Medicine*** **(A)**
Prereq.: 5.62, 10.301
Year: G (2) 2–0–4
Seminar with oral presentations by members on topics of current interest involving broad applications of chemical engineering to medical problems. Visits to local hospitals and discussions with physicians, surgeons, and life scientists on problems of mutual interest. *E. W. Merrill*

10.59 ***Properties of Gases and Liquids*** **(A)**
Prereq.: 5.62, 5.63
Year: G (2) 3–0–6
Intermolecular forces including dipole, multipole, induced dipole, and London-type forces. Application of intermolecular force theories to the problems of predicting equilibrium and transport properties of gases and liquids. Modern theories of liquid structure are reviewed.
R. C. Reid

APPLIED CHEMISTRY

10.602 ***Catalysis*** **(A)**
Prereq.: 5.62 or 10.37
Year: G (1) 3–0–6
Relationships of activity and selectivity to physical and chemical properties of a solid catalyst. Components and preparation of catalysts. Physical adsorption, chemisorption. Physical characterization of catalysts; surface area, pore size distribution. Examination of catalyst structures and surfaces by modern instrumental methods. Kinetic models and correlation of rate data. Electronic factors in catalysis; geometrical factors; concept of the unstable intermediate. Acid catalysts and molecular sieve catalysts. Multifunctional catalysis. Homogeneous catalysis by organometallic compounds. Case studies of several industrial catalysts and associated catalytic processes. *C. N. Satterfield, M. Modell*

10.61 ***Physics and Chemistry of Surfaces*** **(A)**
Prereq.: 5.62
Year: G (1) 3–0–6
Thermodynamic, kinetic, and chemical factors underlying surface and interfacial phenomena. Intermolecular forces, orientation at interfaces and the origins of surface tension. Capillarity and the effects of surface curvature on bulk phase properties. Thermodynamics of adsorption at interfaces; the Gibbs adsorption isotherm. Electrical phenomena at interfaces: origins of surface poten-

tial, structure of the diffuse double layer, electrokinetic phenomena. Surface-active agents, contact angles, spreading, and wetting phenomena. Properties of colloidal electrolytes, micelles, solubilization phenomena, monolayers. Correlation of these fundamentals of surface and interfacial phenomena with important industrial applications as: emulsions, foams, flotation, detergency, adhesion, and lubrication. Survey of some important surface phenomena in biological systems. *E. R. Gilliland*

10.62 *Electrochemistry* (A)
Prereq.: 5.62
Year: G (2) 3–0–6
Application of principles of thermodynamics, surface chemistry, mass transport, catalysis, and reaction kinetics to the operational characteristics of electrochemical systems. Outline of methods of experimental electrochemical investigations. Discussions of current electrochemical practice including selected industrial electrolytic processes, primary and secondary batteries, and fuel cells. *H. P. Meissner*

10.631 *Surface and Colloid Chemistry*
Prereq.: 5.60
Year: U (2) 2–0–4
Consideration of selected phenomena and processes relevant to chemical engineering characterized by large interfacial area relative to phase volume. Surface chemistry and physics: interfacial tension and pressure, contact angle, capillarity, wetting, surface active agents and monolayers. Colloid particles: electrical double layer theory, preparative methods, flocculation, and sedimentation. Control of rate processes at a phase interface, including nucleation and crystallization. *E. R. Gilliland*

10.64 *Structure and Properties of Polymers* (A)
Prereq.: 5.42, 5.60
Year: G (2) 3–0–6
Relationship of molecular structure and composition of organic high polymers to their bulk physical properties. Kinetic theory of rubber elasticity, glass transition behavior, viscoelastic theory, melt rheology, crystallinity in polymers. Effects of orientation, crosslinking, plasticization, copolymerization and presence of fillers on the properties of plastics, elastomers, fibers, films, and foams. Physical properties including mechanical (dynamic and transient), electrical, optical, gas transport properties. *E. W. Merrill*

10.65 *Chemical Engineering Kinetics* (A)
Prereq.: 10.37
Year: G (2) 3–0–6
Application of chemical kinetics to development and improvement of industrial processes. Non-ideal reactor analysis, including residence time distributions, concepts of mixedness and segregation, dispersion and CSTR models. Mass and energy transfer limitations in heterogeneous reaction systems. Reactor stability and sensitivity to operating parameters. Choice and design of reactors for heterogeneous reactions including fluidized beds, slurry-type reactors and trickle beds. Emphasis on interpretation and correlation of experimental data and application to kinetic and reactor design problems. *C. N. Satterfield*

10.66 *Surface Science and Engineering* (A)
Prereq.: 5.62
Year: G (2) 3–0–6
Molecular constitution of interfaces, origin of surface tension; relation to intermolecular forces. Capillarity and surface thermodynamics; monolayer formation, properties, and degree of ordering. Description of supra-ordered microstructures and their formative processes: flocculation, nucleation and crystal growth, coacervation and gelation. Sorption in — and transport through — such structures: Langmuir, BET, Polanyi, Zimm-Lundberg treatments; elementary consideration of membrane transport phenomena and flow in microporous media. *E. R. Gilliland*

10.68 *Physical Chemistry of Polymers* (A)
Prereq.: 5.42, 5.62
Year: G (1) 3–0–6
Principal emphasis on linear, random-coiling, non-electrolytic polymers. Conformation properties of the isolated random-coiling macromolecule, including the radius of gyration, segment density distribution, effective diameter in the computation of excluded volume and entropy elasticity. The definition of the *dilute* polymer solution based on volume fraction of "free" solvent external to random coils. The statistical thermodynamics of polymer solutions, derived (following Flory) for the *dilute* and for the *concentrated* solution. Applications to osmotic phenomena and to phase equilibria including fractionation. Thermodynamic and conformational properties deduced from light scattering of polymer solutions. Extension of thermodynamic analysis to the theory of the intrinsic viscosity of polymer solutions. Special topics include: (a) non-Newtonian viscosity of polymer solutions (including gradient dependence of intrinsic viscosity); (b) response of dilute polymer solutions in turbulent flows (including the Tom's effect); (c) thermodynamic and hydrodynamic properties of certain biological polymers, including the hyaluronates. *E. W. Merrill*

10.69 *Polymerization Processes* (A)
Prereq.: 5.42, 5.62
Year: G (2) 3–0–6
Synthesis of polymers with emphasis on interrelationships of reaction kinetics, chemical equilibria, fluid mechanics, heat transfer, and mass transfer. Specific topics include condensation polymerization; classical free radical polymerization in solution and in bulk; high-pressure radical polymerization of ethylene; emulsion polymerization and bead polymerization; cationic polymerization of isobutylene; anionic polymerization; Ziegler-Natta and related heterogeneous, stereoregulating polymerizations, various processes for generating cross-linked polymers or elastomers ("vulcanization" of elastomers, epoxy resin reactions, isocyanate-urethane reactions, maleic polyester-styrene reactions), and processes for chemical conversion of side groups on previously synthesized polymers (acetylation of cellulose, deacetylation of polyvinyl acetate, sulfonation or quaternization of polystyrene). *E. W. Merrill*

10.70 *Principles of Combustion* (A)
Prereq.: ——
Year: G (1) 3–0–6
Application of the principles of chemical kinetics (including chain reactions) and of mixing and diffusion to combustion processes. Problems on rate processes in the combustion of gaseous, liquid, and solid fuels. Principles of model analysis. Thermodynamics of high-temperature processes, with applications to chemical processing and to high-output power plants such as turbines, rockets, ramjets. *H. C. Hottel*

10.72 *Seminar in Air Pollution Control* (A)
Prereq.: 10.302 or 10.312
Year: G (2) 2–0–4
Review of combustion sources of pollution and of criteria and legislation for maximum allowable emission rates. Methods for reduction of SO_2, particulate, and NO_x formation by modifications of the combustion process. Absorption systems for SO_2 and NO_x removal. Methods for reduction of particulate emission. Stack dispersion. Survey of above topics by faculty and guest lecturers. Term projects for detailed studies of promising new techniques of pollution control. *A. F. Sarofim, H. C. Hottel*

10.74 ***Radiative Transfer*** **(A)**
Prereq.: 10.301
Year: G (2) 3–0–6
Heat transmission in high-temperature operations and interaction of radiative and other transport mechanisms. Radiation geometry; matrix algebra in application to radiative transfer in enclosures; zoning method as alternative to integral equation; use of machine computation. Thermal radiating characteristics of surfaces, gases, and particle clouds. Radiation methods of temperature measurement. Synthesis of analytical and empirical approach to produce approximations of engineering utility. Quantitative design of several furnaces and high-temperature systems. *A. F. Sarofim*

10.76 ***Oral Technical Presentation***
Prereq.: ——
Year: G (1) 2–0–4
Workshop using audio and visual aids to develop abilities to deliver lucid, succinct oral talks in a variety of simulated situations. Registration limited to 10 students. *R. C. Reid*

SCHOOL OF CHEMICAL ENGINEERING PRACTICE

10.82 ***School of Chemical Engineering Practice — Bound Brook Station*** **(A)**
Prereq.: ——
Year: G (1 or 2) 0–12–0
Conducted in the main plant of the Organic Chemicals Division of American Cyanamid Company at Bound Brook, New Jersey. Highly diversified operations, including process development and production of dyes, synthetic pharmaceuticals, organic pigments, rubber chemicals, intermediates, textile chemicals, plastics, resins, and related products. ——

10.83 ***School of Chemical Engineering Practice — Bound Brook Station*** **(A)**
Prereq.: 10.82
Year: G (1 or 2) 0–12–0
Continuation of 10.82. ——

10.84 ***School of Chemical Engineering Practice — Bound Brook Station*** **(A)**
Prereq.: 10.83
Year: G (1 or 2) 0–12–0
Continuation of 10.83. ——

10.85 ***School of Chemical Engineering Practice — Bound Brook Station*** **(A)**
Prereq.: 10.84
Year: G (1 or 2) 0–12–0
Continuation of 10.84. ——

10.86 ***School of Chemical Engineering Practice — Oak Ridge Station*** **(A)**
Prereq.: ——
Year: G (1 or 2) 0–12–0
Conducted at the Oak Ridge, Tennessee, Station located at the Oak Ridge National Laboratory of the Atomic Energy Commission, operated by Union Carbide Company, Nuclear Division. Work under direction of Institute faculty residing at Oak Ridge with emphasis on the application of engineering principles to the solution of research and development problems arising from the programs of the Oak Ridge National Laboratory. (*Application should be made three to four months in advance to allow ample time for routine entry procedures.*) ——

10.87 ***School of Chemical Engineering Practice — Oak Ridge Station*** **(A)**
Prereq.: 10.86
Year: G (1 or 2) 0–12–0
Continuation of 10.86. ——

10.88 ***School of Chemical Engineering Practice — Oak Ridge Station*** **(A)**
Prereq: 10.87
Year: G (1 or 2) 0–12–0
Continuation of 10.87. ——

10.89 ***School of Chemical Engineering Practice — Oak Ridge Station*** **(A)**
Prereq: 10.88
Year: G (1 or 2) 0–12–0
Continuation of 10.88. ——

GENERAL

10.90 ***Experimental Research Problem*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
For special and graduate students who wish to carry out some minor investigation in a particular field. Subject and hours to fit individual requirements. *G. C. Williams*

10.91 ***Experimental Research Problem***
Prereq.: ——
Year: U (1, 2) *Arr.*
For undergraduate students who wish to carry out a special investigation in a particular field. Topic and hours to fit individual requirements. *H. P. Meissner*

10.92 ***Seminar on Technology Assessment***
Prereq.: ——
Year: G (1) 2–0–4
Examines methods for predicting the long-range impact of technological developments on society. Approaches will be explored whereby the broad social effects of exploiting or restricting a technological development can be considered and effectively expressed. Case studies in specific technological developments drawn from the field of chemical processing. Invited speakers from industry, government, and within M.I.T. will describe their experience in conducting and interpreting such studies. Emphasis on developing a methodology for technology assessment. Evaluation of techniques involving modeling, simulation, forecasting, morphological analysis, and modern decision theory, including use of the computer where appropriate. The role of the government in influencing technological change will be considered. (*Open to undergraduate students with permission of instructor.*) *L. B. Evans*

10.93 ***Teaching Experience in Chemical Engineering*** **(A)**
Prereq.: ——
Year: G (1, 2) 2–0–4
For qualified graduate students interested in teaching as a career. Tutorial or classroom teaching under the supervision of a faculty member. Students selected by interview. Total enrollment limited by availability of suitable teaching assignments. *G. C. Williams*

10.95 ***Special Problems in Chemical Engineering*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
Directed research and study of special chemical engineering problems. *G. C. Williams*

10.96 ***Selected Topics in Chemical Engineering*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
Topics of current interest, varying from year to year. *G. C. Williams*

10.991 ***Seminar in Chemical Engineering*** **(A)**
Prereq.: ——
Year: G (1) 2–0–4

10.992 ***Seminar in Chemical Engineering*** **(A)**
Prereq.: ——
Year: G (2) 2–0–4
For students working on doctoral theses. *E. R. Gilliland*

11.
Urban Studies and Planning

INTEGRATIVE CONCEPTS AND AREAS OF SPECIALIZATION

INTRODUCTORY INTEGRATIVE CONCEPTS

11.01 *The Planning Process*
(11.10) *(Revised: Unit change)*
Prereq.: ——
Year: G (1) 3–0–6
Evaluation of current developments in the field of urban studies and planning with special emphasis on housing, the planning process, and the uses of research. Areas of specialization in the Department and evolving views on the role of the planner are also examined. *L. Rodwin*

11.02 *Perspectives on Urban Issues*
(11.105) *Prereq.:* 11.05, 11.07
Year: U (1) 3–0–6
Examination of the ways in which "urban problems" are dealt with and the ways in which society sets priorities for dealing with these problems. Analysis of various formulations of urban policy in relation to the machinery for policy-making and with regard to the content of various academic disciplines. The intent of the colloquium is to examine different ways of thinking about urban issues rather than to present a comprehensive body of knowledge. *(Restricted to Course XI juniors.)* *Staff*

11.03 *Urban Problems in American Society: Responses and Strategies*
(11.585) *Prereq.:* 11.02
Year: U (2) 3–0–6
An examination of the implicit urban policy of the U. S. institutional structure — public and private, at the local, regional and national levels. Case studies focus on the evolution of federal urban programs dealing with some of the following areas: housing, urban renewal and development, poverty and community decay, crime, new communities and national urban growth, migration patterns, mass transportation and open space and recreational development. Discussions on topics such as the diffusion of particular perceptions of problems, decision-making in bureaucracies, evaluation and design of urban programs. *(Restricted to Course XI seniors.)* *Staff*

11.04 *Models and the Metropolis*
(11.19) *Prereq.:* 18.01, 18.02
Year: U (1) 4–0–8
Discussion of the principles and characteristics of modeling in the social sciences and examination, in detail, of current tries at reducing the metropolis to systematics.
A. Fleisher

11.05 *Urban Social Structure and Process*
(11.50) *(Revised: Unit change)*
Prereq.: —
Year: U (2) 3–0–6
Examination of the city as a social system, including an analysis of the sources and implications of social stratification. Study of the conflict relations among various segments of the urban population — race, religion, and so on — and their implications; examination of segregation and its effects. The physical and environmental characteristics of a city as outputs of social systems, as well as social constraints upon behavior are considered.
Staff

11.06J *Urban Problems and Policies* (A)
(11.580J) (Same subject as 17.982J)
Prereq.: 11.01; 11.05 or 11.501
Year: G (2) *Arr.*
Analysis of political roots and social consequences of selected urban policies, ranging from law enforcement, welfare, and education to transportation, urban renewal and model cities. Study of numerous proposals for change. *B. J. Frieden, A. A. Altshuler*

11.07 *Economic Issues in Urban Planning*
(11.60) *Prereq.:* 14.01, 14.02
Year: U (1) 3–0–6
Economic, social and technological factors which affect the functions and physical environment of the city. Analytical techniques for predicting the effect of alternative policies on the growth and structural change of metropolitan areas with respect to economic, spatial, and employment characteristics. Urban fiscal relationships. Economies of scale in providing urban services, demand for public services, sources of tax revenue, and distributional implications of alternative tax-expenditure policies. *J. R. Harris*

11.08 *The Urban Transportation Problem* (A)
(11.21) *(Revised: Unit change)*
Prereq.: 11.07, 11.11
Year: G (2) 2–0–7
Examination of transportation as a group of systems related to urban structure and particular urban and social problems. The planning of urban transportation as a professional activity characterized by several methodological approaches, and as a set of public issues.
R. Gakenheimer

11.09 *Technology and the City*
(New)
Prereq.: —
Year: U (2) 3–0–6
Seminar dealing with the impact of technology on the form and function of cities and urban regions. Focus on the "processes" of change especially institutional adaptation to technological innovation. Topics to be discussed include the design and implementation of new social institutions and service networks. *D. Schon*

11.11 *Components of the Urban Environment*
(Revised: Unit change)
Prereq.: —
Year: U (1) 4–0–8
Physical nature and characteristics of the urban environment and its component parts. Land uses for residences, commerce, industry, institutions, etc. Circulation elements; streets, expressways, transit, parking. Physical structure and relationship of parts of city and regional development. *(Enrollment restricted to juniors, seniors, and graduate students.)* *J. T. Howard*

HOUSING, COMMUNITY DEVELOPMENT AND URBAN ECONOMICS

11.20 *Introduction to Housing Problems*
(11.24) *(Revised: Unit change)*
Prereq.: 11.05; 11.11 or 14.01
Year: U (1) 3–0–6
The meaning and scope of housing problems. Focus on the interdisciplinary nature of housing problems — their sociological, political, economic, and architectural components — as well as on the emergence of public policy in the housing area and the social and political context from which the elements of that policy have emerged.
L. C. Keyes

11.21 ***Real Estate Economics: Issues in Development*** (11.65)
(Revised: Unit change)
Prereq.: 11.07 or 11.20 or 14.01
Year: G (2) 3–0–6
Discussion of the various factors affecting the location, construction, financing, and marketing of real estate and buildings. Special emphasis placed on the relationship of public policy to the activities of the private sector. Case studies and guest lecturers. *D. Weisberg*

11.22 ***The Construction of Housing*** **(A)**
(New)
Prereq.: 11.20, 11.21
Year: G (1) 2–0–7
Analysis of the structure and operation of the residential construction industry. Topics include the industrial organization of residential building, the structure of housing markets, the role of housing in aggregate economic policy, the labor market, construction site management, and other aspects of the production process. *Q. Mills*

11.23 ***Housing Analysis and Public Policy*** **(A)** (11.25)
Prereq.: 11.20, 11.21
Year: G (2) *Arr.*
Seminar focusing on housing market studies and how they can and should be used by public agencies. Emphasis on the application of economic and political analysis to housing policies such as rent control, urban renewal, and homeownership for the poor. Housing policy issues viewed in the context of formulating objective criteria for establishing priorities and evaluating alternative housing strategies, including rent supplements, housing allowances, public housing, etc. *A. Solomon*

11.24 ***Planning for Community Facilities***
(New)
Prereq.: 11.11
Year: U (2) 3–0–6
Seminar dealing with the politics and problems of planning for community facilities at the city-wide and neighborhood levels. Discussion of such issues as site selection, financing, and strategies for decentralization. Analysis of relevant federal, state, and local programs and legislation. Illustrative material deals with the problems of planning for various facilities including fire stations, libraries, health centers, service agencies, and multi-service centers. *R. Hollister*

11.251 ***Issues and Strategies in Community Development***
(New)
Prereq.: —
Year: G (1) *Arr.*
Current issues in community development: tactics, experiences and alternative strategies. *(Primarily for those enrolled in the Community Fellows Program; others admitted by permission of the instructor.)* *M. King, F. Jones*

11.252 ***Seminar in Community Development***
(New)
Prereq.: 11.251
Year: G (2) *Arr.*
Continuation of 11.251. Discussion and analysis of case studies presented by Community Fellows. Emphasis on the preparation of written reports. *(Permission of instructor required.)* *F. Jones, M. King*

11.261J ***Urban Economic Analysis I*** **(A)** (11.67J)
(Same subject as 14.573J)
Prereq.: 14.03, 14.05; or 14.04, 14.06
Year: G (2) 3–0–6
Patterns and processes of growth and structural change within metropolitan areas. The land use market and the spatial structure of the metropolitan community. The housing market; demand and supply, growth, aging, and renewal. The urban transportation system and its problems. Models of the metropolis. In each of these topics, emphasis on the resource allocation process, its efficiency and implications for income distribution. *(11.44 would be desirable but is not required as a prerequisite.)* *J. Rothenberg*

11.262J ***Urban Economic Analysis II*** **(A)** (11.68J)
(Same subject as 14.574J)
Prereq.: 11.261J
Year: G (2) 3–0–6
Continuation of 11.261J (14.573J). The nature and problems of government decision-making in metropolitan areas. The economies of segregation, congestion, and pollution in the metropolitan area. Urban-suburban relations: market and government. Welfare economics and the normative theory of local public policy. Applied normative analysis: criteria for public expenditures; cost-benefit analysis. Examination of public policy issues in current urban problems: poverty, race, the spatial form of the city, optimal land use patterns growth and renewal, development and new communities. *J. Rothenberg*

CITY DESIGN AND SPATIAL POLICY

11.30 ***Introduction to City Design and Spatial Policy***
(New)
Prereq.: ——
Year: U (2) 3–0–6
An introduction to the design of the urban spatial environment: techniques for analyzing qualities of the environment, roles of the designer in the processes of urban development and change; historical evolution of approaches to city design; roles and values in design; the effect of public policy on the form and character of the spatial environment. *G. Hack*

11.31 ***Urban Landscape***
(Revised: Unit change)
Prereq.: ——
Year: G (1) 2–0–7
The city and its components as direct, personal, sensuous experience; view, movement, light, sound, climate, space, visible activity; identity, spatial and temporal images, meaning and development. Field observation and seminar discussions. *K. A. Lynch*

11.32 ***City Design*** **(A)**
(Revised: Unit change)
Prereq.: 11.30
Year: G (2) 2–0–7
Seminar on the principles and techniques of design of the large scale spatial environment. The relation between city form and objectives, the processes of design and management, the relation to the socio-economic context. *(Limited enrollment, primarily for students in urban design or city planning whose principle interest is in this area and who have had some experience in large-scale design.)* *K. A. Lynch*

11.33 ***Environmental Programming*** **(A)**
(Revised: Unit change)
Prereq.: 11.11, 11.30 or 11.31
Year: G (1) 2–0–7
Seminar on ways in which human purposes can be translated into explicit and testable requirements for large scale environments. Conceptual, human, social, managerial, technological and design factors influencing the translation process. Special emphasis on the sensory, psychological and esthetic functions of environments. Aspects of environmental programming for public facilities, service systems, and residential environments in highly urbanized and developing areas. *W. L. Porter*

11.34J ***Analysis of Urban Design*** **(A)**
(11.38J) *(Revised: Unit change)*
(Same subject as 4.23J)
Prereq.: 4.20, 11.30 or 11.31
Year: G (2) 3–0–6
Analysis of the processes and the products of urban design. Discussion of descriptions of environments and of transformations and tests of the descriptions. Examination of techniques, especially computer-based, which can be used to aid the designer. Development of criteria by which to evaluate the adequacy of computer languages to represent design ideas, accommodate design processes, and to aid the designer. An independent project required. *W. L. Porter*

11.351 ***Psychology of the Environment***
(11.34) *(Revised: Unit change)*
Prereq.: 9.70
Year: G (1) 2–0–7
Applications to environmental planning and design of methods and findings in psychology. Discussion of perception, attention, memory, thinking, inter-personal attitudes and behavior, needs and values. Use of experimental, observational, and survey methods in a series of exercises in environmental assessment. *M. C. Potter*

11.352 ***Research Seminar in Environmental Psychology*** **(A)**
(11.35) *(Revised: Unit change)*
Prereq.: 11.351
Year: G (2) *Arr.*
Advanced analysis of special topics in environmental psychology, emphasizing research methods for determination of the effects of particular environmental designs on the primary user. Development and execution of individual or group research projects. *M. C. Potter*

11.36 ***Problems in Urban Design*** **(A)**
(11.06) *Prereq.:* 11.30, 11.31, 11.711
Year: G (2) *Arr.*
Advanced problems in planning for the form of the environment at the scale of cities or regions. *T. Lee*

11.37J ***Collaborative Design*** **(A)**
(11.05) (Same subject as 4.162J)
Prereq.: 11.711
Year: G (1) *Arr.*
Project work on design problems which will benefit from collaboration between architects and city planners or between these groups and other disciplines.
W. L. Porter, J. R. Meyer, J. Beinart

11.38 ***Theory of City Form*** **(A)**
(11.81) *(Revised: Unit change)*
Prereq.: 11.07, 11.11, 11.30
Year: G (2) 2–0–7
Analysis of the functioning, effects, and implications of the general form of the urban physical environment. Effect of this form on basic human objectives. *(Limited enrollment. Not offered 1971–72.)* ——

11.391 ***Emerging Life-Styles and Their Habitats***
(11.371) *Prereq.:* ——
Year: G (1) *Arr.*
Sharing of first hand experiences in disarming character structures, free school education, communal living, cooperative enterprise, liberation of physical environments, and survival skills. *K. Linn*

11.392 ***Neighborhood Commons: Landscape***
(11.361) ***Architecture in the Service of Community***
Prereq.: ——
Year: G (2) *Arr.*
Field work in socially relevant common and open space development. Citizen participation in the planning and building of neighborhood meeting places, people's parks and playgrounds especially in the context of emerging life-styles. The class will also deal with the development of green spaces indoors, work in greenhouses and visits to the residential environments of the "green-thumbed" participants. *K. Linn*

DEVELOPING AREAS

11.40 ***Urban and Regional Growth Issues in***
(11.45) ***Developing Countries*** **(A)**
Prereq.: 11.07
Year: G (2) *Arr.*
Problems of cities and regions in developing countries in relation to national economic and social development policies. Extended readings and paper required.
L. Rodwin

11.41 ***Metropolitan Planning in Developing Countries***
(New)
Prereq.: ——
Year: G (1) 3–0–6
The nature of metropolitan urban structures in developing countries. Discussion of urban problems with an emphasis on analytical strategies, the development of planning methods, and the evaluation of programs.
R. Gakenheimer

11.421 ***Urban Settlements, Squatters, and***
(11.461) ***Social Change*** **(A)**
Prereq.: 11.05 or 11.07; 11.11 or 11.20
Year: G (1) *Arr.*
Lectures and seminars on the urban accommodations of the low-income sectors in urbanizing countries and the formation of squatter settlements. Examination of the principal social, economic, and physical determinants of housing and settlement forms and development procedures in the context of a transitional economy. *J. Turner*

11.422 ***Seminar in Urban Settlements,***
(11.462) ***Squatters, and Social Change*** **(A)**
Prereq.: 11.421
Year: G (2) *Arr.*
Seminar continuation of 11.421 for deeper examination of case studies. *(Permission of instructor required.)*
J. Turner

11.43 ***Social Aspects of Development*** **(A)**
(11.575) *(Revised: Unit change)*
Prereq.: 11.05 or 11.55; 11.21
Year: G (1) 2–0–7
Seminar discussion of the social and cultural aspects of economic development: urbanization, changing systems of social stratification, urban family structure, and the concept of a "culture of poverty." Treatment of the themes so as to show a sense of the social cultural transformations implied by economic development and how "social problems" may be thought about in terms of their technical, economic, and institutional parameters.
L. R. Peattie

11.44J ***Regional Economic Analysis*** **(A)**
(11.66J) (Same subject as 14.572J)
Prereq.: 14.03, 14.05; or 14.04, 14.06
Year: G (2) 3–0–6
Analysis of regional economies with emphasis on the sources, characteristics, and implications of spatial concentrations of economic activities. Urban development in its regional setting is examined and the special problems of lagging areas in both developing and developed countries explored in some detail. Methods of integrating national and regional planning investigated. The following analytical tools developed and applied: location theory, spatial competition, general equilibrium models of interregional activity with emphasis on input-output and linear programming models; models of regional income determination. Special attention paid to spatial factors affecting the demand for transportation services. *J. R. Harris*

11.451 ***Case Studies in National and Regional Planning***
(New)
Prereq.: ——
Year: G (1) 3–0–6
Discussion of current approaches and problems dealing with national and regional planning in developing countries. Weekly seminars led by Fellows in the Special Program in Urban and Regional Studies ((SPURS) and invited speakers. Independent study and preparation of presentations by individual students or teams of students. (*Permission of instructor required.*) *J. R. Harris*

11.452 ***Seminar in National and Regional Planning***
(New)
Prereq.: 11.451
Year: G (2) *Arr.*
Continuation of 11.451, but with greater emphasis on the preparation and critique of written reports. (*Permission of instructor required.*) *J. R. Harris*

SOCIAL POLICY AND GOVERNMENTAL INSTITUTIONS

11.501 ***Social Policy***
(11.51) *(Revised: Unit change)*
Prereq.: ——
Year: G (1) 3–0–6
Examination of different conceptions of social policy with special attention to issues of distribution and redistribution. These issues examined in a number of different fields, such as: income transfers, medical care, social services, manpower training, education and housing. After reviewing each of these sectors, an attempt at an overall assessment of the relationship between social policy and income distribution based on empirical studies in the United States and selected advanced industrial societies in Western Europe. In addition to a review of issues of distribution, attention given to problems of citizen participation, coordination, evaluation and social change. The seminar concludes with an interpretation of the limits and the future of social policy. *M. Rein*

11.502 ***Social Service Systems*** **(A)**
(New)
Prereq.: 11.05, 11.501
Year: G (2) 2–0–7
Examination of the fragmented pattern of urban social services and the strategies to coordinate them. Traditionally, welfare, manpower training, education, medical care and housing all initiated service strategies in an effort to be more responsive to these problems. In addition, new forms of information, referral and advocacy emerged under the auspices of Community Action, Model Cities and other federal programs. These strategies critically examined. Examination of parallels with current European reforms and exploration of their implications for the development of policy in the United States. *M. Rein*

11.511 ***Urban Planning and Social Policy*** **(A)**
(11.55) *(Revised: Unit change)*
Prereq.: 11.01, 11.05 or 11.501
Year: G (1) 2–0–7
Approaches to complex urban problems involving both social institutions and the physical environment, drawing on methods of urban planning and social welfare planning. Evaluation of strategies for dealing with problems of poverty, housing, social service delivery, health care, income maintenance. Review of recent experiences and consideration of alternative policies. (*Offered jointly with the Florence Heller Graduate School for Advanced Studies in Social Welfare, Brandeis University.*) *B. J. Frieden*

11.512 ***Seminar in Urban Social Policy*** **(A)**
(11.56) *Prereq.:* 11.01, 11.05 or 11.501
Year: G (2) 2–0–7
Advanced seminar in planning methods for elected areas of urban social policy; emphasis on program and policy design. Focus, varying from year to year, on current issues in such fields as health services, low income housing, and manpower training. (*Offered jointly with the Florence Heller Graduate School for Advanced Studies in Social Welfare, Brandeis University.*) *B. J. Frieden*

11.52 ***Deliberate Social Change in the Cities*** **(A)**
(11.591) *Prereq.:* 11.09 or 11.501
Year: G (1) *Arr.*
Studies of theories and strategies of social and institutional change in urban settings, case studies in the formation of community corporations, urban development corporations, the advocate planning role, the neighborhood health center as a means to social change, low-income housing. Examination of relationships between social and technological change. Work toward a theory of social change, taking account of the stance and role of the change-agent, the institutional forms involved, and the special areas of concern. *D. A. Schon*

11.53 ***Educational Policy and the Community*** **(A)**
(New)
Prereq.: 11.05, 11.501
Year: G (1) *Arr.*
The seminar examines some basic issues in educational policy and planning, especially as they have emerged in various national educational strategies, and analyzes a number of attempted or proposed strategies for altering the American educational system. (*Enrollment limited.*) *L. R. Peattie*

11.54 ***Health Planning*** **(A)**
(New)
Prereq.: 11.05, 11.501
Year: G (1) 3–0–6
Seminar dealing with problems of planning for the delivery of community, regional and national health services. Analysis of current programs and policies along with various political and economic strategies for enhancing the accessibility and efficiency of medical services and health care programs. *R. Hollister*

11.55 ***Planning and Poverty***
(11.57) *(Revised: Unit change)*
Prereq.: 11.05
Year: U (2) 2–0–7
Varying approaches in theory and in action to the problem of "the slums." Readings on the nature of slums and of descriptions of slum life; guest lectures by people dealing with slum problems in the world of action. A paper required based on some first-hand experience with a social program. *L. R. Peattie*

11.561J ***Urban American History***
(11.485J) (Same subject as 21.484J)
Prereq.: One first year Humanities sequence
Year: U (1) 3–0–6

11.562J ***Urban American History***
(11.484J) (Same subject as 21.485J)
Prereq.: 11.561J
Year: U (2) 3–0–6
A seminar on American urban history from roughly 1890 to present. Among the subjects to be considered the concept of the "good" community, the nature of the ethnic ghetto, the decentralization of the American metropolis, the disintegration of the political machine, the professionalization of the police, the bureaucratization of the school, the character of the black ghetto, and the demand for community control. The first term devoted to reading and discussion, research and writing. (*11.562J not offered 1971–72.*) *R. M. Fogelson*

11.571 *Urban Legal Issues*
(11.701) *(Revised: Unit change)*
Prereq.: 11.05, 11.07 or 11.11
Year: U (1) 2–0–7

11.572 *Urban Legal Issues* (A)
(11.702) *(Revised: Unit change)*
Prereq.: 11.501, 11.571
Year: G (2) 2–0–7

Seminars on the legal process and the application of legal solutions to the problems of urban society. Focus varies from term to term, ranging from legal assistance in the "war" against poverty to zoning, and the law of land use, urban renewal, and housing code enforcement. *Staff*

11.581 *Institutional Change in Urban America* (A)
(11.851)
Prereq.: 11.05, 11.501; or 11.522
Year: G (1) *Arr.*

11.582 *Seminar in Institutional Change in Urban America* (A)
(11.852)
Prereq.: 11.581
Year: G (2) *Arr.*

A seminar on institutional change in urban America from roughly 1890 to the present. Topics: centralization, professionalization, and bureaucratization of the police, schools, welfare, and other urban institutions. First term: readings and discussions. Second term: research seminar and preparation of papers. *(Limited enrollment. Permission of instructor required.)* *R. M. Fogelson, M. Rein*

11.59 *Seminar in Planning Theory* (A)
(11.80) *Prereq.:* 11.01, 11.501
Year: G (2) *Arr.*

Current theories and research in planning, planning organization and action, and the relationship of physical planning to social planning and the general theory and process of planning. Required papers and extensive readings. *(Limited enrollment.)* *Staff*

PLANNING, ANALYTICAL AND RESEARCH METHODS

PLANNING METHODS

11.70 *Representation*
(11.001) *(Revised: Unit change)*
Prereq.: ——
Year: U (1) 1–3–5

Use of graphic techniques to record or control the environment and to express ideas: freehand drawing, elementary drafting, three-dimensional models, surveying and mapping, diagrams, graphic presentation. The common principles underlying these techniques and their use as tools in analysis. For entering planning students without background in design fields. *Staff*

11.711 *Community and Regional Planning Methods*
(11.01)
Prereq.: ——
Year: U (1, 2) *Arr.*

11.712 *Community and Regional Planning Methods* (A)
(11.03)
Prereq.: 11.711
Year: G (1, 2) *Arr.*

Studies and practice in the methods and processes of community and regional planning. Examination of current methods of planning and decision making, development of new ones, and their practical field application. Course combines seminar and field-work formats, with readings and discussion keyed to ongoing involvement of the class in a real community planning program. *P. Herr*

11.72 *City Planning Techniques*
(11.12) *Prereq.:* 11.11
Year: G (2) 3–0–6

Survey, analysis, and design methods and practices in comprehensive planning: population and economic development, land use circulation, other components of the city or metropolitan general plan; relationship of planning to implementation techniques, zoning, urban renewal, etc. *J. T. Howard*

11.73 *Site Planning*
(11.15) *(Revised: Unit change)*
Prereq.: ——
Year: U (1) 1–8–3

Arrangement of structures on the land: building grouping, land use and circulation planning, site engineering, landscaping. Lectures and brief exercises in design and field analysis. *(Limited enrollment.)* *T. Lee*

11.74 *PPBS and Approaches to Data Management*
(New)
Prereq.: ——
Year: G (2) 3–0–6

Examination of Planning, Programming, Budgeting Systems (PPBS) as a strategy for the management and control of resource allocation. Approaches to data management and data management systems viewed with a particular emphasis on the importance of information in the goal setting and evaluation aspects of the planning process. The seminar includes lectures along with a review of various case studies illustrating the technical and institutional problems of implementing such systems at the federal, state, and local levels. Opportunities also provided for field work in the Boston metropolitan area for those students interested in gaining practical experience with the problems of implementing data management systems. *K. Colton*

ANALYTICAL AND RESEARCH METHODS

11.801 *Urban Studies Laboratory I*
(11.505) *Prereq.:* ——
Year: U (2) 2–5–5

Program introducing undergraduates to the types of data and the methods of collecting and analyzing these data appropriate to the field of urban studies and planning. Students have access to computer systems which contain the results of a variety of data gathering activities and to facilities for statistical analysis and display. *(Primarily for second and third year students in Course* XI*; others by the permission of instructor.)* *R. A. Walter*

11.802 *Urban Studies Laboratory II*
(New)
Prereq.: ——
Year: G (1) 2–2–5

Seminars and exercises introducing graduate students to the types of data and the methods of collecting and analyzing these data relevant to Urban Studies and Planning. No previous computer experience necessary. Original group research projects required. *(Primarily for entering graduate students in Course* XI*; others by permission of instructor.)* *R. A. Walter*

11.81 *Information and Social Research Methods* (A)
(11.90) *(Revised: Unit change)*
Prereq.: 11.801 or 11.802
Year: G (1) 3–0–6

Lectures and seminars dealing with various approaches to social research and the ways in which research may contribute to the formulation and evaluation of policy. Discussion of methodological issues pertaining to the use

of case studies, comparative research, and experiments. Problems connected with the introduction of research findings into the planning process also examined.
R. Weiss

11.82 *Survey Research Methods*
(11.905) *Prereq.:* 11.801 or 11.802
Year: U (2) *Arr.*
Interdisciplinary seminar with practical work and field experience, in conjunction with the Boston Survey Research Program of the M.I.T.-Harvard Joint Center for Urban Studies. Survey theory, methodology, and measurement and practice, for students seeking a thorough understanding of social survey research processes through intensive involvement in a major field undertaking. *M. Axelrod*

11.83 *Laboratory in Models of Urban Growth* (A)
(11.20) *(Revised: Unit change)*
Prereq.: 11.04
Year: G (2) 2–5–5
Deals with detailed studies of the design, workings, and results of selected simulation models of metropolitan change and their use in the evaluation of public policy. Term projects consist of investigations into some aspects of a model's design and/or behavior. *(Enrollment limited. Permission of instructor required.)* *A. Fleisher*

11.84 *Computer Systems Seminar* (A)
(11.912) *Prereq.:* 11.04, 11.83
Year: G (2) *Arr.*
Advanced discussion of existing computer systems and current research on new systems that help the planner to communicate with the machine. Discussion of the computer realization of mathematical models. Opportunity for the student to do individual research in the area of planner-machine communications.
W. M. McMains

11.851 *Computer Services*
(11.910) *(Revised: Unit change)*
Prereq.: ——
Year: U (1) *Arr.*

11.852 *Computer Services*
(11.911) *(Revised: Unit change)*
Prereq.: ——
Year: U (2) *Arr.*
Small group instruction in the basic principles of digital computers and programming languages. Practice in writing programs in algebraic and problem-oriented languages. Special tutorials arranged for students with no previous contact with computers. Seminars vary in length and suited to students' needs. *C. Libby*

11.86J *Analysis of Urban Service Systems* (A)
(11.915J) (Same subject as 6.515J, 16.76J)
Prereq.: 1.07 or 6.28 or 6.579 or 18.303; 11.802 or 15.062 or 18.075
Year: G (2) *Arr.*
Lectures describe quantitative techniques useful in the analysis of large scale, urban service systems (e.g., fire and police departments, emergency ambulance services, airports, mass transit systems) such as geometrical probability, multi-server queueing theory, spatial location, scheduling and sequencing techniques cost. Cost structures and utility theory and relevant methods of simulation. Discussion of problems with validation of models, and the estimation of parameters while emphasizing the development of models of system operations approaches to the evaluation of policy.
A. Fleisher, R. C. Larson, A. R. Odoni

SPECIAL SEMINARS AND PROGRAM OPTIONS

11.901 *Research Seminar: Topics in Urban Studies and Planning* (A)
(New)
Prereq.: 11.01
Year: G (1) 3–0–6

11.902 *Research Seminar: Topics in Urban Studies and Planning* (A)
(New)
Prereq.: 11.01
Year: G (2) 3–0–6
Topics for 1971–1972 include: urban growth strategies, the educative city, computer systems and computer-aided evaluation. *(Open to students by arrangement with staff members in charge of individual research projects.)* *Staff*

11.911 *Reading Seminar in Urban Studies and Planning* (A)
(11.92) *Prereq.:* 11.01
Year: G (1) *Arr.*

11.912 *Reading Seminar in Urban Studies and Planning* (A)
(11.92) *Prereq.:* 11.01
Year: G (2) *Arr.*
Reading and discussion of special topics in urban studies and planning. *(Open to graduate students by arrangement with individual members of the staff.)* *Staff*

11.915J *Analysis of Urban Service Systems* (A)
(Same subject as 6.515J and 16.76J)
Prereq.: 1.07 or 6.28 or 18.303
Year: G (2) *Arr.*
Quantitative techniques useful in the analysis of large scale, urban service systems (e.g., fire and police departments, emergency ambulance services, airports, mass transit systems). Unified study of geometrical probability, multi-server queueing theory, spatial location theory, scheduling and sequencing techniques and relevant methods of simulation. Validation of models and parameter estimation. Cost structures and utility theory. Applications: geometrical configuration of service areas; response time to high priority situations; stacking and delays at airports. Emphasis on development of policy-relevant models of system operation. Promising areas for future research are outlined.
R. C. Larson, A. Fleisher, A. R. Odoni

11.921 *Undergraduate Tutorial in Urban Studies*
(New)
Prereq.: ——
Year: U (1) 3–0–6

11.922 *Undergraduate Tutorial in Urban Studies*
(New)
Prereq.: ——
Year: U (2) 3–0–6
Reading and discussion of special topics in urban studies. *(Open to undergraduates by arrangement with individual members of the staff.)* *Staff*

11.93 *Preparation for Thesis* (A)
(11.95) *Prereq.:* ——
Year: G (1, 2) *Arr.*
Selection of thesis subject, definition of method of approach, and preparation of preliminary thesis outline. Independent study, supplemented by frequent individual conference with staff members. *(Restricted to doctoral candidates.)* *Staff*

11.941 ***Special Studies in Urban Studies and*** (11.961) ***Planning*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*

11.942 ***Special Studies in Urban Studies and*** (11.962) ***Planning*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*

Small group study of advanced subjects under staff supervision. For graduate students wishing to pursue further study in advanced areas of urban studies and city and regional planning not covered in regular subjects of instruction. *Staff*

11.951 ***Special Topics in Urban Studies and*** (11.971) ***Planning***
Prereq.: ——
Year: U (1, 2) *Arr.*

11.952 ***Special Topics in Urban Studies and*** (11.972) ***Planning***
Prereq.: ——
Year: U (1, 2) *Arr.*

Small group study of special topics under staff supervision. For undergraduates wishing to pursue further study or field work in specialized areas of urban studies or city and regional planning not covered in regular subjects of instruction. *Staff*

11.961 ***Urban Field Work and Internships***
(New)
Prereq.: 11.711
Year: U (1, 2) *Arr.*

11.962 ***Urban Field Work and Internships*** **(A)**
(New)
Prereq.: 11.01, 11.711
Year: G (1, 2) *Arr.*

Practical application of city and regional planning techniques to towns, cities, and regions, including problems of replanning, redevelopment, and renewal of existing communities. Includes internships in municipal and state agencies and departments under staff supervision. *J. Gray*

12.

Earth and Planetary Sciences

UNDERGRADUATE SUBJECTS

12.00 ***Evolution of the Earth***
(New)
Prereq.: ——
Year: U (1) 2–0–4

Introduction to the concept and measurement of geologic time; evolution of the major features of the earth. Rock- and time-stratigraphy; biologic and radiometric chronometry; origin of the earth, oceans, and atmosphere; structure and evolution of continents and ocean basins; continental drift and lithosphere-plate motions; mountain-making. Closing discussion of the scale of perturbations generated by human activities. *R. S. Naylor*

12.001 ***Introductory Oceanography — The Sea Floor***
(New)
Prereq.: ——
Year: U (1) 2–0–4

An introductory course in sea floor oceanography reviewing the major features of the ocean bottom and how they are revealed by geophysical methods and deep drilling. *F. Press*

12.002 ***The Earth and the Planets***
Prereq.: ——
Year: U (2) 2–0–4

Selected topics in the physics and chemistry of the earth and solar system. Dynamics of orbits, properties of the atmosphere surface, and interior of the planets including the earth. Interplanetary medium, planetary magnetic fields, solar wind, and interactions. General lecture and a specialized recitation meeting each week. Recitation as workshop for in-depth study in one of these areas: orbits, interiors, surfaces and atmospheres.
M. N. Toksöz, G. Simmons

12.01 ***Earth Surface Processes***
(New)
Prereq.: 8.01
Year: U (1) 2–2–2

Introduction to the geology of the near-surface parts of the earth. Development of landforms by moving water, wind, and ice; production, transportation, and deposition of sedimentary materials; sedimentary rocks; marine topography and sediments; description of folds and faults. Laboratory study of sedimentary processes and sedimentary rocks; basic geologic mapping techniques. Three weekend days of field work. *J. B. Southard*

12.02 ***Physics and Chemistry of Geological Materials***
(New)
Prereq.: 3.091, 8.02
Year: U (2) 3–4–5

Introduction to rock-forming minerals and their occurrence in the earth and other terrestrial planets. Distribution of major elements; application of phase diagrams to simple rock systems; Clapeyron's equation effects of fluid pressure; chemical differentiation in igneous, sedimentary, and metamorphic processes; applications of mineralogy to studies of Mars, the moon, and the interior of the earth. Laboratory emphasis on crystal structure related to the physical and chemical properties of minerals and identification of minerals which occur in common rocks. Two weekend days of field work. *R. G. Burns, T. R. McGetchin*

12.03 ***Structural Geology***
Prereq.: 12.02
Year: U (1) 3–4–5

Survey of rock structures and mechanics of rock deformation. Elementary concepts of plastic flow and fracture of materials with discussion of observed strains in all types of rocks in relation to mineral deposits, intrusion and metamorphism. Introduction to the geology of North America and survey of the important tectonic elements in other continental and oceanic areas. Laboratory work in map interpretation; five Saturdays of field work on mapping local structures. *W. F. Brace*

12.051 ***Crystallography***
Prereq.: ——
Year: U (1) 2–2–4

Introduction to the nature of crystalline matter. Patterns of atoms in crystals and how they are investigated. Crystal symmetry; point groups, crystal forms, space groups. Use of X-ray diffraction in the study of crystals. The rotating-crystal, Weissenberg, and precession methods. Modern methods of determining the arrangements of atoms in the cell, Fourier synthesis, the Patterson function, and refinement. Buerger, *Introduction to Crystal Geometry;* Buerger, *Contemporary Crystallography.*
M. J. Buerger

12.052 ***Theoretical Crystallography***
Prereq.: 12.051
Year: U (2) 2–0–4

Introduction to the theory of the structure of crystals, and application of crystal structure concepts to crystallog-

raphy and mineralogy, including elementary crystal chemistry, structures of the silicates, polymorphism and transformations, disordered structures, solid solution and segregate phase formation, crystal growth and habit, crystal imperfection and lineage structure, and plastic deformation of crystals. (*Manuscript book chapters.*)
M. J. Buerger

12.061 *Petrology I*
Prereq.: 12.02
Year: U (1) 3-6-3
Principles and practice of optical crystallography by means of the immersion method of mineral identification. Application of X-ray powder diffraction to the rock-forming minerals. Introduction to the phase equilibria of silicate melts. Heinrich, *Microscopic Identification of Minerals;* Bloss, *Introduction to Optical Crystallography;* Turner and Verhoogen, *Igneous and Metamorphic Petrology.*
H. W. Fairbairn

12.062 *Petrology II*
Prereq.: 12.061
Year: U (2) 2-6-4
Distribution, association, and origin of igneous and metamorphic rocks. Laboratory study of igneous and metamorphic rock-forming minerals with petrographic microscope. Turner and Verhoogen, *Igneous and Metamorphic Petrology;* Williams, Turner and Gilbert, *Petrography;* Heinrich, *Microscopic Identification of Minerals.*
H. W. Fairbairn

12.064 *Sedimentary Petrology*
(*New*)
Prereq.: 12.02
Year: U (2) 2-2-2
Physical and chemical sedimentary processes. Survey of modern depositional environments and the composition and distribution of modern sediments. Petrology of major sedimentary rock types: classification, composition, primary textures and structures. Lithification and diagenesis. One weekend field trip. *J. B. Southard*

12.066 *Analysis of Geological Materials*
Prereq.: 12.02
Year: U (2) 2-2-2
Introduction to instrumental techniques for the analysis of geologic materials. Topics on applications of X-ray spectrometry, X-ray diffraction, neutron activation analysis, atomic absorption spectrophotometry, mass spectrometry, optical emission spectrometry, electron-probe microanalysis, and chromatography. One of these techniques in detail and the others in outline form. (*Enrollment limited to 12 students; admission only by permission of the instructor.*) *F. A. Frey*

12.091-12.094 *Special Problems*
Prereq.: ——
Year: U (1, 2) *Arr.*
For students desiring reading or special laboratory or field work on geological or geophysical problems in sedimentology, petroleum geology, economic geology, paleontology, exploration geophysics, space physics, and other fields. *Staff*

12.111 *Astronomy I*
Prereq.: ——
Year: U (1) 2-0-4
Introduction to the methods and principles of modern astronomy. Topics: astronomical coordinate systems, time, and theoretical principles of celestial navigation; solar system astronomy, including the earth as a planet, its motions; the moon, planets and satellites; meteors and comets, meteoritics; time scale of the solar system, and a review of theories of its origin. At least one trip to an observatory for students. *W. H. Pinson*

12.112 *Astronomy II*
Prereq.: ——
Year: U (2) 2-0-4
Topics: atmospheres of the sun and stars; stellar radii and masses; stellar interiors; binary systems; intrinsic variable stars; peculiar stars; stellar motions; nebulae and stellar clusters; the interstellar medium; stellar evolution; galaxies and models of the universe and the cosmic time scale; radio sources; review of theories of origin of the universe. Some attention to instrumentation used in modern astrophysics. Trips to an astronomical observatory. *W. H. Pinson*

12.114 *Workshop in Astronomy*
(12.113) *Prereq.:* 12.111, 12.112
Year: U (2) 0-8-0
Workshop in observational astronomy, conducted every Friday night at Whitin Observatory, Wellesley College. Instructions in operating telescopes, celestial photography, and in making various measurements of magnitudes, positions, spectral lineshifts, etc. Laboratory exercises and student projects. 12.112 may be taken concurrently with 12.114, and either or both prerequisites may be waived with permission of the instructor.
W. H. Pinson

12.115J *Dynamical Astronomy*
(12.613J) (Same subject as 8.293J, 16.441J)
Prereq.: 8.03, 18.075
Year: U (1) 3-0-9
Kepler's laws and the law of gravitation; one- and two-body motion: orbits in space and time; disturbed motion of two bodies as a special case of the general problem of n bodies: variation of orbital elements, planetary theory, expansion of the disturbing function, periodic and secular effects; resonance and stability; linear stability theory, periodic orbits and resonance in the three-body problem, examples involving planets, satellites, and asteroids; techniques of observation and computation: astronomical coordinate systems and time, optical, radio, and radar observations, numerical integration of orbits, orbit determination, maximum-likelihood estimation of orbit initial conditions and astronomical constants.
C. C. Counselman, I. I. Shapiro, W. Wrigley

12.121 *Exploration of the Solar System I*
(*New*)
Prereq.: 8.02, 18.02
Year: U (1) 3-2-7

12.122 *Exploration of the Solar System II*
(*New*)
Prereq.: 8.02, 18.02
Year: U (2) 3-0-9
A survey of the instrumental techniques and strategy underlying measurements of the solar system. A description of optical, ultraviolet, infrared, radio, radar and particle detectors as applied to remote observations made either from the ground or from space probes. The role of occultation techniques and two-frequency propagation paths as a means of studying the solar corona, interplanetary plasma and planetary atmospheres. The use of planetary atmospheric entry and landing probes to make direct *in situ* measurements of planetary characteristics. First term: emphasis on remote-sensing observations, primarily ground-based. Second term: occultation, two frequency, bistatic, and *in situ* observations, primarily using space probes.
G. H. Pettengill, T. B. McCord, J. S. Lewis

12.131J ***Planetary Physics and Chemistry I***
(Same subject as 5.121J and 8.291J)
Prereq.: 8.02, 18.02
Year: U (1) 3–0–9

12.132J ***Planetary Physics and Chemistry II***
(Same subject as 5.122J and 8.292J)
Prereq.: 8.02, 18.02
Year: U (2) 3–0–9

Study of the planetary system: evolution, composition, present configuration, dynamics, interiors, surfaces, atmospheres, and magnetospheres of the planets and, where appropriate, similar aspects of the satellites, asteroids, and comets. Theoretical interpretations of the existing data will be stressed. First term: a general description of the solar system and its origin and a comprehensive discussion of the outer planets. Second term: solar system dynamics, the interplanetary medium, and the interiors, surfaces, and atmospheres of the inner planets. *J. S. Lewis, I. I. Shapiro*

12.141 ***Remote Sensing of the Earth***
(New)
Prereq.: ——
Year: U (1) 3–0–6

A review and discussion of methods and motives for studying the earth's surface from airplanes, balloons and spacecraft. The application of remote sensing techniques to problems of geology, geophysics, resources, ecology and environment preservations. The course will be taught as a seminar with one two-hour session per week. Students will be expected to prepare one discussion session and one term paper on a topic of interest. Graduate credit can be arranged. *(Approval of instructor required.)*
T. B. McCord, T. R. McGetchin

12.143 ***Experimental Optical Astronomy***
(New)
Prereq.: 8.02
Year: U (1) 3–3–6

An introductory course in optical astronomy using the new M.I.T. Astrophysical Observatory. Motives and methods for observing astronomical objects at near-ultraviolet, visible, near and mid-infrared wavelengths (0.3 – 30 μ). Discussion of the descriptive parameters which are measured and the observational hazards, such as atmospheric absorption, which complicate measurements. Elements of telescope use, discussion of modern auxiliary equipment such as photometers and spectrometers and data systems. Lectures and laboratory using the M.I.T. Astrophysical Observatory. A research paper, hopefully discussing a simple observational project carried out by the student using a telescope, will be required. *T. B. McCord*

12.21 ***Physical Oceanography***
Prereq.: 8.02
Year: U (1) 3–0–9

Introductory survey of oceanic circulation and dynamics. Descriptive aspects of water mass movement, currents, and physical properties of the ocean. Dynamic models of currents and waves using equations of fluid dynamics. *(Similar to 19.83. Not offered 1971–72.)*
C. I. Wunsch

12.221-12.229 ***Project Studies in Oceanography***
(12.852–12.858) *Prereq.:* ——
Year: U (1, 2) 0–12–0

Extended participation in the work of a research group, including independent study of the literature, direct involvement in the group's research (commensurate with the student's skills and preparation), or project work under an individual faculty member extending over more than one term. Admission by arrangement with individual M.I.T. and Woods Hole faculty members. *Staff*

12.30 ***Survey of the Earth and Planetary Sciences***
Prereq.: ——
Year: U (1) 3–3–6

Introduction to current problems in geology, geophysics, geochemistry, planetary science, oceanography and meteorology. Topics include: structure and dynamics of the earth's crust and interior, rocks and minerals of the crust, interior of the earth and terrestrial planets, major geomorphic processes responsible for alteration of the earth's surface, age dating, distribution of isotopes and chemical elements in the earth, surface properties of terrestrial planets as revealed by earth-based observations and flight experiments, physical and chemical oceanography, dynamics and chemical evolution of the earth's atmosphere and planetary atmospheres, a review of problems of special or current interest. Lectures, laboratory and occasional speakers. *T. R. McGetchin*

GRADUATE SUBJECTS

Geology and Geochemistry

12.301-12.304 ***Seminar in Geology and Geochemistry*** **(A)**
Prereq.: ——
Year: G (1 or 2) *Arr.*

Problems of current interest in geology and geochemistry. Subject matter varying from term to term.
Staff (12.301, 12.303);
R. S. Naylor (12.302, 12.304)

12.32 ***Sedimentology and Sediment Movement*** **(A)**
Prereq.: 12.04
Year: G (1) 3–1–8

Aspects of turbulent flow mechanics relevant to sediment movement. Mechanics of sediment erosion, transportation, and deposition: modes of particle entrainment and motion in turbulent shear flows; sequence and hierarchy of sediment bed forms, with detailed consideration of ripples and dunes; turbidity currents in the laboratory and in nature. Interpretation of primary structures and textures in modern and ancient sediments on the basis of sediment-transportation mechanics. Occasional laboratory demonstrations and exercises. *J. B. Southard*

12.325 ***Sedimentology Seminar*** **(A)**
Prereq.: 12.32
Year: G (1 or 2) 2–0–4

Discussion of current research and problems in sedimentology, sedimentary petrology, and sediment transport mechanics. Content varying from term to term.
J. B. Southard

12.35 ***Rock Mechanics*** **(A)**
(New)
Prereq.: 8.03, 18.03, 2.30 or 12.03
Year: G (1) 3–0–9

Review of certain tensor and non-tensor properties of crystals, including elastic, thermal and optical properties, cleavage and fracture, twin and translation gliding and surface properties. Derivation of aggregate from single crystal properties with application to rocks under geologic conditions. The microstructure of rocks and rock masses in its application to elasticity, strength, ductility, and transport properties of rocks. Modern theories of brittle fracture, plastic flow, and frictional behavior of rocks. *W. F. Brace*

12.355 ***Seminar in Rock Mechanics*** **(A)**
Prereq.: 12.35
Year: G (1 or 2) 2–0–4

Discussion of current research or advanced topics in tectonics, rock mechanics or experimental structural geology. *W. F. Brace*

12.361 *Workshop on Geophysical Laboratory Measurements* (A)
(New)
Prereq.: 8.03, 18.03, 3.11 or 12.501
Year: G (1) 0–3–3
A series of laboratory problems is planned illustrating the measurement of pressure, temperature, and displacements in a variety of time scales. Experiments include, but are not restricted to, static elastic properties, dynamic elastic properties, thermal expansion, viscosity, thermal and electrical conductivity. *(Enrollment is limited to 10 students.)* *C. Goetze*

12.362 *Physics of Geologic Materials* (A)
(New)
Prereq.: 8.03, 12.501, 18.03
Year: G (2) 3–0–9
A survey of the effects of high pressure, temperature, and stress on the physical properties of crystalline materials of geophysical interest. Including equations of state as derived from static and shock measurements, theories of melting, theoretical, field and laboratory evidence concerning the flow of rocks under static and oscillating shear stresses. *C. Goetze*

12.385-12.399 *Special Problems in Geology-Geochemistry* (A)
(New)
Prereq.: ——
Year: G (1 or 2) *Arr.*
For graduate students desiring to perform special investigations, special laboratory work, or special field work in geology, petrology, mineralogy or geochemistry. *C. Goetze* (12.385); *W. F. Brace* (12.386); *M. J. Buerger* (12.387); *R. G. Burns* (12.388); *H. W. Fairbairn* (12.389); *F. A. Frey* (12.390); *P. M. Hurley* (12.391); *T. R. McGetchin* (12.392); *R. S. Naylor* (12.393); *W. H. Pinson* (12.394); *R. R. Shrock* (12.395); *J. B. Southard* (12.396); *J. S. Lewis* (12.397); *Staff* (12.398, 12.399).

12.40 *Chemistry of the Earth* (A)
(Revised: Content change)
Prereq.: 5.60
Year: G (2) 3–0–6
Applications of thermodynamics to the chemical development of the earth in the following subjects: origin, interior chemical constitution and equations of state, magma generation and solid and melt phase equilibria, trace element partitioning, and the phase rule in igneous and metamorphic petrology. Reading assignments cover major chemical and geological distributions, and principles of physical geochemistry. *P. M. Hurley*

12.411 *Isotope Geology* (A)
Prereq.: 12.02
Year: G (1) 3–0–6
Applications of the variations in the relative abundance of radiogenic and stable isotopes to geologic problems. Topics including geochronology, studies of petrogenesis, geologic processes that can be traced by stable isotope fractionations, techniques, and instrument design.
P. M. Hurley

12.42 *Geochemistry of the Solid State* (A)
Prereq.: 12.052, 3.12
Year: G (1 or 2) 2–0–4
Study of modern theories of chemical bonding in solids as applied to various problems in geochemistry and mineralogy. Topics include crystal field theory and applications to transition metal geochemistry; molecular orbital theory and properties of sulphides; the use of recent experimental techniques, such as Mössbauer, infrared and electronic absorption spectroscopy, for determining site populations in crystal structures; and the influence of cation distributions on physical and chemical properties of minerals. (Burns, *Mineralogical Applications of Crystal Field Theory.*) *R. G. Burns*

12.45 *Geochemistry* (A)
Prereq.: 5.60
Year: G (1) 3–0–6
Study of the distribution of the elements. Application of modern chemical theory to the location of elements in geologic systems, thorough discussion of the existing data of geochemistry, and application of geochemical data to general geologic problems. *F. A. Frey*

Geophysics and Planetary Physics

12.50 *Survey of the Earth and Planetary Sciences* (A)
Prereq.: ——
Year: G (1) 3–3–3
Introduction to current problems in geology, geophysics, geochemistry, planetary science, oceanography and meteorology. Topics covered include: structure and dynamics of the earth's crust and interior, rocks and minerals of the crust, interior of the earth and terrestrial planets, major geomorphic processes responsible for alteration of the earth's surface, age dating, distribution of isotopes and chemical elements in the earth, surface properties of terrestrial planets as revealed by earth-based observations and flight experiments, physical and chemical oceanography, dynamics and chemical evolution of the earth's atmosphere and planetary atmospheres, a review of problems of special or current interest. Lectures, laboratory and occasional speakers.
T. R. McGetchin

12.501 *Physics of the Earth* (A)
Prereq.: 8.03, 18.03
Year: G (1) 3–0–6
Survey of the earth's interior, thermal regime, composition, structure, elastic and inelastic properties, equation of state as revealed by physical measurements on the surface and on laboratory samples. Reviews results of heat flow, seismology, earth gravity and magnetism, high-pressure geophysics and regional geophysics.
G. Simmons, F. Press

12.502 *Geophysical Interpretation and Data Processing* (A)
(New)
Prereq.: 12.501
Year: G (2) 3–0–6
Gravity and magnetic methods for geophysical prospecting. Solution of the appropriate differential equations, and numerical methods for analysing data. Seismic surveying techniques and interpretation. The use of digital computers in geophysics. Data processing techniques, the scope and limitation of digital methods. *Staff*

12.52 *Geoelectricity and Geomagnetism* (A)
(12.51) *Prereq.:* 8.03, 18.076
Year: G (2) 3–0–9
Survey of the electric, magnetic and electromagnetic properties and processes in the earth's environment. The plasma environment of the earth's magnetosphere and ionosphere and electromagnetic wave and particle phenomena occurring therein. Electric properties of the earth's interior. Magnetohydrodynamic origin of the magnetic fields of the earth and other astronomical bodies. *T. R. Madden*

12.521 *Elements of Seismology* (A)
Prereq.: 18.075
Year: G (1) 3–0–9
A basic subject in seismology and the utilization of seismic waves for the study of the earth's interior. Introduction of techniques necessary for understanding of elastic wave propagation in layered media, and dispersion. Seismic ray theory and the interpretation of travel times. Surface wave dispersion and free oscillations of the earth. Seismicity, magnitude, energy. Structure of the earth's interior. *M. N. Toksöz*

12.522 *Advanced Seismology* (A)
Prereq.: 12.521, 18.284
Year: G (2) 3–0–9
Advanced methods of theoretical seismology; the general properties of seismic waveforms; separate discussions on sources and media; head waves, normal modes, leaky modes, and exact synthetic seismograms in layered media; seismic scattering due to lateral heterogeneity of the earth; near-field and far-field of seismic radiation from elastic dislocations; determination of earthquake source parameters. *K. Aki*

12.581-12.589 *Seminar in Geophysics* (A)
Prereq.: ——
Year: G (1 or 2) *Arr.*
Problems of current interest in geophysics; subject matter varying from term to term. *Staff* (12.581, 12.582); *K. Aki, M. N. Toksöz* (12.583); *T. R. Madden* (12.584); *F. Press, G. Simmons* (12.585); *Staff* (12.586, 12.587); *I. I. Shapiro* (12.588); *Staff* (12.589).

12.591-12.599 *Special Problems in Geophysics* (A)
Prereq.: ——
Year: G (1 or 2) *Arr.*
For graduate students desiring to perform special investigations, special laboratory work, or special field work in geophysics. *Staff* (12.591, 12.592); *K. Aki, M. N. Toksöz* (12.593); *T. R. Madden* (12.594); *F. Press, G. Simmons* (12.595); *Staff* (12.596, 12.597); *I. I. Shapiro* (12.598); *T. B. McCord* (12.599).

12.614J *Dynamical Problems of the Solar System* (A)
(Same subject as 8.954J, 16.442J)
Prereq.: 12.613J
Year: G (2) 3–0–9
Introduction to current research in solar systems dynamics, tidal friction, evolution of spin and orbital resonances, and tests of gravitational theories.
C. C. Counselman, I. I. Shapiro, W. Wrigley

12.623 *Planetary Surfaces* (A)
(New)
Prereq.: ——
Year: G (1) 3–3–6
Discussion of the physical and chemical state of the surfaces of solar system objects. Earth and spacecraft-borne observations (at ultraviolet, visible, infrared, and radio wavelengths, radar studies); physical state, composition, geology, landforms; surface processes: erosion, space-weathering, cratering, material transport, volcanism; terrestrial analogs used where possible. (*Permission of instructor required.*)
T. B. McCord, T. R. McGetchin

12.631J *Planetary Atmospheres* (A)
(Same subject as 5.125J)
Prereq.: ——
Year: G (1) 3–0–6
Discussion in light of recent spectroscopic and space-probe data of compositions, structures, and origins of the atmospheres of the planets. Thermodynamics of atmospheric structure, cloud precipitation, and mineral buffers of pressures of reactive gases. Photolysis; escape rates, mineralogy of surface rocks. Chemical behavior of a solar-composition atmosphere; the solar nebula, the interiors of the major planets. Models for the origin and development of planetary atmospheres. (*Permission of instructor required. Not offered 1971–72.*) *J. S. Lewis*

12.636J *Current Research in Meteoritics* (A)
(Same subject as 5.129J)
Prereq.: ——
Year: G (2) *Arr.*
Discussion of current research and special problems in meteoritics. Composition and structure of important classes of meteorites; meteorite dating methods and their results; thermodynamics of meteoritic minerals; geochemistry and isotopic chemistry of meteoritic material and lunar surface material. Evidence concerning the origin of meteorite classes and proposed genetic relationships. Conditions in the solar nebula. *J. S. Lewis*

12.691-12.699 *Special Problems in Planetary Physics* (A)
Prereq.: ——
Year: G (1 or 2) *Arr.*
For graduate students desiring to perform special investigations, special laboratory work, or special field work in planetary physics. *Staff* (12.691, 12.692); *G. H. Pettengill* (12.693); *I. I. Shapiro* (12.694); *T. B. McCord* (12.695); *C. C. Counselman* (12.696); *T. R. Madden* (12.697); *Staff* (12.698, 12.699).

Oceanography

12.71 *Introduction to Physical Oceanography*
(12.70) *Prereq.:* 8.02, 18.02
Year: G (1) 3–0–6
Designed to acquaint beginning graduate students not specializing in a physical discipline of oceanography with the rudiments of physical oceanography. Topics: observations from a rotating coordinate system, the astronomical tides, the planetary energy budget, types and scales of oceanic variability, kinematics and dynamics of the most elementary types of motion, air-sea interaction, the observed structure of the oceans — distribution of properties and current patterns, transmission of acoustic and electromagnetic energy. (*Given at Woods Hole Oceanographic Institution.*) *W. Schmitz (Woods Hole Staff)*

12.73 *Marine Geology* (A)
(12.72) *Prereq.:* ——
Year: G (1) 3–1–6
Physiography, stratigraphy, and structure of the ocean floor and processes of its evolution and modification; major results of early oceanographic expeditions and summary of first concepts; development of instruments and methods, including a brief review of sampling devices and underway techniques, such as echosounding and seismic reflection; theories of ocean basin evolution; composition, origin and transportational history of marine sediments; application of present knowledge of the modern marine environment to the genetic interpretation of ancient rocks. (*Permission of instructor required. Given at Woods Hole Oceanographic Institution.*)
D. A. Ross, Hollister (Woods Hole Staff)

12.74 *Marine Geophysics* (A)
Prereq.: 12.72
Year: G (2) 3–0–6
Crustal and upper mantle structure of continental margins, ocean basins, island arcs and oceanic ridges; and implications for deep earth structure and dynamic processes. Introductory theory and application of techniques in seismic reflection, seismic refraction; earthquake seismology; earth gravity; geomagnetism and heat-flow. Current instrumentation and data processing techniques. (*Given at Woods Hole Oceanographic Institution.*) *R. P. Von Herzen (Woods Hole Staff)*

12.75 *Chemical Oceanography* (A)
(12.83) *Prereq.:* 5.01
Year: G (1) 3–0–6
Topics: major ion composition, ionic species and equilibrium concepts, trace elements, the carbonate and silicate systems, dissolved gases, stable isotopes, radionuclides, and organic matter in the sea. Integration of the marine geochemistry of the lithosphere, atmosphere and biosphere. Lectures on selected topics by various members of the Woods Hole staff. (*Given at Woods Hole Oceanographic Institution.*)
P. Brewer (Woods Hole Staff)

12.76 *Seminar in Marine Physics* (A)
(12.815) *Prereq.:* 12.21
Year: G (1, 2) 2–0–7
Reading and discussion of classical and contemporary books and papers having relevance to the marine aspects of earth science. Varying scope and content to meet the special needs and interests of the participants.
W. S. von Arx (Woods Hole Staff)

12.791-12.799 *Special Problems in Oceanography at Woods Hole* (A)
(New)
Prereq.: ——
Year: G (1 or 2) *Arr.*
For graduate students desiring to perform special investigations, special laboratory work or special field work in oceanography. (*Chemical Oceanography* 12.791, 12.792, 12.793; *Oceanographic Geology and Geophysics* 12.794, 12.795, 12.796; *Physical Oceanography* 12.797, 12.798, 12.799). *Woods Hole Staff*

12.81 *Waves and Tides* (A)
Prereq.: 18.350
Year: G (1) 3–0–9
Aspects of tide and wave motion in the sea. Derivation of the tide producing forces. Hydrostatic and non-hydrostatic approximations. Observations of tides, tidal friction, internal tides. Content varying from year to year. *C. I. Wunsch*

12.83 *Marine Geochemistry* (A)
Prereq.: 5.01, 5.60
Year: G (1) 3–0–9
Composition of sea water: chemistry of aqueous solutions, ionic association and dissociation and relevant calculations: concepts of steady state and residence times of species and discussion of static versus dynamic chemical models of the ocean. Effect of oceanic circulation on the chemistry illustrated by the CO_2, silicate and isotopic distributions. Discussion of authigenic sediments, control of sea water composition, geochemical cycles. Emphasis on development of problems and topics by students and on calculations. *J. Edmond*

12.85 *Oceanographic Time Series* (A)
(New)
Prereq.: 6.573 or 6.576
Year: G (1) 3–0–6
This course will examine aspects of the problems encountered in using real, finite, discrete time series data from actual oceanographic experiments. A case study approach will be taken. Topics treated will vary, but might include z-transforms, Wiener filters, minimum phase systems, spectra, bi-spectra, non-linear filters, array antennas. Students should know a computer programming language.
C. I. Wunsch, R. Thompson (Woods Hole Staff)

12.881-12.889 *Seminar in Oceanography* (A)
(12.891-12.899) *Prereq.:* ——
Year: G (1 or 2) *Arr.*
Topics in marine geophysics, physical, dynamical and chemical oceanography. Content varying from term to term. *M.I.T. and Woods Hole Staff*

12.891-12.899 *Special Problems in Oceanography at M. I. T.* (A)
(New)
Prereq.: ——
Year: G (1 or 2) *Arr.*
For graduate students desiring to perform special investigations, special laboratory work or special field work in oceanography. *C. I. Wunsch* (12.891); *F. Press* (12.892); *G. Simmons* (12.893); *J. Edmond* (12.894); *Staff* (12.895-12.899).

13.
Ocean Engineering

13.00 *Introduction to Marine Hydrodynamics*
Prereq.: 1.05 or 2.201 or *13.002*
Year: U (1) 3–1–8
Hydrostatics of floating and submerged bodies. Basic hydrodynamics applications to resistance and propulsion; wave hydrodynamics, including excitation and response of floating or submerged bodies and structures such as breakwaters or towers. Mathematical models for surfaces in a flow field, source, dipole and vortex representation. Application to propeller, hydrofoil, and control surfaces. Engineering characteristics of hydrodynamic systems, such as propellers and vehicles; matching characteristics for desired results. *D. E. Cummings*

13.001 *Introduction to Marine Applied Mechanics*
Prereq.: 8.01, 18.02
Year: U (2) 4–0–8
Basic mechanics of solids and fluids with emphasis on the marine field. Rigid body mechanics. Tensor notation. Potential fields. Laplace's equation. Mechanical equilibrium. Principal stresses, Mohr's circle. Strain and strain rate. Compatibility and continuity. Mechanical properties of solids and fluids. Constitutive equations. Isotropy, material derivatives. Examples of typical problems in Marine Applied Mechanics, such as beams, laminar boundary layers, etc.
D. E. Cummings

13.002 *Marine Applied Mechanics*
Prereq.: 13.001, *18.03*
Year: U (1) 4–0–8
Continuation of 13.001. Theory of Elasticity, Plane stress, and Plane strain. Navier-Stokes equations. Temperature stresses. Principle of virtual work, torsion of rods, potential flow, beam deflections. Free and forced beam vibrations. Wave equation, waves in gases, solids, and at fluid interfaces. Further work on constitutive equations. Energy considerations. Examples of solutions to biharmonic and Laplace's equation, such as fluid flow around bodies and elastic stress in flat plates.
N. Jones

13.01 *Applied Hydrostatics*
Prereq.: ——
Year: G (S) 1–7–2
Elementary principles of naval ship design and statics of naval architecture. Work in the project room on fairing of naval ship lines, calculations for and drawing of displacement and other curves, cross curves of stability, curves of statical stability and floodable length curves for a naval ship from preliminary design data. (*Primarily for students in Course* XIII-A*; others admitted with permission of instructor.*) *W. C. Dietz*

13.02 *Marine Hydrodynamics* (A)
Prereq.: 1.05 or 1.612 or 2.201 or 13.002; 13.00 or 13.01; 18.075
Year: G (2) 3–1–8
Development of hydrodynamic principles and their application to marine vehicles. Dimensional analysis, similitude, and model testing. Solutions of the Navier-Stokes equations and boundary-layer approximations. Water waves, ship-generated waves, and motions in a seaway. Lifting surfaces, thin-wing theory, cavitation, and propeller theory. Maneuvering and control of vehicles in calm water. *J. N. Newman*

Descriptions

13.03 ***Advanced Hydromechanics of Ship Design*** **(A)**
Prereq.: 13.00 or 13.02; 18.075
Year: G (2) 3–0–6
Advanced work in the application of theoretical and experimental hydrodynamics to the solution of marine vehicle design problems in the area of resistance, powering, steering, motion response, and control. Advanced considerations of motion stability and control and the behavior of uncontrolled and controlled ships in waves and rough seas. Discussion of modern model testing and computational techniques, and recent research and progress in marine vehicle dynamics. Student use of recently developed computer programs for seakeeping analysis in problem assignments. *(Not offered 1971–72.)*
M. A. Abkowitz

13.04 ***Two-Dimensional Hydrofoil Theory*** **(A)**
Prereq.: 13.02, 18.076
Year: G (1) 3–0–9
Thin hydrofoil theory: lifting and thickness problems, conformal mapping and singular integral equation techniques, treatment of leading edge non-uniformity by matched asymptotic expansions and by computer technique based on conformal mapping. Design of high speed subcavitating sections. Supercavitating hydrofoil theory. Free surface effects, planing problem. Unsteady subcavitating and supercavitating hydrofoil theory. Demonstration experiments in variable pressure water tunnel.
J. E. Kerwin, P. Leehey

13.05 ***Three-Dimensional Hydrofoil Theory*** **(A)**
Prereq.: 13.04
Year: G (2) 3–0–9
Lifting line and lifting surface theory by matched asymptotic expansions and computer techniques based on singularity distributions. Topics in propeller theory, including propeller lifting-line and lifting-surface theory and applications to the design of homogeneous flow and wake adapted propellers. Selection of topics in three-dimensional theory from the following: free surface effects and planing, supercavitating hydrofoils and propellers, unsteady flow about hydrofoils and propellers, hydroelastic and vibration effects. Demonstration experiments in variable pressure water tunnel.
J. E. Kerwin, P. Leehey

13.06 ***Propulsion Hydrodynamics*** **(A)**
Prereq.: 1.05 or 2.201; *13.00* or *13.02*
Year: G (2) 2–0–4
Propulsion devices, particularly marine propellers, similitude and related selection parameters, interaction between propulsion and vehicle, momentum and energy considerations, extremals and optimization, cavitation effects, and special aspects of marine propulsion devices including unsteady and vibratory considerations. *(Alternate years. Offered 1971–72.)*
S. C. Powell

13.07 ***Free Surface Hydrodynamics*** **(A)**
Prereq.: 18.076
Year: G (1) 3–0–6
Water wave phenomena pertinent to problems in naval architecture and ocean engineering. Generation, propagation, and diffraction of plane progressive waves. Exciting and restoring forces on floating and submerged bodies. Ship waves and wave resistance. Selected topics of interest in non-linear wave propagation, internal waves, slender-body theory, or seakeeping. *(Some background in water waves assumed, equivalent to that covered in 13.02.)*
J. N. Newman

13.08 ***Stability and Motion Control of Ocean Vehicles*** **(A)**
Prereq.: 13.00 or 13.02; 18.075
Year: G (1) 3–0–6
Development of the equations of motion in six degrees of freedom and the formulation of mathematical models for ocean vehicle dynamics. Concepts of automatic contro and the amplification of the model to include the effects of such controls and the various excitations and restraints resulting from an ocean environment or system arrangement. Discussion of the relationships between the mathematical model and physical reality. Solution of the equations for stability determination and for various important vehicle motion responses in a sea environment. Analysis and discussion, by the case study method, of the motion evaluation and reduction for a variety of types of ocean vehicles in their particular environment, such as hydrofoil boats, surface effect ships, buoys, towed and moored bodies, surface ships, drilling platforms, flip-ships, submersibles, submarines, and others. *(Not offered 1971–72.)*
M. A. Abkowitz

13.10 ***Introduction to Structural Mechanics***
Prereq.: 2.01 or 2.015 or 13.001
Year: U (1) 3–0–6
Selected structural mechanics concepts applicable to marine structures: stability and determinancy of structures, methods for computing deflections, principles of virtual forces and displacements, statically indeterminate structures. Matrix analysis of structures using force and displacement methods, effect of shear and axial forces. Stability of equilibrium and buckling of columns, large deflection theory of columns, theory of inelastic stability, initially curved members, linear theory of elastic stability. Stationary potential energy, Rayleigh-Ritz method, beam-columns. Plastic analysis of beams, stress concentration, cylindrical and spherical shells.
A. E. Mansour

13.11 ***Theory of Plates and Shells*** **(A)**
Prereq.: 2.01 or 13.002, 18.075
Year: G (1) 3–0–6
General theory of isotropic plates, circular and rectangular plates, influence of large deflections, orthotropic plates, stability of rectangular plates, thermal effects, discussion of applicability to the design of typical ship structures. General theory of isotropic shells. The behavior of typical shells encountered in ocean engineering structures, such as cylindrical, conical, and spherical shells. *(Not offered 1971–72.)*
N. Jones

13.12 ***Marine Structures*** **(A)**
Prereq.: 13.10
Year: G (2) 3–0–6
Hull loading conditions and resulting bending moments, inertia effects, statistical approach, sea spectrum, response amplitude operator and response spectrum, strength variability and probability of failure. Hull primary response, two dimensional stress analysis, box girder analysis, primary longitudinal and girth stresses, shear stresses and deflection. Linear shear lag theory, stress function method, effective breadth concept. Effect of deckhouses and superstructures on primary strength, two beam analysis, shear effects. Torsional strength and stiffeners. Orthotropic plate theory and stiffened plates, rigidity coefficients and design considerations. Ship transverse strength and elastic analysis of frames using matrix method. Basic concept of finite element method and application to marine structures.
A. E. Mansour

13.13 ***Plastic Analysis of Structures*** **(A)**
Prereq.: 2.01 or 13.002, 18.03
Year: G (2) 3–0–6
Elastic-plastic behavior of thick-walled cylinder. Yield criteria. Drucker's stability postulate, normality and convexity. Limit theorems. Static plastic collapse of beams, plates, shells, shell intersections, and other structures encountered frequently in ocean engineering and naval architecture. Discussion of relevant experimental work. Influence of finite deflections. Shakedown theorem. General theorems for the dynamic behavior of

rigid-plastic structures. Theoretical and experimental behavior of beams, plates, and shells when subjected to dynamic loads of an intensity sufficient to cause plastic flow. *N. Jones*

13.151J *Welding Engineering* (A)
(Same subject as 3.36J)
Prereq.: 3.13 or 3.141
Year: G (1) 3–0–6
Detailed study of processing variables involved in joining materials by welding, brazing, and adhesive bonding. Synthesis of elementary physical phenomena such as transient heat flow, phase transformations, and dimensional changes into the complex over-all reactions associated with joining. Testing, inspection, and properties of finished joints. Laboratory demonstrations of arc, electron beam, resistance, and other electric welding processes. *K. Masubuchi, T. B. King*

13.161J *Materials for Ocean Engineering*
(Same subject as 3.701J)
Prereq.: ——
Year: G (2) 4–1–6
Properties of metals used for the construction of ships and ocean engineering structures. Fracture characteristics, microstructures, processing, heat treatment, and corrosion resistance of ferrous and non-ferrous metals.
K. Masubuchi, C. F. Floe

13.20 *Ocean Engineering Energy Conversion Systems*
Prereq.: 2.403, 13.001
Year: U (1) 4–0–8
External characteristics of energy conversion devices of types common in ocean engineering, developed from fundamental considerations. Thermal, mechanical, hydraulic, and electrical machines: system dynamics and coupling of combinations of components. (*Alternate years. Offered 1971–72.*) *S. C. Powell*

13.21 *Ship Power and Propulsion* (A)
(*Revised: Unit change*)
Prereq.: 2.402 or 2.403
Year: G (1) 4–1–7
Critical examination of ship propulsion requirements for the design of systems and components. Selection of propulsion devices and system parameters to satisfy ship performance requirements or demonstrate feasibility. Optimization of propulsion system parameters on the basis of life cycle costs or other constraints. Design and analysis projects and calculations specifically selected to stimulate professional application of engineering fundamentals. *A. D. Carmichael, S. C. Powell*

13.22 *Naval Ship Propulsion* (A)
(*Revised: Unit change*)
Prereq.: 2.402
Year: G (1) 4–1–7
Critical examination of naval ship propulsion requirements for the design of systems and components. Selection of propulsion devices and system parameters to satisfy ship performance requirements or demonstrate feasibility. Optimization of propulsion system parameters on the basis of minimum weight, life cycle costs, or other constraints. Design and analysis projects and calculations specifically selected to stimulate professional application of engineering fundamentals. (*Primarily for students in Course* XIII-A*; others admitted with permission of instructor.*) *W. C. Dietz, A. D. Carmichael*

13.25J *Thermodynamics of Power Systems*
(Same subject as 2.41J)
Prereq.: 2.403
Year: U (2) 3–0–9
Application of thermodynamics to power-generating systems. Thermodynamics of combustion and mixtures of gases. Analysis of Carnot, Rankine, Brayton, Otto, and Diesel cycles. Availability. Performance of modern steam plant, gas turbines, internal combustion engines, refrigeration plant, marine power plant. Economic and pollution aspects. New power generation concepts, such as fuel cells, MHD, vapor engines. The class will be split into several groups towards the end of the term to consider some of these topics in more detail.
A. D. Carmichael, J. B. Heywood

13.26J *Thermal Power Systems* (A)
(Same subject as 2.601J)
Prereq.: 2.402 or 2.403; 2.201
Year: G (2) 3–0–9
Design of thermal power system components and system optimization. Review of thermodynamics, gas dynamics and heat transfer. Design of axial and centrifugal compressors and pumps, axial and radial inflow turbines, heat exchangers, evaporators, boilers and condensers. Problems and examples will be taken from the fields of space, electrical utility and marine power systems. Knowledge of elementary heat transfer and simple thermal power cycles will be assumed.
A. D. Carmichael, W. N. Rohsenow

13.27 *Ocean Engineering Power Systems* (A)
(*New*)
Prereq.: 2.403
Year: G (1) 2–0–4
Application of power in the oceans for submersibles, diver transportation, buoys, and drilling rigs. Current and potential methods of providing power including thermal engines, nuclear energy, radioactive isotopes, fuel cells, and batteries. Problems of the ocean environment. *A. D. Carmichael*

13.30 *Ship Structural Analysis and Design*
Prereq.: 2.01 or 13.001; *13.00* or 13.01
Year: U (1) 3–0–6
General and local structural reactions of marine vehicles to their environment including consideration of materials, structural configurations, modes of failure, elastic and plastic instability, and elementary plate theory. Integration and optimization of primary longitudinal structure.
J. H. Evans

13.31 *Ship Structural Design*
Prereq.: 13.30
Year: U (2) 0–3–1
Determination of the major loadings on a marine vehicle. Derivation of the major structural characteristics for an optimum solution. *J. H. Evans*

13.32 *Ocean Engineering Structures* (A)
Prereq.: 2.01 or 13.001
Year: G (1) 3–0–6
Seminar on the structural analysis and design of semi-submerged mobile drilling platforms, submarine vehicles, bottom habitations and stayed structures, including moorings. Consideration of critical structural details. Configuration optimization of pressure vessel structures, moorings, buoy systems and anchoring devices.
J. H. Evans

13.34 *Ship Structural Design* (A)
Prereq.: 13.12 or 13.30
Year: G (1) 0–5–0
Determination of load distribution on the hull of surface ship types and development of optimized primary longitudinal structure. *J. H. Evans*

13.36 *Ocean Engineering Structural Design* (A)
Prereq.: 13.32
Year: G (2) 0–5–0
Development of structural designs to suit specific design requirements and parametric optimization for some of the following: stayed mast, stiffened cylindrical shell

under external hydrostatic pressure, mooring system in static equilibrium, simple offshore platform space frame, dynamics of coupled surface/submerged systems.

J. H. Evans

13.39 *Analysis of Techniques for Fabricating Structures* (A)
Prereq.: 3.13 or 13.151J or 13.161J
Year: G (2) 2–0–4
Analysis of problems related to the fabrication of structures, such as ships, aircrafts, rockets, pressure vessels, buildings, and ocean engineering structures by various joining processes including welding, riveting, and adhesive bonding. Discussion of such problem areas as fracture characteristics of welded structures; residual stress, distortion, and stress relieving; advanced welding metallurgy; non-destructive testing of structural welds. Laboratory demonstrations of some tests. *K. Masubuchi*

13.40 *Introductory Ship Design*
(Revised: Unit change)
Prereq.: 13.00, 13.10 or 13.30; or 13.79
Year: U (2) 2–4–6
Problem definition, formulation of mathematical model and general solution to ship design problem. Engineering and economic principles involved in selection of dimensions and coefficients of commercial ships; design of hull form; principles governing internal subdivision for maximum survivability; ship operability in rough seas; design exercise in application of principles.

P. Mandel, C. Chryssostomidis

13.41 *Principles of Ship Design* (A)
(Revised: Unit change)
Prereq.: 13.00 or 13.02, 13.10 or 13.12 or 13.30 or 13.79
Year: G (1) 2–4–6
Ship in context of a larger system; formal optimization procedures applied to ship design; assumption of subsystems sufficiency; mathematical model of ship design process; engineering and economic principles governing selection of dimensions and coefficients of ships and submarines; design of hull form; principles governing internal subdivision for maximum survivability; influence of hull form and dimension selection on operability in rough seas. Design exercise in application of principles. *(Not recommended for students who have taken 13.40.)*

P. Mandel, C. Chryssostomidis

13.42 *Design of a Waterborne Vehicle* (A)
Prereq.: 13.41
Year: G (1, 2, S) *Arr.*
Determination of performance criteria for a waterborne vehicle or platform based on a set of system mission requirements derived by the student in consultation with instructor. Preparation of the preliminary design of the vehicle or the floating platform fulfilling the selected performance criteria. Participation by several students in a single project encouraged. *(Primarily for graduate students in Ocean Engineering; others admitted with permission of instructor. Permission of instructor-in-charge required for summer term registration.)*

P. Mandel, C. Chryssostomidis

13.43 *Naval Ship-System Design I* (A)
Prereq.: 2.015, 13.00 or 13.02, 13.01
Year: G (S) 3–0–6
Principles involved in the design of selected hull, electrical, machinery and weapon systems for naval ships and their influence on the configuration and arrangement of ships. *(Primarily for students in Course* XIII-A*; others admitted with permission of instructor.)* *W. R. Porter*

13.44 *Naval Ship-System Design II* (A)
Prereq.: 13.12 or 13.30, 13.43, 13.50
Year: G (1) 0–5–0
Analyses of problems involved in the design of naval ship systems and their incorporation in a ship. Presentation of results of these studies. *(Primarily for students in Course* XIII-A*; others admitted with permission of instructor.)*

W. R. Porter, W. C. Dietz

13.45 *Principles of Naval Ship Design* (A)
Prereq.: 13.12 or 13.30, 13.22, 13.43, 13.80, 18.076
Year: G (1) 2–0–4
Fundamental considerations in selecting and providing the military features of naval ships. *(Primarily for students in Course* XIII-A*; others admitted with permission of instructor.)*

W. R. Porter

13.46 *Conceptual Design of Naval Ships* (A)
Prereq.: 13.41, 13.45, 13.50
Year: G (1, 2) *Arr.*
Project-type studies, including preparation of necessary drawings and calculations to support formulation and preliminary design of naval ships. *(Primarily for students in Course* XIII-A*; others admitted with permission of instructor.)*

W. R. Porter, W. C. Dietz

13.47J *Special Studies in Systems Engineering* (A)
(Same subject as 1.16J, 2.191J, 6.604J)
Prereq.: ——
Year: G (2) 2–4–6
Development of basic techniques employed in planning and design of complex systems through involvement in specific projects. Entire class works on a single project which changes each year. Specific background developed through lectures dealing with the selected project. Subgroups of class work on portions of problem and coordinate results through class meetings. Results presented formally at end of term. Recent projects included study of issues of vital importance to the long-range well being of New England, including electric power production, recreational opportunities, air and water pollution and a study of the potential for expanding industrial and agricultural activity in Saudi Arabia based upon utilization of natural gas now being wasted.

E. G. Frankel, R. E. Stickney, W. W. Seifert

13.50 *Computer Applications to Marine Problems*
Prereq.: 18.075
Year: G (2, S) 2–2–4
Steps required in the development of useable computer programs for the solution of engineering problems including problem definition, numerical analysis, program organization, FORTRAN IV programming, development of program tests, debugging and program documentation. Assigned projects and lectures based on realistic problems in naval architecture and ocean engineering selected to illustrate many of the advantages and difficulties encountered in computer applications. *(Primarily for seniors and graduate students in ocean engineering; others admitted by permission of the instructor.)*

J. E. Kerwin, D. E. Cummings

13.60 *Application of Operational Methods*
Prereq.: 6.28
Year: U (1) 4–0–8
Model construction, criteria development and solution methods for meaningful operational problems in transportation, production, service, economic development and other areas. Linear, non-linear, and dynamic programming; inventory theory, gaming models, waiting line problems, and simulations, primarily in deterministic form. Emphasis on structuring of real world problems into mathematical models and selection of most

effective variable sets and objective function within constraints of possible solution methods and sensitivity of results and assumptions or data. *E. G. Frankel*

13.61 *Network Theory and Planning Techniques* (A)
Prereq.: 1.07 or 6.28; 1.143 or 13.60
Year: G (2) 3–0–6
Decision trees, sequential network plans, critical path methods, PERT, decision critical path methods, graphical evaluation and review techniques, flow graph theory, probabilistic conditional decision network analysis, planning, scheduling and routing problems. *E. G. Frankel*

13.62 *Shipping Economics* (A)
Prereq.: 13.00, 13.20, *13.40*
Year: G (2) 3–0–6
Economic aspects of ship operation and design, including application of engineering economic principles to the evaluation of shipping enterprises as systems and their components. Principles of optimization and semi-analytical techniques applicable thereto. *(Students with a background in transportation engineering who lack prerequisites may apply to the instructor for admission. Alternate years. Not offered 1971–72.)* *S. C. Powell*

13.63 *Transportation Systems Inventory Control and Reliability* (A)
(New)
Prereq.: 1.143, 6.28
Year: G (2) 3–0–6
Statistical methods of transportation system inventory theory. Markov and semi Markov models for systems and service reliability and maintainability. Transportation system dynamics and control. Effect of component availability on systems performance. Replacement and maintenance strategy. System operating and investment policy formulation. *E. G. Frankel*

13.64J *Water, Air and Interface Vehicles*
(Revised: Unit change)
(Same subject as NS51 J)
Prereq.: ——
Year: U (2) 2–0–6
The competitive position of diverse water, air and interface vehicles in the world today determined from basic engineering principles. Development of the concepts of buoyancy, hydrodynamic lift, hydrodynamic drag, propulsor thrust and scaling laws as applied to surface ships, deep submersibles, dirigibles, airplanes, hydrofoil craft, planing craft and air-cushion vehicles. Comparison of the most significant performance criteria among these different vehicle types as well as evaluation of the effect of vehicle size, and speed and fluid density on these performance criteria. *P. Mandel, W. R. Porter*

13.65 *Ship Production Analysis* (A)
Prereq.: 1.143 or 13.60; 13.40 or 13.41
Year: G (1) 2–0–4
Operations research; mathematical and econometric models of ship production. Production process design and control. Modern production techniques. Network and flow analysis. *E. G. Frankel*

13.66 *Economics of Marine Systems* (A)
Prereq.: 1.14 or 14.02 or 15.001
Year: G (1) 3–0–6
Review of microeconomics and its relationship to systems analysis; the private and public economics of marine transportation and natural resource systems; description of charter markets and shipping cartels; introduction to cost/benefit analysis and application to maritime subsidy programs and public investments in port and harbor improvements; discussion of the economics of international fisheries and of the management of the ocean bed and the coastal zone. *J. W. Devanney*

13.67 *Marine Decision-Making Under Uncertainty* (A)
Prereq.: 1.07 or 6.28
Year: G (2) 3–0–6
Introduction to Bayesian decision theory and adaptive dynamic programming, application of these methods to a number of marine decisions under uncertainty including capital investment, timing of charters, the layup decision, maintenance and overhaul policies, and offshore research and exploration. Introduction to conflict situations and zero and non-zero sum game theory. Application to civil and military problems. *J. W. Devanney*

13.700-13.709 *Special Problems in Ocean Engineering*
Prereq.: ——
Year: U (1, 2, S) *Arr.*
Special reading, study, design, and/or investigation under supervision of a specially qualified member of the faculty. Topics in ocean engineering, naval architecture or marine engineering individually arranged to suit the interests of the student. Consult S. C. Powell for subject number which will be assigned in accordance with the technical area of the topic selected. *Staff*

13.710-13.719 *Special Problems in Ocean Engineering* (A)
Prereq.: ——
Year: G (1, 2, S) *Arr.*
Special reading, study, design, and/or investigation under supervision of a specially qualified member of the faculty. Topics in ocean engineering, naval architecture or marine engineering individually arranged to suit the interests of the student. Consult S. C. Powell for subject number which will be assigned by the Department in accordance with the technical area of the topic selected. *Staff*

13.72 *Methods of Harmonic and Statistical Analysis* (A)
Prereq.: 18.076
Year: G (2) 3–0–9
Mathematical basis and applications of dealing with random physical phenomena such as ocean waves, vehicle motions and noise in instrumentation circuits. Topics: Fourier analysis; generalized harmonic analysis; random processes; correlation functions; linear systems; Kramers-Kronig relations; systems with frequency dependent parameters. *J. H. Milgram*

13.73 *A Survey of Ocean Engineering*
Prereq.: ——
Year: U (2) 1–0–1
Series of lectures to acquaint undergraduate students in ocean engineering with the many facets of the field including naval architecture and marine engineering. Exploration of relationships and interfaces with the various engineering and scientific disciplines. Use of current problems and research projects as for illustration. Each session conducted by a different faculty member, with concentration on that faculty member's area of interest. *Staff*

13.74 *Marine Systems Control*
(Revised: Unit change)
Prereq.: 18.075
Year: G (1) 3–0–9
Definition and structure of marine systems. The cardinal functions of ship control, navigation, perception, communication, propulsion, power and environment control. Introduction to concepts of integrated command and control. Modeling of marine vehicle motion and power plant dynamics. Equations of motion, basic concept of linear stability and automatic control Applications and case studies analyzed with emphasis on locating

instrumentation problems and on solution methodology. Hardware/software attributes. Case studies of instrumentation and control covering motion control systems for surface ships, submarines, manned and unmanned submersibles; marine navigation and steering; deep ocean drilling platform positioning; marine power plant control. Paper or term study involving digital/analog simulation. *P. P. Dogan, A. D. Carmichael*

13.79 *Applied Ocean Engineering*
(New)
Prereq.: 2.403, *13.002*
Year: U (1) 3–1–5
Hydrostatics and stability calculations for ocean engineering structures and vehicles including damaged and partially floating conditions. Preliminary calculations to insure that an ocean engineering structure and vehicle will have sufficient structural strength, and will have the desired performance characteristics in smooth and rough seas. Dynamic modeling and extrapolation of scale test results. Selection of main propellers and auxiliary thrusters to match vehicle and power plant. Calculations for subsystems requirements, such as life support, vehicle control, anchoring, and mooring.
C. Chryssostomidis

13.80 *Mechanical Vibration* (A)
Prereq.: 2.01, 2.02
Year: G (1) 3–0–6
Free and forced vibration of systems of a single degree of freedom; complex variable and vector representation; Fourier series; harmonic analysis by tabular and mechanical methods; systems of several degrees of freedom; torsional systems; balance of rotating machinery and reciprocating engines; elements of torsional vibration problems in reciprocating engines. *J. P. Den Hartog*

13.81J *Principles of Acoustics* (A)
(Same subject as 2.060J, 16.081J)
Prereq.: 2.03 or 13.80 or 16.01; 2.201
Year: G (1) 3–0–9
Derivation of acoustic equations: energy, intensity, speed of sound, acoustical impedance. Generation of sound: fundamental source terms, expansions in multipoles, interpretation of forces, stresses, as multipoles. Sound generation by solid bodies in contact with fluid; airfoils, vibrating surfaces, radiation impedance. Sound propagation: atmosphere acoustics, ray theory, refraction, absorption, scattering. Non ideal behavior, finite amplitude effects. Sound in finite spaces, propagation in ducts and rooms. Sound attenuation in porous materials. Sound in rooms: wave and ray theory, reverberation, and decay of energy. Transmission of sound between coupled spaces. Demonstrations of measuring and analysis techniques and basic phenomena.
P. Leehey, R. H. Lyon, S. E. Widnall

13.82 *Acoustics and Shock Response of Marine Structures* (A)
Prereq.: 13.80 or 13.81J, 18.076
Year: G (1) 3–0–6
Steady-state and transient interaction between vibrating elastic plates or shells and the ambient water. Sound radiation and scattering by plane and curved surfaces. Asymptotic far-field and short-wave length solutions of the wave equation. Acoustic transients. Advanced concepts of structural vibrations: effect of rotary inertia, shear, and curvature on vibrations of plates; asymptotic high-frequency formulation of shell response. Interaction of a pressure step-wave and an elastic shell (linear theory); sound radiation by a propeller in a non-uniform wake. (*Alternate years. Not offered 1971–72.*)
M. C. Junger

13.83 *Hydroacoustics* (A)
Prereq.: 13.80 or 13.81J, 18.076
Year: G (2) 3–0–6
Topics in underwater acoustics important to modern naval architecture and marine engineering. Physics of water; mechanism of cavitation; cavitation noise. Radiation of sound by various types of sources. Transmission of sound in the ocean. Fundamentals of active and passive sonars. Vibrations in marine structures and machinery. Engineering applications to ship and submarine noise control. *P. Leehey*

13.84J *Flow Noise* (A)
(Same subject as 2.065J)
Prereq.: 1.05 or 2.201 or 16.02; *2.061* or *6.571*; 6.35
Year: G (2) 3–0–9
Lighthill's theory of aerodynamic sound. Source, dipole and quadrupole radiation. Sound radiated from subsonic and supersonic jets. Curle's theory of the influence of solid boundaries. Aeolian tone, edge tone, feedback and resonator effects. Turbulent boundary-layer noise: fluctuating wall pressure statistics, structural response and radiation, eddy Mach wavy radiation. Comparison of theory with experimental results. Laboratory demonstrations. *P. Leehey*

13.85 *Fundamentals of Underwater Sound Applications* (A)
Prereq.: 18.03
Year: G (2) 3–1–5
Fundamentals relating to the design of transmitters and receivers of underwater sound as well as related signal processing, as controlled by physical principles and physical and chemical properties of the ocean and its boundaries. Analysis of present-day sonar systems and exploration of future design directions. Comparison between light and sound as oceanic sensors. Acoustic wave equation. Absorption in sea water. Transmitting and receiving arrays. Reflection and scattering in the ocean. Refraction, shadow zones, surface channels, convergence zones, deep sound channel. Ray analysis. Mode analysis. Reverberation. Noise. Elementary signal processing. Sonar design principles. Depth sounders, speedometers and logs, echo locators, imaging systems, oceanographic sensors, seismic systems, defense systems, communications and beacons. Discussion of applications in charting, navigation, station keeping, fishing, petroleum exploration, telemetry. Demonstration and test of various systems in the Strobe Laboratory of the Electrical Engineering Department, in the Acoustics and Vibration Laboratory, and in the field. (*Primarily for graduate students. Ocean-related curriculum not required. Juniors and seniors admitted with the approval of the instructor.*)
I. Dyer

13.90 *Ocean Engineering Laboratory*
(New)
Prereq.: ——
Year: U (S) 0–12–0
Experience in engineering for the ocean environment. Designing ocean engineering equipment which will function at sea. Emphasis on precise location, both surface and bottom; mooring systems; design and use of electronic, acoustical, mechanical and optical equipment. Underwater work, search and salvage. About two weeks at M.I.T. planning experiments. One month at Maine Maritime Academy in Castine, Maine executing experiments. Remaining time at M.I.T. writing report. One or two large ocean engineering projects undertaken each summer. Research vessels and other equipment provided through cooperation of Maine Maritime Academy. (*Enrollment limited. Preference for admission to the subject based on potential contribution to the projects by the student.*) *D. E. Cummings*

13.92J *Public Policy and Use of the Seas* (A)
(Same subject as 17.870J)
Prereq.: 17.57
Year: G (1) 3–0–6
Policies of the United States and other nations toward use of the seas. Interfaces between technology and public policy. Problems in management of coastal zone; use of Continental Shelf; utilization of ocean resources; pollution; models for international seabed regime. New lines of ocean policy. (*Prerequisite may be waived for students in ocean engineering programs with permission of the instructor.*) *N. J. Padelford*

13.93 *Evolution and Utilization of Marine Resources*
(*New*)
Prereq.: 3.091 or 5.01, 8.02, *18.03*
Year: U (1) 3–0–9
Evolution of marine resources as result of oceanic and geological processes. Application of natural resource economics — including planning of exploratory and development programs — for selecting suitable marine resources for efficient utilization. Application of marine technology and adaptation of land-based resource technology. *A. A. H. Keil, J. W. Devanney*

13.990 *Oceanographic Systems I*
Prereq.: ——
Year: G (S) 2–4–6
Orientation subject for students entering the M.I.T. – Woods Hole Oceanographic Institute joint program in ocean engineering, providing a broad spectrum of experience with the ocean environment and oceanographers. Lectures, special seminars, reading, laboratory and sea experience; participation in summer seminars at W.H.O.I. (*Given at Woods Hole Oceanographic Institution.*)
A. J. Williams III (Woods Hole Staff)

13.991 *Oceanographic Systems II*
Prereq.: 13.990
Year: G (S) 2–4–6
Continuation of 13.990 during second summer term in the M.I.T. – W.H.O.I. joint program in ocean engineering. Preparation for second academic year in academic, research and thesis activities. Experience in depth in a chosen field. Lectures, seminars, laboratory and sea experience. (*Given at Woods Hole Oceanographic Institution.*)
A. J. Williams III (Woods Hole Staff)

13.992 *Oceanographic Systems Analysis I*
Prereq.: 6.28 or 6.57 or 6.571 or 13.60
Year: G (1) 3–0–6
Recovery of information from the ocean; interaction of a natural system (the ocean) with artificial systems (instruments) and subsequent processing of data produced. Oceanographic measurement process as problem in systems analysis. Planning oceanographic cruises as problems in design of experiments. Measures of system effectiveness. Elements of information theory, communications theory, linear systems analysis, decision theory and instrument engineering. (*Given at Woods Hole Oceanographic Institution.*) *Woods Hole Staff*

13.993 *Oceanographic Systems Analysis II*
Prereq.: 13.992
Year: G (2) 3–0–6
Advanced technology applied to measurement of specific oceanographic quantities. Analysis of selected oceanographic expeditions and cost-effectiveness of same. Development of a subsystem in fundamental ocean engineering. Guided seminars, assigned reading and original work in a system design project. (*Given at Woods Hole Oceanographic Institution.*) *Woods Hole Staff*

13.994 *Buoy Engineering* (A)
(*Revised: Unit change*)
Prereq.: 2.01; 2.03 or 13.80; 18.03
Year: G (1) 3–0–6
Classes of buoy systems; advantages and disadvantages. Outline of theoretical and practical aspects of buoy system design. Analysis of single point moored buoy system. Hydrostatics of floating body. Drag forces on surface and subsurface floats. Dynamic response of free buoys. Equilibrium of elastic and non-elastic mooring lines in constant and varying currents. Exciting forces and modes of dynamic response of surface and subsurface buoy systems. Numerical solutions and computer models. Introduction to analysis of multileg systems. Incidence of scientific measurement requirements on system design. Surface and subsurface buoy design. Mooring line components; metals and non-metals. Buoy system installation and retrieval, back-up recovery systems. Student project and sea trip. (*Given at Woods Hole Oceanographic Institution.*)
H. O. Berteaux (Woods Hole Staff)

13.995 *Oceanographic Deep Submergence Engineering* (A)
Prereq.: 2.02, 2.201, 2.403, 13.32, 13.992
Year G (2) 2–3–4
Seminars, system design projects and case studies in feasible deep ocean instrument system as a response to defined scientific missions. Applications of oceanic parameters, fluid and solid mechanics, structural analysis, engineering materials, power sources, machinery systems, life support, safety, navigation and surface and submerged logistics. Emphasis on the manned submerged logistics. Emphasis on the manned submersible as part of an integrated sensing and measuring system. May include a short oceanographic cruise. (*Given at Woods Hole Oceanographic Institution.*)
J. W. Mavor, Jr. (Woods Hole Staff)

13.999 *Special Projects in Ocean Engineering* (A)
(*New*)
Prereq.: ——
Year: G (1, 2, S) *Arr.*
Special problems in ocean engineering carried out under the supervision of qualified members of the staff of the Woods Hole Oceanographic Institution. *Woods Hole Staff*

14.
Economics

GENERAL ECONOMICS AND THEORY

14.01 *Economic Principles I*
Prereq.: ——
Year: U (1, 2, S) 3–0–6
Introduction to fundamental economic concepts and analysis, economic interdependence and the operation of a mixed economy, the determinants of the over-all levels of economic activity, fiscal and monetary policy and international trade and payments. Current economic problems. *R. M. Solow*

14.02 *Economic Principles II*
Prereq : 14.01
Year: U (1, 2) 3–0–6
Continuation of 14.01. The composition and pricing of output of particular industries, supply and demand analysis and competition and monopoly. Current economic problems. *R. W. Crandall*

14.03 ***Prices and Production***
Prereq.: 14.02
Year: U (2) 3–0–6
Basic theory, partial and general, of the firm, household, production and markets, treated at the intermediate level. Emphasis on applications, such as cost-benefit analyses, price regulation, technical change, and income distribution. *R. W. Crandall*

14.04 ***Intermediate Microeconomic Theory***
Prereq.: 14.02
Year: U (1, 2) 4–0–8
Basic theory of consumer behavior, production, pricing, market structures in a partial equilibrium framework, general equilibrium, welfare, and capital. (*Credit given only for either 14.03 or 14.04.*) *P. Bardhan, J. Rothenberg*

14.05 ***Economic Fluctuations and Growth***
Prereq.: 14.02
Year: U (1) 3–0–6
Theory of income determination, static and dynamic. Emphasis on applications to fiscal and monetary policy. *A. G. Hines*

14.06 ***Intermediate Macroeconomic Theory***
Prereq.: 14.02
Year: U (1, 2) 4–0–8
Theory of national income determination, static and dynamic; components of aggregate demand; national accounts. Theory of growth and inflation. (*Credit given only for either 14.05 or 14.06.*) *R. M. Solow, R. F. Engle*

14.09 ***Reading Seminar in Economics***
Prereq.: 14.04, 14.06
Year: U (1, 2) *Arr.*
Reading and discussion of particular topics in economics. (*Open to advanced undergraduate students by arrangement with individual faculty member.*) *Staff*

14.101 ***Mathematics for Economists***
Prereq.: ——
Year: G (1) 3–0–6
Simple and unified introduction to elements of mathematics necessary to the economist with emphasis on calculus. *R. F. Engle*

14.102 ***Mathematics for Economists***
Prereq.: 14.101
Year: G (1) 3–0–6
Continuation of 14.101. Single equation linear difference and differential equations; vector spaces and matrices; system of linear difference and differential equations and latent roots; properties of non-negative square matrices; quadratic forms. *F. M. Fisher*

14.114 ***Economics and Finance: Principles and Policies I***
Prereq.: ——
Year: G (S) 4–0–9
Introductory discussion of the determination of national income and its fluctuations; the composition and pricing of output; financial institutions and the functioning of money and capital markets; fiscal and other stabilization policies; industrial economics, price policy and the relations of government and business; and international economics. (*Restricted to Sloan Fellows.*) ——

14.115 ***Economics and Finance: Principles and Policies II***
Prereq.: 14.114
Year: G (1) 3–0–6
Continuation of 14.114. (*Restricted to Sloan Fellows.*) *P. N. Rosenstein-Rodan*

14.116 ***Economics and Finance: Principles and Policies III*** **(A)**
Prereq.: 14.115
Year: G (2) 3–0–6
Continuation of 14.115. (*Restricted to Sloan Fellows.*) ——

14.121 ***Economic Analysis I*** **(A)**
Prereq.: 14.04
Year: G (1) 4–0–8

14.122 ***Economic Analysis II*** **(A)**
Prereq.: 14.121
Year: G (2) 4–0–8
General theory of equilibrium under competition and monopoly. Theory of consumer choice, of demand, of the firm, of production and distribution, of welfare economics. *R. L. Bishop* (*14.121*), *P. A. Samuelson* (*14.122*)

14.123 ***Advanced Economic Theory I*** **(A)**
Prereq.: 14.102, 14.122
Year: G (1) 3–0–6
Topics centered around modern general equilibrium theory and its extensions. Linear programming, the simplex and duality theorems, and relation to economic analysis. Leontief systems, non-negative square matrices, the Hawkins-Simon and other conditions. Existence, optimality, and stability of competitive equilibrium. The von Neumann model of production as extended; prices and outputs. The turnpike theorem and related topics. *R. M. Solow*

14.124 ***Advanced Economic Theory II*** **(A)**
Prereq.: 14.122
Year: G (2) 3–0–6
Special topics in economic theory, drawn from micro-economics and macroeconomics. Content varying from year to year; current emphasis on theory of capital and behavior under uncertainty. ——

14.125 ***Mathematical Price Theory*** **(A)**
Prereq.: 14.102, 14.122
Year: G (1) 3–0–6
Systematic mathematical treatment of topics in neo-classical price theory. Theory of the firm and household; general equilibrium; related topics. *F. M. Fisher*

14.132 ***Schools of Economic Thought*** **(A)**
Prereq.: 14.121
Year: G (1) 3–0–6
Economic ideas developed by different groups of economists in recent times. *P. A. Samuelson*

14.151 ***Mathematical Approach to Economics*** **(A)**
Prereq.: 14.122
Year: G (2) 3–0–6
The use of mathematical methods in all the fields of economics. *P. A. Samuelson*

14.191 ***Economics Seminar*** **(A)**
Prereq.: 14.121
Year: G (1) 3–0–6

14.192 ***Economics Seminar*** **(A)**
Prereq.: 14.121
Year: G (2) 3–0–6
Special economic problems. ——

14.193 ***Seminar: Topics in Economics*** **(A)**
Prereq.: 14.121, 14.451
Year: G (1) 3–0–6

14.194 ***Seminar: Topics in Economics*** **(A)**
Prereq.: 14.122, 14.452
Year: G (2) 3–0–6
Topics in economics of current interest. ——

14.195 ***Reading Seminar in Economics*** **(A)**
Prereq.: 14.121
Year: G (1) *Arr.*

14.196 ***Reading Seminar in Economics*** **(A)**
Prereq.: 14.121
Year: G (2) *Arr.*

Reading and discussion of special topics in economics. (*Open to advanced graduate students by arrangement with individual members of the staff.*) *Staff*

INDUSTRIAL ECONOMICS

14.20 ***Industrial Organization and Public Policy***
Prereq.: 14.02
Year: U (1) 3–0–6

Analysis of market structures in the U.S. economy. Measures of market concentration and monopoly power. Detailed study of the effectiveness of American antitrust policy and public utility regulation. *R. W. Crandall*

14.22 ***Economics of Particular Industries***
Prereq.: 14.04
Year: U (1) 3–0–9

Analysis of key economic features of particular industries such as nature of production process, characteristics of demand for its output, financial problems, growth, stability, and location. Entire term ordinarily to be spent on two or three industries such as transportation, chemical, machinery, fuel and power, minerals, and retail. (*Not offered 1971–72.*) *R. W. Crandall*

14.23 ***Economics of Fuel and Power***
Prereq.: 14.02
Year: G (2) 2–0–4

Survey of the main trends in production, pricing, and investment costs of coal, electric power, crude oil, and refined oil products. Economics of nuclear power. (*Intended for students of either economics or engineering. Not offered 1971–72.*) *M. A. Adelman*

14.271 ***Problems in Industrial Economics*** **(A)**
Prereq.: 14.04
Year: G (1) 3–0–6

Small and large enterprises in the American economy; market structures; degrees of monopoly and competition; requisites of public policy. *R. W. Crandall*

14.272 ***Government Regulation of Industry*** **(A)**
Prereq.: 14.271
Year: G (2) 3–0–6

Follows 14.271. Development of anti-trust policy, generally and in specific cases. "Public utility" price fixing, government ownership as alternative. *R. W. Crandall*

14.282 ***Economics of Technology and Innovation*** **(A)**
Prereq.: 14.04
Year: G (1) 3–0–6

Analysis of the economic and engineering concepts of technology, alternative estimates of production and cost functions. Theories of adjustment to technological change and research and development with case studies of innovation processes. Technological adaptation in less developed areas. Economics of education and training. (*Not offered 1971–72.*) *R. S. Eckaus*

14.291 ***Industrial Economics Seminar*** **(A)**
Prereq.: 14.271
Year: G (1) 3–0–6

14.292 ***Industrial Economics Seminar*** **(A)**
Prereq.: 14.271
Year: G (2) 3–0–6

Readings, discussions, reports on such topics as industrial price policies, government regulation of industry, competitive practices, and similar problems in industrial economics. ——

STATISTICS

14.30 ***Introduction to Statistical Method in Economics***
Prereq.: 18.02
Year: U (1) 4–0–8

Self-contained introduction to statistics with economic applications. Elements of probability theory, sampling theory, statistical estimation, regression analysis and hypothesis testing. Elementary econometrics and other applications of statistical tools to economic data. *R. F. Engle*

14.31 ***Econometrics***
(*Revised: Unit change*)
Prereq.: 14.30 or 14.381
Year: U (2) 3–4–5

Introduction to basic econometric techniques with strong emphasis on applications. Problems in estimating such economic variables as consumption-income-price relationships, production functions, and in simulating economic models. *E. Kuh*

14.371 ***Statistical Inference I*** **(A)**
Prereq.: 18.02
Year: G (1) 3–0–9

Axiomatic probability, random variables, distribution functions, mathematical expectation, characteristic and generating functions, probability distributions, transformations of random variables, convolution, the probability structure of correlation and regression. *H. A. Freeman*

14.372 ***Statistical Inference II*** **(A)**
Prereq.: 14.371
Year: G (2) 3–0–9

Modern statistical inference. Sampling theory, point and interval statistical estimation, maximum likelihood theory, the Gauss-Markov theorem and least squares, testing statistical hypotheses, decision function theory, the general linear hypothesis. *H. A. Freeman*

14.373 ***Time-Dependent Probability*** **(A)**
Prereq.: 14.371 or 18.303
Year: G (1) 3–0–6

Markov chains and Markov processes, the relevant ergodic theorem, Kolmogorov equations, time series theory: spectral density functions, harmonic representation, autoregressive models. *H. A. Freeman*

14.374 ***Design and Analysis of Scientific Experiments*** **(A)**
Prereq.: 14.381
Year: G (2) 3–0–6

Application of statistical theory to the design and analysis of scientific experiments. Factorial and fractional factorial designs. Applications to experimentation in the physical, chemical, biological, medical, and social sciences. *H. A. Freeman*

14.381 ***Statistical Method in Economics***
Prereq.: 14.101 or 18.02
Year: G (1) 4–0–8

Self-contained introduction to probability and statistics which serves as a background for advanced econometrics. Elements of probability theory, sampling theory, asymptotic approximations, decision theory approach to statistical estimation focusing on regression, hypothesis testing and maximum likelihood methods. Illustrations from economics and application of these concepts to economic problems. *R. F. Engle*

14.383 ***Econometric Theory*** **(A)**
Revised: Unit change
Prereq.: 14.102; 14.30 or 14.372 or 14.381
Year: G (1) 4–0–8

Principal statistical problems in the analysis of economic phenomena, including identification, least-squares bias, and autocorrelation, with emphasis on newer estimation procedures. *F. M. Fisher, R. E. Hall*

14.384 ***Applied Econometrics*** **(A)**
Prereq.: 14.383
Year: G (2) 3–0–6
Econometric applications to supply and demand analysis and macroeconomic models. Emphasis on using structural econometric models for policy and forecasting. An empirically oriented term paper required.
E. Kuh, R. E. Hall

14.386 ***Advanced Topics in Econometrics*** **(A)**
Prereq.: 14.383
Year: G (2) 3–0–6
Selected topics including specification error, non-linear estimation, simulation, aggregation, and the derivation of economic policy models. *A. G. Hines, F. M. Fisher*

14.39 ***Economic Research Seminar***
Prereq.: 14.04, 14.06, 14.30
Year: U (1) 2–0–10
Introduction to research procedures in economics in preparation for thesis. Students to prepare reports on research topics. *Staff*

14.391 ***Workshop in Economic Research*** **(A)**
(New)
Prereq.: 14.122, 14.452
Year: G (1) 2–0–10
14.392 ***Workshop in Economic Research*** **(A)**
(New)
Prereq.: 14.122, 14.452
Year: G (2) 2–0–10
Designed to develop research ability of students through intensive discussion of dissertation research as it proceeds, carrying out of individual or group research projects, and critical appraisal of current reported research. Workshops divided into various fields, depending on interest, and size. *Staff*

NATIONAL INCOME AND FINANCE

14.40 ***Monetary and Banking Policy***
Prereq.: 14.06
Year: U (2) 3–0–9
Monetary factors affecting the level of national income and relationships of financial institutions to these factors. Financial organization of society: the money-banking system, credit institutions, capital markets, and international financial relations. *D. K. Foley*

14.41 ***Distribution of Income and Employment Opportunity***
Prereq.: 14.02
Year: U (2) 3–0–6
Analysis of public policies deriving from concerns about the equity of the distribution of income and employment opportunities in the United States. Particular attention to manpower training, public assistance, the "war on poverty," and the economic problems of Afro-Americans.
M. J. Piore

14.43 ***Public Finance***
Prereq.: 14.04, 14.06
Year: U (1) 3–0–9
Effects of government revenue and expenditure programs on the level and distribution of economic activity; intergovernmental fiscal problems; relationship of fiscal to other economic policies. *P. A. Diamond*

14.451 ***Theory of Income and Employment*** **(A)**
Prereq.: 14.06
Year: G (1) 4–0–8
Examination of principal determinants of aggregate levels of income and employment. *D. K. Foley*

14.452 ***Economic Growth and Fluctuations*** **(A)**
Prereq.: 14.451
Year: G (2) 4–0–8
Application of theory of income and employment to analysis and measurement of changes in level of economic activity over time, and the study of inflation. *R. E. Hall*

14.462 ***Monetary Economics I*** **(A)**
Prereq.: 14.121, 14.451
Year: G (2) 3–0–6
Examination of sources and determinants of supply of money with special attention to roles of commercial banks, Federal Reserve System, and Treasury. Discussion of nature of demand for money. Role of monetary policy in determination of level of economic activity.
F. Modigliani

14.463 ***Monetary Economics II*** **(A)**
Prereq.: 14.122, 14.452
Year: G (1) 3–0–6
General equilibrium theory of money, interest, prices, and output; portfolio problems, cost of capital, and the effects of monetary phenomena on investment and accumulation of wealth with special reference to problems arising from uncertainty. *D. K. Foley*

14.471 ***Fiscal Economics I*** **(A)**
Prereq.: 14.121, 14.451
Year: G (1) 3–0–6
14.472 ***Fiscal Economics II*** **(A)**
Prereq.: 14.121, 14.451
Year: G (2) 3–0–6
Examination, both theoretic and quantitative, of governmental fiscal institutions and behavior: the budget process, taxation, expenditure, pricing, and debt activities. *P. A. Diamond (14.471); E. C. Brown (14.472)*

INTERNATIONAL, INTERREGIONAL, AND URBAN ECONOMICS

14.51 ***Urban Economics***
Prereq.: 14.02
Year: U (1, 2) 3–0–6
Analysis of selected economic problems of urban areas in the United States. Metropolitan growth and suburbanization. Housing markets, segregation and urban renewal. Transportation systems. Ghetto economic development. Scale, finance and decentralization of public services. Development of methodological approaches through discussion of policy issues.
R. E. Grieson, M. D. Edel

14.52 ***Economics of the Soviet Union***
Prereq.: 14.02
Year: U (2) 3–0–6
Historical background. Russian agriculture and industry before the Communist revolution. Economic ideology of the Communist regime. General approach to industrialization. Allocation of resources. Agriculture and industry. Management and labor. Recent changes and discussions. Evaluation of the Soviet experiment. Lessons for underdeveloped countries. *(14.53 is desirable preparation but not a prerequisite. Not offered 1971–72.)*
E. D. Domar

14.53 ***Comparative Economic Systems***
Prereq.: 14.02
Year: U (1) 3–0–6
Analytical study of economic problems in different economic systems. The economic ideology of capitalism, utopian writings, Marxism and socialism. Comparison of several capitalist and socialist countries, including the United States, West Germany, Sweden and Yugoslavia. Role of the price system, investment decisions, economic growth, etc. *(Not offered 1971–72.)* *E. D. Domar*

14.54 *International Trade*
Prereq.: 14.04, 14.06
Year: U (2) 3–0–9
Theory of international trade and finance, and application to current problems, such as exchange restrictions, economic development, and foreign aid. *P. Bardhan*

14.572J *Regional Economic Analysis* (A)
(Same subject as 11.44J)
Prereq.: 14.04, 14.06; or 14.03, 14.05
Year: G (2) 3–0–6
Analysis of regional economies with emphasis on the sources, characteristics, and implications of spatial concentrations of economic activities. Urban development in its regional setting is examined and the special problems of lagging areas in both developing and developed countries explored in some detail. Methods of integrating national and regional planning investigated. The following analytical tools developed and applied: location theory; spatial competition; general equilibrium models of interregional activity with emphasis on input-output and linear programming models; models of regional income determination. Special attention paid to spatial factors affecting the demand for transportation services. *J. R. Harris*

14.573J *Urban Economic Analysis I* (A)
(Same subject as 11.261J)
Prereq.: 14.03 or 14.06, 14.04, 14.05
Year: G (1) 3–0–6
Patterns and processes of growth and structural change within metropolitan areas. The land use market and the spatial structure of the metropolitan community. The housing market; demand and supply, growth, aging, and renewal. The urban transportation system and its problems. Models of the metropolis. In each of these topics, emphasis on the resource allocation process, its efficiency and implications for income distribution.
J. R. Harris

14.574J *Urban Economic Analysis II* (A)
(Same subject as 11.262J)
Prereq.: 11.261J or 14.573J
Year: G (2) 3–0–6
Continuation of 14.573J. The nature and problems of government decision-making in metropolitan areas. The economies of segregation, congestion, and pollution in the metropolitan area. Urban-suburban relations: market and government. Welfare economics and the normative theory of local public policy. Applied normative analysis: criteria for public expenditures; cost-benefit analysis. Examination of public policy issues in current urban problems: poverty, race, the spatial form of the city, optimal land use patterns, growth and renewal, development and new communities. *J. Rothenberg*

14.581 *International Economics I* (A)
Prereq.: 14.04, 14.06
Year: G (1) 4–0–8
Theory of international trade and applications in commercial policy. *J. N. Bhagwati*

14.582 *International Economics II* (A)
Prereq.: 14.581
Year: G (2) 4–0–8
Adjustment in international economic relations with attention to foreign exchange markets, balances of payments, and the international monetary system.
P. Bardhan

LABOR ECONOMICS AND INDUSTRIAL RELATIONS

14.63 *Labor Relations*
Prereq.: ——
Year: U (1, 2) 3–0–6
An introductory analysis, through an integrated social science approach, of the institutions which have developed in response to "human resource problems." The growth, structure, and objectives of management and organized labor groups, collective bargaining as part of a dynamic accommodation process between organizations that have economic, political, and social characteristics.
J. E. Annable

14.64 *Labor Economics and Public Policy*
Prereq.: 14.02 or 14.63
Year: U (1, 2) 3–0–6
Particular applications of the analytical tools developed in prerequisite subjects to two aspects of the industrial relations scene: (1) the economics of collective bargaining, problems presented by wage determination at firm, industry, and economy levels; and (2) the development of public policy on the rights and obligations of employers, unions, and workers. (*Permission of instructor required.*)
M. J. Piore, D. Q. Mills

14.671J *Labor Economics* (A)
(Same subject as 15.671J)
Prereq : 14.64 or 15.663
Year: G (1) 3–0–6
Primary emphasis on the determination of wage levels and wage differentials through an analysis of labor supply and labor demand, as affected by economic as well as by institutional factors. The impact of unions on both wage and non-wage elements of collective bargaining in the light of the characteristics and objectives of particular unions. Other special topics growing out of recent research in labor economics.
M. J. Piore, C. A. Myers

14.672J *Public Policy on Labor Relations* (A)
(Same subject as 15.672J)
Prereq.: 14.64 or 15.663
Year: G (1) 3–0–6
Major trends in labor legislation, the legality of union activities, protection of the right to organize and bargain collectively, regulation of wages and hours, governmental machinery for the adjustment of labor disputes, and social insurance. The broad economic and social questions raised by these trends. (*Not offered 1971–72.*)
M. J. Piore, D. V. Brown

14.674J *Comparative Systems of Industrial Relations and Human Resource Development* (A)
(Same subject as 15.674J)
Prereq.: 14.64 or 15.663
Year: G (2) 3–0–6
International and comparative analysis of industrial relations systems and systems of human resource development. Concentration on an examination of selected issues involving interest groups and the strategies of economic development, including discussion of the nature and functions of labor and management organization in different contexts; the role of the state in establishing procedures and in shaping the substance of industrial relations; the participation of interest groups in the formulation of economic and social policy; manpower and economic growth in the context of comparative systems of human resource development; external influences on national industrial relations systems and human resource development. *C. A. Myers*

14.691J *Research Seminar in Industrial Relations* (A)
(Same subject as 15.691J)
Prereq.: 14.671J or 14.672J
Year: G (1) 3–0–6
Discussion of important areas for research in industrial relations, frameworks for research, research techniques, and methodological problems. Centered mainly on the thesis research of advanced graduate students.
C. A. Myers

14.692J ***Research Seminar in Industrial Relations*** **(A)**
(Same subject as 15.692J)
Prereq.: 14.691J
Year: G (2) 3–0–6
Continuation of 14.691J. *C. A. Myers*

ECONOMIC HISTORY

14.71 ***Economic History***
Prereq.: 14.02
Year: U (1) 3–0–6
Survey of growth in the American and European economy in the nineteenth and twentieth centuries. Topics including the economic effects of governmental policies, the causes and effects of technical change, the role of specific institutions, the economic causes of political conflicts. Content varying from year to year, with emphasis usually on the United States. *P. Temin*

14.731 ***American Economic History*** **(A)**
Prereq.: 14.121
Year: G (1) 3–0–6
Basic survey of the beginnings of American industrialization, emphasizing a quantitative approach and the period from 1760 to 1860. The nature of the colonial economy, economic problems of political independence, factors inducing the growth of industry (and specific industries), problems of antebellum agriculture and slavery. *P. Temin*

14.733 ***European Economic History*** **(A)**
Prereq.: 14.121
Year: G (1) 3–0–6
Development of the European economy since 1750 and, especially since 1850, with emphasis on growth and slowdown, the transition from local to national and European-wide institutions, and extra-European relations. *(Not offered 1971–72.)* *C. P. Kindleberger*

14.734 ***Problems in Economic History*** **(A)**
Prereq.: 14.731 or 14.732
Year: G (2) 3–0–6
Analysis of problems of industrial society, concentrating on the century after 1860 and on the American experience. Subject matter varying from year to year on topics such as the effects of wars on welfare and growth, the nature of the long deflation of the late nineteenth century, the contrast in international relations before and after 1914, the depression of the 1930's. *P. Temin*

ECONOMIC DEVELOPMENT

14.74 ***Economic Growth and Development***
Prereq.: 14.02
Year: U (1) 3–0–6
Analytical treatment of the problems of economic growth and development combined with comparative studies of the growth of advanced and underdeveloped economies. Considerations of policy measures to promote economic development and growth. *M. D. Edel*

14.771 ***Problems of Economic Development*** **(A)**
Prereq.: 14.772
Year: G (1) 3–0–6
Applications of development theory. Studies of structure of less-developed economies, technological constraints, interaction of foreign trade and internal development, international financial problems. *P. N. Rosenstein-Rodan*

14.772 ***Theory of Economic Development*** **(A)**
Prereq.: 14.121, 14.451
Year: G (2) 3–0–6
Analysis of theories of economic development with attention to alternative patterns of resource scarcity, population growth, and models of growth. Econometric and programming models for planning. Investment criteria in less-developed countries. *J. Bhagwati*

14.781 ***Problems in Russian Economic History*** **(A)**
(New)
Prereq.: 14.121
Year: G (1) 3–0–9
A comparative study of the major problems in Russian economic history prior to 1917 both for their own sake and as a background for understanding of the events of 1917 and of the Soviet policies since. The exact topics covered may vary from year to year depending on the interests of the participants, but the land and peasant problems and industrialization methods will be emphasized. *(Not offered 1971–72.)* *E. D. Domar*

14.782 ***Capitalism, Socialism and Growth*** **(A)**
Prereq.: 14.121, 14.451
Year: G (2) 3–0–6
A comparative study of capitalist and socialist economies mainly from the point of view of development and growth, and with major emphasis on the economy of the Soviet Union. *(Not offered 1971–72.)* *E. D. Domar*

15.
Management

MANAGERIAL ECONOMICS

15.001 ***Managerial Economics***
Prereq.: ——
Year: U (1) 4–0–8
Introduction to fundamental concepts of the economics of the firm and of industry. The mechanisms of supply and demand. Operation of the price-profit system. Market structures and market behavior in specific industries. Analyses of economic problems of relevance to management. *P. W. MacAvoy*

15.012 ***Economics for Management I***
Prereq.: ——
Year: G (1) 3–0–6
Microeconomics for students of management. How the price-profit system works through operation of supply and demand. Market structures and market behavior in specific industries. Regulation of competition. *(Restricted to Sloan School of Management graduate students; others admitted only with permission of instructor.)*
P. W. MacAvoy

15.014 ***Economics for Management II***
Prereq.: 15.012
Year: G (2) 3–0–6
Macroeconomics for students of management. Study of the determination of national income and the level of economic activity; monetary economics and growth; prices and business cycles; stabilization policies, monetary and fiscal, and balance of payments problems. *(Restricted to Sloan School of Management graduate students; others admitted only by permission of instructor.)* *L. C. Thurow*

15.039 ***Economics for Management I***
Prereq.: ——
Year: G (1) 3–0–6
Microeconomics for advanced students of management. Subject matter of 15.012 treated in greater theoretical depth, with advanced work in econometric models and more complex econometric case studies. *(Primarily for doctoral students in the Sloan School of Management.)*
S. S. Alexander

15.041 ***Economics for Management II***
Prereq.: 15.039
Year: G (2) 3–0–6
Macroeconomics for advanced students of management. Subject matter of 15.014 treated in greater theoretical depth, with advanced work and case studies. Attempts made to construct a large-scale econometric model of the American economy. (*Primarily for doctoral students in the Sloan School of Management.*) *S. S. Alexander*

15.042 ***Seminar in Economics for Management*** **(A)**
Prereq.: 15.014
Year: G (2) 3–0–6
Review of basic economic theories of the firm, the industry and the economy, with emphasis on those aspects useful for analyzing the American experience. Detailed discussion of case studies applying the theories, including industry studies of the pricing effects of market structure, economy-wide forecasts, and studies of the effects of government regulatory, monetary, and fiscal policies. (*Restricted to doctoral candidates in the Sloan School of Management.*) *P. W. MacAvoy*

OPERATIONS RESEARCH/STATISTICS

15.052 ***Industrial Statistics***
Prereq.: 18.03
Year: U (1, 2) 4–0–8
Introduction to statistical methods with application to engineering and administrative problems. Basic statistical distributions including binomial, hypergeometric, Poisson, exponential, normal, and Chi-square. Introduction to acceptance sampling, quality control, and the analysis of variance. (*Not offered 1971–72.*) *D. Durand*

15.053 ***Quantitative Methods for Management***
Prereq.: 18.02
Year: U (1) 4–0–8
Introduction to mathematical programming emphasizing applications to management problems. Formulation and solution of linear optimization models. Simplex method, duality theory, sensitivity analysis. Transportation and network flow problems. Introduction to dynamic programming, integer programming and branch-bound methods. (*Limited enrollment.*) *Staff*

15.054 ***Statistical Decision Theory I***
Prereq.: 6.28
Year: U (2) 3–0–6
Decision making under uncertainty. Rationales of decision makers, utility, the concept of the value of perfect information. The Bayesian approach. Preposterior, optimal fixed-size, and other forms of analysis of statistical decision problems. *G. M. Kaufman*

15.061 ***Mathematics for Management I***
Prereq.: ——
Year: G (1) 4–0–8
Introduction to probability and statistics emphasizing applications to management problems. Such topics as set theory, basic probability theory, an introduction to decision making under uncertainty, Bernoulli, Poisson, normal, and Markov processes and aspects of statistical inference. *Staff*

15.062 ***Mathematics for Management II***
Prereq.: ——
Year: G (1, 2) 4–0–8
Introduction to mathematical programming emphasizing applications to management problems. Formulation and solution of linear optimization models. Simplex method, duality theory, sensitivity analysis. Transportation and network flow problems. Introduction to dynamic programming, integer programming and branch-bound methods. *Staff*

15.063 ***Statistics for Model Building*** **(A)**
Prereq.: 15.061
Year: G (1) 3–0–6
Applied statistics for management. Topics: regression analysis, non-linear regression, simultaneous equations, discriminant analysis, factor analysis, experimentation, and other special topics. Oriented toward appplications, but sufficient theory covered for assuring proper use. Applications project required. *G. L. Urban, G. A. Pogue*

15.065 ***Statistical Decision Theory*** **(A)**
Prereq.: 6.28
Year: G (1, 2) 3–0–6
Development of a basic theory of decision making under uncertainty. Rationales of decision makers, utility, the concept of the value of perfect information. The Bayesian approach to decision making; its relationship to classical statistics. Pre-posterior analysis and optimal fixed-size analysis for common random processes. Discussion of normal vs. extensive form analysis of statistical decision problems. *G. M. Kaufman*

15.066 ***Sampling of Finite Populations*** **(A)**
Prereq.: 15.052 or 15.062
Year: G (2) 3–0–6
This subject is designed specifically for students in advanced marketing and demand analysis. Cluster sampling; equal and unequal sized cluster; cluster sampling with and without subsampling; multistage sampling; combinations of cluster sampling and stratified sampling; disproportionate stratified sampling; two-phased and sequential sampling. (*Not offered 1971–72.*) *D. Durand*

15.073 ***Stochastic Systems*** **(A)**
Prereq.: 15.061
Year: G (1) 3–0–6
Topics include: Poisson and compound Poisson processes, renewal theory, Markov chains, semi-Markov and regenerative processes, Markov decision processes, birth and death processes. Applications of discrete and continuous time stochastic optimization models in management science and operations research. (*Knowledge of the material in 18.100 useful but not required.*) *R. E. Welsch*

15.075 ***Mathematical Statistics*** **(A)**
Prereq.: 6.28, 18.700
Year: G (2) 3–0–6
Topics selected from: analysis of variance, estimation, theory of statistical inference, large sample theory, and sequential analysis. (*Knowledge of the material in 18.100 useful but not required.*) *R. E. Welsch*

15.077 ***Bayesian Analysis Studies*** **(A)**
Prereq.: 15.065
Year: G (1) 3–0–6
Primary emphasis on Bayesian methods in multivariate problems. Content varying from year to year. Typical topics: the multivariate normal distribution, best of several processes problem, stratified sampling, bias, extended natural conjugate analysis of the normal process, multiple regression, multivariate regression, simultaneous equation systems, Bayesian interpretation of standard multivariate inference statements. Term paper on selected multivariate statistical problems. *G. M. Kaufman*

15.081 ***Mathematical Programming*** **(A)**
Prereq.: 18.700
Year: G (1, 2) 3–0–6
Introduction to mathematical optimization. Linear programming: simplex method, duality, sensitivity analysis, geometric view. Transportation and network flow problems. Elements of integer programming: cutting planes, branch and bound methods. Introduction to generalized programming. *J. D. C. Little*

Descriptions

15.083 *Combinatorial Optimization* (A)
(New)
Prereq.: 15.081
Year: G (1) 3–0–6
Subject devoted to integer programming and related topics. Integer programming topics: group optimization methods, cutting plane method and faces of an integer polyhedron, Benders' method for mixed integer programming. Other topics: minimum spanning trees and the traveling salesman problem, special properties of and algorithms for covering problems, matroid optimization problems. Applications including fixed charge problems, network synthesis, scheduling problems, nonlinear programming. *J. F. Shapiro*

15.084J *Nonlinear Programming and Discrete Optimal Control* (A)
(New)
(Same subject as 6.664J)
Prereq.: 18.100
Year: G (1) 3–0–9
Review of linear programming. Unconstrained optimization and convex analysis. Generalized Lagrange multipliers, duality theory and the Kuhn-Tucker theorem. Nonlinear programming algorithms including quadratic programming, method of feasible directions, cutting plane and penalty function methods. Discrete maximum principle. Computational methods and discretization of continuous optimal control programs. Dynamic programming and control of Markov chains. *(Knowledge of 18.700 useful but not required.)*
J. F. Shapiro, S. K. Mitter

15.094J *Optimization in Finite and Infinite Dimensions* (A)
(New)
(Same subject as 6.665J)
Prereq.: 15.084J
Year: G (2) 3–0–9
Constructive fixed point theory. Contraction mappings and dynamic programming. Elementary Hilbert space theory. Convex programming and duality theory in Hilbert space. Optimal control problems and the maximum principle. Approximation and iterative methods in function space. *J. F. Shapiro, S. K. Mitter*

15.099 *Seminar in Applied Mathematics* (A)
Prereq.: 15.062
Year: G (2) 3–0–6
Discussion of current literature in the field with the purpose of reviewing and building upon the basic material covered in 15.061 and 15.062. Emphasis on mathematical techniques applicable in interdisciplinary theses and other studies and their applications in fields of interest to management. *Staff*

SLOAN PROGRAM

15.181 *Management Information and Controls*
Prereq.: ——
Year: G (S) 3–0–6
Theory and techniques underlying the generation of information measuring results of managerial efforts and the uses of such information for financial reporting, evaluation of alternative courses of action, motivation of efficient behavior, control, and managerial decision making. Application of theory to project analyses, transfer pricing, and issues arising out of decentralized structures. *(Restricted to Sloan Fellows.)* ——

15.182 *Quantitative Methods*
Prereq.: ——
Year: G (S) 3–0–6
Mathematical and statistical tools necessary for modern managerial analysis. Introduction of fundamental concepts underlying various techniques recently developed to facilitate managerial decision making under uncertainty. Emphasis on basic understanding and evaluation of modern quantitative techniques rather than technical expertise. *(Restricted to Sloan Fellows.)*
W. H. Hausman

15.183 *Readings in Power and Responsibility* (A)
Prereq.: ——
Year: G (1, 2) 3–0–6
Detailed examination of major historical ideas affecting American industrial philosophy and processes. *(Restricted to Sloan Fellows.)* ——

15.184 *Structure of American Law*
Prereq.: ——
Year: G (S) 3–0–6
Analysis of the American legal system as a process for ordering our society. Consideration of selected legal problems to reveal the operation of the major component elements of the system: the judicial, legislative, administrative and private law-making power. Consideration of substantive law primarily from the standpoint of the process for generating and modifying legal policy. Emphasis on the problems of the law of business institutions. Extensive reading of case law as well as textual materials and legal essays. Research projects involving use of a law library. *(Restricted to Sloan Fellows.)*
S. M. Jacks

15.185 *Operations Management* (A)
Prereq.: 15.181, 15.182
Year: G (1) 3–0–6
Theoretical approaches to problems faced by an operating manager. Emphasis on developing general principles of model-based planning and control on the operational level. Topics covered include scheduling systems, network based management systems (PERT/CPM and extensions). Resource allocation problems, and principles of implementation for integrated systems. Supporting topics in information systems, simulation theory, and operations research as needed. Applications from the public and private sector are covered to illustrate and extend material introduced. *(Restricted to Sloan Fellows.)*
W. B. S. Crowston

15.186 *Marketing* (A)
Prereq.: 15.181, 15.182
Year: G (1) 3–0–6
Structure of consumer and industrial demand. Study of problems of achieving suitable distribution within the perspective of total promotional problem. Intensive study of several marketing management problems, such as formation of sound product policy, evaluation of promotion programs, and determination of market potentials. *(Restricted to Sloan Fellows.)* *Staff*

15.187 *Organizational Psychology* (A)
Prereq.: 15.184
Year: G (1, 2) 3–0–6
Analysis — through lectures, discussions, and class exercises — of management of human resources in industry. Emphasis on internal relations of management. *(Restricted to Sloan Fellows.)* *M. Haire*

15.188 *Labor-Management Relations and Public Policy* (A)
Prereq.: 15.184
Year: G (1) 3–0–6
Brief survey of the background of labor law, followed by analysis of the nature of the collective bargaining process, its major issues and points of contention. Discussion of selected problems in public policy. *(Restricted to Sloan Fellows.)* *C. A. Myers*

15.194 ***Foreign Policy for Executives***
Prereq.: ——
Year: G (2) 3–0–6
Examination of significant problems of contemporary American foreign policy and international relations of particular concern to management. Special attention given to developments in Communist countries, problems of the emerging nations, changes in Western Europe, issues of defense and arms control, and planning and administering foreign policy operations. *(Restricted to Sloan Fellows.)* ——

15.198 ***Seminar in Administration*** **(A)**
Prereq.: 15.181
Year: G (1) 3–0–6

15.199 ***Seminar in Administration*** **(A)**
Prereq.: 15.181
Year: G (2) 3–0–6
Study of fundamental economic, financial, organizational and administrative relationships analyzed and discussed by experienced leaders in business, labor and public administration. Examination of managerial philosophies and practices in the field and in seminar discussions. *(Restricted to Sloan Fellows.)* *P. P. Gil*

INTERNATIONAL BUSINESS

15.221 ***International Business Management I*** **(A)**
Prereq.: 15.012
Year: G (2) 3–0–6
Theory of, and institutional restraints acting on, international business, with emphasis on the pressure to effect harmonization of a firm's objectives with those of foreign business associate or customer, host government, and parent government. Discussion of historical flows of trade and investment and the impact of such flows on host and parent societies, followed by coverage of institutional restraints in the legal, informational, financial, and commercial areas. Specific problem areas dealt with: sources of foreign market information and evaluation of same, conflict of law regarding property and rights of aliens, taxation of international income, antitrust law, adjudication of international business disputes, investment guarantees, international banking operations, foreign exchange controls, financing of foreign trade, trade agreements and trading areas, international shipping and communications. Term project: an analysis of a foreign market for a specified product and firm.
R. D. Robinson

15.222 ***International Business Management II*** **(A)**
Prereq.: 15.221
Year: G (1) 3–0–6
In-depth examination of two or three foreign environments and familiarization with several important analytical constructs relevant to their understanding, followed by focus on characteristic organizational and operational problems arising from the international nature of the firm. Specific problem areas: development of an international business structure, selection of the appropriate form of international business relationship, communication across national cultural frontiers, selection of management personnel, management of labor-management relations under diverse circumstances, impact of different factor mixes on production, reduction of financial risk, development of an optimum control system. Term project: a role-playing game calling for design of the legal, administrative, and control structure of an internationalizing firm. *R. D. Robinson*

15.223 ***International Business Environments*** **(A)**
Prereq.: 15.012
Year: G (1) 3–0–6
Divided into four sections. Focus of each section on a different region (Europe, Latin America, Japan, North America). Subject areas in each: historical inputs; social-psychological dimensions; political and economic structure; characteristics of labor organizations, financial institutions, and market structure. Relation of such environmental variables to company organization, managerial behavior, corporate policy. Treatment of important social issues confronting the business community. Sections meet separately for most sessions, but comparative material presented in joint sessions. Insofar as scheduling permits, students permitted to move among sections following subjects of greatest personal interest on an interregional basis. Active student participation in class presentation required.
R. D. Robinson, P. M. Goldberg

15.224 ***Intercultural Communication I*** **(A)**
Prereq.: 15.221
Year: G (2) 3–0–6

15.225 ***Intercultural Communication II*** **(A)**
Prereq.: 15.224
Year: G (1) 3–0–6
Subjects designed as a sequence of experiences providing in-depth exposure to a culture with which the student has not had significant prior contact. Requirements for each student: development of a working proficiency (oral) in a major language of his target area; completion of a background reading course under the supervision of a faculty member; three months devoted to pursuit of some general line of inquiry within his target area subject to approval of his reading course instructor and the instructor in charge of this subject; a working paper reporting on his experience abroad. Defrayment of expenses for the language training (if M.I.T. facilities inadequate) and expenses incurred by reason of residence and travel abroad the student's liability. Normal time for the overseas experience during the summer between a student's first and second years. A required working paper in 15.225, as well as consultation with the two instructors involved. *(Required for Ph.D. students offering international management as their major applied field. Requirements for Ph.D.: an article-length report of publishable quality; passing an oral examination measuring understanding of the foreign culture, including the relevant language.)* *R. D. Robinson*

HISTORY AND ENVIRONMENT

15.251 ***Managerial Environment***
Prereq.: 15.001, 15.301
Year: U (2) 4–0–8
The nature of the environment affecting the operation and growth of purposeful organizations. Social, political, and technological changes, and their impact on managerial problems and responsibilities. The multidimensional character of issues posed by environmental changes. Interaction of business, government, and nonprofit organizations with technology and society at large.
Staff

15.262 ***Management Environment***
Prereq.: ——
Year: G (1, 2) 3–0–6
Opportunity for survey coverage and intensive study of the executive's interactions with, and responsibilities to, his environment. Factors examined may include the employees; the local community; the labor force; other corporations; consumers; local, national and foreign governments; and local, national and world economies. Emphasis on student participation both in planning and execution of subject program. *Staff*

ORGANIZATION STUDIES

15.301 ***Managerial Psychology***
Prereq.: ——
Year: U (1, 2) 3–0–6
Core subject for all students majoring in management. Survey of individual and social psychology and organization theory interpreted in the context of the managerial environment. *T. J. Allen*

15.302 *Social Psychology*
Prereq.: 15.301
Year: U (2) 3–0–6
Cognitive processes such as learning, perception, and problem solving as individual phenomena and within the social context. Detailed examination of basic social psychological concepts such as influence, attitudes, communication, conflict, and interpersonal relations to provide understanding of the dynamics of group behavior. Provision of conceptual tools for application in the study of human behavior in organizations. *G. F. Farris*

15.304 *Complex Organizations*
Prereq.: 15.302
Year: U (1) 3–0–6
Patterns of authority and control, socialization processes, member reference, group orientations (cosmopolitan vs. local), decision making structures, methods of conflict resolution as essential elements in any organization. Examination and comparison of different forms of organization (e.g., manufacturing companies, administrative agencies, research laboratories, hospitals) within the framework of these factors in terms of their implications for various dimensions of organizational performance (e.g., productivity, innovation and creativity). ——

15.305 *Statistics for Behavioral Science*
Prereq.: ——
Year: U (1) 3–0–6
The tools required for proper treatment of behavioral science research data. Descriptive and inductive statistics. Introduction of parametric and non-parametric techniques for the analysis of data. Fundamentals of measurement theory as a basis for determining the applicability of alternate techniques for data analysis. *Staff*

15.306 *Behavioral Science Research Methods*
Prereq.: 15.304, 15.305
Year: U (1) 3–0–9
Introduction to methods of behavioral science research. General strategy of behavioral research (systematic vs. impressionistic investigation, hypothesis formulation, the probabilistic nature of data, etc.): research design (purposes, variance control, control of extraneous variables, use of control groups, randomized designs, factorial designs, two-group, multigroup and correlated-groups designs). Specific technologies of various designs (questionnaire construction, sampling, interviews, systematic observation). Theory and research findings. Organization of research project. *Staff*

15.307 *Behavior Science Research Practicum*
Prereq.: 15.306
Year: U (2) 2–8–8
Development and completion of research project planned in 15.306 during previous term. Interpretation and application of research findings in management environment. Experimentation with such techniques as field survey work, laboratory experimentation, computer simulation, field consulting relationships. (*Restricted to undergraduates in the Sloan School of Management who are in the Behavioral Science Program.*) *Staff*

15.309 *Administrative Theory and Practice*
Prereq.: 15.905
Year: U (1) 3–0–6
Organizational and operational problems of administration. Typical areas include productivity and morale, manager development, personnel management. Readings, case analyses, term papers, and outside speakers where appropriate. *L. B. Moore*

15.311 *Human Factors in Management*
Prereq.: ——
Year: G (1) 3–0–6
Opportunity for the student to become familiar with the methods, subject matter, and findings of social psychology, to look into literature in the field, and to raise questions about his reading. Detailed examination of a few subjects within social psychology which are particularly relevant to the problems of industrial management, with class discussions and reading on such subjects as motivation, learning and behavior change, leadership. (*Restricted to Sloan School of Management graduate students; others admitted only by permission of instructor.*) *Staff*

15.312 *Seminar on Influence, Attitude Change and Adult Socialization* (A)
Prereq.: 15.311
Year: G (1) 3–0–6
Seminar for advanced Master's and doctoral students in organization studies, covering organization influences on attitudes and values, the development of occupational identity, and models of attitude change. Emphasis on gathering data and student research projects.
E. H. Schein

15.313 *Personality Theory and Assessment* (A)
Prereq.: 15.334
Year: G (2) 3–0–6
Application of psychological theory and method to understanding individual personality. Development of clinical skills through intensive analysis of live subjects and case studies. (*Enrollment limited to ten students; admission by permission of instructor.*) *D. A. Kolb*

15.316 *Industrial Sociology* (A)
Prereq.: 15.311
Year: G (1) 3–0–6
Examination of some sociological problems of industrial organizations: technological change and organizational specialists; professionalization of management; relations of industry to community and society. Field studies, secondary analysis of survey data, and library research on selected problems. ——

15.317 *Comparative Analysis of Organizations* (A)
Prereq.: 15.311
Year: G (1) 3–0–6
Comparative analysis of the structure and functioning of different types of organization: manufacturing organizations, research laboratories, schools, hospitals, armies, courts, administrative agencies, occupational associations, etc. Review of social science literature on organizations with special attention to problems of authority structures, management succession, and inter-organizational relations. Integral part of specialization in organization theory and research for Master's candidates, together with 15.318, 15.319, 15.332, and a thesis on organization theory and research. ——

15.318 *Organization* (A)
Prereq.: 15.311
Year: G (2) 3–0–6
Study of organizational theory as it applies to actual organizational behavior. Specific examples of organizational behavior problems analyzed at policy level: how policy, explicit and implicit, affects behavior in the total organization. Discussion of selected organization research studies, papers, cases. (*Enrollment limited to 20 students; admission only by permission of instructor.*) *P. P. Gil*

15.319 *Seminar on Organization Change* (A)
Prereq.: 15.311
Year: G (1) 3–0–6
The processes of deliberate organizational change: the "change-agent" and "client-systems," criteria for and of effective change programs, strategic variables effected

in change (e.g., power, communication, conflict), and technologies for producing change (e.g., consulting, training, research). Integral part of specialization in organization theory and research for Master's candidates, together with 15.317, 15.318, 15.332, and a thesis on organization theory. *(Enrollment limited to 15 students; admission by permission of instructor.)* *R. Beckhard*

15.321 *Seminar in Managerial Behavior* (A)
Prereq.: 15.312 or 15.319; 15.318
Year: G (2) 2–0–7
Independent study and reports by individual students (or teams of students) within the field of the social psychology of managerial behavior. *(Admission by permission of instructor.)* *R. Beckhard*

15.325 *Surveys and Experiments on Organizations* (A)
Prereq.: 15.311
Year: G (1, 2) 3–0–6
Review of methodological problems of designing sample surveys, laboratory experiments, and field experiments. Introduction to problems of experimental design and techniques for analyzing data. Analysis of the nature of organizational experiments and the interplay between surveys, laboratory experiments, and field experiments. Practice in designing and conducting surveys and experiments on organizational problems. *(Enrollment limited to 16 students; admission by permission of instructor.)*
D. Sirota, D. G. Marquis

15.326 *Behavioral Theories of the Firm* (A)
Prereq.: 15.318
Year: G (2) 3–0–6
Research seminar for students of organizational behavior. Study of a small number of researchable topics in that area. Derivation of a model and set of operational hypotheses for describing and explaining each type of behavior. Design and planning of a research project to test a subset of these hypotheses. Discussion, critique, and aid of seminar members' own dissertation research plans, time and mutual interests permitting. Integral part of specialization in organization theory for Master's candidates, together with 15.317, 15.319, 15.332, and a thesis in organization theory. *(Primarily for doctoral candidates; others admitted by permission of instructor.)* ——

15.332 *Administrative Theory and Practice* (A)
Prereq.: 15.915
Year: G (1) 3–0–6
Selected significant administrative areas with emphasis upon organization and its operational problems. Comparative study of current practice and relevant research findings. Typical areas include productivity and morale, manager development, personnel practices, communication, appraisal, motivation and performance, ethics and morality. Readings, case problems, term papers, and outside speakers where appropriate. Integral part of specialization in organization theory and research for Master's candidates, together with 15.317, 15.318, 15.319 and a thesis on organization theory and research.
L. B. Moore

15.333 *Management of Industrial Change* (A)
Prereq.: 15.311
Year: G (2) 3–3–3
Examination of the improvement function in management. Review of literature on creativity as it affects innovation in industrial operation. Human relations problems in industrial change. The role of the manager in fostering improvement. Use of the conference as an improvement tool. Field work in comparative analysis of representative improvement programs. *L. B. Moore*

15.334 *Practicum in Organization Development* (A)
Prereq.: 15.319
Year: G (1) 3–0–6
An intensive examination of organization development methods such as laboratory training, action research, grid organization development, job enlargement and organization design. Case analysis of the application of these methods to educational, governmental and industrial organizations. Use of previous summer work placements in organization development departments as a foundation for developing organization development skills. Integral part of specialization in organization development for Master's candidates, together with 15.311, 15.319, and a thesis on organization development. *(Admission by permission of instructor. Limited to students who have participated in previous supervised summer work placement in organization development.)* *D. A. Kolb*

15.336 *Research Management* (A)
Prereq.: 15.311
Year: G (1) 2–0–7
Lectures and discussion on topics ranging from the performance of individual scientists and engineers to the organization and management of research and development groups and laboratories, and the impact of research and development on the national economy.
D. G. Marquis

15.337 *Seminar on Communication Problems in Science and Technology* (A)
Prereq.: 15.311
Year: G (1) 3–0–6
Utilization of scientific and technological information by research and development "problem solvers." Nature of the flow of information in science and technology. The "publication explosion" and the system's response to it. Role of the professional societies in dissemination of information. Impact of bureaucratic organization on flow of information. Problems of information flow between science and technology. Transfer of technology among nations. *T. J. Allen*

15.338 *Seminar on Management Problems in Science and Technology* (A)
Prereq.: 15.336
Year: G (1, 2) 2–0–7
Discussions of problems and current research in the management of science and technology. Weekly seminars led by members of the faculty and invited speakers. Independent study and preparation of reports by individual students or teams of students. *D. G. Marquis*

15.341 *Seminar in Behavioral Sciences I*
Prereq.: ——
Year: G (1) 3–0–6
Development of basic concepts for understanding individual, group, and organizational behavior through critical analysis of important works in the field. Areas covered: cognitive, affective, change, control, input, throughput, output, and structural processes. Emphasis on use of behavioral science concepts for stimulating new and useful management science research and the application of behavioral science results to typical management problems. *(Restricted to doctoral candidates in the Sloan School of Management.)* *A. L. Patz*

15.342 *Seminar in Behavioral Sciences II*
Prereq.: 15.341
Year: G (2) 3–0–6
Continuation of 15.341, but with greater emphasis on structuring management related behavioral science research. *(Restricted to doctoral candidates in the Sloan School of Management.)* *A. L. Patz*

15.343 ***Advanced Seminar in Social Psychology*** **(A)**
Prereq.: 15.311 or 15.342
Year: G (2) 3–0–6
More intensive coverage of the topics covered in 15.311. Detailed examination of basic social psychological factors such as power, communication, conflict, change, and interpersonal and group relations. Students will be expected to formulate research projects. (*Restricted to Ph.D. candidates in the Sloan School of Management, others admitted only by permission of instructor.*) *M. Haire*

15.344 ***Doctoral Seminar on Career Development and Adult Socialization*** **(A)**
Prereq.: 15.312
Year: G (2) 2–0–7
Seminar for doctoral students in organization studies, covering the topics of career choice, career paths in organizations, career crises, personal changes induced by occupational career, and organizational factors such as recruitment, training, and management development. Emphasis on research and theory. (*Admission by permission of instructor.*) *E. Schein*

15.345 ***Doctoral Seminar in Organization Studies I*** **(A)**
Prereq.: ——
Year: G (1, 2) 2–0–7

15.346 ***Doctoral Seminar in Organization Studies II*** **(A)**
Prereq.: 15.345
Year: G (1, 2) 2–0–7
Seminar covering the basic fields of social psychology, individual psychology, and sociology for purposes of preparing the doctoral candidate for his doctoral examinations. Basic concepts, theories, and research methods serving as focus for the seminar. (*Restricted to doctoral candidates.*) *Staff*

15.348 ***Mathematical Behavioral Science*** **(A)**
Prereq.: 15.012, 15.062, 15.311
Year: G (2) 3–0–6
Subject designed to develop a student's capability in applying mathematical techniques to behavioral science research problems. Use of research literature relating to the particular technique being discussed. Emphasis on understanding the heuristics for applying and the implicit assumptions underlying each mode of mathematical expression. Relevant theorems derived and illustrated only to the extent necessary for analysis. Applications of analytical techniques to include: game theory, information theory, selected stochastic models, linear dynamics, analysis of general functional forms, structure of mathematical programs, discrimination functions, and complex determinate systems. (*Primarily for doctoral candidates; others admitted by permission of instructor.*) ——

FINANCE

15.412 ***Financial Management*** **(A)**
Prereq.: 15.012
Year: G (1, 2) 3–0–6
Survey and analysis of problems facing the financial manager. A prerequisite for management students concentrating in finance or a terminal subject for students wishing to understand the finance function. Topics covered: functions and operations of the capital markets; introduction to portfolio theory; valuation of real assets and securities; management of short-term assets and liabilities; long-term financing decisions, including questions of dividend policy and capital structure; capital budgeting and investment program decision-making; determinants of the firm's cost of capital; and overall financial planning. (*Primarily for Sloan School of Management graduate students; others admitted only by permission of instructor.*) *S. C. Myers*

15.414 ***Business Forecasting*** **(A)**
Prereq.: 15.061
Year: G (1) 3–0–6
Forecasting problems of concern to production and financial decisions within the firm. Time divided about equally between short-run (daily, weekly, monthly) forecasting using exponential smoothing and related techniques, and aggregate industry and economy-wide economic forecasting with longer horizons of six months or more. Two term papers required. Computer-oriented subject. Usage of a programming facility, TROLL, developed particularly for econometric simulation and forecasting problems. *E. Kuh*

15.416 ***Financial Administration of Industry*** **(A)**
Prereq.: 15.412
Year: G (1) 3–0–6
Analysis of specific financial problems of corporations, government and non-profit organizations. Applications of models for cash management, capital budgeting, cost-benefit analysis, short- and long-range financial planning, and other problems. Emphasis on the assumptions and logical structure of the models. Course project involves application of class material to actual current financial problems of a corporation or other organization. *G. A. Pogue*

15.418 ***Taxation and Business Management*** **(A)**
Prereq.: 15.412
Year: G (1) 3–0–6
Analysis of effect of taxation on conduct of business. Concentration on major decisions in which taxes impinge on the firm or its managers; concern with both theory and relevant empirical evidence. Topics covered: the "double-taxation" of dividends; the effect of capital gains taxation on the flow of capital and labor to business; incentives for investment; compensation planning; the effect of taxation on effort; alternatives to income taxation. *D. M. Holland*

15.422 ***Investments*** **(A)**
Prereq.: 15.412
Year: G (1) 3–0–6
Analysis of investments in common stocks, bonds and other risky assets. Primary focus on portfolio construction, efficient diversification of investments, and the selection of portfolios by investors. Consideration of equilibrium pricing of capital assets under uncertainty and its implications for evaluating the performance of investment trusts and portfolios. Discussion of random-walk "efficient" market and emphasis on its implications for charting techniques and security analysis. Other areas covered: the pricing of hybrid securities such as warrants, convertible bonds and options; effects of dividend policy, earnings projections, new issues and other events containing information on security prices. Strong emphasis on empirical testing of hypotheses. *M. S. Scholes*

15.423 ***The Management of Financial Intermediaries*** **(A)**
Prereq.: 15.422
Year: G (2) 3–0–6
Analysis of the problems facing financial intermediaries. The role and operations of financial intermediaries in the primary and secondary markets. Management of assets and liabilities under conditions of uncertainty. The evaluation of primary and secondary investments. A consideration of the specific problems facing banks, investment companies, pension funds, savings and loan associations and insurance companies. Other areas covered include: control of financial operations, analysis of the effects of the legal framework on intermediation, and an analysis of the markets in which financial intermediaries engage. *P. H. Cootner*

15.432 ***Capital Markets and Financial Institutions*** **(A)**
Prereq.: 15.412
Year: G (2) 3–0–6
The role and functioning of the capital and money markets as a device for the allocation of resources, the channeling of investable funds, and the reallocation of risk; financial institutions operating in these markets, principles governing the management of their assets and liabilities. *F. Modigliani*

15.441 ***Research Seminar in Finance*** **(A)**
(New)
Prereq.: 15.412
Year: G (1) 3–0–6
Presentation and analysis of original research in finance. *(For Sloan School doctoral candidates in finance. Others admitted only by permission of instructor.)* *F. Modigliani*

MANAGEMENT INFORMATION AND CONTROL

15.501 ***Information and Decision Systems I***
Prereq.: ——
Year: U (1) 3–0–6
Introduction to basic concepts and techniques of collecting, processing, and reporting information generated by an organization. Emphasis on basic financial and management accounting concepts. Introduction to computers and techniques of decision making for various management decisions such as capital budgeting. *J. F. Rockart*

15.515 ***Information and Decision Systems I***
Prereq.: ——
Year: G (1) 3–0–6
Introduction to basic concepts and techniques of collecting, processing, and reporting information generated by various organizations. Emphasis on basic financial and management accounting concepts. Introduction to computers and techniques of financial decision making. Examination of the organizational goal structure and decision-making process which determines information needs. *J. F. Rockart, J. W. Wilcox*

15.516 ***Managerial Accounting*** **(A, except XV)**
Prereq.: ——
Year: G (1, 2) 3–0–6
Concepts and methods pertinent to financial information and control systems with emphasis on managerial uses. Relevant content of 15.515 plus selected topics from 15.521 and 15.544. Designed to provide comprehensive coverage for students electing only a small number of management subjects. *(Not open to students who have taken 15.515.)* *T. M. Hill, M. R. Sertel*

15.521 ***Managerial Information and Controls*** **(A)**
Prereq.: 15.515 or 15.516
Year: G (1, 2) 3–0–6
Consideration of issues involved in the use of control systems as an effective management tool and in building a framework useful in the design and evaluation of management control systems. Critical evaluation of uses and limitations of various forms of management control systems presently used by companies. Systems involving budgeting, profit planning and use of investment or profit centers. Examination of several issues bearing on management control systems, including program planning and budgeting, cost-effectiveness analysis and experience with centralized systems such as those operating in Eastern European countries. Case materials from a variety of organizational settings to supplement readings. *M. S. S. Morton, J. F. Rockart*

15.532 ***Advanced Concepts in Managerial Information for Planning and Control*** **(A)**
Prereq.: 15.012, 15.061, 15.515
Year: G (1, 2) 3–0–6
Analysis of fundamental elements and requirements of efficient planning and control systems in organizations. Theories of the firm extended. Introduction to feedback control, control hierarchies and planning. Theory of efficient divisionalization, with emphasis on the issues underlying centralization versus decentralization. Behavioral issues in mapping the hierarchy of tasks into an organization of willful agents. Applications to financial and standard cost accounting, and budgeting. Further application to statistical approaches to control and planning, to uses of formal models, to the impact of computers, and to new measures and areas of development in the field. *Z. S. Zannetos, J. W. Wilcox*

15.541 ***Mathematical Elements of Planning and Control*** **(A)**
(New)
Prereq.: 18.901
Year: G (2) 3–0–6
A research level subject which investigates fundamental concepts and methods for analysis and design of planning and control systems from a mathematical point of view. These concepts and methods referred to include controllability, identifiability, observability, aggregation, separability, decomposition and synthesis, optimality (Pareto and Core), equilibrium, and stability. Definitions of social systems and organizations and applications to these of the above are developed. Methods of controlling and coordinating such systems via incentive schemes, information systems, and primal methods are studied from the viewpoints of realizability, optimality, and effects on organizational structure. *(Permission of instructor required.)* *M. R. Sertel, P. R. Kleindorfer*

15.544 ***Measurement Theory and Problems*** **(A)**
Prereq.: 15.515, 15.532
Year: G (1) 3–0–6
In-depth examination of issues underlying accounting theory as applied to measurement of income and wealth. Analysis of various meanings of concepts such as value, progress, objectivity, reliability, freedom from bias, validity, verifiability, and efficiency and methods for quantifying them. Emphasis on relationships between measurements of economic theory, statistics and accounting theory. Detailed examination of implications of computerized systems for measurements for assessing managerial efficiency and for financial reporting. *Z. S. Zannetos, M. R. Sertel*

15.545 ***Control Processes and Systems*** **(A)**
Prereq.: 15.532
Year: G (2) 3–0–6
Attempts to evolve a unified theory of managerial control by analysis and synthesis of concepts from diverse disciplines. Formal definition of structures and systems. Nature and structure of cybernetic and purposively intelligent entities. Unified approach to causal, power, control and organizational structures. Concepts of identification, controllability, centralization, decentralization, decomposability, optimality and stability. *M. S. S. Morton, M. R. Sertel*

15.549 ***Seminar in Information and Control Systems*** **(A)**
Prereq.: 15.532, 15.568
Year: G (2) 2–0–7
Advanced treatment of various topics in the area of sophisticated information and control systems. Characteristics of systems which possess the necessary intelligence to filter, analyze, and associate cause and effect before reporting exceptions to management. The impact of developments in cybernetics, artificial intelligence, and

management sciences in the design of managerial information and control systems. Presentation and study of the result of ongoing research of faculty and students. (*Primarily for doctoral candidates and other advanced graduate students.*) *Z. S. Zannetos, J. W. Wilcox*

MANAGEMENT INFORMATION SYSTEMS

15.554 *Management Information Technology*
Prereq.: 15.501
Year: U (1, 2) 3–0–6
Introduction to computer systems and computer systems programming. Topics include: Machine language, assemblers, and compilers. Input/output device control. List processing, searching, and sorting. File systems and storage management. Students required to prepare and test several assembly language programs.
D. N. Ness, W. A. Martin

15.564 *Management Information Technology I* (A)
Prereq.: 15.515
Year: G (1, 2) 3–0–6
More intensive coverage of subject matter in 15.554.
D. N. Ness, W. A. Martin

15.565 *Management Information Technology II* (A)
(*New*)
Prereq.: 15.564
Year: G (2) 3–0–6
Introduction to the hardware and software technology available for information and control systems, including higher level languages such as PL/1, special software packages, on-line real-time computer systems, and time-sharing and resource allocation. Telecommunications. Graphics terminals and data collection devices also discussed. Development of student's understanding of computer technology so that he can successfully employ it in new and creative ways in an organization.
W. A. Martin

15.568 *Management Information Systems* (A)
Prereq.: 15.564, 15.761, 15.812
Year: G (1, 2) 3–0–6
Managerial applications of digital computers particularly in areas where decisions are fairly structured. Emphasis on the use of computers in integrated information and decision systems. Topics covered include information-based theories of management, a brief survey of information technology, the cost and value of information, techniques of system analysis and design, organizational implications of information technology. Lectures, case studies, programming project, and field studies.
M. S. S. Morton, J. F. Rockart

15.569 *Management Decision Systems* (A)
Prereq.: 15.568
Year: G (2) 3–0–6
Focus on methods of supporting unstructured decisions. Decision analysis and techniques of model building that involve a manager's internal heuristic model are covered. In addition the design and use of interactive graphics terminals to support such decisions are discussed, particularly for uses which impact on the process of management decision making. *G. A. Gorry, M. S. S. Morton*

15.571 *Advanced Computer Systems* (A)
Prereq.: 6.251 or 15.565
Year: G (1, 2) 2–0–7
Seminar in advanced computer systems. Topics of current faculty interest, such as operating systems, time sharing, multiprocessing and multiprogramming.
G. A. Gorry, D. N. Ness

15.572 *Systems Simulation* (A)
Prereq.: 15.061, 15.564
Year: G (1) 2–0–7
Introduction to simulation and model building using high-speed digital computers. Study of discrete (as opposed to continuous) simulation systems and specialized languages such as GPSS, SIMSCRIPT, SIMULA, and GASP. Techniques required to use FORTRAN for event-oriented simulation. Consideration of the proper experimental design, statistical analysis of results, effects of random-number generation techniques and validation. Several homework problems involving use of M.I.T. computers. Term project required. *M. M. Jones*

LAW

15.601 *American Legal System*
Prereq.: 14.01
Year: U (1, 2) 3–0–6
Analysis of the American legal system as a process for ordering our society. Consideration of selected legal problems to reveal the operation of the major component elements of the system: the judicial, legislative, administrative and private law-making power. Consideration of substantive law primarily from the standpoint of the process for generating and modifying legal policy. Emphasis on the problems of the law of business institutions. Extensive reading of case law as well as textual materials and legal essays. Research projects involving use of a law library. *S. Jacks*

15.605 *Labor Law*
Prereq.: 15.601
Year: U (1) 3–0–6
The legal structure of labor-management relations. Review of evolution of labor relations law in the twentieth century and intensive study of the current Federal labor legislation. Among subject areas examined from the legal standpoint are the organization of labor, negotiation and administration of the collective agreement, the status of economic weapons (strikes, boycotts, lockouts, etc.), the relations between the individual and his union, and the role of federalism in the law of labor relations. Extensive use of case materials, including tape-recorded cases. *S. Jacks*

15.616 *American Legal System* (A)
Prereq.: 15.012
Year: G (1, 2) 3–0–6
More intensive coverage of subject matter covered in 15.601. *S. Jacks*

INDUSTRIAL RELATIONS

15.663 *Labor Management Relations*
Prereq.: ——
Year: G (1, 2) 3–0–6
Structure and functioning of management and unions in handling of industrial relations; union policies; problems likely to arise. Reconciliation of union and management policies. Public policy in labor-management relations. (*Restricted to Sloan School of Management graduate students; others admitted only by permission of instructor.*) *D. Q. Mills*

15.664 *Management of Human Resources* (A)
Prereq.: 15.663
Year: G (2) 2–0–7
Seminar with emphasis on managerial responsibilities and policies in the effective utilization of people in organizations. Topics: managers and their personnel concepts, management organization for personnel administration, organization planning and management development, manpower planning and personnel budgets, recruitment and selection, promotion and transfer, training, performance appraisal, discipline, managing change, and wage and salary administration. Field research on selected problems. *M. Haire*

15.671J *Labor Economics* (A)
(Same subject as 14.671J)
Prereq.: 14.64 or 15.663
Year: G (1) 3–0–6
Primary emphasis on the determination of wage levels and wage differentials through an analysis of labor supply and labor demand, as affected by economic as well as by institutional factors. The impact of unions on both wage and non-wage elements of collective bargaining in the light of the characteristics and objectives of particular unions. Other special topics growing out of recent research in labor economics. *C. A. Myers, M. J. Piore*

15.672J *Public Policy on Labor Relations* (A)
(Same subject as 14.672J)
Prereq.: 14.64 or 15.663
Year: G (1) 3–0–6
Major trends in labor legislation, the legality of union activities, protection of the right to organize and bargain collectively, regulation of wages and hours, governmental machinery for the adjustment of labor disputes, and social insurance. The broad economic and social questions raised by these trends. *D. V. Brown, M. J. Piore*

15.674J *Comparative Systems of Industrial Relations and Human Resource Development* (A)
(Same subject as 14.674J)
Prereq.: 14.64 or 15.663
Year: G (2) 3–0–6
International and comparative analysis of industrial relations systems and systems of human resource development. Concentration on an examination of selected issues involving interest groups and the strategies of economic development, including discussion of the nature and functions of labor and management organization in different contexts; the role of the state in establishing procedures and in shaping the substance of industrial relations; the participation of interest groups in the formulation of economic and social policy; manpower and economic growth in the context of comparative systems of human resource development; external influences on national industrial relations systems and human resource development. *C. A. Myers*

15.691J *Research Seminar in Industrial Relations* (A)
(Same subject as 14.691J)
Prereq.: 15.671J or 15.672J
Year: G (1) 3–0–6
Discussion of important areas for research in industrial relations, frameworks for research, research techniques, and methodological problems. Centered mainly on the thesis research of advanced graduate students.
C. A. Myers

15.692J *Research Seminar in Industrial Relations* (A)
(Same subject as 14.692J)
Prereq.: 15.691J
Year: G (2) 3–0–6
Continuation of 15.691J. *C. A. Myers*

MANAGEMENT LABORATORY

15.703 *Management Laboratory*
Prereq.: 14.01 or 15.905
Year: U (1, 2) 3–3–3
Philosophy and methodology of industrial improvement. Application of tools and techniques of improvement to real problems in industry. Formation of a planned program for continued improvement within a company. Economic and human factors in the improvement process. Problems in management creativity. Laboratory experimentation. Participation in actual company situations. *H. F. Goodwin*

15.714 *Advanced Management Laboratory* (A)
Prereq.: 15.515
Year: G (1, 2) 3–3–3
Improvement as a management philosophy. Coordination of methods of analysis, design, measurement, and control of improvement activity. Critical analysis and various improvement techniques and methods of implementing improvement in industry. Involvement in actual industrial situations. *H. F. Goodwin*

OPERATIONS MANAGEMENT

15.751 *Management Science Field Study*
Prereq.: 6.28, 15.053
Year: U (1) 4–0–8
Problems of practical application of management science techniques. Review of pertinent literature, field work, and case studies. Consideration of organizational, data, computational and dynamic aspects of automatic decision systems in production, marketing, and financial areas. *W. B. S. Crowston*

15.761 *Operations Management* (A)
Prereq.: 15.012, 15.062, 15.311
Year: G (1, 2) 3–0–6
Study of decision-making for the economic problems of operations management. Development of generally applicable concepts and techniques for designing and implementing planning and control systems on the operational level. Topics covered include scheduling systems, network based management systems (PERT/CPM and extensions), resource allocation problems, and principles of implementation for integrated systems. Supporting topics in information systems, simulation theory, and operations research as needed. Applications from the public and private sector are covered to illustrate and extend material introduced.
W. B. S. Crowston, P. R. Kleindorfer

15.781 *Capacity Planning: Production and Distribution Systems* (A)
Prereq.: 15.062, 15.915
Year: G (1) 4–0–5
Examination of studies from current literature on problems of locating, time-phasing, and determining the size of additions to capacity. Topics covered include replacement theory, warehouse location, assembly-line balancing, as well as general readings on methods of analysis. Discussion of case studies as time permits.
W. B. S. Crowston

15.791 *Operations Planning and Control Systems* (A)
Prereq.: 15.761
Year: G (1, 2) 3–0–6
Treatment of operations planning and control system design problems from the mathematical, economic, information, and operational points of view. Demand forecasting, inventory control, and integrated production and inventory control systems. Aggregate planning of operations; interaction between aggregate and detailed planning. Job shop scheduling systems, including underlying sequencing theory and research in heuristic methods. Network based management systems and extensions. Lectures, discussions, case studies, and term project. *W. H. Hausman, P. R. Kleindorfer*

15.792 *Manufacturing Decisions Seminar* (A)
Prereq.: 15.761
Year: G (2) 3–0–6
Primary focus on the improvement of decision processes regulating the organization's operations. Design variables affecting the decision process: organizational structure, information system, decision programs and algorithms, and the reward-penalty system. Mutual interdependence of the four classes of design variables as they affect organizational performance; selection of appropriate combination of design variables to accomplish given tasks. *J. R. Galbraith*

Descriptions

15.793 ***Studies in Public Operations Management*** **(A)**
(New)
Prereq.: 15.761
Year: G (1) 3–0–6
Planning-Programming-Budgeting System/Systems Analysis and its application to problems in the management of public operations. Focus on the identification and description of the major features of significant operations management problems facing public and other non-market organizations and on the development of models for analyzing these problems. Case studies and term project. *P. R. Kleindorfer*

15.795 ***Seminar in Operations Management*** **(A)**
(New)
Pr req.: 15.761
Year: G (2) 3–0–6
Examination of studies from current literature devoted to formal methods for analyzing operations management problems. Discussion of case studies as time permits.
W. B. S. Crowston

MARKETING

15.812 ***Management Science in Marketing*** **(A)**
Prereq.: 15.062
Year: G (1, 2) 3–0–6
Analysis of the marketing problems of businesses and other public and private institutions. Consideration of the marketing environment of an organization and its strategies with respect to marketing decisions. Development of an understanding of the consumer or other client of an organization based on behavioral science concepts. Study of marketing decision areas, including product planning, pricing, advertising, selling, promotion, distribution, and competitive strategies. Models and information system concepts presented as applicable.
P. A. Naert, A. J. Silk

15.823 ***Business Game*** **(A)**
Prereq.: 15.812 or 15.905
Year: G (1, 2) 3–0–6
Managerial decision making brought out through team participation in a complex computerized business game. Marketing planning, decision planning, decision making in product development, distribution channels, pricing, sales force, advertising, production and inventory control, and financial planning. Appreciation for interactions and the need for imaginative strategies and integrated policies. Emphasis on producing workable solutions to ill-structured problems by systematic problem definition, strategy formulation, data collection, and evaluation of alternatives. *A. E. Amstutz*

15.824 ***Influence Processes and Mass Communications*** **(A)**
Prereq.: 15.061
Year: G (2) 3–0–6
Focus upon management problems arising in connection with attempts to communicate with and influence a market or some other "public" in an organization's external environment. The sociological and social psychological literature on mass communications, attitude change, and the diffusion of innovations as the foundation of the subject. Primary emphasis on bringing models and research findings from these fields to bear on the problems of marketing communication. Lectures, discussions, case problems, and research project.
A. J. Silk

15.825 ***Marketing Models*** **(A)**
Prereq.: 15.062, 15.812
Year: G (2) 3–0–6
Examination of the state of the art in marketing models with emphasis on recent advances. Topics include: new product planning models, adaptive control models, microanalytic simulation of competitive environments, stochastic models of consumer behavior, and on-line interactive use of models. Criticism in depth of a number of models and participation in model development project. *G. L. Urban*

15.826 ***Marketing Issues in Public Systems*** **(A)**
(New)
Prereq.: 15.812
Year: G (1) 3–0–6
The marketing-like problems of politicians, government agencies, hospitals, universities and other institutions serving the public. Exploration of the application of management science and behavioral science to the relationship between public organizations and their clienteles. Specifically, consideration of the design, communication and distribution of services so as best to serve the public. Emphasis on normative applications of information systems and models to specific problems. Areas to be considered include family planning, political campaigns, citizen feedback systems, medical systems, and others as may be suggested.
J. D. C. Little, G. L. Urban

15.832 ***Measurement for Management*** **(A)**
Prereq.: 15.061
Year: G (2) 3–0–6
Focus upon management's need for non-accounting measurements and information from sources both internal and external to the organization. Methods for generating measurements of response. Development of scales of measurement and psychometric procedures. Sampling theory from both a classical and a Bayesian viewpoint. Parametric and non-parametric statistical procedures for analyzing measurements. Examples from all areas of management. *P. A. Naert, A. J. Silk*

15.838 ***Research Seminar in Marketing*** **(A)**
Prereq.: 15.812
Year: G (2) 3–0–6
Seminar on current marketing literature and current research interests of faculty and students. Topics such as the theory of consumer behavior, simulation of consumer product markets, marketing experimentation, and the development of behavioral models from consumer panel data. *Staff*

INDUSTRIAL DYNAMICS

15.852 ***Principles of Dynamic Systems I***
Prereq.: 18.03
Year: U (1, 2) 3–0–9
Introduction to modeling of social systems, emphasizing the study of feedback structures and their behavior. Development of concepts that allow one to understand the mechanisms underlying growth, stagnation and cyclical fluctuation. Examples and practice at formulating models of industrial, economic, social, and ecological systems. Introduction to state-variables, and modern control theory. Study of some of the effects of delays, multiple feedback loops, and non-linearities. Laboratory illustration of principles using analog simulation. Aim of building an intuitive foundation for simulation studies of complex systems. *J. Henize, D. L. Meadows*

15.853 ***Principles of Dynamic Systems II***
Prereq.: 15.852
Year: U (2) 3–0–9
Continuation of topics from 15.852 with increased emphasis on control theory and the behavior of nonlinear systems. *J. Henize*

15.854 ***Design of Information and Control Systems for Resource Management***
Prereq.: 15.852
Year: U (1, 2) 3–0–6
Design of information and control systems for resource management, using feedback control theory and Industrial Dynamics. The focus of the subject on theory and methodology for designing information and control structures that will cope effectively with realistic conditions of random noise and unforeseen shifts in the environment. Topics examined include: evaluating different information sources; measuring the effect on performance of random error, bias, delay, and sampling frequency of information flow; specifying forecast accuracy; balancing control actions in a multiple control point structure; and incorporating non-linear control responses. Frequent use of model building and computer simulation. *C. V. Swanson*

15.855 ***Applications and Implementation of Industrial Dynamics***
Prereq.: 15.852
Year: U (1, 2) 3–0–6
Similar to 15.875. *E. Roberts*

15.858 ***Research Seminar in Dynamics of Management Systems I***
Prereq.: 15.853
Year: U (1) 3–0–6

15.859 ***Research Seminar in Dynamics of Management Systems II***
Prereq.: 15.858
Year: U (2) 3–0–6
Class design project involving the construction of a useful dynamic model in a major unexplored problem area. The first term consists primarily of research, conceptualization, and definition of the problem. The second term is directed toward constructing and using the complete model. The problem area chosen changes from year to year. *D. L. Meadows*

15.872 ***Principles of Dynamic Systems I*** **(A)**
Prereq.: 18.03
Year: G (1, 2) 3–0–9
Introduction to modeling of social systems, emphasizing the study of feedback structures and their behavior. Development of concepts that allow one to understand mechanisms underlying growth, stagnation and cyclical fluctuation. Examples and practice at formulating models of industrial, economic, social, and ecological systems. Introduction to state-variables and modern control theory. Study of some of the effects of delays, multiple feedback loops, and non-linearities. Laboratory illustration of principles using analog simulation. Aim of building an intuitive foundation for simulation studies of complex systems. *J. Henize, D. L. Meadows*

15.873 ***Principles of Dynamic Systems II*** **(A)**
Prereq.: 15.872
Year: G (2) 3–0–9
Continuation of topics from 15.872 with increased emphasis on control theory and the behavior of nonlinear systems. *J. Henize*

15.874 ***Design of Information and Control Systems for Resource Management*** **(A)**
Prereq.: 15.872
Year: G (1, 2) 3–0–6
Design of information and control systems for resource management, using feedback control theory and Industrial Dynamics. The focus of the course is on the theory and methodology for designing information and control structures that will cope effectively with the realistic conditions of random noise and unforeseen shifts in the environment. Topics examined include: evaluating different information sources; measuring the effect on performance of random error, bias, delay, and sampling frequence of information flow; specifying forecast accuracy; balancing control actions in a multiple control point structure; and incorporating non-linear control responses. Frequent use of model building and computer simulation. *C. V. Swanson*

15.875 ***Applications and Implementation of Industrial Dynamics*** **(A)**
Prereq.: 15.872
Year: G (1, 2) 3–0–6
Treatment of the process and problems of application and implementation of industrial dynamics. Class divided into teams, each studying the major systems problems of a cooperating organization. Goal of student effort: eventual implementation of policy changes in the organization. Study of previous and current industrial dynamics applications in industry and government. Discussion sessions with management consultants and operations research staff. Selected readings to help develop understanding of the implementation process. (*Enrollment limited. Admission by permission of instructor.*) *E. B. Roberts*

15.876 ***Growth Dynamics*** **(A)**
Prereq.: 15.854 or 15.874
Year: G (1, 2) 3–0–6
Examination of the representation, analysis, and design of growth processes from the point of view of feedback systems and Industrial Dynamics. Focus on corporate growth, although the principles and techniques apply more widely. Study of the market-firm interactions relevant to corporate growth and design of resource management policies to foster more successful growth. Examination of growth dynamics in other areas. Term project expected. *C. V. Swanson*

15.878 ***Research Seminar in Dynamics of Management Systems I*** **(A)**
(*Revised: Unit change*)
Prereq.: 15.873
Year: G (1) 3–0–6

15.879 ***Research Seminar in Dynamics of Management Systems II*** **(A)**
(*Revised: Unit change*)
Prereq.: 15.878
Year: G (2) 3–0–6
Class design project involving the construction of a useful dynamic model in a major unexplored problem area. First term consists primarily of research, conceptualization, and definition of the problem. Second term directed toward constructing and using the complete model. The problem area chosen changes from year to year. *D. L.Meadows*

GENERAL POLICY AND SPECIAL

15.901 ***Undergraduate Studies Program***
Prereq.: ——
Year: U (1, 2) *Arr.*
Special program for juniors and seniors in the Sloan School of Management departing from the usual format of concentration on academic subjects as the primary vehicle for learning. Independent and group study of subjects of personal interest, with emphasis on using the group as a resource in the planning and management of one's own education. (*Enrollment limited to twelve students per class. Admission only by permission of the undergraduate studies program committee of the Sloan School of Management.*) *L. B. Moore*

15.903 ***Introduction to Industrial Management***
Prereq.: ——
Year: U (1) 3–0–6
Basic treatment of fundamental principles and general practices of industrial management. Specific coverage of selected important facets of marketing, finance, production, accounting, and managerial psychology. Infor-

mation and procedures utilized in managerial decision making. Relationship of scientist and engineer to functions and decisions of management and the management of research and development. (*Not open to Course* XV *students.*)

15.905 *Information and Decision Systems II*
Prereq.: 15.501
Year: U (2) 4–0–8
Introduction to the functional fields of finance, marketing and operations. Exposure to a number of major problems in these fields with special emphasis on the interdependence of the functions. Not an exhaustive treatment but enough depth in each field to serve as a basis for further study, with overview and integration to provide context in which further detailed study has more meaning. Students are expected to develop problem-solving skills in defining problems, creating alternatives, assessing consequences of alternatives, and developing criteria for choice of alternatives. *Staff*

15.915 *Information and Decision Systems II*
Prereq.: 15.515
Year: G (2) 4–0–8
Introduction to the functional fields of finance, marketing, and operations. Exposure to a number of major problems in these fields with special emphasis on the interdependence of the functions. Not an exhaustive treatment but enough depth in each field to serve as a basis for further study, with overview and integration to provide context in which further detailed study has more meaning. Development of problem-solving skills in defining problems, creating alternatives, assessing consequences of alternatives, and developing criteria for choice of alternatives. *Staff*

15.921 *New Enterprises* (A)
Prereq.: 15.412, 15.515
Year: G (1) 2–0–7
Organization and management of technically based companies. Financing of new enterprises through private, corporate and public capital sources. The role of government and the impact of Federal R and D on corporate growth. Trends in science and technology in terms of business opportunities. Preparation of cases by study of the operations of local companies and detailed development. of plans for launching of new business ventures. (*Enrollment limited to 15 students: admission by permission of instructor.*) *R. S. Morse*

15.931 *Corporate Strategy, Policy, and Planning* (A)
Prereq.: 15.014, 15.062, 15.311, 15.915
Year: G (1, 2) 3–0–6
A terminal subject dealing with the approach to general management problems affecting all facets of the enterprise. Discussions and readings tracing strategy practice, methodology and theory, including a Field Study. Attempt to develop the integrative ability of students to use knowledge gained in core subjects and to prepare them for launching their careers in management with a balanced understanding of their organization as an entity. *E. H. Bowman*

15.951 *Special Studies in Management*
Prereq.: ——
Year: U (1, 2) *Arr.*
Special tutorial arrangement with a faculty member for guided reading, research, laboratory, or teaching experience. *Staff*

15.961-15.969 *Special Studies in Management* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
For graduate students who desire to do advanced work or to carry out some special investigation of a management problem not specifically covered elsewhere and not qualifying as a thesis. Readings, conferences, laboratory and field work, and reports. *Staff*

16.

Aeronautics and Astronautics

16.001 *Thermodynamics and Statistical Mechanics*
Prereq.: 18.02
Year: U (2) 4–0–8
Introductory concepts and definitions. Heat and work. First and Second Laws of Thermodynamics. Reversible processes. Irreversibility. Entropy and absolute temperature. Analysis of cycles. Availability. Application to flow processes and energy conversion. Introduction to statistical thermodynamics. Bose-Einstein, Fermi-Dirac, and Boltzmann statistics. Applications to properties of solids. Ideal gas mixtures. Chemical equilibria.
H. Y. Wachman, A. Solbes

16.01 *Dynamics*
Prereq.: 8.02, *18.03*
Year: U (1, 2) 4–2–6
Dynamics, with applications to aeronautical and astronautical problems. Kinematics and dynamics of particles and of groups of particles. Relative motion as seen by accelerating and rotating observers. Particles of variable mass. Mass properties of rigid bodies, the inertia tensor, geometric and mass symmetries. Kinematics and dynamics of a rigid body in general motion. Euler's dynamical equations, gyroscope equations.
J. E. Potter, R. L. Halfman

16.02 *Aerodynamics*
Prereq.: 16.001
Year: U (1, 2) 4–2–6
Study of the interaction caused by a relative velocity between a gas and interior or exterior boundaries. Particular emphasis is placed on problems related to flight. Basic equations and boundary conditions for the interactions are developed. The effects of viscosity on elementary flow fields are examined with the idea of suggesting simplifying approximations, such as delineation of boundary layers and inviscid flow regions. Other topics discussed include one-dimensional flow of perfect gases, converging-diverging nozzles, characteristics of strong and weak waves, supersonic airfoil theory, two-dimensional constant density flows and three-dimensional wing theory. *E. E. Covert*

16.031 *Topics in Fluid Mechanics*
Prereq.: 16.02
Year: U (2) 3–0–6
Application of Navier-Stokes equations; exact solutions exhibiting boundary-layer behavior. Boundary-layer approximation; study of boundary layers of type occurring in aeronautical applications. Karman momentum integral method, Thwaites method and related topics. Transition phenomena. Turbulent boundary layers. Potential flow theory and its interrelationship with viscous flow. Green's Theorems. Properties of source, doublet and vortex sheets. Application to thin wing theory. Two-dimensional thin airfoil theory, Prandtl lifting-line approximation, small aspect ratio approximation. Prandtl-Glauert-Gothert transformation for subsonic compressibility effects. (*Not offered 1971–72.*)
J. E. McCune, M. Finston

16.041 *Aerodynamics — Viscous Fluids* (A)
Prereq.: 16.02, *18.075*
Year: G (1) 3–0–9
Introduction to viscous flows. Basic flow equations; exact solutions; low Reynolds number cases; boundary layer flows; brief discussion of stability; transition; turbulent boundary layers. Lectures to be supplemented by occasional demonstrations. (*Not offered 1971–72.*) *Staff*

16.042 *Aerodynamic Heating* (A)
Prereq.: 16.041, *18.076*
Year: G (2) 3–0–9
Extension of discussion in 16.041 to include thermodynamic aspects. Kinetic heating at high speeds; heat transfer through boundary layers; discussion of methods of reducing surface temperatures. Application to hypersonic aircraft and re-entry bodies, including real gas effects at high temperatures. (*Not offered 1971–72.*)
M. Finston

16.051 *Advanced Gas Dynamics* (A)
Prereq.: 16.02, *18.075*
Year: G (1) 3–0–9
Dynamics of a perfect gas. Irrotational and rotational flows. Character and analysis of subsonic, transonic, supersonic and hypersonic, inviscid, multidimensional flows. Non-steady flow, shock waves, similarity concepts, blast waves, characteristics, small disturbances, approximation procedures, integral and numerical methods. Application to shock tubes, wings, blunt and slender bodies, blast waves. *J. P. Moran, J. R. Baron*

16.052 *Real Gas Dynamics* (A)
Prereq.: 16.051
Year: G (2) 3–0–9
Dynamics of a real gas. High-temperature and rarefied flow under situations including vibrational excitation, translational, chemical, and radiative non-equilibrium. Radiation coupled gas dynamics. Wave propagation with relaxation phenomena, dispersion. Extension of similarity, characteristics, and shock concepts. Surface reaction coupling. Application to hypersonic test facilities, mass transfer, blunt and slender configurations, viscous layers, wakes. *J. R. Baron*

16.065 *Physics of High-Speed Gas Flows* (A)
Prereq.: 18.076
Year: G (1) 3–0–9
16.066 *Physics of High-Speed Gas Flows* (A)
Prereq.: 16.065
Year: G (2) 3–0–9
Elements of statistical mechanics and kinetic theory. Discussion of the Boltzmann equation and its integration to give the Navier-Stokes equations. Rarefied gas dynamics. Elements of quantum mechanics. Mechanisms of dissociation, ionization, radiation, and relaxation. Elements of electrodynamics of continuous media. The physics of a continuous medium in motion.
L. Trilling

16.067 *Gas-Surface Interactions* (A)
Prereq.: 8.05 or 8.211
Year: G (1) 3–0–9
Discussion of behavior of a rarefied gas at a solid boundary in terms of processes occurring on collisions of gas molecules with the surface. Processes including reflection and diffraction of molecular beams, energy and momentum accommodation, and adsorption. Experimental and theoretical methods for treating accommodation coefficients and free molecule drag coefficients. Discussion of the origin of van der Waals forces and the application of Lennard-Jones potential to interface problems. *H. Y. Wachman*

16.071 *Aerodynamics of Wings and Bodies* (A)
Prereq.: 16.02
Year: G (1) 3–0–9
16.072 *Aerodynamics of Wings and Bodies* (A)
Prereq.: 16.071
Year: G (2) 3–0–9
Coordinated presentation of theoretical methods useful for predicting performance and stability of thin lifting surfaces and slender vehicles in high-speed flight. Review of fluid mechanics, with emphasis on potential aerodynamics. Constant-density flow and procedures for indirectly introducing real-fluid effects. Application of the method of inner and outer solutions as a framework for analyzing cases such as the following: slender bodies or wing-body combinations, thin airfoils, and thin planar wings in subsonic and supersonic flight. Drag optimization techniques, non-planar lifting surfaces, flows with free vortices, transonic motion, unsteady flows, and other special topics selected in the light of currently important aeronautical problems. *S. E. Widnall*

16.081J *Principles of Acoustics* (A)
(Same subject as 2.060J, 13.81J)
Prereq.: 2.03, 16.01; 2.201
Year: G (1) 3–0–9
Derivation of acoustic equations: energy, intensity, speed of sound, acoustical impedance. Generation of sound: fundamental source terms, expansions in multipoles, interpretation of forces, stresses, as multipoles. Sound generation by solid bodies in contact with fluid; airfoils, vibrating surfaces, radiation impedance. Sound propagation: atmosphere acoustics, ray theory, refraction, adsorption, scattering, non-ideal behavior, finite amplitude effects. Sound in finite spaces, propagation in ducts and rooms. Sound attenuation in porous materials. Sound in rooms: wave and ray theory, reverberation, and decay of energy. Transmission of sound between coupled spaces. Demonstrations of measuring and analysis techniques and basic phenomena.
S. E. Widnall, R. H. Lyon, P. Leehey

16.082 *Aerodynamic Noise* (A)
Prereq.: 16.02, 18.05, 18.06
Year: G (2) 3–0–9
Elements of acoustics. Subsonic and supersonic jet noise. Physical mechanisms of aerodynamic noise including turbulence, shock-turbulence interaction, feedback resonance and flow instabilities. Jet noise suppression. Discussion of V/STOL noise. Compressor, propeller and helicopter rotor noise. Physical aspects of broad band noise, interaction tones and combination tones. Other current noise research problems including sonic boom, blade slap and transonic compressor.
S. E. Widnall

16.105 *Applied Aerodynamics*
Prereq.: 16.02
Year: G (2) 3–0–6
A survey of current analytic and experimental techniques appropriate to industrial applied aerodynamics. Characteristics of the atmosphere. Calibration of aircraft air data systems. Wind tunnels and wind tunnel measurements. Determination of airfoil section characteristics. Induced drag. Skin friction drag. Estimation of wave drag and sonic boom pressure signatures. Propeller theory, sizing and efficiency. Aircraft power plant characteristics. Flight mechanics, including trajectory analysis and classical performance calculation. Longitudinal dynamics of a rigid airplane. Flight test techniques. *E. E. Larrabee*

Descriptions

16.11 ***Introduction to Boundary Layers***
Prereq.: 16.02
Year: U (2) 3–0–6
Simple examples of boundary layers in fluid flow; methods of calculation and measurement of boundary layers; stagnation flow and jets; boundary layer separation and wakes; heat transfer and compressible boundary layers; instability and transition; turbulent boundary layers.
J. Bicknell, L. Trilling

16.12 ***Multivariable System Dynamics*** **(A)**
Prereq.: 16.01
Year: G (2) 3–0–6
Case studies of multivariable dynamic systems ranging from traditional conservative mechanical vibrations, linear circuits, and feedback control systems to vehicle dynamics, optimization of non-linear systems, and optimal filtering. Treatment of sets of linear, variable-coefficient, differential equations using matrix and vector notations, adjoint functions, the state-space approach, and digital computation.
R. L. Halfman, J. E. Potter

16.15 ***Advanced Flight Vehicle Stability and Control*** **(A)**
Prereq.: 16.11
Year: G (1) 3–0–6
Analytic solutions for non-linear problems in flight mechanics. Linear approximations to flight vehicle dynamics, including: classical airplane stability theory, stability derivative estimation, dynamic similarity laws, gust response, inertial cross coupling and spinning. Dynamics of simple aircraft-controller combinations. Analysis of flight test dynamic stability data.
E. E. Larrabee

16.20 ***Mechanics of Solids***
Prereq.: 8.01 or 8.011; 18.02, 18.022 or 18.024
Year: U (1, 2) 4–2–6
A first and basic course in mechanics and in the analysis of structures. Principles of mechanics, vector properties of forces and moments, equilibrium of groups of particles. Consideration of static load-bearing behavior of beams, trusses, columns and other structural elements out of which buildings, bridges, rockets as well as aircrafts and spacecrafts are constructed. Treatment of basic concepts and principles applied in structural analysis and design: concept of stress (a measure of internal forces generated in a structure), concept of strain (a measure of deformation), constitutive relationships (a description of stress-strain relations), equilibrium requirement (Newton's laws) and certain continuity requirements. Examination of the contributions of earlier workers in this field, including those of Galileo, Coulumb, Navier, Poisson and Cauchy. *E. A. Witmer, L. L. Bucciarelli*

16.201 ***Structural Mechanics***
Prereq.: 16.20
Year: U (1) 4–0–6
Application of solid mechanics to analysis of flight vehicle structures. Plane stress, plane strain problems. Bending, shear, torsion of rods and thin wall beams. Introduction to energy principles and computer-oriented structural analysis such as matrix and finite element methods. Applications to statically indeterminate structures and solid continuum. Buckling of column and stability phenomena. Theories and modes of structural failure. *J. W. Mar*

16.21 ***Plates, Stability and Thermoelasticity*** **(A)**
(Revised: Content change)
Prereq.: 16.201
Year: G (2) 3–0–9
Analysis of anisotropic plates typical of laminated composite structures. Coupling of and duality in bending and stretching of plates, transverse shear effect. Theory of stability of structures and applications to buckling of plates. Equations of thermal elasticity. Heat transfer and thermal stress analysis for supersonic and hypersonic aircrafts. *J. W. Mar*

16.22 ***Shell Structures*** **(A)**
Prereq.: 16.201
Year: G (1) 3–0–9

16.23 ***Shell Structures*** **(A)**
Prereq.: 16.22
Year: G (2) 3–0–9
Elements of tensor analysis. General formulation of elasticity in curvilinear coordinates. Introduction to differential geometry. Development of shell equations in tensor form. Membrane behavior of thin shells. Bending behavior of thin shells. Various topics such as shallow shells, shells of revolution, asymptotic integration, large deflections, buckling, and inflated shells. *(Not offered 1971–72.)* *J. W. Mar*

16.24 ***Plasticity, Viscoelasticity and Creep*** **(A)**
(Revised: Content change)
Prereq.: 16.201
Year: G (1) 3–0–9
Plastic stress-strain relations of materials. Yield conditions, flow rules and strain-hardening rules. Characterization of linear viscoelastic behaviors, creep compliance and relaxation modulus, discrete element models, spectrum and dynamic representations. Viscoelastic stress analyses, corresponding principle and integral equation solutions. Non-linear creep laws. Structural analyses in presence of creep. Creep buckling.
T. H. Pian

16.25 ***Advanced Topics in Structural Mechanics*** **(A)**
(Revised: Content change)
Prereq.: 16.201
Year: G (2) 3–0–9
Varying content. New methods and problems in the structural design and analysis of aerospace vehicles.
P. Tong

16.27 ***Variational and Matrix Methods of Structural Mechanics*** **(A)**
(Revised: Content change)
Prereq.: 16.201
Year: G(1) 3–0–9

16.28 ***Variational and Matrix Methods of Structural Mechanics*** **(A)**
(Revised: Content change)
Prereq.: 16.27
Year: G (2) 3–0–9
Structural analysis through the use of variational principles. Principles of stationary potential energy, stationary complementary energy and Reissner's principles. Approximate solutions by Rayleigh-Ritz, finite element and finite difference methods. Tools in numerical analysis, interpolation and integration. Use of computer for setting up and the solution of large system of algebraic equations. Solution of trusses, frames, plane stress, plane strain and plate bending and shell of revolution problems. Modified variational principles for variety of finite element formulations. Advanced problems involving plastic behavior, large deflection, elastic stability. Application of finite element methods to other continuum mechanics problems.
P. Tong, T. H. H. Pian

16.30 ***Principles of Automatic Control***
Prereq.: 6.14, 16.01
Year: U (1, 2) 3–0–9
Analysis of automatic control systems, including analytical, graphical, and analog methods. Formulation of control system performance equations leading to solutions for transient and steady-state inputs. Non-dimen-

sionalized treatment of simple linear systems and extension to more involved automatic control loops. Selected aeronautical and astronautical control problems.
H. P. Whitaker, J. J. Deyst

16.31 *Principles of Instrumentation and Control* (A)
Prereq.: 16.30
Year: G (1) 3–0–9
Generalized concept of system design and synthesis with consideration of intercoupled relationships among multiple inputs and outputs, practical limitations of physical components to satisfy the static and dynamic specifications of system response to control inputs and disturbing inputs, and the adaptation to parameter variations. Use of analog and digital computers as design tools. Principles of random processes and optimum linear system design for random inputs. Sampled data system analysis and the design of on-line digital controllers.
Y. T. Li, R. E. Curry

16.32 *Principles of Instrumentation and Control* (A)
Prereq.: 16.31
Year: G (2) 3–0–9
Brief treatment of time-varying linear control systems. General treatment of the principles of analysis and design of feedback control systems incorporating non-linear components. Extensive treatment of the multiple-input describing function method as applied to stability analysis, steady-state response to forcing functions and transient response. Introduction of modern control theory for the determination of control logic for optimum transient response with discrete or continuous signals in open and closed loop configurations. Brief discussion of optimum filtering estimation and identification concepts.
Y. T. Li, R. E. Curry

16.33 *Instrumentation, Guidance and Control Laboratory* (A)
Prereq.: 16.30
Year: G (1) 2–3–4
Experiments related to current research and development projects, set up and conducted at various sections of Draper and Lincoln Laboratories. Supervised by Laboratory staff with guidance from faculty members. Two lectures per week by faculty. Provision of background material by Laboratory staff. Students work in groups of three or four and perform a new experiment on alternating weeks. *S. Ezekiel*

16.34 *Automatic Control of Flight Vehicles* (A)
Prereq.: 16.30
Year: G (2) 3–0–9
Application of design techniques and principles to advanced automatic control systems for air and space vehicles. Synthesis of control systems from standpoint of meeting mission specifications. Analysis of adaptive control systems; their use in meeting performance requirements over widely changing environments encountered by high-speed aircraft and manned spacecraft. Typical engineering problems associated with design of control equipment, considering limitations and uncertainties of components, random input effects, mass cross-coupling effects, etc. (*16.15 recommended as preparation.*)
H. P. Whitaker

16.35 *Special Problems in Instrumentation Control and Guidance* (A)
Prereq.: 16.30
Year: G (1 or 2) *Arr.*
Problems of interest to qualified individual students in consultation with the instructor. *Staff*

16.36 *Comparative Instrumentation* (A)
Prereq.: 16.30
Year: G (2) 3–0–9
Generalized fundamental treatment directed toward planning of measuring systems. Analysis of measurement concepts, components, system configurations and test methods with emphasis on comparison between different techniques. Detailed examination and error analysis of important classes of practical instruments stressing the general techniques used to improve accuracy. Students may also elect 16.361, an associated laboratory subject. *L. R. Young*

16.361 *Experimental Projects in Instrumentation* (A)
Prereq.: 16.30
Year: G (2) 0–4–2
Individual projects for detailed investigation of equipment in instrumentation, guidance, or control, emphasizing current research and development. Projects carried out in one of the departmental or special laboratories.
S. Ezekiel, L. R. Young

16.37 *Statistical Problems in Automatic Control* (A)
Prereq.: 16.30, 18.075
Year: G (2) 3–0–9
Statistical problems of importance to control system engineers. Review of probability theory with application to such problems as system reliability and multidimensional random errors. Measurement of the statistics of random variables and processes. Extensive treatment of random processes in linear systems using both transfer function and state space descriptions. Design of optimum filters according to Wiener and Kalman.
W. E. Vander Velde

16.371 *Estimation and Control of Stochastic Processes* (A)
Prereq.: 16.37, 18.100
Year: G (1) 3–0–9
Probability spaces, random variables, brownian motion and linear stochastic differential equations. Conditional expectations and optimal estimation theory. Markov processes and the Kolmogorov equations. Optimal control in the presence of system process and measurement disturbances. Applications to the control and guidance of aerospace vehicles. *J. J. Deyst*

16.38 *Physical Components of Control Systems* (A)
Prereq.: 6.14
Year: G (2) 3–0–6
Effect of component performance characteristics on the control system problem. Consideration of mechanical, electrical and electromechanical components with emphasis on non-ideal effects. Specification of components to meet particular system requirements. Numerous lecture references to applications in aircraft, missile, and spacecraft guidance. *R. K. Mueller*

16.381 *Applied Modern Optics* (A)
Prereq.: 8.03
Year: G (1) 3–0–9
Propagation of light in a vacuum and in a medium. Polarization, reflection, interference, diffraction and scattering. Temporal and spatial coherence. Electro- and magneto-optic effects. Detection of light. Basic principles of laser operation, amplitude and frequency stabilization. Noise in laser amplifiers and oscillators. Modulation and deflection of light. Non-linear optics. Applications of lasers in holography rotation sensing, velocity and displacement detection, ranging and communication. *S. Ezekiel*

16.39 *Applied Optimal Control* (A)
Prereq.: 18.087
Year: G (1) 3–0–9
Design of optimal and near-optimal controls and systems emphasizing computational techniques for finding the solutions to complex problems which do not admit analytic solution. Treatment of both parameter optimization and functional optimization methods. Computer facilities available to the class for computational experiments on a voluntary basis. *W. E. Vander Velde*

16.40 *Principles of Flight Guidance*
Prereq.: 16.01
Year: U (1) 3–1–8
Guidance requirements for representative space and atmospheric flight missions analyzed in terms of mission phases, navigation, flight path corrections and steering laws. Implementation of guidance systems using celestial, inertial, and radio techniques in conjunction with data processing. Examples include air traffic control and a complete manned space flight.
W. M. Hollister

16.41 *Space Dynamics and Gyroscopic Instruments* (A)
Prereq.: 16.01
Year: G (1) 4–0–8
Consideration of origins of inertial space concepts and application to interpretation of measured data. Generalized theory of accelerations and velocities of bodies in spaces which are moving with respect to inertial space. Application of general theory and of Newtonian mechanics to theory of gyroscopic instruments. Space integrators and stabilization. Development of treatment from standpoint of engineer, using methods of vectors and of conventional analysis. Application to gyroscopic devices in airborne and marine navigation.
W. Wrigley, W. M. Hollister

16.42 *Inertial Guidance* (A)
Prereq.: 16.30, 16.41
Year: G (2) 4–0–8
Principles of design of inertial navigation systems, starting from dynamics of measurement components and kinematics of system behavior. Methods of mechanizing equations of motion of physical pendulum and gyro compass. Inertial navigation systems for space close to earth and marine use. Characteristics of five-gimbal, three-gimbal and gimballess systems. Mechanization of a satellite navigator. Question of extension to interplanetary regions. *W. R. Markey, W. Wrigley*

16.43J *Life Support and Physiological Modeling in Manned Systems* (A)
(Same subject as 2.181J)
Prereq.: ——
Year: G (2) 3–3–6
Environmental control and physiological characteristics of man as related to unusual acceleration, thermal, atmospheric radiation or other stresses. Advanced models of sensory and neuromuscular systems. Lectures and student critique of current research. Design of systems involving man. Student projects in small groups throughout the term. (*Permission of instructor required.*)
L. R. Young, T. B. Sheridan

16.441J *Dynamical Astronomy*
(Same subject as 8.293J, 12.115J)
Prereq.: 8.03, 18.075
Year: U (1) 3–0–9
Kepler's laws and the law of gravitation; one- and two-body motion: orbits in space and time; disturbed motion of two bodies as a special case of the general problem of n bodies: variation of orbital elements, planetary theory, expansion of the disturbing function, periodic and secular effects; resonance and stability; linear stability theory, periodic orbits and resonance in the three-body problem, examples involving planets, satellites, and asteroids; techniques of observation and computation: astronomical coordinate systems and time, optical, radio, and radar observations, numerical integration of orbits, orbit determination, maximum-likelihood estimation of orbit initial conditions and astronomical constants.
W. Wrigley, I. I. Shapiro, C. Counselman

16.442J *Dynamical Problems of the Solar System* (A)
(Same subject as 8.954J and 12.614J)
Prereq.: 16.441J
Year: G (2) 3–0–9
Introduction to current research in solar systems dynamics, tidal friction, evolution of spin and orbital resonances, and tests of gravitational theories.
W. Wrigley, I. I. Shapiro, C. Counselman

16.45J *Space Communications* (A)
(Same subject as 6.569J)
Prereq.: ——
Year: G (1) 3–0–9
Study involving the important interaction between the orbital and dynamical characteristics of spacecraft, the transmission of electromagnetic signals over long distances, and the concepts of modern communication theory. Stress on interplay between these diverse topics in practical space communication systems. Discussions of spacecraft dynamics, stabilization, attitude control, propagation effects and pertinent modulation and coding methods. (*Some background in space dynamics or in communications assumed. Permission of instructor required. Not offered 1971–72.*) *J. V. Harrington*

16.46 *Astronautical Guidance I* (A)
(*Revised: Unit change*)
Prereq.: 18.075
Year: G (1) 3–0–9
Fundamentals of celestial mechanics; orbital initial value, boundary value and orbital transfer problems; two-body and n-body approximate and precision orbit determination. One-way and round-trip trajectory problems to the moon and planets. Fundamentals of space vehicle navigation with particular emphasis on self-contained techniques; statistical error analysis. Techniques of linear perturbation theory, vector and matrix algebra freely applied. *R. H. Battin*

16.47 *Astronautical Guidance II* (A)
(*Revised: Unit change*)
Prereq.: 16.37 or 16.46
Year: G (2) 3–0–9
Techniques of powered-flight guidance and navigation; velocity-to-be-gained methods; terminal control. Linearized and explicit techniques for fixed- and variable-time-of-arrival guidance. Optimum navigation and guidance policies. Guidance of continuous and low-thrust vehicles; guidance for satellite rendezvous; atmospheric entry guidance. Effect of component inaccuracies on performance of missions. *R. H. Battin*

16.48 *Elements of Digital Control Computers* (A)
Prereq.: ——
Year: G (1) 3–0–6
Introduction to the composition of digital computers for automatic control. Reviews methods of logical analysis and deals with digital computer organizations, logical circuit elements, input-output methods, and fixed and erasable memory systems. *A. L. Hopkins*

16.481 *Digital Computer Controlled Systems* (A)
(New)
Prereq.: 16.31
Year: G (2) 3–0–9
Review of the sampling process; z-transforms; classical and statespace models of linear systems; system stability. Digital compensator design: minimal prototype systems; root locus and frequency response methods; compensator for multi-input/multi-output systems; quadratic synthesis techniques. Review of basic computer input-output techniques; computer system organizations; system analysis; software. Selected applications of digital computer control, including digital autopilots and industrial process control. *A. L. Hopkins, R. E. Curry*

16.491 *Selected Topics in Celestial Mechanics* (A)
Prereq.: 8.03, 18.076
Year: G (1) 3–0–6
Review of the two-body problem. Variational principles in dynamics, leading to Lagrange's equations, the canonical equations, and canonical transformations. The Hamilton-Jacobi equation, with solution for the Kepler problem, leading to canonical perturbation methods, Delaunay variables, and Lagrange's variational equations. Gravitational potential of a planet and rotational motions of the Earth and moon. First order theory of the orbits of artificial satellites, including the effects of atmospheric drag. *J. P. Vinti*

16.492 *Selected Topics in Celestial Mechanics* (A)
Prereq.: 16.491
Year: G (2) 3–0–6
The Brouwer-Von Zeipel method and the method of Lie transforms, with applications to the orbits of artificial satellites and lunar orbiters. Separable problems, including the spheroidal method, Staeckel systems, and the effects of general relativity on the orbit of a planet or satellite. Selected topics from the three-body problem, planetary and lunar theory, resonant motions, periodic orbits, and stability theory. *J. P. Vinti*

16.50 *Vertical Take-Off Aircraft* (A)
Prereq.: 16.02
Year: G (1) 3–0–6
Analysis of inherent performance stability and control characteristics of vertical take-off and landing aircraft, including helicopters and ducted fan, tilt wing, jet vectored-lift, and jet vertical-lift aircraft. *N. D. Ham*

16.51 *Advanced Vertical Take-Off Aircraft* (A)
Prereq.: 16.50
Year: G (2) 3–0–6
Application of fundamental principles of aeroelasticity, airplane dynamics, aerodynamics, and automatic control to problems encountered in the design of helicopters. Problems of control and stability during transition to horizontal flight, design of stabilization systems, vibration and flutter of rigid or articulated rotors, and analysis of rotor airloads in forward flights. *N. D. Ham*

16.53 *Rocket Propulsion*
Prereq.: 16.001; 16.02
Year: U (2) 3–0–6
Velocity requirements for orbital and interplanetary trajectories. Solid propellant grain design, nozzle performance. Thermochemistry of liquid propellant rockets, flow of chemically reacting gases, calculation of specific impulse. Turbopumps. Heat transfer in nozzles. The rocket engine treated as a complete system. *W. S. Lewellen, D. E. Stickler*

16.531 *Mechanics of Two-Phase Flow* (A)
Prereq: 16.02
Year: G (2) 3–0–9
Introduction to the mechanics of fluid-particle flow with emphasis on an understanding of the roles played by each phase in various physical phenomena. Transport properties of particle-fluid suspension. Continuum description of particle-fluid flow. Dynamics of particles in nozzle flows, normal shocks and mixing and combustion zones. Incompressible fluid-particle flow. Sedimentation and fluidization. Electrodynamics of suspensions. *(Not offered 1971–72.)* *C. K. W. Tam*

16.532 *Rocket Combustion Problems* (A)
Prereq.: 16.53
Year: G (1) 3–0–9
Examination of the behavior of combustion and flow systems characterized by high volumetric energy release rates. Special reference to rocket propulsion applications. Various rate controlling processes considered individually, in terms of simple combustion examples. Mixed rate control and ignition processes. Steady and unsteady combustion behavior of solid, liquid, and hybrid rocket systems. Rate processes in chemical laser systems. Primary attention to empirical treatment of rocket combustion technology. *D. E. Stickler*

16.54 *Aircraft Engines*
Prereq.: 16.001; 16.02
Year: U (1) 3–0–6
Performance characteristics of ramjets and gas turbine engines, related to the characteristics of components — inlets, compressors, combustors, turbines, nozzles. Engine-airframe performance characteristics. Emphasis on factors which will determine future trends in engine development. *J. L. Kerrebrock, J. F. Louis*

16.541 *Aircraft Turbine Engines* (A)
Prereq.: 16.54
Year: G (2) 3–0–9
Internal fluid mechanics of turbomachinery. Steady two-dimensional and three-dimensional flow theories of compressors and turbines. Unsteady flow and associated noise production in turbomachinery and in complete engines. Stress and associated temperature limitations in turbines. Influence of blade cooling techniques. Thermodynamics and performance of gas turbine engines. Discussion of various engine types: turbojet, turbofan, turboprop, and hybrid engines.
J. F. Louis, J. L. Kerrebrock

16.542 *Topics in Computational Fluid Physics* (A)
Prereq.: 18.081
Year: G (2) 3–0–9
Consideration of the role of computing in theoretical and experimental fluid dynamics. Survey of numerical and non-numerical applications of computing in theoretical fluid physics. Detailed study of numerical procedure for viscid, inviscid, compressible, and incompressible flows; examination of particulate methods for ionized gases. Topics in numerical stability, resolution, time-reversibility, and coarse graining. Illustrations from supersonic and transonic aerodynamics, viscous flow over bodies, and plasma dynamics. *D. A. Oliver*

16.55 *Ionized Gases* (A)
Prereq.: 8.211
Year: G (1) 3–0–9
Equilibrium description of ionized gases, composition, energy states, statistical mechanics and ionization equilibrium. Kinetic theory, motion of charged particles in magnetic fields, distribution function, collisions, Boltzmann equation, characteristic lengths and times, cross sections, transport properties. Gas-surface interaction, thermionic emission, surface ionization, sheaths, probe theory. Radiation in plasmas, diagnostics. *A. Solbes*

16.551 ***Plasma Propulsion and Power Generation*** **(A)**
Prereq.: 16.55
Year: G (2) 3–0–9
Study of advanced power generation and propulsion concepts employing high temperature ionized gases and conducting fluids. Emphasis of both the underlying physics of ionized gases and general systems and mission requirements for thrust and power generation. Selected application to concepts ranging over electrostatic, electromagnetic, and electrothermal thrusters, plasma diodes, liquid metal magnetohydrodynamic generators and magneto plasmadynamic generators. *D. A. Oliver*

16.561 ***Nuclear Rockets*** **(A)**
Prereq.: 16.53, 18.075
Year: G (1) 3–0–9
Study of the problems and potentialities of utilizing nuclear energy for space propulsion systems. Typical subjects: suitable missions, fission reactor physics, compromises involved in designing a solid-core nuclear rocket, radiation shielding, and the fluid dynamic and heat transfer problems which must be solved to make various advanced nuclear systems technically feasible. *W. S. Lewellen*

16.58J ***Advanced Topics in Plasma Kinetic Theory*** **(A)**
(New)
(Same subject as 22.65J)
Prereq.: 16.59, 22.64J
Year: G (2) 3–0–9
Varying content, including topics of current interest. Typical subjects: theories of collective phenomena such as linear instability and non-linear saturation mechanisms in plasma, particularly in regimes described by the Vlasov-Maxwell equations. Effects of wave-particle resonance; trapping and scattering of particles by waves. Linear theory of instabilities in inhomogeneous plasmas. Reflection and eigenmode problems in bounded systems. Diffusion phenomena and anomolous resistivity associated with wave-particle interaction. Discussion of experiments. *J. E. McCune, T. H. Dupree*

16.59 ***Introduction to Plasma Kinetic Theory*** **(A)**
Prereq.: 6.631J or 22.61
Year: G (2) 3–0–9
Collective behavior in collisionless fully ionized plasmas; theory of the Vlasov equation. Waves in plasma without magnetic field, particle-wave resonance; Landau damping. Resonant and non-resonant electrostatic instabilities. Dynamics of a magnetized plasma; particle drifts, currents, constants of the motion; adiabatic invariants. Moment equations and the "double-adiabatic" approximation. Drift-kinetic equation; low-frequency instabilities. Examples of micro-instability in anisotropic plasmas. Micro-turbulence and "collisions"; approximations to the plasma kinetic equation. *J. E. McCune, J. D. Callen*

16.60 ***Advanced Special Project*** **(A)**
Prereq.: —
Year: G (1, 2, S) *Arr.*
Study, original investigation, or laboratory project work of graduate level by qualified students. Topics selected in consultation with instructor. *Staff*

16.601 ***Advanced Special Subject*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
Organized lecture or laboratory subject consisting of graduate level material not available in regularly scheduled subjects. *Staff*

16.605 ***Special Projects***
Prereq.: ——
Year: U (1, 2) *Arr.*
Study or laboratory project work of undergraduate level by qualified students. Topics selected in consultation with the instructor. *Staff*

16.62 ***Experimental Projects***
Prereq.: 8.02
Year: U (1, 2) 2–6–4
Designed to help the student to gain practical insight through "project" experiments. Emphasis on preparation of the project goals, planning of details for the necessary apparatus, conducting of the experiment and relation of the experimental results to the initial goals. Provides not only an opportunity for the student to assemble and apply the knowledge he has gained, but also provides him with a link between theory and practice. *Staff*

16.65 ***Experimental Techniques in Aerodynamics*** **(A)**
Prereq.: 16.02
Year: G (1) 3–0–9
Study of experimental techniques in aerodynamics from two points of view. First, discussion of the problems of specific instrumentation. Then, consideration of the relative motion between the model and airstream in terms of both moving and stationary models. Attention given to practical considerations that may be encountered in actual test programs, as well as consideration of the problems of using testing facilities now being developed. *E. E. Covert*

16.70 ***Aircraft and Spacecraft Design***
Prereq.: ——
Year: U (1) 2–4–0
Lectures on preliminary design procedure with applications to an airplane and a satellite. Practice in drawing and in the detail design of components. *F. K. Bentley*

16.71 ***Flight Vehicle Engineering***
Prereq.: ——
Year: U (2) 2–3–7
Design of an atmospheric flight vehicle to satisfy stated performance, stability, and control requirements. Emphasis on individual initiative and application of fundamental principles and the compromises inherent in the engineering design process. (*Restricted to seniors in Course* XVI.) *N. D. Ham*

16.73 ***Space Systems Engineering***
Prereq.: 16.01, 16.201
Year: U (1) 4–0–8
Review of fundamental principles used in engineering development of space vehicles and application to specific mission analysis. Trajectory kinematics, booster requirements, entry dynamics, propulsion systems, structural design, thermal protection, weight estimation, environmental control and component layout. *R. H. Miller*

16.74 ***Advanced Systems Engineering*** **(A)**
(Revised: Unit change)
Prereq.: 16.201 or 16.53 or 16.73
Year: G (2) 2–3–7
Application of the engineering sciences to a typically complex aerospace systems design project. Mission analysis, system analysis and design, system integration. Specialized technical fields supported by outside guest lecturers. Students will participate as teams, each responsible for one of several subsystems, providing actual experience in project organization and the methods by which individuals and teams work together to define and achieve a mutual goal. *Staff*

16.751 ***Flight Transportation*** **(A)**
Prereq.: 16.30
Year: G (1) 3–0–6
Integrated discussion covering basic concepts and operational characteristics of flight transportation systems. Methods of predicting vehicle performance, anticipating future design trends, and determining direct operating costs; airport design and functional layout; guidance and control techniques, both in terminal area and en route; communication and radar system performance.
R. H. Miller

16.752J ***Flight Transportation Seminar***
(Same subject as 1.222J)
Prereq.: ——
Year: G (1) 1–0–2
Economics of airline operation, problems of financing, and of domestic and international route allocation. Subject developed around seminars presented by speakers from the regulatory agencies, national and international organizations and industry on particular phases of flight transportation. Preparatory lecture preceding each seminar. Opportunity for students to conduct studies in their area of major specialization on a particular topic covered by the subject.
R. W. Simpson, R. L. deNeufville

16.76J ***Analysis of Urban Service Systems*** **(A)**
(New)
(Same subject as 6.515J, 11.86J)
Prereq.: 1.07 or 6.28 or 18.303
Year: G (2) *Arr.*
Lectures describe quantitative techniques useful in the analysis of large-scale, urban service systems (e.g., fire and police departments, emergency ambulance services, airports, mass transit systems) such as geometrical probability, multi-server queueing theory, spatial location, scheduling and sequencing techniques cost. Cost structures and utility theory and relevant methods of simulation. Discussion of problems with validation of models, and the estimation of parameters while emphasizing the development of models of system operations approaches to the evaluation of policy.
A. R. Odoni, A. Fleisher, R. C. Larson

16.77 ***Flight Transportation Operations***
(16.772) ***Analysis II*** **(A)**
Prereq.: 1.143 or 15.081
Year: G (2) 3–0–6
Study of the application of linear programming and network flow theory to operational problems in flight transportation systems. Review of graph theory. Network flow theory. Integer programming and branch and bound methods. Dynamic programming. Review of the implementation of computerized mathematical programming systems. Application of the theory to scheduling, aircraft and crew routing, timetable optimization, passenger traffic flow, flight planning, etc. Student use of computer to solve large-scale problems and for term project.
R. W. Simpson

16.78J ***Planning and Design of Airport Facilities*** **(A)**
(Same subject as 1.23J)
Prereq.: 1.11 or 1.146; 1.20 or 1.201 or 16.751
Year: G (2) 3–0–6
The planning and design of airports, airport terminals and airport access systems. Synthesis of current practice and advanced concepts. Airfield layout: airspace requirements; number and orientation of runways; capacity of alternative configurations. Impacts of airport on environment: effect upon urbanization and metropolitan development process; noise and related environment considerations; Multidimensional evaluation of benefits and costs to air travellers, airport operators and local communities. Optimal strategies for terminal design: tradeoffs between vehicular concepts and constructed facilities; strategies for capacity expansion; review of current practice. Survey of behavioral patterns; demand function; cost-effectiveness analysis of alternative means of providing service. Special attention to the most advanced design concepts in the United States and Europe and the insight they provide for the design of airport systems of the future.
R. Simpson, R. L. de Neufville, N. H. M. Wilson

16.82 ***Aerospace Engineering***
Prereq.: ——
Year: U (1) 3–0–3
The work of engineers and scientists in aerospace technology with the Apollo moon project and the supersonic transport as examples. Mission analyses, research and development problems in fluid mechanics and propulsion, materials and structures, automatic control and flight guidance. Interaction among these disciplines in flight vehicle design.
Staff

16.84 ***Aerospace Engineering***
Prereq.: ——
Year: U (1) 3–2–7
Same lectures and subject matter as 16.82 but with additional discussion meetings and outside preparation.
W. McKay

16.85 ***Industrial Practice***
Prereq.: ——
Year: U (2) 0–8–0
Seven months of engineering practice carried out by the cooperative students at the plants of organizations participating in the cooperative program.
R. H. Miller

16.91 ***Continuum Vibrations*** **(A)**
(Revised: Content change)
Prereq.: 16.201
Year: G (1) 3–0–6
Vibrations of simple and complex structures: bars, strings, beams, plates, and multi-mass systems. Variational principles in dynamics: Hamilton's principle and Lagrange's equations. Vibration analysis of structural mode shapes and frequencies by differential equation, integral equation, lumped parameter, and energy (Rayleigh-Ritz and finite element) approaches; various solution methods, frequency bounds, etc. Introduction to the analysis of static and dynamic aeroelastic phenomena (divergence, flutter, etc.); self-excited vibrations of parked boosters, flexible pipes with flowing fluid, and power transmission lines.
J. Dugundji

16.92 ***Advanced Aeroelasticity*** **(A)**
Prereq.: 16.02, *16.91*
Year: G (2) 3–0–9
Presentation of field of aeroelasticity from unified viewpoint applicable to flight structures as well as suspension bridges, buildings and other structures. Derivation of aeroelastic operators and unsteady airloads from governing variational principles. Static aeroelastic and flutter instabilities of simple systems, one-dimensional and two-dimensional structures. Selected topics of current interest.
J. Dugundji

16.94 ***Dynamics of Structures*** **(A)**
Prereq.: 16.91
Year: G (2) 3–0–9
Normal coordinate and generalized coordinate analyses of small-deflection linear-elastic transient responses of structures to various loadings: gusts, random turbulence, impact, etc. Application of finite difference, finite element, and conventional lumped parameter methods to analyze both small-deflection and large-deflection transient responses of structures; features of various finite-difference operators, stability, damping, etc. Extension to treat elastic-plastic strain hardening, strain-

rate, and temperature-dependent material behavior. Prediction of energy absorption and permanent deformation by rigorous and by various approximate methods. Impact and the propagation of stress waves in solids and structures; spall fracture. Selected topics of current interest. *E. A. Witmer*

17. *Political Science*

UNDERGRADUATE SUBJECTS

EMPIRICAL POLITICAL AND SOCIAL THEORY

17.01 *Political Science Laboratory*
Prereq.: 17.02
Year: U (1) 2–6–4
Coordinated set of project-type research experiences concerning individual, community, national, and international affairs. Emphasis on using procedures of experimental or quasi-experimental inference to test normatively significant hypotheses about political life. Enrollment limited to 30. *D. Hibbs*

17.02 *Society and Man*
Prereq.: One first-year Humanities sequence
Year: U (1, 2) 3–0–6
Introduction to the social sciences. Focus on the relation of the individual to his society, considering both the individual's capacity to affect his society and his society's effect on him. Life in the contemporary world examined by such methods as sociological surveys, psychological experiments, mathematical models, and political and anthropological studies. *M. Ross*

17.03 *Power, Influence and Policy Decisions*
Prereq.: ——
Year: U (1) 3–0–6
Study of the distribution of power in selected types of social units: small groups, organizations, communities, institutions, and nations. Emphasis is placed upon the development of concepts and research techniques necessary for empirical power analysis. Data are drawn from social units in the United States. (*Not offered 1971–72.*) *F. W. Frey*

17.04 *Mathematical Politics*
Prereq.: 17.02
Year: U (2) *Arr.*
Mathematical modeling of political processes including alternate descriptions and evaluations of their inputs, mechanisms and outcomes. Election or referendum campaigns, national decision making, and international conflict. (*A year of previous social science work or reading required. Not offered 1971–72.*) *Staff*

NORMATIVE POLITICAL AND SOCIAL THEORY

17.11 *Introduction to Normative Political Theory*
(*Revised: Unit change*)
Prereq.: ——
Year: U (1) 1–0–3
Introduction to some major issues in normative political thought: criteria for evaluating forms of government; evaluations of the quality of different forms. Discussion of writings of relevant authors from ancient and modern times. This year this will be a half-term introductory course. Students may then move into one of several more advanced political theory courses concurrently or subsequently. *I. Pool*

17.12J *Political Ideas and Industrial Society*
(Same subject as 21.542J)
Prereq.: ——
Year: U (1) 3–0–6
Identification of certain fundamental problems of industrial society through readings of selected nineteenth- and twentieth-century political and social theorists. Use of economic and historical materials in an attempt to relate political ideas to the problems raised by industrialism. *S. Berger, B. Mazlish*

17.13 *Critiques of Technological Society*
Prereq.: 17.02
Year: U (1) 3–0–6
Attempt at developing a typology of social criticism from the works of selected nineteenth and twentieth century critics of technological society. Emphasis on inter-relationships between analytical and prescriptive characteristics of theory. Examination of writings by Ellul, Juenger, Mumford, Fromm, Brown, Marcuse, and others. *C. Schaefer*

17.14 *Revolution and the Theory of Politics*
(*New*)
Prereq.: ——
Year: U (2) 3–0–6
Course in political theory focusing on certain political problems during three periods of crisis: English Revolution, French Revolution, and the socialist revolutions. Explores range of alternative solutions to problems of authority, obedience, representation, and social justice in works of such theorists as Locke, Hobbes, Rousseau, Burke, Marx, and Luxemburg. *S. Berger, D. Blackmer*

AMERICAN POLITICAL PROCESS

17.21 *Introduction to the American Political Process*
Prereq.: ——
Year: U (1, 2) 3–0–6
Examination of the functioning of the American political system in terms of the social and institutional bases of political power, the evolution of contemporary problems associated with the modern Presidency and with the contributions of Congress and the judiciary to the policy process. Particular emphasis on the interrelationships of power at the national level, on changing external contexts affecting institutional patterns and the behavior of policy elites, and on the problematics of policy articulation in the contemporary era. *W. D. Burnham*

17.22 *Political Parties*
Prereq.: 17.21 or 17.52
Year: U (1) 3–0–6
Analysis of political parties and their role in decision making in the political system. Primary attention to the American party system, national party organization, Presidential nominating conventions, electoral strategies and especially the dynamics of American voting behavior. Comparison with parties and electoral behavior in other political systems, especially those of Western Europe. Attention paid to extremist political movements and the behavior of electorates under acute stress.
W. D. Burnham

17.23 *Judicial Process*
Prereq.: 17.21 or 17.31
Year: U (2) 3–0–6
Introduction to the study of judicial processes at various levels of the political system. Topics including inferences on the interpretation, appreciation, and modification of legal norms. *Staff*

17.24 *Politics and Television*
(*New*)
Prereq.: ——
Year: U (1, 2) 3–0–6
The role of television, the most powerful mass medium, in shaping American public attitudes towards elections and issues, especially national and international policies. Topics included: the relative importance to a candidate of TV news mentions as compared to print news mentions; the influence, if any, of TV political commercials on elections and policies; news "management" by both government and the mediamen; Vietnam as a crisis of perception; attitudes about science and technology reflected on the home screen. *E. Diamond*

17.25 *Bureaucracy*
Prereq.: 17.21
Year: U (2) 3–0–6
Study of the structure of public organizations and the politics of bureaucracy in the United States. Examination of major theories of bureaucracy and public administration with reference to specific cases involving policy making, policy execution and the relationship among elected and appointed officials. Special emphasis on the roles of scientists and professionals in the administrative process. (*Not offered 1971–72.*) *H. M. Sapolsky*

17.26 *The Politics of National Economic Control*
Prereq.: ——
Year: U (2) 3–0–6
Analysis of the policy-making processes and major political issues associated with government efforts to guide the American economy and produce a just distribution of wealth. *A. A. Altshuler*

URBAN POLITICS

17.31 *Urban Politics*
Prereq.: —
Year: U (1) 3–0–6
Analysis of local political systems and their interaction in dealing with contemporary metropolitan problems. Emphasis on sociocultural bases of political systems and sources of political influence. *A. A. Altshuler*

17.34 *The Governance of Cambridge*
Prereq.: ——
Year: U (2) 3–0–6
Study of a unique city charter (Plan E-PR) and practical problems in making it operative. Emphasis, inter alia, on selected topics such as: the roles of the city council and the manager; public housing; the redevelopment authority; traffic; health and hospitals; and public education. *T. Mahoney*

17.35 *Politics of Poverty and Community Action*
Prereq.: 17.21
Year: U (1) 3–0–6
The politics of low-income, relatively powerless groups; determinants of participation, modes of political action (focusing on protest and community organization); analysis of probabilities of success of various political strategies. *M. Lipsky*

17.36 *Politics of Urban Education*
Prereq.: 17.02
Year: U (1) 3–0–6
Analysis of current educational criticism in light of traditional educational theories, with particular attention to the forms of control of public education through centralization, decentralization, and "community control." Contributions to the development of subject matter by those students interested in field work in education through teaching and tutoring. *L. Menand*

SCIENCE AND PUBLIC POLICY

17.41 *Government, Politics, and Technology*
Prereq.: ——
Year: U (1) 4–0–8
An examination of the impact of science and technology on political structures and processes; the major public policy issues that technological advance poses for governments; the ways in which science modified patterns of political activity and institutions; the role of the scientist in political decision making. *E. B. Skolnikoff*

17.42 *Congress and Policy for Science and Technology*
(*New*)
Prereq.: ——
Year: U (1) 3–0–6
Development of the role of Congress in determining national policy, especially in relation to science and technology. Emphasis on the workings of the Congress, Executive/Congressional relations, the problems of determining national policy for science, and especially a critical evaluation of "technology assessment." *E. Daddario*

DEFENSE POLICY

17.43 *Evolution of Strategic Nuclear Systems*
Prereq.: 17.57
Year: U (1) 3–0–6
Introduction to the history of the development of strategic nuclear forces and strategy. Consideration of major alternative postures and their implications for deterrence and arms control. Projections of the future role and limitations of strategic nuclear forces. *W. W. Kaufmann*

17.44 *Evolution of Forces for Limited War*
Prereq.: 17.43
Year: U (2) 3–0–6
Introduction to the history of concepts about limited war developed since World War II. Comparison of nuclear and non-nuclear forces for the deterrence and conduct of limited war. Analysis of the problem of escalation and its control. Consideration of current U.S. requirements for limited war forces. *W. W. Kaufman*

POLITICAL AND SOCIAL PSYCHOLOGY

17.46 *Political Psychology*
Prereq.: 17.02
Year: U (2) 2–1–6
Selected topics in the relevance of psychology to political behavior including the relationship between personality and political systems and recent psychological findings on the social control of men's behavior. (*Not offered 1971–72.*) *R. E. Feldman*

17.47 *Ego and Youth*
Prereq.: —
Year: U (1) 3–0–6
Seminar tracing the sources and courses of ego-involvement in young people. Brief allusion to intergenerational conflicts in classical literature, from the *Antigone* of Sophocles to Turgenev's *Father's and Sons*. Attention focussing on modern analytical works from Marx through Freud to Erikson. Exploration of the relatively new role of the mass media, American and global, in the socialization of youth. Process of "growing up" as a common concern of all past, present, and prospective societies. *D. Lerner*

POLITICAL DEVELOPMENT AND COMPARATIVE POLITICS

17.51 ***Introduction to Political Development***
Prereq.: —
Year: U (1) 3–0–6
Consideration of the major problems of political development in the developing areas of Asia, Africa, and Latin America, focusing on a number of representative cases. *M. Weiner*

17.52 ***Comparative Political Systems***
Prereq.: 17.02
Year: U (2) 3–0–6
Comparative study of the organization and use of political and economic power in contemporary foreign political systems: Britain, West Germany, and France. Emphasis on the development of attitudes and political customs and the components of democratic political systems. *Staff*

17.53 ***Political and Economic Development of Tropical Africa***
Prereq.: 17.02 or any political science subject
Year: U (1) 3–0–6
Study and evaluation of the major theories, facets and problems of economic and political development in tropical Africa. *W. R. Johnson*

17.54J ***Economic Development, Political Structure, Imperialism, and Social Discontent in Low Income Countries***
(New)
(Same subject as 21.428J)
Prereq.: ——
Year: U (2) 3–0–6
A survey of the facts of social discontent in low income countries; critique of possible causes lying in economic status, political structure, and international relationships, and discussion of their social, political, and international implications. *(Open to graduates; graduates will write a term paper).* *E. Hagen, R. E. MacMaster*

17.55J ***Nationalism in Africa***
(Same subject as 21.551J)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Examination of the ideological, political, and economic bases of imperialism, colonialism and nationalism; the partition of Africa, the nature of alien rule, and the response of Africans thereto during the nineteenth and twentieth centuries. *R. I. Rotberg*

INTERNATIONAL RELATIONS AND FOREIGN POLICY

17.56 ***International Relations***
Prereq.: 14.01 or 17.02 or 21.05
Year: U (1, 2) 3–0–6
Introduction to the study of real and potential international systems. Topics: international warfare, the impact of technology on war and the arms race, the balance of power, classical and modern imperialisms, regional and universal international organizations. Focal concern with causes of war and conditions of peace. *N. C. Field, Staff*

17.57 ***Principles and Problems of American Foreign Policy***
Prereq.: 17.56
Year: U (1) 3–0–6
Underlying patterns and major objectives of American foreign policy. Examination of social and institutional structures within which foreign policy is made. Analysis of substantive foreign policy issues: Great Power relations, alliance problems and U.S. policy toward developing areas. *C. Schaefer*

17.58 ***Seminar in International Politics***
Prereq.: 17.56
Year: U (2) 3–0–6
Seminar focusing on contemporary international politics in Asia and Africa (first term) and Western Europe (second term). Dynamics of national and international behavior will be examined with special regard for American policy. *(This course is coordinated with 17.785).* *C. Schaefer*

17.59 ***Arms Control, Disarmament, and Foreign Policy***
Prereq.: 17.56
Year: U (1) 3–0–6
Analysis of the problems of disarmament and arms control and the issues involved for American foreign policy and world peace, against a background of diplomatic factors, technological change, and politico-military strategy. *(Not offered 1971–72.)* *L. P. Bloomfield*

17.60 ***Causes of War***
(New)
Prereq.: 17.56
Year: U (1) 3–0–6
A general survey of major theories of war and a look at select wars in the nineteenth and twentieth centuries in an effort to determine, however tentatively, the relative weights attached to various "causes." Students will be given a choice between reading (extensive survey of the literature) or research (investigation into the determinants, "causes" and consequences of specific wars). Seminar discussions will attempt to combine both emphases. *N. C. Field*

MISCELLANEOUS SEMINARS

17.61-17.66 ***Reading Seminar in Social Science***
Prereq.: ——
Year: U (1, 2) *Arr.*
Reading and discussion of special topics in the fields of social science. Open to advanced undergraduates by arrangement with individual staff members. *Staff*

17.67 ***Undergraduate Research Seminar***
Prereq.: ——
Year: U (1, 2) *Arr.*
Extended participation in the work of a research group, including independent study of the literature, direct involvement in the group's research commensurate with the student's skills and preparation, or project work under an individual faculty member extending over more than one term. *(Admission by arrangement with individual faculty member.)* *Staff*

17.68 ***Cooperative Work-Study Program***
Prereq.: ——
Year: U (1, 2) *Arr.*
Approved degree-relevant work in local, state, or federal government, public or private social agencies, private research-oriented organizations, or law firms, ordinarily done during summers or second semester of the junior year. Close contact between the student and his faculty advisor while participating in such a program and giving proof of additional academic output, normally an appropriate term paper. Applications for a proposed program must be made at least three months prior to its beginning, except by approval of the undergraduate departmental committee. *Staff*

17.69 ***Pre-thesis Reading Seminar***
Prereq.: ——
Year: U (1, 2) 3–0–6
Intensive reading on topics of interest to students in preparation for senior thesis under guidance of thesis supervisor. A written paper required, forming a substantial part of the senior thesis. *Staff*

GRADUATE SUBJECTS

POLITICAL COMMUNICATION AND BEHAVIOR

17.701 *Public Opinion and Propaganda*
Prereq.: ——
Year: G (2) 3–0–6
History and development of public opinion as a factor in public policy: relationship of public opinion and private attitudes; organization of political parties and pressure groups; techniques used by them; conditions of effective and ineffective communications. *I. D. Pool*

17.705 *Mass Media and Communication Systems*
(Revised: Unit change)
Prereq.: ——
Year: G (1) 3–0–6
Examination of the pattern of communication in societies at different stages of development. Comparison of networks of oral communication with systems based on mass media. The role of opinion leaders, informal communication networks, literacy, the press, radio, film, and international communications. *I. D. Pool*

17.710 *Political Socialization* (A)
Prereq.: ——
Year: G (2) 3–0–6
Study of the processes by which societies and groups regularly teach their members how to behave politically. Examination of approaches to socialization of anthropology, psychoanalysis, and social psychology. Analysis of the main socializing agencies (family, peer group, school, occupation, religion, and voluntary association) to ascertain their distinctive influences. Investigation of national differences in political socialization and ideas of national character. *(Open to qualified undergraduates. Not offered 1971–72).* *F. W. Frey*

17.715 *The Analysis of Power* (A)
Prereq.: ——
Year: G (1) 3–0–6
Study of the concepts, measurement techniques, research findings, and hypotheses used in the analysis of power relations. Emphasis on American political institutions and other societies where appropriate evidence is available. *(Open to undergraduates by permission of instructor only. Not offered 1971–72.)* *F. W. Frey*

17.720 *Survey Research Methods* (A)
Prereq.: ——
Year: G (2) 3–0–6
Introduction to survey research, with some study of problems in the philosophy of social science and of social scientific experimentation. Focus on the complete survey operation from problem selection through data analysis and presentation. A class survey project is required. *(Open to undergraduates by permission of instructor only. Not offered 1971–72.)* *F. W. Frey*

17.725 *Changing Outlooks and Identities in World Affairs* (A)
Prereq.: ——
Year: G (1) 3–0–6
Group identity and political change, changes in human relations resulting from changes in power relations, new conceptions of self and others arising, e.g., out of the end of colonial rule and the emergence of new national sovereignties in Asia and Africa, and from the end of the world generally and in the United States in particular; problems of national identity, racialism, ethnicity, pluralism in the re-shaping of political systems and, in particular, of the American society. *(Open to qualified undergraduates.)* *H. R. Isaacs*

17.727 *Personality, Society, and Politics*
Prereq.: ——
Year: G (2) *Arr.*
The gradual inclusion of the social environment in psychoanalytic theory. The psycho-sexual and psychosocial stages of man in their relation to social institutions. Personality in followership and in leadership. Application to selected political problems. *(Open to qualified undergraduates.)* *L. W. Pye*

17.730 *Identity and Ideology*
Prereq.: 17.02
Year: G (2) 3–0–6
Study of personality theory and political behavior with special emphasis upon the relationships between characterological elements and themes and appeals in political ideologies. Case studies of the personal development of historic leaders and the impact of their personalities upon historical processes. *(Open to qualified undergraduates. Not offered 1971–72.)* *L. W. Pye*

17.731 *Graduate Seminar in Political Psychology* (A)
Prereq.: ——
Year: G (2) *Arr.*
Examination of the influence of personality, situational and cultural factors on the individual's reaction to perceived authority. Emphasis on experimental sociopsychological data and the design of new experiments. Investigation of differences in cognitive and behavioral characteristics which may be found in different populations. A required original laboratory or field experiment. *(Open to undergraduates by permission of instructor only. Alternate years. Not offered 1971–72.)* *R. E. Feldman*

17.735 *Research Seminar in International Communications* (A)
Prereq.: ——
Year: G (1) *Arr.*

17.736 *Research Seminar in International Communications* (A)
Prereq.: ——
Year: G (2) *Arr.*
Cooperative examination of key problems in this field. *(Open to undergraduates by permission of instructor only.)* *D. Lerner*

17.738 *Field Seminar in Political Communications and Behavior*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the field of Political Communication and Behavior in preparation for the general qualifying examination. *Staff*

AMERICAN GOVERNMENT

17.743 *Graduate Seminar in American Politics* (A)
(Revised: Unit change)
Prereq.: 17.21
Year: G (2) 3–0–6
Analysis of the American political system with primary emphasis on the national level. Examination of American political culture, federalism, the American party system, representation and public policy, and the major institutional components of the national policy process. Special attention to contemporary and comparative research on American politics and government. Discussion also includes some reference to the explicit and implicit theoretical assumptions of such work, as well as critiques of these assumptions. *(Open in exceptional cases to qualified undergraduates by permission of the instructor only.)* *W. D. Burnham*

17.745 *Dynamics of Electoral Politics*
(New)
Prereq.: ——
Year: G (2) 3–0–6
Analysis of mass voting behavior in the United States, past and present. Evaluation of leading theories of American electoral politics in light of inferences from data analysis. Primary emphasis on longitudinal system dynamics and other properties, both quantitative and nonquantitative. Some comparative analysis of electoral dynamics and theories of electoral politics in other Western political systems. Attention to American voting behavior since 1960. *W. D. Burnham*

17.750 *Private Organizations and the Political Process*
Prereq.: ——
Year: G (2) 3–0–6
Analysis of the roles private organizations play in the American political system. Examination of the internal government and external political relations of voluntary associations, professional societies, labor unions, and business firms. Special emphasis on theories of formal organization useful in explaining political behavior. (*Open to qualified undergraduates. Not offered 1971–72.*)
H. M. Sapolsky

17.755 *Field Seminar in American Government*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the American Government field in preparation for the general qualifying examinations. *Staff*

COMPARATIVE POLITICS

17.760 *Comparative Asian Politics* (A)
Prereq.: 17.930
Year: G (2) *Arr.*
Comparative analysis of political systems of Asia. Special attention to the processes of social change and the problem of political stability. Study will cover the transition from traditional and colonial systems to the contemporary ones. (*Open to qualified undergraduates.*) *L. W. Pye*

17.765 *Chinese Politics* (A)
Prereq.: 17.935 or 17.940
Year: G (2) 3–0–6
Analysis of contemporary Chinese politics, both pre-Communist and Communist. Special focus upon the process of modernization and political development of the Chinese civilization. (*Open to qualified undergraduates. Not offered 1971–72.*) *L. W. Pye*

17.767 *Comparative Asian Politics: Political Development in India* (A)
Prereq.: 17.02; 17.52 or 17.930
Year: G (2) 3–0–6
Examination of the Indian political system focusing on problems of modernization. Topics: India's traditional political and social organization; the impact of the West; the development of political parties and interest groups; patterns of political participation; the ideology and characteristics of Indian political elites; problems of national integration; the "value" debate in Indian economic development; the political dimensions of economic policy. (*Open to undergraduate majors in the Humanities and Social Sciences.*) *M. Weiner*

17.770 *Comparative African Politics: Research Seminar* (A)
Prereq.: 17.53 or 17.55J
Year: G (2) 3–0–6
Comparative analysis of the political systems of tropical Africa. Particular attention to special problems concerning traditional social and political organizations, the impact of imperialism and colonialism, the rise of nationalism, liberation movements and post-independence institutions. (*Open to undergraduates by permission of instructor only.*) *W. R. Johnson*

17.771 *Comparative Afro-American and African Politics* (A)
(New)
Prereq.: 17.53 or 17.55J or 21.463 or 21.485J or 21.973
Year: G (2) 3–0–6
Analysis of the "colonial analogy" between the political and economic experience and plight of black people in urban American ghettoes and African peoples. Examination of the similarity and differences in the political economy of the two experiences of dependency, and of efforts to overcome this dependency. (*Open to undergraduates.*) *W. R. Johnson*

17.775 *Seminar: Politics and Government of Sub-Sahara Africa* (A)
Prereq.: 17.53
Year: G (1) 3–0–6
Study of problems relating to nation building, political development, political integration, and broader political union in Africa. Study of the interrelation of political structures, ideas, and processes. (*Open to undergraduates by permission of instructor only.*) *W. R. Johnson*

17.780 *Theories and Approaches to the Study of Comparative Politics* (A)
Prereq.: 17.940
Year: G (2) 3–0–6
A comprehensive examination of various approaches which underlie our study of comparative politics, with literature drawn primarily from Western Europe. The utility of alternate conceptualizations and theoretical formulations found in the general literature on comparative politics. (*Open to undergraduates by permission of instructor only. Alternate years. Offered 1971–72.*) *L. W. Pye*

17.782J *Race Relations and Politics in the Caribbean*
(Same subject as 21.579J)
Prereq.: ——
Year: G (2) 3–0–6
Comparative study of the role of color and race in the politics of the Caribbean. Attention to problems of modernization and leadership in French, Dutch, and English speaking areas. (*Open to advanced undergraduates.*)
R. I. Rotberg

17.783 *Comparative Politics of Latin America* (A)
Prereq.: ——
Year: G (2) *Arr.*
Exploration of issues in making cross-national and intra-national comparisons of political systems emphasizing the specific problems raised by the need to use and integrate diverse data bases (historical, economic, organizational, attitudinal). (*Open to qualified undergraduates.*) *Staff*

17.785 *Euratlantica: Western Europe in World Politics*
(Revised: Unit change)
Prereq.: ——
Year: G (2) 1–0–4
Introduction to the present position of Western Europe in the world, covering particularly economics, security, and the technological gap, followed by discussion of the foreign policies of the major West European states. Special attention to the changing attitudes of the European elites. Offered as a coursette during last eight weeks of spring term. Graduate students without sufficient background in international politics of Western Europe are encouraged to take the full subject listed as 17.58. (*Open to qualified undergraduates.*)
D. Lerner, C. Schaefer

17.790 *Domestic Politics of Western Europe*
Prereq.: ——
Year: G (1) 3–0–6
Comparative study of politics and society in France, Great Britain, Germany and Italy. Analysis of the "cases" of the integration of feudal remnants and the problem of democratic control of economic planning. (*Open to undergraduates by permission of instructor.*) *S. Berger*

17.793 *Research Seminar in Comparative Politics: Western Europe*
Prereq.: ——
Year: G (2) 3–0–6
For students planning research in Western European countries. Discussion of current work in the field. Training in the use of European primary source materials and in research methods applicable to European problems. Presentation of students' own research projects. *S. Berger*

17.795 *Politics in the Transitional Middle East* (A)
Prereq.: 17.52
Year: G (2) 3–0–6
Comparative analysis of structures of power in Turkey, Iran, and Egypt. Problems in locating and explaining changes in configurations of power in the Middle East, especially related to efforts at social and economic development. The relationship between attitudinal patterns and social structure. Various political science approaches to the common analysis of both Western and non-Western politics; the development of political theories of cross-cultural generality. (*Open to undergraduates by permission of instructor only. Not offered 1971–72.*) *F. W. Frey*

17.797 *Field Seminar in Comparative Politics*
Prereq.: —
Year: G (2) *Arr.*
Comprehensive review of the Comparative Politics field in preparation for the general qualifying examinations. *Staff*

COMMUNIST STUDIES

17.801 *Communism and Revolution*
Prereq.: ——
Year: G (1) 3–0–6
The ideology and practice of Communist political and social revolution, with primary emphasis on Soviet experience through the Stalin era. Marx, Lenin, and the Bolshevik seizure of power; role of the Communist party; the trauma of forced change in a backward society; the totalitarian model. Introduction to the problems of contemporary Soviet politics. Qualified students encouraged to do comparative research on a second communist revolutionary experience. (*Not offered 1971–72.*) *D. L. M. Blackmer*

17.805 *Soviet Foreign Policy and the Communist World* (A)
Prereq.: 17.801
Year: G (1) 3–0–6
Primarily an examination of recent Sino-Soviet relations, but including also Soviet dealings with East Europe and, to a lesser extent, with the non-ruling parties. Brief review of Soviet state and party relations with China and East Europe during the Stalin period, followed by a more detailed analysis of the course of events since 1953. (*Open to qualified undergraduates.*) *W. E. Griffith*

17.808 *Soviet Political System* (A)
Prereq.: 17.801
Year: G (2) 3–0–6
Research seminar on the operation of the Soviet system, with special emphasis on change and continuity since Stalin's death. The transition from a developing to a modern industrial society and its consequences for the Communist party and other Soviet institutions. Case studies of such contemporary problems as literature, industrial management, agriculture, elite politics. Interest group theory and other comparative approaches to the evolution of Soviet society. (*Open to undergraduates by permission of instructor only.*) *D. L. Blackmer*

17.811 *Research Seminar on Sino-Soviet Relations and International Communism* (A)
Prereq.: 17.805
Year: G (2) *Arr.*
Techniques of research in Communist affairs, with special reference to Sino-Soviet relations after the death of Stalin: the decipherment of esoteric communications with respect to changes of policy and personnel and to inter-party relations. Readings, research problems, and a seminar paper. (*Not offered 1971–72.*) *W. E. Griffith*

17.815 *Communist Propaganda* (A)
Prereq.: 17.801
Year: G (2) 3–0–6
After brief consideration of Nazi and other totalitarian propaganda doctrine and practice, a detailed study of doctrine, strategy, and tactics of Soviet and Chinese propaganda operations. Some attention to other Communist propaganda operations. (*Not offered 1971–72.*) *W. E. Griffith*

17.820 *Domestic and Foreign Politics of East Europe*
Prereq.: ——
Year: G (1) 3–0–6
Analysis of the domestic problems and foreign relations of the Communist states of East Europe since World War II. (*Open to qualified undergraduates.*) *W. E. Griffith*

17.825 *Radical and Revolutionary Ideologies*
Prereq.: 17.801
Year: G (2) 3–0–6
Consecutive treatment of the following: the background of Marxism in German idealistic philosophy; the thought of Marx, Engels, Bakunin and Anarchism; the revisionists, the orthodox Marxists, the leftist Marxists, the origins of Russian radicalism and Russian Marxism; Lenin, Trotsky, Bukharin, Stalin; Fascism; the interwar neo-Marxists; Titoism; East European revisionism; Maoism; ideology in the Sino-Soviet split; revisionist Marxism in Eastern Europe, in Western Europe; radicalism in Cuba; the Chinese Cultural Revolution; Asian and African Socialism; North Vietnam; Radicalism and the New Left in North America and Western Europe (the civil rights movement, Black Power; the U.S., English, French, German, and Italian student movements and rebellions). (*Open to qualified undergraduates.*) *W. E. Griffith*

17.827 *Field Seminar in Communist Studies*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the Communist Studies field in preparation for the general qualifying examinations. *Staff*

DEFENSE POLICY

17.830 *Development of General War Systems and Strategies* (A)
Prereq.: 17.58 or 17.880
Year: G (1) 3–0–6
Analysis of major U.S. policy decisions concerning general war systems and strategies in the postwar period. Emphasis on the technological, strategic, political, budgetary, and environmental factors that have affected these decisions. Examination of the role of innovation

and analysis in the evolution of general war systems and strategies. (*Open to undergraduates by permission of instructor only.*) *W. W. Kaufmann*

17.832 *Development of Limited War Systems and Strategies* (A)
Prereq.: 17.830
Year: G (2) 3–0–6
Analysis of major U.S. policy decisions concerning limited war systems and strategies in the postwar period. Emphasis on the determination of force structures and on changing views about the utility of nuclear weapons, the problem of escalation, and the relationship between limited war and general war forces and strategies. (*Open to undergraduates by permission of instructor only.*)
W. W. Kaufmann

17.835 *Research Problems in Defense* (A)
Prereq.: 17.838
Year: G (2) 3–0–6
Examination of a major problem-area in the realm of U.S. defense policy. Main focus on history of the evolution of the problem, consideration of U.S. objectives, and examination of alternative solutions to the problem. (*Open to undergraduates by permission of instructor only.*)
W. W. Kaufmann

17.838 *Principles of Systematic Policy Analysis* (A)
Prereq.: ——
Year: G (1) 3–0–6
Systems analysis of policy choices mainly in the defense area. Cost-benefit analysis and related techniques. Political and bureaucratic constraints on analytic procedures. The role of judgment in problem formulation and in the selection of cost and benefit criteria. (*Open to undergraduates by permission of instructor only.*)
G. W. Rathjens

17.840 *Seminar in Systematic Policy Analysis* (A)
Prereq.: 17.838
Year: G (2) 3–0–6
Collaborative research on simplified policy choices illustrative of the problems facing the Federal and local governments today. Cases selected from such areas as defense, poverty programs, urban affairs, and education. Cost-benefit calculations. (*Open to undergraduates by permission of instructor only.*) *G. W. Rathjens*

17.841J *The Nuclear Arms Race and Arms Control — Technology, Management, and Government Policy* (A)
(*New*)
(Same subject as 6.508J)
Prereq.: ——
Year: G (1) 3–0–6
The decision making process relating to national security based on the interaction of technological assessments with political and economic judgments. Both the development of nuclear weapons systems and disarmament considerations must take into account existing and projected technology. The course includes a critical examination of the decisions to develop ballistic missiles, ABM, MIRVs, etc. Also a review of the Nuclear Test Ban Treaty and SALT. To the extent possible experts who have played key roles in the topics covered invited to give guest lectures. (*Open to graduate students and seniors.*) *G. W. Rathjens, J. P. Ruina*

17.844 *Research and Development and National Security* (A)
Prereq.: ——
Year: G (2) 3–0–6
Management of government sponsored research and development in the U.S., its interrelations with national policy and organization; the problem of ascertaining those relations among the technological community, the Congress, the Executive Branch, and industry which will best facilitate the generation of new ideas and the further development of technology; case studies and problems in other countries. (*Open to undergraduates by permission of instructor only.*) *A. G. Hill*

17.846 *Field Seminar in Defense Policy*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the defense studies field in preparation for the general qualifying examinations.
Staff

SCIENCE AND PUBLIC POLICY

17.850 *Science, Technology and the State* (A)
Prereq.: 17.21
Year: G (1) 3–0–6
History of development of science and technology in the American government, especially post-war. Current science policy issues, with emphasis on allocation of resources, government/private sector relations, decision-making machinery in government and role of scientists and engineers. (*Open to qualified undergraduates.*)
E. B. Skolnikoff

17.855 *Technology and Public Policy* (A)
Prereq.: 17.41 or 17.850
Year: G (2) 3–0–6
Important subject areas in which science and technology take form as substantive issues of public policy. Techniques for forecasting and analyzing the impact of technology on society. Intensive examination of several illustrative policy areas such as outer space, the marine environment, arms and arms control, etc. (*Open to undergraduates by permission of instructor only. Not offered 1971–72.*) *H. M. Sapolsky*

17.856J *Seminar in Technological Assessment and Public Policy: Selected Topics* (A)
(*New*)
(Same subject as 6.509J)
Prereq.: ——
Year: G (2) 3–0–6
Examination of several cases of the interaction of technological judgment and expertise with political and economic policy questions. The cases examined chosen at the beginning of the course taking into account the interests of the class and will include some of the following: (1) communication satellites; (2) electric power sources and the environment; (3) air traffic control; (4) manned space flight; (5) supersonic transport. Focus of the seminar discussion on how these issues were, or are being, affected by the nature and use of technical knowledge, extrapolations and projections, and on the interaction of technical experts with the executive and legislative branches of government. Also consideration of the nature of "objectivity" in rendering technical advice and counsel. Some of the leading "actors," technical and political, as guest lecturers. (*Open to graduate students and seniors.*) *G. W. Rathjens, J. P. Ruina*

17.860 *Public Management of Science and Technology* (A)
Prereq.: ——
Year: G (2) 3–0–6
A study of the Federal government's support and use of science and technology, emphasizing major organizational and political issues. An analysis of the problems of organizational competition, policy planning and coordination, Executive-Congressional relations, the science advisor's role in government, innovation, and institutional autonomy. (*Open to undergraduates by permission of instructor only.*) *Staff*

17.863 *Science and American Foreign Policy* (A)
Prereq.: 17.850
Year: G (2) 3–0–6
Examination of the scientific component in U.S. foreign-policy making, including the scientific and technological bases of key issues in foreign policy, opportunities scientific programs offer for the more effective realization of U.S. objectives; role of scientists in foreign policy process. (*Open to qualified undergraduates. Not offered 1971–72.*)
E. B. Skolnikoff

17.865 *International Response to Science and Technology* (A)
Prereq: 17.850
Year: G (2) 3–0–6
Seminar examining some of the international political, legal and institutional implications of selected areas of science and technology. The past and possible future responses of the international political system to new technologies or technology-related problems. Examination primarily from the perspective of the development of international law and international institutions. Concentration of case materials primarily in the field of space communications and international regulation of atomic energy with some attention given to the emerging fields of the deep ocean and international problems in pollution and environmental control. Conducted jointly with Professor Chayes of the Harvard Law School. (*Registration limited. Permission of instructor required.*)
E. B. Skolnikoff

17.870J *Public Policy and Use of the Seas* (A)
(Same subject as 13.92J)
Prereq.: 17.57
Year: G (1) 3–0–6
Policies of the United States and other nations toward use of the seas. Interfaces between technology and public policy. Problems in management of coastal zone; use of Continental Shelf; utilization of ocean resources; pollution; models for international sea bed regime. New lines of ocean policy. *N. J. Padelford*

17.875 *Field Seminar in Science and Public Policy*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the Science and Public Policy field in preparation for the general qualifying examinations. *Staff*

INTERNATIONAL RELATIONS AND FOREIGN POLICY

17.880 *Theories of International Relations* (A)
Prereq.: 17.56 or 17.57
Year: G (1) 3–0–6
Selective review and critical discussion of the literature of international relations. Comparison of disciplinary foci and conceptual frameworks proposed by authors such as Aron, Lasswell and Wright. Examination of work by Carr, Claude, Deutsch, Guetzkow, Haas, Hoffman, Kaplan, Kelman, Lenin, Morganthau, and other materials for their substantive hypotheses, normative orientations, data resources, and research possibilities. (*Open to undergraduates by permission of instructor only.*)
N. C. Field

17.881 *Methods Seminar in International Politics*
(*New*)
Prereq.: ——
Year: G (2) *Arr.*
A critical review of empirical approaches to the study of international politics and a survey of recent methodological innovations and applications. Interdisciplinary emphasis with particular reference to problems of analysis in international relations. (*Open to undergraduates by permission of the instructor.*) *N. C. Field*

17.885 *The Law of Nations* (A)
Prereq.: 17.58 or 17.880
Year: G (1) 3–0–6
Role of law in international relations. Nature and subjects of international law. Rights and duties of states. Territorial questions with special reference to boundaries, marginal waters, the high seas, air and outer space. Peaceful settlement of disputes. Use of force and the international rule of law. (*Open to qualified undergraduates.*)
N. J. Padelford

17.887 *The U.N. System and Problems of Political Development* (A)
Prereq.: 17.58 or 17.880
Year: G (2) 3–0–6
Process and politics of the U.N. system. The role of international agencies in political and economic development. Concepts of integration and community. Problems of collaboration with international institutions. (*Open to undergraduates by permission of the instructor only. Not offered 1971–72.*) *N. J. Padelford*

17.888 *Aid, Trade, and Foreign Investment: The Politics of Economic Relations Between Rich and Poor Nations*
(*New*)
Prereq.: ——
Year: G (2) 3–0–6
Exploration of the links between economic dependents, economic growth, and political influence in the changing international context. Are foreign resources necessary for economic growth? Sources of foreign capital and expertise in the nineteenth century and currently: political implications of changed patterns. Aid, trade, foreign investment from rich and poor nations' viewpoints. Old and new "spheres of influence." Prospects for changing the international rules of the game. (*Open to qualified undergraduates.*) *J. Nelson*

17.890 *Comparative Foreign Policy*
Prereq.: ——
Year: G (2) 3–0–6
Comparative analysis of national and international dynamics insofar as these pertain to foreign policy formulation and implementation. Review of the pertinent literature and an emphasis on cross-national and cross-time perspectives. Special focus on major powers, Scandinavia, Canada, Japan, and selected Asian and African states. (*Open to undergraduates by permission of instructor only. Not offered 1971–72.*) *N. C. Field*

17.893J *Research Seminar in Imperialism and Colonialism* (A)
(Same subject as 21.578J)
Prereq.: One graduate subject in Comparative Politics or International Politics
Year: G (1) 3–0–6
Topics in the economic, social, and cultural bases of imperialism and colonialism, its theory and practice. (*Open to undergraduates by permission of instructor only. Not offered 1971–72.*) *R. I. Rotberg*

17.895 *U.S. Foreign Policy — Contemporary Directions* (A)
Prereq.: 17.56 or 17.57
Year: G (1) 3–0–6
Critical analysis of recent U.S. foreign policy in the context of past tendencies and future possibilities. Roots of U.S. policy; origins of the Cold War; "intervention/unilateralism" as a theme; the prospects for multilateralism and international cooperation. Relationship of political, military, and other component elements. (*Open to undergraduates by permission of the instructor only. Not offered 1971–72.*) *L. P. Bloomfield*

17.897 *U.S. Foreign Policy — Plans and Strategies* (A)
Prereq.: 17.895
Year: G (2) *Arr.*
Planning and execution of foreign policy in the context of broad national purposes. Foreign policy goals and interests, and short- and long-term operational doctrines and strategies. Technology of policy planning, emphasis on simulation and other special techniques for more rational contingency planning. Class-designed political exercise, which counts as one of the required Political Science Methodologies. (*Open to undergraduates by permission of instructor only. Not offered 1971–72.*)
L. P. Bloomfield

17.899 *Research: International Relations and Foreign Policy* (A)
Prereq.: 17.895 or 17.897
Year: G (1) *Arr.*
Problem approach to selected areas and issues, based on particular student interests. (*Not offered 1971–72.*)
L. P. Bloomfield

POLITICAL AND ECONOMIC DEVELOPMENT

17.901 *Personality, Social Stability, and Social Change*
Prereq.: 17.46
Year: G (2) 3–0–6
Critique of evidence concerning "epigenetic evolution" v. social learning (including Skinnerian) theories of the development of personality, and implications of alternative theories for political theorizing. (*Open to qualified undergraduates. Not offered 1971–72.*) *E. E. Hagen*

17.905 *Seminar in Social Stability and Change* (A)
Prereq.: 17.901
Year: G (2) *Arr.*
(1) Critique of system theories of social systems (Deutsch, Almond-Powell, Easton, Parsons); relationship of personality theory to systemic analysis. (2) Models since Kardiner of the relationship of personality to stability and change in social-political structure. (*Open to undergraduates by permission of instructor only. Not offered 1971–72.*)
E. E. Hagen

17.907 *Seminar in Mechanisms and Forms of Protest*
Prereq.: ——
Year: G (1) 3–0–6
Comparative analysis of the varieties of self-assertion; resistance movements, rebellions, millennialism, and struggles for independence. In 1971, concentration on the nature and methodology of rebellion. (*Open to advanced undergraduates.*) *R. I. Rotberg*

17.910 *The Development of Political Organizations* (A)
Prereq.: 17.935
Year: G (1) 3–0–6
Examination of the factors involved in the origins, development, and maintenance of various types of political organizations. Particular attention given to the creation of political parties and the maintenance of local party organizations in underdeveloped areas. (*Not offered 1971–72.*) *M. Weiner*

17.913 *Social Organization and Political Change in Developing Areas* (A)
Prereq.: 17.930 or 17.935
Year: G (1) 3–0–6
Analysis of principles of social organization, social stratification, and social mobility as they affect various aspects of political development such as political participation, political leadership, political organization, legitimacy, and political integration. (*Not offered 1971–72.*)
M. Weiner

17.915 *Theories of Political Development* (A)
Prereq.: 17.57
Year: G (1) *Arr.*
Study of various analytical models of the political process in transitional societies. Systematic examination of factors influencing political behavior in changing societies; functions of politics in such societies. (*Open to qualified undergraduates.*) *L. W. Pye*

17.917 *Migration and Political Development*
Prereq.: ——
Year: G (1) 3–0–6
Exploration of the political causes and consequences of population movements across international boundaries and within states. Detailed examination of the following: the political effects of urban migration; the political behavior of political refugees; the consequences of internal population movements in multi-ethnic societies; the economic and political impact of migrants on the receiving country; the effects of migration on the country of origin. Case materials drawn from historic Europe and America as well as from contemporary Asia and Africa. *M. Weiner*

17.918 *Urbanization and Political Development*
(*New*)
Prereq.: ——
Year: G (1) 3–0–6
An analysis of the impact of urbanization on national political development. Interaction among urbanization, industrialization, social modernization. Are there alternatives to concentrated urbanization? Contrast in rural and urban political patterns. The political impact on outmigration on rural areas. Political integration of migrants and the urban poor. The shifting urban-rural balance. (*Open to qualified undergraduates.*) *J. Nelson*

17.920 *Field Research in Political Development* (A)
Prereq.: 17.720
Year: G (2) *Arr.*
Seminar in field research methods for political research in developing areas. Intended only for students who will begin field research the following academic year.
M. Weiner

17.927 *Field Seminar in Political and Economic Development*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the field of Political and Economic Development in preparation for the general qualifying examinations. *Staff*

POLITICAL ANALYSIS

17.930 *Concept Formation and Research Technique in the Social Sciences*
Prereq.: ——
Year: G (1) 3–0–6
Requirements for testable concepts and theory building with behavioral data. Logical foundations of evidence and inference, quantity and quality, parts and wholes, cause and effect. Research technique in sample surveys, controlled experiment, clinical diagnosis, statistical tests. Emphasis on reanalysis of extant and created data. (*Open to qualified undergraduates.*) *D. Lerner*

17.935 *Theory of Political Processes*
(*Revised: Unit change*)
Prereq.: ——
Year: G (1) 1–0–3
Analysis of various theories of the political process. Particular attention paid to theories concerning the formation of a consensus about the legitimacy of a gov-

ernment and the consequences of conflict and conformity within nations. A different author read and discussed each week. Coursette, first part of term. (*Open to qualified undergraduates.*) *I. D. Pool*

17.940 *Introduction to the Social Sciences* (A)
Prereq.: ——
Year: G (1) 3–0–6
Extensive reading and analysis of the classic works in modern social and political science theory. Systematic review of the various traditions of contemporary social science. (*Open to qualified undergraduates.*) *L. W. Pye*

17.945 *Topics in Political Theory*
Prereq.: ——
Year: G (1) *Arr.*
International interaction: The balance of power. Shifting coalitions, feedback, and multipolarity. Empire-building and the decomposition of empire. The initiation and termination of conflict. *Political Power and Society:* The dimensions of power: coercion, influence, authority. Authority and influence. The ruling class. The Marxian hypothesis. Political stability and instability. Revolution. *Typology of Political Systems:* Classical typologies (Plato, Aristotle, Polybius). Imperial and feudal rule. The problem of "oriental despotism." Bureaucratic absolutism. Consensual, pluralistic and totalitarian democracy. (*Open to undergraduates by permission of instructor only.*) *Staff*

17.947 *Philosophy and Social Science*
(*New*)
Prereq.: ——
Year: G (2) *Arr.*
An examination of some philosophical problems in social science focusing on perception, meaning, explanation and causality. A review and critical discussion of the sceptic, phenomenological and contextualist positions. (*Open to undergraduates by permission of the instructor.*)
C. Schaefer

17.950 *Logic of Social Research*
(*Revised: Unit change*)
Prereq.: ——
Year: G (1) 1–0–3
Reading of theoretical treatments and discussion of the application to major social science studies of the following topics: observation, experimentation, measurement, explanation, theory, and models. Coursette, second part of term. (*Open to qualified undergraduates.*) *I. D. Pool*

17.952 *Statistics for the Social Sciences*
Prereq.: ——
Year: G (1) 3–0–6
Basic concepts and techniques useful in social science. Summarizing empirical distributions, random variables and theoretical distributions; estimation of unknown parameters; measuring and testing statistical relationships between variables, including correlation, regression, and non-parametric methods, with emphasis on the question of which techniques are appropriate to which kind of data. No mathematical or statistical prerequisites. (*Open to qualified undergraduates.*) *D. Hibbs*

17.955 *Introduction to Mathematical Models in the Social Sciences*
Prereq.: ——
Year: G (2) 3–0–6
Introduction to the use of mathematical models and formal mathematical analysis in sociology and political science. Study of the necessary mathematics as a part of the subject. For students with little mathematical background. (*Open to qualified undergraduates.*) *Staff*

17.957 *Introduction to Computers in the Social Sciences*
(*Revised: Unit change and Content change*)
Prereq.: ——
Year: G (1, 2) 1–0–2
An elementary course for students without previous experience in computer applications. Includes the basic concepts of computers, of programming, of problem oriented languages, of data management and analysis, and of simulation and modeling. Approximately eight sessions scattered throughout the academic year. Problem sets assigned. Second term open only to those students who took first term. *I. D. Pool*

17.960 *Interactive Data Analysis*
(*Revised: Content change*)
Prereq.: ——
Year: G (1) 2–3–4

17.961 *Interactive Data Analysis*
(*New*)
Prereq.: 17.960
Year: G (2) 2–3–4
A two term sequence about computers — their operation and application. A non-engineering introduction to hardware and software concepts emphasizing the relationship between technology and the management of symbols. An introduction to programming from the standpoint of understanding the problem solving potential of the modern computer. Various social data applications discussed within the framework of a theory in an application area chosen by the student. Course members will have hands-on access to a dedicated computer installation being developed by the instructors. (*Open to undergraduates with computer background.*)
S. D. McIntosh, D. M. Griffel

17.962 *Ecology of the Social Sciences*
Prereq.: ——
Year: G (2) *Arr.*
Examination of time-place conditions under which each of the social sciences originated and developed. The social sciences are conceived as varied responses to specific problems generated by specific time-place environments. The focus is on the philosophical and methodological responses to new problems of social policy. (*Open to qualified undergraduates.*) *D. Lerner*

17.964 *Field Seminar in Political Analysis*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the political analysis field in preparation for the general qualifying examinations.
Staff

CONCEPTS AND METHODS

17.973 *Multivariate Political Analysis* (A)
Prereq.: 17.952, 17.955
Year: G (2) *Arr.*
Focus on multivariate data analysis procedures. Second half of a year sequence with first half being taught as Government 200 at Harvard. Topics: multiple regression analysis, analysis of variance and covariance, time series analysis, multi-equation consol modeling, and dimensional analysis. Social and political research applications undertaken and discussed. Students must have taken at least one previous course in statistics. (*Open to undergraduates by permission of instructor only. Alternate years. Offered 1971–72.*) *D. Hibbs*

17.975 *Seminar on Complex Models of Social Systems* (A)
Prereq.: 17.952, 17.955
Year: G (2) *Arr.*
Weekly seminar on the use of statistical, mathematical, and computer utilization skills needed for modeling cognitive, interpersonal, organizational, governmental, and

societal processes and structures. Critical analysis of modern systems theory and a comparison (using case studies) of the different tools of contemporary formal analysis offered. Taught in conjunction with Professors Jackson and Price of Harvard University as part of a coordinated training program in modeling complex social and political systems. Previous exposure to multivariate statistics and computer modeling required. (*Open to undergraduates by permission of instructor only. Not offered 1971–72.*) *D. Hibbs*

17.978 *Collective Decisions* (A)
Prereq.: 17.95?, 17.955
Year: G (1) 3–0–6
An inquiry into the relationships between individual and collective rationality, treating such subjects as the Prisoner's Dilemma, the Arrow Paradox, collective goods, centralized and decentralized decision-making. Assessment of the capabilities and limitations of a number of decisional procedures in terms of formal concepts derived from welfare economics, power analysis, and general systems theory. (*Open to undergraduates by permission of instructor only. Alternate years. Not offered 1971–72.*)
H. R. Alker

17.979 *Field Seminar*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the field of concepts and methods in preparation for the general qualifying exam.
Staff

URBAN STUDIES

17.980 *Seminar in Urban Politics* (A)
Prereq.: ——
Year: G (1) 3–0–8
Examination of politics of urban America. Focus on structures of power, mass participation, policy processes and urban bureaucracy, and problems of metropolitanization and decentralization. (*Open to qualified undergraduates.*) *M. Lipsky*

17.982J *Urban Problems and Policies* (A)
(Same subject as 11.06J)
Prereq.: 17.31 or 17.980
Year: G (2) *Arr.*
Analysis of political roots and social consequences of selected urban policies, ranging from law enforcement, welfare, and education to transportation, urban renewal, and Model Cities. Study of numerous proposals for change. (*Open to qualified undergraduates.*)
A. A. Altshuler, B. J. Frieden

17.987 *Politics of Urban Bureaucracy*
Prereq.: ——
Year: G (2) 3–0–6
Analysis of selected bureaucracies playing important roles in urban politics, with primary focus on explaining determinants of bureaucrat-client interaction. (*Open to qualified undergraduates who have taken 17.21 with consent of instructor.*) *M. Lipsky*

17.988 *Community Development in Urban Ghettos*
Prereq.: Any political science subject
Year: G (2) 3–0–6
Politics of community building and community oriented economic development in minority areas of large cities. Problems of increasing collective political and economic power of ghetto residents. Experience of community development corporations. (*Open to qualified undergraduates.*) *W. R. Johnson*

17.989 *Comparative Urban Politics*
Prereq.: 17.32, 17.33
Year: G (2) 3–0–6
Parallels and contrasts in political organization, leadership patterns, and political styles in large cities of the United States, selected European nations, and selected developing nations. Analysis of variations in the economic and social structure of urban life, the history and pace of urban growth, and national political systems as explanations for the varying patterns of urban politics. Examination of programs to cope with urban growth and integration of recently-arrived and/or underprivileged social groups; analysis of factors shaping these policies. (*Not offered 1971–72.*) *J. M. Nelson*

17.992 *Field Seminar in Urban Studies*
Prereq.: ——
Year: G (2) *Arr.*
Comprehensive review of the Urban Studies field in preparation for the general qualifying examinations.
Staff

READING SEMINARS

17.995-17.999 *Reading Seminar in Social Science* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Reading and discussion of special topics in the fields of social science. (*Open to advanced graduate students by arrangement with individual staff members.*) *Staff*

18.
Mathematics

GENERAL MATHEMATICS

18.00 *Elementary Number Theory*
Prereq.: ——
Year: U (1) 2–0–4
Elementary theory of whole numbers, including such topics as divisibility, prime and composite numbers, greatest common divisors, solutions of equations in integers, the congruence notation and its application, sums of squares, rational approximations of real numbers, continued fractions, distribution of primes. Emphasis on mathematical rigor and methods of proof. *N. C. Ankeny*

18.001 *Calculus*
(18.012) *Prereq.:* ——
Year: U (1) 4–0–8
Emphasis on the concepts and techniques of calculus relevant to science and technology. Mathematical formulation of problems with an introduction to approximate methods of solution including numerical analysis, perturbation theory, limits, differentiation, integration, series. *D. J. Benney*

18.002 *Calculus*
(18.022) *Prereq.:* 18.001
Year: U (1, 2) 4–0–8
Continuation of 18.001. A sound presentation of the concepts and techniques of calculus relevant to applications. Vectors, partial differentiation, multiple integration, vector calculus. *Term 1: H. P. Greenspan*
Term 2: D. J. Benney

18.01 *Calculus*
Prereq.: ——
Year: U (1) 4–0–8
Study of functions of one variable. Brief review of the elementary functions. Basic properties of functions, such as boundedness, periodicity, growth rate. Limits and continuity. Differentiation, with applications. Solution of the simplest differential equations. Integrability, the definite integral, fundamental theorem of calculus. Applications to geometrical problems. Integration techniques, improper integrals. The mean value theorem and its generalization to Taylor's theorem, with applications to calculation of the elementary functions. *A. P. Mattuck*

18.013 *Topics in Calculus Theory*
Prereq.: 18.01 or 18.001
Year: U (1, 2) *Arr.*
Topics include: limits of sequences, functions, differentiation and integration. Knowledge of standard nonrigorous calculus is assumed. *A. P. Mattuck*

18.02 *Calculus*
Prereq.: 18.01 or 18.014
Year: U (1, 2, S) 4–0–8
Study of functions of several variables. Vector algebra in three-space. Scalar functions of two and three variables; partial differentiation, gradient, approximation techniques. Double and triple integration, with applications. Vector functions of one variable, analysis of space motion, Kepler's laws. Vector functions of two and three variables, vector fields. Line integrals, Green's theorem in the plane, conservative fields. Surface integrals in space; the divergence (Gauss's) theorem; Stokes' theorem. *A. P. Mattuck*

18.023 *Topics in Calculus*
Prereq.: 18.02 or 18.002
Year: U (2) *Arr.*
An elective primarily for students completing 18.02 during the first half of the spring term. Topics according to demand: possibly elementary probability theory (discrete and continuous binomial and Poisson distributions, law of large numbers) and elementary Fourier analysis (heat equation, Fourier series, Fourier transforms). (*Offered only during the second half of the spring term.*) *A. P. Mattuck*

18.03 *Differential Equations*
Prereq.: 18.02 or 18.002
Year: U (1, 2, S) 4–0–8
Examples of initial value problems in science and engineering associated with single equations and with systems of first order equations. Methods of solution include graphical constructions, similarity transformations, series, Laplace transforms, matrices, numerical integration and the phase plane. Emphasis on formulation of natural phenomena in terms of differential equations and on interpretation of the solutions. *A. Toomre, F. Y. M. Wan*

18.031 *Introduction to Linear Algebra and Applications*
Prereq.: 18.02 or 18.002
Year: U (1) 3–0–9
Vector spaces, bases, linear dependence, inner products; linear transformations and their representation by matrices, structure theory of matrices including the Jordan form. Largely linear algebra, but containing some elementary parts of differential equations, notably linear differential equations and systems with constant coefficients. Suitable as background for subjects requiring more linear algebra but less differential equations than 18.03. Credit not permitted in all three of 18.031, 18.032 and 18.03. *L. N. Howard*

18.032 *Ordinary Differential Equations*
Prereq.: 18.031
Year: U (2) 3–0–9
Existence and numerical computation for initial value problems; structure of linear systems with variable coefficients; boundary-value problems; techniques for nonlinear problems; regular and singular perturbation theory. An intermediate level differential equations subject based on 18.031; credit not permitted in all three of 18.031, 18.032 and 18.03. *L. N. Howard*

18.033 *Computing Problems Related to Calculus*
(*New*)
Prereq.: 18.03
Year: U (2) 3–3–6
A study of several of the more common computing problems arising in calculus, including finding the roots of nonlinear equations, numerical solution of ordinary differential equations, and matrix operations. No previous programming experience required — programming taught as the first topic. Students expected to write programs using the methods studied in the lecture. (*Limited enrollment.*) *D. G. Schaeffer*

18.041 *Principles of Applied Mathematics*
Prereq.: 18.03
Year U (1) 3–0–9
18.042 *Principles of Applied Mathematics*
Prereq.: 18.03
Year: U (2) 3–0–9
A general introduction to the fundamental principles of applied mathematics: propagation, equilibrium, stability, optimization, cybernetics and random processes. Development of the related mathematics, applications and experiments. *S. A. Orszag* (18.041); *S. A. Papert* (18.042)

18.051 *Surveys of Higher Mathematics*
Prereq.: 18.01
Year: U (1) 3–0–9
Survey of a limited number of topics of current interest and of broad cultural significance, designed for students not majoring in mathematics, and stressing the central role of mathematics in today's world. Topics varying from year to year, and including: current developments in logic, the evolution of geometry, contemporary views on space and time, discrete vs. continuous mathematics, the mathematics of communication, chance and choice, elements of group theory, transfinite arithmetic, elements of field theory, non-standard analysis, etc. (*Not open to mathematics majors.*) *G. C. Rota*

18.07 *Review of Mathematics*
Prereq.: ——
Year: G (S) 8–0–12
Review of calculus and differential equations. (*Primarily for students in Course XIII-A.*) *Staff*

18.071 *Advanced Calculus* (A, *except Courses II, VI, VIII, XII, XIII, XVI, XVIII, XXII*)
Prereq.: 18.03
Year: G (1) 3–0–9
18.072 *Advanced Calculus* (A, *except Courses II, VI, XVI, XVIII, XXII*)
Prereq.: 18.071
Year: G (2) 3–0–9
Functions of a complex variable, ordinary differential equations, special functions, Sturm-Liouville problems. Advanced vector analysis, potential theory, Fourier series and integral transforms, boundary value problems. (*Essentially the same material as that covered in 18.075 and 18.076, but at an advanced level to satisfy the prerequisites for the Methods of Applied Mathematics sequence beginning with 18.305.*) *P. J. Greenberg*

Descriptions

18.075 ***Advanced Calculus for Engineers* (A, *except Courses II, VI, VIII, XII, XIII, XVI, XVIII, XXII*)**
Prereq.: 18.03
Year: G (1, 2, S); U (1, 2, S) 3–0–9
Functions of a complex variable; calculus of residues; conformal mapping. Ordinary differential equations; integration by power series; Bessel and Legendre functions. Expansion in series of orthogonal functions, including Fourier series. Hildebrand, *Advanced Calculus for Applications.* *F. B. Hildebrand*

18.076 ***Advanced Calculus for Engineers* (A, *except Courses II, VI, XVI, XVIII, XXII*)**
Prereq.: 18.075
Year: G (1, 2, S) 3–0–9
Vector analysis: orthogonal curvilinear coordinates. Calculus of variations. Solution of classical equations of mathematical physics, including applications of conformal mapping and the Laplace transformation. Partial differential equations; characteristics. Hildebrand, *Advanced Calculus for Applications.* *F. B. Hildebrand*

18.085 (18.081) ***Methods of Applied Mathematics for Engineers* (*A, except VI and XVIII*)**
Prereq.: 18.075
Year: G (1, 2) 3–0–9
Operations with matrices and determinants; linear vector spaces; characteristic-value problems. Techniques of calculus of variations; constraints, direct methods. Formulation and treatment of integral equations; Green's function; analytical and numerical methods of solution. Hildebrand, *Methods of Applied Mathematics.* *F. B. Hildebrand*

18.093 ***Tutoring in Mathematics***
Prereq.: 18.02 or 18.002
Year: U (1, 2) *Arr.*
Tutoring freshman mathematics with the assistance of staff. Limited enrollment. Permission must be secured in advance to register for this subject. *A. P. Mattuck*

18.094 ***Seminar in Mathematical Education***
Prereq.: ——
Year: U (1) 2–4–6
Study of school mathematics from an advanced standpoint together with practical experience in teaching. The seminar will investigate school mathematics curricula and teaching methods in light of modern ideas on teaching intuition and thinking skills. Students required to engage in 4 hours of practical work per week with children. (*Enrollment by permission of instructor. Not offered 1971–72.*) *S. A. Papert*

ANALYSIS

18.100 ***Analysis* (A, *except XVIII*)**
Prereq.: 18.03 or 18.031
Year: U (1, 2); G (1, 2) 3–0–9
Real numbers and euclidean n-space; open, closed and compact subsets of n-space. Continuous and differentiable functions. Uniform convergence. Fourier series, power series and analytic functions. *R. M. Dudley*

18.101 ***Analysis* (A, *except XVIII*)**
Prereq.: 18.100; 18.700 or 18.702
Year: G (2) 3–0–9
Normed linear spaces. Lebesgue integration in euclidean space. Differentiable maps, Jacobians and the inverse function theorem. Change of variables. Differential forms and Stokes theorem. *D. G. Schaeffer*

18.102 ***Harmonic Analysis and Potential Theory***
Prereq.: 18.100
Year: U (2) 3–0–9
Elementary theory of Fourier series and Fourier integrals; theory of Lebesgue integration; Riesz-Fischer and Plancherel theorems; Fourier-Stieltjes transforms; applications to partial differential equations and random walks.

18.104 ***Seminar in Analysis***
Prereq.: 18.100
Year: U (1, 2) 3–0–9
Seminars for mathematics majors in several topics, each under the direction of a faculty member whose special interest is in the field of the seminar. Reports and discussion by students on topics taken from current journals or from texts not regularly used in other mathematics subjects. Certain topics may require an additional prerequisite. *R. W. Goodman*

18.115 ***Theory of Functions* (A)**
Prereq.: 18.101
Year: G (1) 3–0–9
Cauchy's integral theorem, residue theorem and applications. Series and product representations of analytic functions. Entire and meromorphic functions. Simple Riemann surfaces. Conformal mapping. Additional topics may be included. *B. Maskit*

18.116 ***Theory of Functions* (A)**
Prereq.: 18.115
Year: G (2) 3–0–9
Topics selected by the instructor, e.g., harmonic functions, Dirichlet problem, Riemann surfaces, uniformization, quasi-conformal mapping, Fourier and Laplace transforms, special functions. *R. M. Dudley*

18.117 ***Functions of Complex Variables* (A)**
Prereq.: 18.115
Year: G (1) 3–0–9

18.118 ***Functions of Complex Variables* (A)**
Prereq.: 18.117
Year: G (2) 3–0–9
Various aspects of the theory of analytic functions. Content varying from year to year, so that students may take the subject in successive years. (*Not offered 1971–72.*) ——

18.125 ***Functions of Real Variables* (A)**
Prereq.: 18.101 or 18.901
Year: G (1) 3–0–9

18.126 ***Functions of Real Variables* (A)**
Prereq.: 18.125
Year: G (2) 3–0–9
Elements of the theory of metric spaces, category and Baire theorem. Measure theory, integration, absolute continuity, product measures. Banach spaces and algebras. Hilbert space and spectral theory. Measured and harmonic analysis on groups; Fourier analysis.
I. E. Segal (18.125); R. M. Dudley (18.126)

18.127 ***Functional Analysis* (A)**
Prereq.: 18.115 or 18.284; 18.125
Year: G (1) 3–0–9

18.128 ***Functional Analysis* (A)**
Prereq.: 18.127
Year: G (2) 3–0–9
General theory of linear topological vector spaces; generalized functions. Spectral and multiplicity theory in Hilbert spaces; general theory of C*- and W*-algebras. Harmonic analysis and infinite-dimensional representations of locally compact and Lie groups. Abstract theory of differential equations; applications. *S. Helgason*

18.129 ***Hilbert Space* (A)**
Prereq.: 18.126
Year: G (1) 3–0–9
The general theory of operators and operator algebras in Hilbert space with illustrative applications. (*Not offered 1971–72.*) *I. E. Segal*

18.135 *Locally Compact Groups* (A)
Prereq.: 18.125 or 18.127
Year: G (2) 3–0–9
Haar measure, group algebras, harmonic analysis on compact and abelian groups, Plancherel theorem, duality theorem. (*Not offered 1971–72.*) ——

18.155 *Differential Equations* (A)
Prereq.: 18.081 or 18.700; 18.115
Year: G (1) 3–0–9
18.156 *Differential Equations* (A)
Prereq.: 18.155
Year: G (2) 3–0–9
Existence theorems in real and complex cases. Linear systems. Regular singular points. Irregular singular points and asymptotic series. Boundary value problems including the non-self adjoint case and the case of infinite intervals. Stability theory and perturbation theory for non-linear differential equations. Periodic orbits. Limit cycles. Differential equation on a torus. (*Not offered 1971–72.*) *N. Levinson*

18.157 *Partial Differential Equations* (A)
Prereq.: 18.101
Year: G (1) 3–0–9
18.158 *Partial Differential Equations* (A)
Prereq.: 18.157
Year: G (2) 3–0–9
The Cauchy-Kowalewski theorem, existence and regularity of solutions of the Dirichlet problem for linear elliptic equations, existence and regularity of solutions of the Cauchy problem for hyperbolic linear equations, fundamental solutions for linear equations with constant coefficients. *W. Ambrose*

18.165 *Pseudodifferential Operators* (A)
Prereq. ——
Year: G (1) 3–0–9
18.166 *Pseudodifferential Operators* (A)
Prereq.: 18.165
Year: G (2) 3–0–9
Distributions, Fourier transforms and H_s-spaces; definition of pseudodifferential operators, their continuity properties, the Schwartz kernel, and the functional calculus. Elliptic and hypoelliptic pseudodifferential operators. The H_s, m-spaces. Boundary value problems. Pseudodifferential operators on manifolds and the Atiyah-Singer index theorem. (*Not offered 1971–72.*) *W. Ambrose*

18.175 *Theory of Probability* (A)
Prereq.: 18.101 or 18.102
Year: G (2) 3–0–9
Survey of contemporary theory of stochastic processes. Independence, zero-one laws, martingales, stopping rules, stationary processes, elements of ergodic theory; Markov chains, characteristic functions, central limit problems, stable laws; renewal theory, Tauberian theory, Gaussian processes and their spectral theory, Brownian motion, the strong Markov property, the variance theorem; Kolmogorov-Smirnov statistics, processes with independent increments, diffusion theory. Topics selected each year from these and others. (*May be repeated for credit.*) *R. M. Dudley*

18.176 *Theory of Probability* (A)
Prereq.: 18.175
Year: G (2) 3–0–9
Topics selected by the instructor, for example, convergence of probability measures, linear processes, Markov processes, stationary processes, ergodic theory, diffusion processes and stochastic differential equations. *R. M. Dudley*

18.177 *Introduction to Stochastic Processes* (A)
Prereq.: 18.171
Year: G (2) 3–0–9
Independence. Zero-one laws of Borel-Cantelli and Kolmogorov. Chebyshev's and Kolmogorov's inequalities. Distribution functions and transforms. Classical limit theorems (deMoivre-Laplace, Poisson, strong law of large numbers). Random walks, Markov chains, Poisson processes, Brownian motion and diffusion. Connection with differential and integral equations. *D. B. Ray*

18.204 *Seminar in Probability*
Prereq.: 18.100
Year: U (1, 2) 3–0–9
Seminars for mathematics majors in several topics, each under the direction of a faculty member whose special interest is in the field of the seminar. Reports and discussion by students on topics taken from current journals or from texts not regularly used in other mathematics subjects. Certain topics may require an additional prerequisite. *J. B. Wadsworth*

18.255 *Abstract Analysis* (A)
Prereq.: 18.126, 18.701
Year: G (1) 3–0–9
18.256 *Abstract Analysis* (A)
Prereq.: 18.255
Year: G (2) 3–0–9
Basic theoretical results about the structures of a mixed analytical-algebraic-geometrical character that are significant in modern analysis, with illustrative applications. (*Not offered 1971–72.*) *I. E. Segal*

18.257 *Mathematical Theory of Quantum Fields* (A)
Prereq.: 18.125
Year: G (2) 3–0–9
The general theory of quantized relativistic fields. Introduction to the problem of the construction of nonlinear fields. (*Not offered 1971–72.*) *I. E. Segal*

18.258 *Group Representations and Elementary Particles* (A)
Prereq.: 18.125
Year: G (2) 3–0–9
The general theory of representations of continuous groups in infinite-dimensional spaces, with applications to the theoretical treatment of elementary particle symmetries. (*Not offered 1971–72.*) *I. E. Segal*

18.270 *Integral Equations* (A, *except XVIII*)
Prereq.: 18.03
Year: G (2) 3–0–9
Objectives: (1) to show how to express physical problems in the form of integral equations, (2) to provide a treatment of the theory of integral equations, and (3) to describe the methods available for solving such equations. Applications to problems arising in several branches of physics and engineering. *P. D. Crout*

18.275 *Numerical Analysis* (A)
Prereq.: 18.075 or 18.301
Year: G (1) 3–2–7
18.276 *Numerical Analysis* (A)
Prereq.: 18.275
Year: G (2) 3–2–7
Introduction to the theory and practice of the solution of equations, interpolation, numerical differentiation and integration, and the numerical solution of ordinary and partial differential equations. Additional topics from the following: summation of series, least-squares methods, smoothing of data, Gaussian quadrature, Chebyshev approximation, harmonic analysis, approximation by exponential functions and by rational functions, determination of characteristic numbers of matrices. Hildebrand, *Introduction to Numerical Analysis*. (*18.276: Not offered 1971–72.*) *F. B. Hildebrand*

18.277 ***Theory of Approximations Methods*** **(A)**
Prereq.: ——
Year: G (1) 3–0–9
Analysis of constructive methods for the solution of algebraic and differential equations and eigenvalue problems. Applications of functional analysis. Constructive theory of functions. Over-relaxation and other iterative schemes for large systems of difference equations. Analysis of the finite element variational method. Familiarity with linear algebra assumed. (*Not offered 1971–72.*) *W. G. Strang*

18.279 ***Partial Difference Equations*** **(A)**
Prereq.: ——
Year: G (2) 3–0–9
Parallel treatment of initial-value problems for partial differential equations and their finite difference analogs; equivalence of convergence and stability for linear systems; von Neumann's method of stability analysis in L_2 by Fourier transform; Lax theory of non-linear conservation laws. *W. G. Strang*

18.284 ***Introduction to Functions of a Complex Variable*** **(A, *except XVIII*)**
Prereq.: 18.03
Year: G (1) 3–0–9

18.285 ***Introduction to Functions of a Complex Variable*** **(A)**
Prereq.: 18.115 or 18.284
Year: G (2) 3–0–9
Complex numbers, analytic functions, Riemann surfaces for certain functions, Cauchy's theorem, singularities, residues, contour integral, conformal mapping, Schwarz-Christoffel transformation, series and sequences, analytic continuation, harmonic functions, conjugate functions, the gamma function, second-order linear differential equations and special functions, Laplace transforms, asymptotic series, saddlepoint method, Hilbert transforms. Singular integral equations.
N. Levinson (18.284); M. R. Foster (18.285)

18.295 ***Tensor Calculus*** **(A)**
Prereq.: 18.081 or 18.700
Year: G (2) 3–0–9
Classical theory of tensors and Riemannian geometry. Applications to mechanics and general relativity. (*Not offered 1971–72.*) *P. J. Greenberg*

APPLIED MATHEMATICS

18.301 ***Introduction to Physical Mathematics I***
Prereq.: 18.032 or 18.700 or 18.702; 18.100
Year: U (1) 3–0–9
Interdependence of mathematics and scientific problems, examples; deterministic and random processes; particle mechanics and differential equations, Brownian motion and random walk. Fourier series; tensors; partial differential equations of mathematical physics and continuum mechanics. *H. Cheng*

18.302 ***Introduction to Physical Mathematics II***
Prereq.: 18.301
Year: U (2) 3–0–9
Calculus of variations, variational principles of mechanics, Lagrange's and Hamilton's equations; conservation principles and symmetry. Transformation theory, Hamilton-Jacobi equation, invariants, Liouville's equation. Applications to orbit theory, adiabatic invariants; fluids and plasmas; collective waves, equilibria and stability. *J. W. K. Mark*

18.303 ***Applications of Probability and Random Variables***
Prereq.: 18.02
Year: U (1, 2) 3–0–9
Theory of probability and random variables on an elementary level with emphasis upon mathematical models having wide applicability. Discrete and continuous random variables, joint distributions, derived distributions, expected value, difference equations, generating functions, some elementary aspects of queueing theory, theory of search and discrete and continuous Markov processes, decision making, and some probabilistic methods in the control of operations. Stress on applications from a wide choice of fields.
D. J. Kleitman, G. P. Wadsworth

18.304 ***Probability and Statistics***
(18.171) *Prereq.: 18.01*
Year: U (1, 2) 3–0–9
Introduction to probabilistic thinking in all branches of science. Starting from specific examples and phenomena, students gradually exposed to the underlying mathematical theories. Content varying from year to year, and possibly including: fluctuation theory for sums of random variables, random walks, Poisson processes, renewal theory, Markov chains, branching processes, estimation testing hypothesis, sufficient statistics, introduction to non-parametric statistics. *G. C. Rota*

18.305 ***Methods of Applied Mathematics I*** **(A)**
Prereq.: 18.072 or 18.284
Year: G (1) 3–0–9

18.306 ***Methods of Applied Mathematics II*** **(A)**
Prereq.: 18.285, 18.305
Year: G (2) 3–0–9
General mathematical theory of partial differential equations and methods of solution with applications to physical problems. Topics include: single equations of the first order; characteristic surfaces; and the classification of equations of higher order and systems of equations; properties of hyperbolic, parabolic, and elliptic equations, boundary conditions and well-posed problems, the application of integral transform and other methods to their solution. Asymptotic approximations. Integral equations; Fredholm and Hilbert-Schmidt theory, singular integral equations, application of integral transforms including Wiener-Hopf method, dual integral equations, Riemann problem. Calculus of variations.
J. W. K. Mark, E. Barouch

18.307 ***Methods of Applied Mathematics III*** **(A)**
Prereq.: 18.302 or 18.305
Year: G (1) 3–0–9
Asymptotic methods of non-linear mechanics. Singular perturbation theory, matched asymptotic expansions, W.K.B. techniques, difference equations, P.L.K. method, multiple scaling procedures, boundary layer techniques, applications to non-linear problems. *C. M. Bender*

18.308 ***Wave Motion*** **(A)**
Prereq.: 18.307
Year: G (2) 3–0–9
Review of linear waves. Non-linear interactions of discrete waves and wave trains. Asymptotic methods for dispersive and non-dispersive waves, characteristics, breaking, permanent waves, Whitham's theory. Non-linear stability. Non-linear random waves, propagation in random media, closure, special topics. *D. J. Benney*

18.325 ***Topics in Applied Mathematics*** **(A)**
Prereq.: ——
Year: G (2) 3–0–9
Content varying from term to term; may be repeated for credit. (*Not offered 1971–72.*) ——

18.330 ***Introduction to Elasticity***
Prereq.: 18.075 or 18.301
Year: U (2) 3–0–9
An introduction to the kinematics and dynamics of a deforming medium. The constitutive equations for elastic bodies. The equations of elasticity. Uniqueness

theorems and variational principles. Two dimensional problems. Applications of complex variable theory and transform methods. Additional topics as time permits.
A. Needleman

18.335 *Theoretical and Applied Elasticity* (A)
Prereq.: 2.071 or 18.330; 18.076
Year: G (1) 3–0–9

18.336 *Theoretical and Applied Elasticity* (A)
Prereq.: 18.335
Year: G (2) 3–0–9
Fundamental equations of nonlinear dynamic elasticity. Energy theorems and variational principles. Adiabatic and isentropic approximations. Waves and shocks in heat conducting and non-conducting media. Linear theory. Saint Venant's principle. Griffith and penny shape crack problems. Non-linear theory of beams and plates. Linear theory of shells. Static geometry duality. Reduction to two simultaneous equations. Exact solutions. Regular and singular perturbation solutions. The Poincare-Lighthill method. Turning point problems in toroidal shells. Marguerre's non-linear theory of shallow shells. Axisymmetric finite deformations of shells of revolution. *F. Y. M. Wan*

18.337 *Topics in Solid Mechanics* (A)
Prereq.: 18.336
Year: G (1) 3–0–9
Special topics in the linear and non-linear theory of beams, plates and shells. (*Not offered 1971–72.*) ——

18.350 *Introduction to Fluid Mechanics*
Prereq.: 18.075 or *18.301*
Year: U (1) 3–0–9
Elementary theorems of ideal fluids. Some basic concepts drawn from the mathematical description. Criteria for equilibrium. Potential flows; vortex motions; conformal transformations. Waves; group velocity; normal modes; instability. Elements of the theory of viscous fluids; some exact solutions; boundary layer theory.
S. A. Orszag

18.355 *Theoretical Hydrodynamics* (A)
Prereq.: 18.350
Year: G (2) 3–0–9
Dynamics of compressible fluids; shock waves; hypersonic flow. Theory of hydrodynamic stability. Introduction to the theory of turbulence; mixing-length concepts. (*Not offered 1971–72.*) *S. A. Orszag*

18.356 *Rotating Fluids* (A)
Prereq.: 18.305, 18.350
Year: G (2) 3–0–9
General theory of rotating fluid motions; transient flows; effects of viscosity, stratification, and compressibility; non-linear interactions; wave motions; applications.
H. P. Greenspan

18.357 *Seminar in Fluid Dynamics* (A)
Prereq.: 18.305, 18.350
Year: G (2) 3–0–9
Discussion of current work on stability theory, non-linear flows, turbulence, hydromagnetics and geophysical fluid dynamics. Students to contribute a critique of a recent paper or the formulation and defense of a novel problem. (*Not offered 1971–72.*) *W. V. R. Malkus*

18.358 *Hydrodynamic Stability and Turbulence* (A)
Prereq.: 18.350
Year: G (2) 3–0–9
Laminar and turbulent flows, stability of fluid motions. Momentum and vorticity transfer theories, similarity theory and other semi-empirical theories, turbulent diffusion, Richardson's law. Statistical theory of homogeneous turbulence, Kolmogoroff's theory, Heisenberg's theory, other theories. Theory of hydrodynamic stability, examples, linear and non-linear modes, transition to turbulence. Instability of self-gravitating fluids, galactic spirals, other gas dynamical problems in astrophysics.
C. C. Lin

18.370 *Dynamical Problems of Astrophysics*
Prereq.: 8.03; 18.071 or 18.075 or 18.301
Year: U (2) 3–0–9
Introduction to some current dynamical problems in astrophysics where the gravitational or electromagnetic interaction of point masses or of continua plays the dominant role. Topics include particle motion in central force, in static electric and magnetic fields; n-body problems and the relaxation of plasmas, star-clusters and galaxies; fluid flow in configuration and phase-space; continuum equations of fluid, stellar and plasma dynamics; integrals of motion and adiabatic invariants; equilibria, waves and instabilities, gas spheres and the adiabatic pulsations of stars, longitudinal plasma oscillations, etc. (*Not offered 1971–72.*) *J. W. K. Mark*

18.375 *Stellar Dynamics and Galactic Structure* (A)
Prereq.: 8.06; 18.076 or 18.302
Year: G (2) 3–0–9
Types and compositions of galaxies; mass distributions and kinematics. General dynamics of stellar systems: Liouville and Boltzmann equations, isolating integrals; encounters, relaxation times; epicyclic stellar orbits. Dynamics of interstellar material: observations; hydromagnetic equations; gravitational stability of a gas. Theory of star clusters and elliptical galaxies. Gravitational stability of a disk-shaped galaxy; spiral structure. (*Not offered 1971–72.*) *C. C. Lin*

18.376 *Galaxies, and Their Dynamics* (A)
(*New*)
Prereq.: 8.03; 18.076 or 18.301 or 18.370
Year: G (2) 3–0–9
Introduction to about a dozen Messier galaxies, the *Palomar Sky Survey*, the *Hubble Atlas of Galaxies*, Arp's *Atlas of Peculiar Galaxies*, and our own galaxy and its immediate neighbors; various estimates and kinematics. Dynamics of stars in elliptical galaxies, and of galaxies in clusters: relaxation, phase mixing, self-consistency. Particle and continuum dynamics in spiral galaxies: orbits, equilibria, instabilities, waves, modes, theories of spiral structure and of bars. Tidal interactions between galaxies: warps, bridges, tails, forced waves. Discussion of galaxy formation and evolution. *A. Toomre*

18.387 *Statistical Mechanics* (A)
Prereq.: ——
Year: G (1) 3–0–9
Selected topics, primarily in equilibrium statistical mechanics, with emphasis on rigorous mathematical results on specific problems. Discussion in detail of exactly soluble models such as the two-dimensional ferromagnetic and ferroelectric models. Mathematical theories of phase transitions. Ruelle, *Statistical Mechanics*. (*Not offered 1971–72.*) *E. H. Lieb*

18.395 *Mathematical Theory of Modern Physics* (A)
Prereq.: 18.285
Year: G (2) 3–0–9
An introduction to the basic principles of high-energy physics, with special emphasis on some of the latest developments in particle physics. Field equations; Feynman diagrams and Feynman rules; Mellin transform; infinite-momentum technique; behavior of high-energy amplitudes in various field theories; impact diagrams: Regge poles and Regge cuts; quantum electrodynamics; strong interactions. *H. Cheng*

18.397 *General Relativity* (A)
Prereq.: 8.06, 8.312, 18.700
Year: G (1) 3–0–9
Structure of space-time manifold; elements of tensor analysis and differential geometry, differential forms, spinors, topology. Symmetry groups. General covariance. Principle of equivalence. Einstein field equations. Exact solutions. Post-Newtonian approximation. Gravitational radiation and radiation reaction. Conservation laws and "pseudotensors." Classification of the Weyl tensor, equation of geodesic deviation, peeling theorem. Continuum mechanics. Thermodynamics. Geometrical optics. Space-like vector fields. Gravitational collapse, singularity theorems. Applications to astrophysics and classical and quantum cosmology. Content varying from year to year. (*Not offered 1971–72.*)
P. J. Greenberg

18.401 *Control Theory*
Prereq.: 18.03
Year: U (2) 3–0–9
Introduction to foundations of control theory. Controllability, stability, observability, time optimal control, convex cost criteria, maximal principle, and related topics will be discussed in suitable linear and nonlinear systems.
S. Grossberg

18.403 *Applied Combinatorial Analysis*
Prereq.: 18.03 or 18.031
Year: U (2) 3–0–9
Discrete optimization problems; linear, integer and dynamic programming; transportation problems.
D. J. Kleitman

18.404 *Seminar in Applied Mathematics*
(18.304) *Prereq.:* 18.301
Year: U (1, 2) 3–0–9
Seminars for mathematics majors in several topics, each under the direction of a faculty member whose special interest is in the field of the seminar. Reports and discussion by students on topics taken from current journals or from texts not regularly used in other mathematics subjects. Certain topics may require an additional prerequisite. (*Not offered 1971–72.*)
Staff

18.405 *Mathematical Learning Theory* (A)
Prereq.: 18.075
Year: G (1) 3–0–9
Introduction of a learning theory with psychological and physiological implications in terms of some non-linear difference — differential networks. Interpretation also as a non-stationary statistical and/or deterministic prediction theory. Global limit and oscillation theorems. Influence of geometry on dynamics (i.e., "anatomy of learning"). Time evolution of entropy. Study of reversible and irreversible behavior. Applications to data: e.g., serial learning (bowing, chaining, backward learning, reminiscence, presentation rate, list length, chunking, context effects), lateral inhibition, thresholds, spiking frequencies, transmitter production and release, ionic fluxes, reaction time, masking, pattern learning and discrimination, extinction and spontaneous recovery, anatomical examples such as cerebellum. Comparison with classical developments: such as, Gestalt, Hull, Pavlov.
S. Grossberg

18.420 *Introduction to Mathematical Theory of Computation*
Prereq.: ——
Year: U (2) 3–0–9
Abstract models of computation: finite automata, iterative arrays, pushdown automata, counter machines, Turing machines, measures of complexity. Introduction to recursive function theory: computable and non-computable functions and unsolvable problems. Small universal systems of computation.
M. J. Fischer

18.424 *Seminar in Computation*
Prereq.: ——
Year: U (1, 2) 3–0–9
Seminars for mathematics majors in several topics, each under the direction of a faculty member whose special interest is in the field of the seminar. Reports and discussion by students on topics taken from current journals or from texts not regularly used in other mathematics subjects. Certain topics may require an additional prerequisite. (*Not offered 1971–72.*)
Staff

18.425 *Theory of Computers* (A)
Prereq.: ——
Year: G (1) 3–0–9
Research seminar intended for advanced graduate students. This subject may be repeated for credit. (*Enrollment by permission of instructor.*)
Staff

18.426J *Algorithms* (A)
(Same subject as 6.546J)
Prereq.: 18.03 or 18.031
Year: G (1) 3–0–9
Basic algorithms of computer science. Parsing, sorting, searching, shortest-path methods, multiplication of matrices and integers, and evaluation of polynomials. Emphasis will be placed on theoretical and experimental methods for the evaluation and comparison of alternative methods. Some algorithms studied will be implemented on a computer. (*Ability to program a computer required.*)
M. J. Fischer, A. R. Meyer

18.427 *Formal Language Theory* (A)
Prereq.: 6.253 or 18.420
Year: G (1) 3–0–9
Methods of language specification. Finite-state, context-free, context-sensitive grammars and general rewriting systems. Deterministic and non-deterministic acceptors: finite-state, pushdown store, stack machines and linear bounded automata. Closure properties of languages under various mappings. Abstract families of languages and balloon automata. Time and space-bounded Turing machines. Decidable and undecidable problems. Parsing of context-free languages.
M. J. Fischer

18.428 *Advanced Topics in Language and Automata Theory* (A)
Prereq.: 6.538 or 18.427
Year: G (2) *Arr.*
Discussion of selected topics of current research interest in the field of language and automata theory. Content varying from year to year, so that graduate students may take the subject in successive years. (*Not offered 1971–72.*)
M. J. Fischer

18.429 *Algorithms Seminar* (A)
(*New*)
Prereq.: 18.426J
Year: G (2) 3–0–9
A workshop in the analysis of algorithms. Opportunity for the student to do individual research on the evaluation of algorithms using theoretical and empirical methods.
M. J. Fischer

18.435 *Mathematical Topics in Artificial Intelligence* (A)
Prereq.: ——
Year: G (2) *Arr.*
Content varying from year to year; may be repeated for credit. Spring 1972: computational theories of language. Analysis and comparison of theoretical models for the syntax and semantics of natural language; the use of procedural representation and concepts; the relation of language to the development of theories of artificial intelligence. Assumes some familiarity with linguistics and computation. (*Permission of instructor required.*)
T. A. Winograd

18.436J *Heuristic Programming and Artificial Intelligence* (A)
(Same subject as 6.544J)
Prereq.: ——
Year: G (2) 3–0–9
The problem of making machines behave intelligently. Application of machines to problems of learning, induction, pattern-recognition, game-playing, theorem-proving, neural nets, self-organizing systems, and other areas where problems have been solved by heuristic programming. Problems in administration and allocation of effort within programs. Models of cognitive processes. Machine aids for human problem solving. (*Ability to program a computer required.*) *S. A. Papert, M. L. Minsky*

COMBINATORICS AND LOGIC

18.505 *Combinatorial Theory* (A)
Prereq.: 18.02
Year: G (1) 3–0–9
Survey of combinatorial problems of current research interest. Topics include enumerative analysis, theory of partitions, graph theory, knot theory, network flow, theory of matroids, matrices of zeros and ones, combinatorial designs, representations of the symmetric group, combinatorial methods in statistical mechanics, combinatorial geometry, Ramsey's theorem, matching theory, asymptotic enumeration. Content varying from year to year, may be repeated for credit. *C. Greene*

18.551 *Introduction to Mathematical Logic*
Prereq.: 18.700 or 18.701
Year: U (2) 3–0–9
Formal systems of mathematical logic. Propositional calculus. Quantification theory. Models, validity, and semantic implication. Completeness theorem, Skolem-Löwenheim theory, proof procedures. Axiomatic theories, e.g. set theory. Brief treatment of undecidability and incompleteness of axiomatic theories. *M. Lerman*

18.555 *Mathematical Logic* (A)
Prereq.: 18.700 or 18.701
Year: G (1) 3–0–9
Classical systems of predicate logic; their use in the formalization of mathematical argument. Completeness theorem, Skolem-Lowenheim constructions, compactness arguments. Brief study of Gödel incompleteness theorem. Elements of model theory; elements of categorical algebra. Applications to algebra and combinatorial problems. *J. MacIntyre*

18.557 *Proof Theory* (A)
Prereq.: 18.555
Year: G (2) 3–0–9
Consistency and incompleteness. Positive results of Gentzen and his school. Negative results of Gödel. Constructive interpretation of classical results. (*Not offered 1971–72.*)

18.565 *Recursion Theory* (A)
Prereq.: 18.551 or 18.555
Year: G (1) 3–0–9
Review of elementary recursive function theory. Constructive ordinals and hyperarithmetic sets. Forcing and priority arguments. Elements of generalized recursion theory. *G. E. Sacks*

18.566 *Higher Recursion Theory* (A)
Prereq.: 18.565
Year: G (2) 3–0–9
Generalized recursion theory. Recursion in objects of finite type. *G. E. Sacks*

18.575 *Theory of Models* (A)
Prereq.: 18.551 or 18.555
Year: G (2) 3–0–9
Elementary equivalence, elementary extensions, saturated models, automorphisms of models, categoricity in power. Element types, model-completeness, elimination of quantifiers. Applications to theories of fields. Nonstandard analysis. *E. M. Kleinberg*

18.585 *Set Theory* (A)
Prereq.: 18.551 or 18.555
Year: G (1) 3–0–9
Axiomatic set theory. Constructible sets. Independence of the axiom of choice and of the generalized continuum hypothesis. A model in which every set of reals is Lebesgue measurable. Measurable cardinals and the existence of nonconstructible sets of integers. *H. Rogers*

18.586 *Set Theory* (A)
Prereq.: 18.585
Year: G (2) 3–0–9
Boolean-valued models. Independence of Souslin's hypothesis. Admissible ordinals. Large cardinal axioms. The axiom of determinateness. (*Not offered 1971–72.*) *E. M. Kleinberg*

ALGEBRA AND NUMBER THEORY

18.700 *Linear Algebra*
Prereq.: 18.02
Year: U (1, 2) 3–0–9
Two options offered, both covering the fundamental material of linear algebra: vector spaces, systems of linear equations, bases, linear independence, matrices, determinants, eigenvalues, inner products, quadratic forms. Option 1 — a fully algebraic treatment, as in Hoffman and Kunze, *Linear Algebra*. Option 2 — including also computational questions and applications, as in Noble, *Applied Linear Algebra*. *W. G. Strang*

18.701 *Algebra I*
Prereq.: 18.02
Year: U (1) 3–0–9

18.702 *Algebra I*
Prereq.: 18.701
Year: U (2) 3–0–9
A unified treatment of algebra, incorporating linear algebra, and somewhat more theoretical than the 18.700–18.703 sequence. Some experience with linear equations and matrices (as in 18.03) would be helpful. First term: elementary linear algebra and group theory, with applications to matrix groups and finite groups. Second term: rings and ideals, elementary field theory, modules over a ring of operators, with applications to linear algebra and abelian groups, group representations. *M. Artin*

18.703 *Basic Algebra*
(*New*)
Prereq.: 18.02
Year: U (1, 2) 3–0–9
A one term treatment, covering the traditional algebra topics which have found greatest application in science and engineering as well as in other mathematical disciplines: group theory, with emphasis on finite groups; ring theory, including ideals, unique factorization, and Boolean rings and algebras; field theory, including properties and applications of finite fields. 18.700 and 18.703 together cover most of basic algebra. 18.700 should precede 18.703 if both subjects are to be taken. Open to students with some experience in abstract thinking (college level mathematics). *A. P. Mattuck*

18.704 *Seminar in Algebra and Number Theory*
Prereq.: 18.100
Year: U (1, 2) 3–0–9
Seminars for mathematics majors in several topics, each under the direction of a faculty member whose special interest is in the field of the seminar. Reports and discussion by students on topics taken from current journals or from texts not regularly used in other mathematics subjects. Certain topics may require an additional prerequisite. *Staff*

18.705 *Algebra II* (A)
Prereq.: 18.700, 18.703; or 18.702
Year: G (1) 3–0–9
Elementary theory of sets, groups, rings, fields, and linear algebra presupposed. More advanced topics in group theory: Sylow theorems, Jordan-Holder theorem, p-groups. Galois theory of field extensions, transcendental extensions, Wedderburn theory of algebras. Group representations. *R. D. Schafer*

18.706 *Commutative Algebra* (A)
Prereq.: 18.700, 18.703; or 18.702
Year: G (2) 3–0–9
Does not formally presuppose 18.705, but maturity in algebra required. Noetherian rings and modules; basis theorem, primary decomposition. Localization, tensor product. Integral dependence, normalization, nullstellensatz. Elementary valuation theory. Dimension theory. Local rings, completions, regular local rings.
L. S. Breen

18.715 *Homological Algebra* (A)
Prereq.: 18.706
Year: G (1) 3–0–9

18.716 *Homological Algebra* (A)
Prereq.: 18.715
Year: G (2) 3–0–9
Abelian categories, derived functors, spectral sequences, the functors Tor and Ext, cohomology of sheaves, homological properties of noetherian rings. Grothendieck topologies, the derived category of an abelian category, local duality theory, semi-simplicial methods and a unified cohomology theory for algebraic structures. (*Not offered 1971–72.*) *D. G. Quillen*

18.725 *Algebraic Geometry* (A)
Prereq.: 18.706
Year: G (1) 3–0–9

18.726 *Algebraic Geometry* (A)
Prereq.: 18.725
Year: G (2) 3–0–9
Introduction to contemporary algebraic geometry. Affine and projective algebraic varieties over arbitrary ground fields. Elementary theory of schemes and sheaves. Cohomology of coherent sheaves on affine and projective schemes. Other topics, varying from year to year, as for example: holomorphic functions and connectedness theorems, existence theorems for formal sheaves; Riemann-Roch theorem for curves and surface applications to classification of curves and surfaces, Riemann hypothesis for curves over finite fields; smooth and etale morphisms, deformation theory, fundamental group. *A. P. Mattuck*

18.727 *Topics in Algebraic Geometry* (A)
Prereq.: 18.726
Year: G (1) 3–0–9
Topics varying from year to year; may be repeated for credit. Topics in the past few years have included generalized Riemann-Roch theorem, etale homology and algebraic spaces. (*Not offered 1971–72.*) *M. Artin*

18.735 *Topics in Algebra* (A)
Prereq.: 18.705
Year: G (2) 3–0–9
Content varies yearly; may be repeated for credit. Topics in the past few years have included algebraic groups, non-commutative rings and algebras, Lie algegras, local rings algebraic K-theory. (*Not offered 1971–72.*) *M. Artin*

18.737 *Nonassociative Algebras* (A)
Prereq.: 18.705
Year: G (1) 3–0–9
Non-associative algebras. Alternative and Jordan algebras. Relationships with Lie algebras, particularly the exceptional simple Lie algebras. Power-associative algebras, or other additional topics as time permits. (*Not offered 1971–72.*) *R. D. Schafer*

18.755 *Lie Groups and Lie Algebras* (A)
Prereq.: 18.101, 18.702, 18.901
Year: G (1) 3–0–9
Topology and structure of the classical linear groups. Basic theory of Lie groups: exponential map, subgroups, homogeneous spaces, automorphism groups, Campbell-Hausdorff formula. Structure of Lie algebras.
B. Kostant

18.756 *Lie Groups and Lie Algebras* (A)
Prereq.: 18.755
Year: G (2) 3–0–9
Semisimple Lie groups and symmetric spaces. Topics in function theory on symmetric spaces, such as Fourier analysis and Radon transform, invariant differential operators and potential theory. Emphasis on connections with classical analysis and representation theory. ——

18.757 *Representations of Lie Groups* (A)
Prereq.: ——
Year: G (2) 3–0–9
The connections between the representation theory of compact Lie groups (highest weights), Lie algebra cohomology and the cohomology of homogeneous spaces (Cartan-Leray theory). Particular emphasis on Schubert cells (Bruhat decomposition) and generalization of Schubert calculus for Grassmannian and flag manifolds. Connections with Hilbert's 15th problem. Elementary knowledge of Lie groups and Lie algebras required.
B. Kostant

18.775 *Algebraic Number Theory* (A)
Prereq.: 18.705
Year: G (1) 3–0–9

18.776 *Algebraic Number Theory* (A)
Prereq.: 18.775
Year: G (2) 3–0–9
Study of algebraic number fields and function fields, local and global. Ideals, ideles, and adeles; valuation theory. Splitting laws, group of units, class numbers, brief discussion of analytic methods. Cohomology of groups and class field theory for number fields and algebraic curves. (*Not offered 1971–72.*) ——

18.781 *Theory of Numbers*
Prereq.: 18.100; 18.700 or *18.701*
Year: U (1) 3–0–9
Study of primes, congruences, and arithmetic functions and proofs of their asymptotic formulae. Approximations of the real numbers by rationals, Kronecker's theorem, and the introduction of geometry of numbers. Quadratic forms and quadratic number fields. Elementary proof of the prime number theorem. (*Not offered 1971–72.*) *N. C. Ankeny*

18.785 ***Analytic Number Theory***
Prereq.: 18.100; 18.700 or 18.701
Year: G (2) 3–0–9
Discussion of Dirichlet series including the Riemann zeta function and Dirichlet L-functions. Proof of the prime number theorem and generalizations to primes in arithmetic progressions. Asymptotic formula for the partition functions including the logarithmic integral of x minus the numbers of primes $\leq x$. (*Not offered 1971–72.*)
H. M. Stark

18.786 ***Topics in Analytic Number Theory***
Prereq.: 18.785
Year: G (2) 3–0–9
Topic to be chosen from such subjects as Waring's problem and the circle method, the large sieve and applications, modular functions and complex multiplication. Content varying from year to year so that graduate students may take the subject in successive years. (*Not offered 1971–72.*)
H. M. Stark

18.787 ***Diophantine Analysis and Transcendence*** **(A)**
(*New*)
Prereq.: ——
Year: G (1) 3–0–9
Theorems of Liousville, Thue-Siegel, and Roth. Transcendence of e and π. The Gelfand-Schneider theorem. Transcendence of values of E-functions and a theorem of Skidlovski. Recent work of Baker and effective improvements of Liousville's theorem. Application to Diophantine equations.
H. M. Stark

TOPOLOGY AND GEOMETRY

18.901 ***Introduction to Topology***
Prereq.: 18.100; *18.700* or *18.701*
Year: U (1, 2) 3–0–9
Topological spaces, connectedness, compactness, continuous functions, separation axioms, product space and function space topologies, plus several additional topics to be chosen by the instructor. ——

18.904 ***Seminar in Topology and Geometry***
Prereq.: 18.901
Year: U (2) 3–0–9
Seminars for mathematics majors in several topics, each under the direction of a faculty member whose special interest is in the field of the seminar. Reports and discussion by students on topics taken from current journals or from texts not regularly used in other mathematics subjects. Certain topics may require an additional prerequisite.
F. P. Peterson

18.905 ***Algebraic Topology*** **(A)**
Prereq.: 18.701, 18.901
Year: G (1) 3–0–9
18.906 ***Algebraic Topology*** **(A)**
Prereq.: 18.905
Year: G (2) 3–0–9
Fundamental group, covering spaces, simplicial homology, simplicial approximation, manifolds. Homology and cohomology of topological spaces, universal coefficient theorem, plus additional topics to be chosen by the instructor.
G. W. Whitehead

18.915 ***Graduate Topology Seminar*** **(A)**
Prereq.: 18.906
Year: G (1) *Arr.*
Study and discussion of important original papers in the various parts of algebraic and differential topology.
D. M. Kan

18.917 ***Advanced Topology*** **(A)**
Prereq.: 18.906
Year: G (2) 3–0–9
Content varying from term to term so that graduate students taking the subject in successive terms may have an introduction to several important phases of topology such as homotopy theory, cohomology theory, fibre spaces, K-theory, combinatorial topology, and/or differential topology.
D. W. Anderson

18.925 ***Differential Topology*** **(A)**
Prereq.: 18.906
Year: G (2) 3–0–9
Introduction to differential topology. Differentiable manifolds, immersion and imbedding theorems, vector bundles, characteristic classes. Other possible topics include surgery, cobordism, piecewise-linear and differentiable structures, Morse theory, Whitehead torsion. (*Not offered 1971–72.*) ——

18.947 ***Cohomology Theories on Manifolds*** **(A)**
Prereq.: 18.101, 18.905
Year: G (1) 3–0–9
18.948 ***Cohomology Theories on Manifolds*** **(A)**
Prereq.: 18.947
Year: G (2) 3–0–9
Transversality, cobordism theory, characteristic classes, formal group laws, structure of the unoriented and complex cobordism rings, K-theory, and De Rham cohomology.
D. G. Quillen

18.950 ***Elementary Differential Geometry***
Prereq.: 18.100
Year: U (2) 3–0–9
Emphasis on classical theory of space curves and surfaces. Frenet formulas, fundamental forms, theorems of Meusnier and Euler, lines of curvature, asymptotic and conjugate lines, geodesics, equations of Gauss, Cadazzi and Weingarten, special surfaces, mapping problems and existence theorems. Additional topics to be chosen from geometry in the large, classical tensor theory and Riemannian geometry. ——

18.951 ***Riemannian Geometry***
Prereq.: 18.101, 18.901
Year: U (2) 3–0–9
Elementary manifold theory, Whitney embedding theorem, intersection theory, integral formulas for intersection numbers, Gauss-Bonnet theorem. ——

18.965 ***Geometry of Manifolds*** **(A)**
Prereq.: 18.101, *18.905*
Year: G (1) 3–0–9
18.966 ***Geometry of Manifolds*** **(A)**
Prereq.: 18.965
Year: G (2) 3–0–9
Real and complex manifolds, differential forms, De Rham and Dolbeault theorems, cohomology of sheaves, differential operators on manifolds, resolution of the solution sheaf of a differential equation: formal and analytic theory.
V. W. Guillemin

18.967 ***Kahler Manifolds*** **(A)**
Prereq.: 18.966
Year: G (1) 3–0–9
Review of the basic properties of complex manifolds as in Chern's *Complex Manifolds without Potential Theory* and Weil's *Introduction a l'etude des variétés kähleriennes*. Elliptic differential equations on compact manifolds. Deformations of structure (Kodaira-Spencer, Kuranishi). Complex surfaces (Kodaira). Periods of Integrals (Griffiths). (*Not offered 1971–72.*)
I. M. Singer

18.968 *Recent Developments in Complex Manifold Theory* (A)
Prereq.: 18.967
Year: G (2) 3–0–9
Equidistribution Theory. Hyperbolic Complex Manifolds. Periods of Rational Integrals. (*Not offered 1971–72.*) *I. M. Singer*

18.975 *Elliptic Operators* (A)
Prereq.: 18.101, *18.905*, 18.951
Year: G (1) 3–0–9

18.976 *Elliptic Operators* (A)
Prereq.: 18.975
Year: G (2) 3–0–9
Local theory of elliptic differential and singular integral operators, extension to vector bundles over manifolds, coercive boundary value problems, K(x), index theorem, and applications, elliptic complexes, fixed point theorem, Spencer resolution. (*Not offered 1971–72.*) *I. M. Singer*

MATHEMATICAL READING

18.999 *Mathematical Reading*
Prereq.: ——
Year: G (1 or 2) *Arr.*
Reading of advanced mathematical treatises under the supervision of some member of the Department. Choice of treatise and allotment of time according to individual cases. (*For graduate students finding it desirable to do advanced work not provided for in the regular subjects. Open to undergraduates only under exceptional circumstances.*) *N. Levinson*

19.
Meteorology

19.02 *Descriptive Meteorology*
Prereq.: ——
Year: U (2) 3–2–7
The general circulation of the earth's atmosphere; the secondary circulations, both tropical and extratropical, including the role of air masses and fronts; the tertiary (local) circulations, including drainage winds, local convection, whirlwinds, showers, thunderstorms, land and sea breeze, large-scale turbulence eddies, föhn winds, etc. Petterssen, *Introduction to Meteorology*, third edition. (*Limited enrollment.*) *J. M. Austin, D. P. Keily*

19.03 *Meteorological Aspects of Air Pollution*
(*New*)
Prereq.: 8.01, 18.02
Year: U (1) 3–0–6
Primary emphasis on the physical processes involved with motion and dilution of material released into the atmosphere. Topics include: equations of motion, influence of surface friction, variation of wind with height, determination of wind fields from conventional weather maps, local wind fields (land-sea breeze, mountain-valley wind); turbulent wind component and its spatial and temporal variations. Dispersion formulae discussed with respect to the variability of atmospheric conditions, the nature of material sources ranging from isolated tall stacks to urban complexes, the significance of structures, valley slopes, elevated temperature inversions, and the time dependence of maximum concentrations. Meteorological concepts illustrated by reference to daily weather information available in the Meteorology Department. Data on contaminant concentrations near stacks and within cities analyzed. *J. M. Austin*

19.15 *Long-Range Forecasting* (A)
Prereq.: 19.45
Year: G (1) 3–0–6
Physical and statistical analysis of large-scale changes of the general circulation, with emphasis on the variable solar influences and climatic trends. Review of extended and long-range forecasting techniques. *H. C. Willett*

19.22 *Air and Sea Instruments* (A)
Prereq.: 12.21 or 13.02 or 19.83; 19.43
Year: G (2) 3–2–6
Lectures and laboratory exercises on the design and response characteristics of typical instruments and instrument systems used for measurements in the atmosphere, in the oceans, and in the sea-air interfacial region. *D. P. Keily*

19.24 *Fluid Dynamics Laboratory* (A)
Prereq.: 1.612 or 2.201 or 16.041 or 18.350 or 19.62
Year: G (2) 2–4–4
Experiments on processes and phenomena in geophysical fluid mechanics. Design of experiments, similarity, experimental methods, data processing. Laboratory work involving quantitative observation of hydrodynamic instability, transport processes and turbulence. *E. L. Mollö-Christensen*

19.34 *Statistical Methods in Meteorology*
Prereq.: 18.02
Year: G (1) 2–0–4
Designed to examine recent developments in statistical weather forecasting and to provide a background for performing and evaluating statistical studies with meteorological data. Statistical forecasting by linear regression, non-linear statistical forecasting, significance of empirical relations, and hypothesis testing. *E. N. Lorenz*

19.35 *Statistical Problems in Meteorology* (A)
Prereq.: 19.34
Year: G (2) 2–0–4
Various statistical problems in meteorology, including such topics as power spectrum analysis, properties of stationary time series, and predictability of atmospheric motion. (*Alternate years. Offered 1971–72.*) *E. N. Lorenz*

19.43 *Synoptic Meteorology I*
Prereq.: 8.01, *18.02*
Year: U (1) 2–2–5
The state of the atmosphere including the three-dimensional variation of significant meteorological variables. The heat budget of the atmosphere on a global and local scale. The physical processes associated with the formation of fog, smog, cumulus clouds, thunderstorms, and tornadoes. Introduction to the dynamics of cyclones and hurricanes. World and local climate. *F. Sanders*

19.44 *Tropical Meteorology* (A)
(*New*)
Prereq.: 19.43, 19.62
Year: G (2) 2–2–5
Structure and behavior of the troposphere between the subtropical belts of high pressure. The general circulation of this region and the theories proposed to explain it. Structure and dynamics of tropical disturbances ranging upward to storm intensity. Prediction of hurricanes. Riehl, *Tropical Meteorology*. (*Alternates with 19.45.*) *F. Sanders*

19.45 *Synoptic Meteorology II* (A)
Prereq.: 19.43
Year: G (2) 3–3–6
Historical development of weather prediction. Application of elementary kinematics and dynamics to patterns of atmospheric flow. Description of structure and behavior of cyclonic and anticyclonic circulations. Simple dynamical prediction models. Petterssen, *Weather Analysis and Forecasting*, second edition, Vol. 1. (*Not offered 1971–72.*) *F. Sanders*

19.46 ***Numerical Weather Prediction*** **(A)**
Prereq.: 18.075
Year: G (1) 3–0–6
Scale analysis of atmospheric motions and the problem of meteorological noise. The quasi-geostrophic forecast system. Finite difference methods and the analysis of computational stability. Derivation and study of some simple atmospheric models for numerical forecasting. *N. A. Phillips*

19.53 ***Synoptic Laboratory*** **(A)**
Prereq.: 19.43
Year: G (2) 0–3–6
Study of atmospheric phenomena in the troposphere and stratosphere by analysis of meteorological data. Consideration of scales ranging from the global general circulation to severe thunderstorm complexes. Data sources include the global network of surface and upper-level balloon sounding stations on land and at sea, aircraft data, rocket soundings in the stratosphere, weather radar, and meteorological satellites. Weather prediction as a probabilistic science. Contemporary operational forecasting as a man-machine system. (*Not offered 1971–72.*) *F. Sanders*

19.61 ***Introduction to Dynamical Meteorology*** **(A)**
Prereq.: 18.075
Year: G (1) 3–0–9
Thermodynamics of moist air, development of hydrodynamical principles for small-scale atmospheric motions. Convective instability and analysis of simple models of turbulent convection. *N. A. Phillips*

19.62 ***Dynamic Meteorology I*** **(A)**
Prereq.: 19.61
Year: G (2) 3–0–9
Hydrodynamic equations for a rotating spherical atmosphere. Quasi-hydrostatic and quasi-geostrophic motions. Divergence and vorticity. Energetics of the atmosphere. *E. N. Lorenz*

19.64 ***Dynamic Meteorology II*** **(A)**
Prereq.: 19.62
Year: G (1) 3–0–9
Large-scale atmospheric motions. Examination of recent theories of the general circulation. Research in the application of fluid mechanics to meteorology and oceanography. *V. P. Starr*

19.65 ***Turbulence and Random Phenomena in Fluid Mechanics*** **(A)**
Prereq.: 1.612 or 2.201 or 16.041 or 18.350
Year: G (2) 3–0–6
Development of descriptions of random fields starting from statistics of ensembles of random functions. Response of systems and fields to random inputs, with examples of filters, dispersive and non-dispersive wave phenomena. Turbulence, descriptors and closure problems. Analogies with kinetic theory. Sources of turbulence, hydrodynamic stability, homogeneous turbulence, equations, spectra, equilibrium and decay. Shear flow turbulence, turbulent boundary layers. The atmospheric boundary layer. Turbulence in a stratified medium. Generation of surface waves by wind. Methods of observation, measurement and analysis. *E. L. Mollö-Christensen*

19.67 ***Planetary Fluid Dynamics*** **(A)**
Prereq.: 18.350
Year: G (1) 3–0–9
Discussion of fluid dynamical problems on the planetary scale with applications to atmospheres and oceans. Convectively and mechanically driven circulations in rotating systems. Boundary layers and equatorial singularities. Stability of planetary motions. Tropical and extratropical cyclogenesis. Energy propagation in physical and Fourier space. *J. G. Charney*

19.68 ***Waves in Oceans and Atmospheres*** **(A)**
Prereq.: 18.305, 18.350
Year: G (2) 3–0–9
Topics: Acoustic, gravitational, inertial and planetary wave propagation. Emphasis on media with spatial and temporal variations. Interaction with mean flows. ——

19.70 ***Elementary Physics of the Atmosphere***
Prereq.: 8.03, *18.02*
Year: U (2) 3–0–6
Treatment of atmospheric radiation, the ozone layer and the upper atmosphere, atmospheric electricity, atmospheric optics, propagation of sound in the atmosphere, and elements of cloud physics. *D. P. Keily*

19.71 ***Atmospheric Precipitation Processes*** **(A)**
Prereq.: 8.03, 19.43
Year: G (1) 2–2–4
Origin and growth of hydrometeors; atmospheric motions of mesoscale and the morphology of convective and stratiform storms. Elementary principles of radar with applications to the observation of precipitation processes on the mesoscale. Laboratory exercises on the evaluation of radar data and on the operation of radar systems. *P. M. Austin*

19.72 ***Physical Meteorology*** **(A)**
Prereq.: 8.04, 18.02
Year: G (2) 3–0–6
Absorption and scattering of solar radiation in the atmosphere and the spatial and temporal distribution of solar radiation at the surface of the earth. Theory of radiative transfer in the atmosphere, radiation charts, and the radiative heat balance of the atmosphere and earth. Nucleation of water and ice in the atmosphere. Growth of drops and ice particles by condensation and accretion. Mechanisms for the release of precipitation and their interaction with the dynamics of the atmosphere. *H. G. Houghton*

19.74 ***Physics of the Upper Atmosphere*** **(A)**
Prereq.: 8.04, 18.03
Year: G (2) 3–0–6
Structure, composition and properties of the atmosphere above the tropopause. Wind velocity, temperature, pressure, composition and density data obtained with rockets and satellites up to heights of about 1000 km; discussion of theories which best account for the observations. Interaction between input radiation, both photons and corpuscles, and atmospheric constituents, together with the effects of conduction, convection, radiation and diffusion. Chapman layer theory applied to the ionosphere and to the layer of ozone. Role of the circulation in the transport of trace substances. Possible influences of pollutants on structure and circulation. Dynamic and energetic interaction between the upper and lower atmosphere. Atmospheric tides, noctilucent clouds, and meteors; various aspects of aurorae pertinent to incident energy stream and interaction. *R. E. Newell*

19.80 ***Surface and Internal Waves*** **(A)**
Prereq.: 18.350, 19.81 or 19.84
Year: G (1) 3–0–6
Kinematics and dynamics of small-scale oceanic wave motion. Mathematical development of surface gravity and internal waves, their generation and decay, interaction with other wave modes; comparison with observations. *R. C. Beardsley*

19.81 ***Introduction to Oceanic Models*** **(A)**
Prereq.: 18.076
Year: G (1, 2) 3–0–6

19.82 ***Introduction to Oceanic Models*** **(A)**
Prereq.: 18.076
Year: G (1, 2) 3–0–6
Detailed development from first principles (but not an exhaustive exploration) of the analytical models for

mechanical and thermodynamical processes in the ocean, intended for oceanography majors. Refresher on fluid mechanics, a survey of the physical properties of the ocean, and the models, including circulation and waves. *W. F. Simmons*

19.83 *Physical Oceanography*
Prereq.: 8.02, *18.03*
Year: U (1) 3–0–9
An introductory survey of the oceanic circulation and dynamics. Descriptive aspects of water mass movement, currents, and physical properties of the ocean. Simple dynamic models of currents and waves. Intended as an introduction to physical oceanography, also suitable for students primarily interested in chemical, biological or geographical oceanography. *R. C. Beardsley*

19.84 *Dynamic Oceanography* (A)
Prereq.: 18.350
Year: G (2) 3–0–6
Dynamics of internal gravity waves and rotational waves. Response of the ocean to large-scale mechanical effects from the atmosphere and theories of ocean circulation. *N. A. Phillips*

19.851 *Undergraduate Research Program*
Prereq.: ——
Year: U (1, 2) *Arr.*

19.852 *Undergraduate Research Program*
Prereq.: ——
Year: U (1, 2) *Arr.*
Extended participation in the work of a research group, including independent study of the literature, direct involvement in the group's research (commensurate with the student's skills and preparation), or project work under an individual faculty member extending over more than one term. (*Admission by arrangement with the individual instructor.*) *Staff*

19.86 *Oceanic Circulations* (A)
Prereq.: 19.67 or 19.84
Year: G (1 or 2) 3–0–6
Large-scale circulation of the oceans as revealed by the analysis of hydrographic data, direct current measurements and the distribution of properties and tracers. Theories of wind-driven and thermohaline circulations. Emphasis on the relation between observations and recent theories of the main thermocline and the associated thermohaline circulation. *H. M. Stommel*

19.87 *Seminar in Physical Oceanography* (A)
Prereq.: 19.67 or 19.86
Year: G (1 or 2) 3–0–6
Readings and discussions of current research topics in physical oceanography. Emphasis on circulations of the ocean with choice of topics from most interesting subjects in current literature. *H. M. Stommel*

19.89 *Special Problems in Oceanography* (A)
Prereq.: ——
Year: G (1, 2) *Arr.*
Reading, consultation, and original investigation on oceanographic problems. (*Permission of instructor required.*) *Staff*

19.891 *Special Problems in Oceanography* (A)
(*New*)
Prereq.: ——
Year: G (1, 2) *Arr.*
Reading, consultation and original investigation on oceanographic problems. *Woods Hole Staff*

19.93 *Special Problems in Oceanography*
Prereq.: 19.83
Year: G (1, 2) *Arr.*
Reading, consultation, and original investigation on oceanographic problems. *Staff*

19.94 *Special Problems in Meteorology*
Prereq.: 19.02
Year: G (1 or 2) *Arr.*
Reading, consultation, and original investigation on meteorological problems. *Staff*

19.95 *Special Problems in Meteorology* (A)
Prereq.: 19.43, 19.62
Year: G (1 or 2) *Arr.*
Reading, consultation and original investigation on meteorological problems of more advanced nature than those in 19.94. *Staff*

19.96 *Special Subject in Meteorology* (A)
Prereq.: 19.43, 19.61
Year: G (1, 2) *Arr.*
Organized lecture or laboratory subject on some aspect of meteorology not normally covered in the regularly scheduled subjects. *Staff*

19.97 *Special Subject in Oceanography* (A)
Prereq.: 19.83
Year: G (1, 2) *Arr.*
Organized lecture or laboratory subject on some aspect of oceanography not normally covered in the regularly scheduled subjects. *Staff*

20.
Nutrition and Food Science

20.U.R *Undergraduate Research Problems*
(20.852) *Prereq.:* ——
Year: U (1, 2) *Arr.*
Extended participation in the work of a research group including: independent study of the literature; direct involvement in the group's research commensurate with the student's skills and preparation; project work under an individual faculty member extending over more than one term. (*Admission by arrangement with individual faculty member.*) *Staff*

20.02 *Nutrition and Food Science Projects Laboratory*
Prereq.: ——
Year: U (2) 1–8–3
Laboratory work with faculty guidance but emphasizing independent work, designed to introduce the student to the principles and techniques of design and execution of experimental projects in food science and technology, biochemical engineering, food toxicology, and experimental and human nutrition. A four- to five-week introductory project, followed by the design and execution of one or more specific projects of the student's own choice, utilizing recent research techniques.
A. J. Sinskey, R. Davies

20.03J *Environmental Measurements Projects Laboratory*
(*New*)
(Same subject as 5.22J and 8.16J)
Prereq.: ——
Year: U (1) *Arr.*

20.04J *Environmental Measurements Projects Laboratory*
(*New*)
(Same subject as 5.23J and 8.17J)
Prereq.: ——
Year: U (2) *Arr.*
An interdisciplinary project laboratory with faculty guidance but emphasizing independent work on measurements related to environmental problems.
C. Cooney, Chemistry Staff, J. G. King

20.11 ***Sensory Qualities of Foods***
Prereq.: ——
Year: U (1) 2–0–4
Consideration of those unique properties which differentiate foods from other biological and chemical systems. Discussion of man's perception of flavor, color, and texture. Relationship of these qualities to acceptance and the composition of natural and processed foods. Measurement and description of these properties and techniques for evaluating changes in food quality resulting from processing and storage. *E. L. Wick*

20.13J ***Food Engineering***
(Same subject as 2.642J)
Prereq.: 2.641
Year: U (2) 4–0–5
Quantitative study of selected unit operations of the food industry with consideration of basic principles governing each operation, as well as of important applications. Emphasis on fluid flow, heat transfer, evaporation, distillation, dehydration, filtration and extraction.
C. Cooney, A. L. Hesselschwerdt

20.15 ***Advanced Food Engineering*** **(A)**
Prereq.: 20.13J
Year: G (1) 1–6–3
Analysis of process design and economics through classroom discussion and visits to selected food processing plants. At each plant, the process engineer will discuss the general layout, equipment choice and operation, quality control devices, economics and legal aspects of the operation. Suitable unit operations will also be investigated in the pilot plant. The class as a whole will work on development of a new process. *J. M. Flink*

20.20 ***Flavor Chemistry and Flavor Methodology*** **(A)**
Prereq.: 5.41, 20.32
Year: G (1 or 2) 2–0–4
Chemistry of foods with particular reference to the compounds responsible for flavor and odor. Physical and chemical techniques for the separation, purification, and identification of these compounds. Consideration of the behavioral sciences with respect to evaluation of food acceptability. (*Alternate years. Offered 1971–72.*)
E. L. Wick

20.30 ***Physiological and Nutritional Biochemistry***
Prereq.: 5.41
Year: U (2) 4–0–8
A study of the dynamic interaction between the animal and its environment, particularly the diet. Chemical and metabolic phenomena involved in the development and maintenance of the mammalian organism. Regulation as a means of adaptation. *S. A. Miller, J. P. Flatt*

20.32 ***Methods in Biochemical Analysis*** **(A)**
(*Revised: Content change and unit change*)
Prereq.: 5.41, 7.05
Year: G (1) 3–0–6
Principles of chromatography, spectrometry, electrophoresis, and other basic techniques for the separation, identification and quantitative analysis of food and tissue components. Isotopic techniques in biological research. Special topics in clinical analysis, food analysis, toxicology and enzymology. *J. K. Palmer, G. Wolf, Staff*

20.321 ***Biochemical Analysis Laboratory*** **(A)**
(*New*)
Prereq.: 5.41, 7.05
Year: G (1) 1–6–2
Laboratory application of selected analytical techniques discussed in 20.32. (*Not offered 1971–72.*)
J. K. Palmer, G. Wolf, Staff

20.33 ***Nutritional Biochemistry and Metabolism*** **(A)**
Prereq.: 7.05, 20.63
Year: G (2) 3–0–6
Functions and metabolism of individual nutrients, interrelationships and nutritional requirements. Influence of environment and physiological state on metabolic processes and nutritional needs. Emphasis on recent research. *V. R. Young*

20.34 ***Advanced Nutritional Biochemistry and Metabolism*** **(A)**
Prereq.: 20.30
Year: G (1) 3–0–6
Discussion of topics in mammalian metabolism with a bearing on adaptive and other mechanisms that underlie responses to nutritional status.
H. N. Munro, S. T. Jacob

20.35 ***Nutrition, Growth, and Development*** **(A)**
Prereq.: 20.33
Year: G (1) 2–0–4
Examination of the development of metabolic and physiologic functions with primary consideration of mechanisms for the regulation of these events. The role of diet in these processes and in the determination of later functional capability emphasized. *S. A. Miller*

20.36 ***Human Nutrition*** **(A)**
Prereq.: 20.30
Year: G (1) 3–0–6
Designed for teaching the basic principles of human nutrition and world-wide nature and distribution of nutritional disease. Emphasis on understanding requirements for specific nutrients in individuals and populations, evaluation of food intakes and dietary habits, and on nutritional needs during pregnancy and lactation, growth and maturation, and disease. Analysis of both malnutrition in developing countries and underprivileged populations and the problems of overnutrition in industrialized societies. (*Permission of instructor required for students who have not taken prerequisite.*)
N. S. Scrimshaw

20.361 ***Field Studies in Human Nutrition*** **(A)**
Prereq.: 20.30
Year: G (1) 0–3–1
First-hand observation and discussion of community, nutritional, and related health problems. Visits to hospitals, out-patient clinics, health centers, nursing homes, state institutions, and ghetto housing plus evaluation of the nutritional status of a population group.
J. C. Edozien

20.37 ***Endocrinology*** **(A)**
Prereq.: 7.01, 7.05, 20.30
Year: G (2) 3–0–6
Structure and function of the endocrine glands. Basic nature of abnormalities causing endocrine disease. Biosynthetic mechanisms, hormone transport, molecular basis of hormone action and control systems will be stressed. Weekly clinical demonstrations at the Massachusetts General Hospital will illustrate endocrine pathophysiology. (*Open to qualified seniors.*)
J. B. Stanbury

20.38 ***Environmental Factors in Food Quality***
Prereq.: 3.091 or 5.01 or 5.41 or 5.60
Year: U (2) 3–0–9
Introduction to the chemical and physical basis of food preservation and the impact of processing and storage on the nutritive value of human food supplies. Consideration of Food and Drug Law; stability of vitamins, lipids and proteins; selected food processes which have classically been employed; newer food processes such as irradiation and microwave processing. Discussion on the application of present and future technology to solution of world food problems. *S. R. Tannenbaum*

20.391 ***Mammalian Protein and Nucleic Acid Metabolism*** **(A)**
Prereq.: 20.33
Year: G (2) 2–0–4
Recent studies on mammalian protein and nucleic acid metabolism and their relevance to nutritional investigations. The regulation of metabolic pathways in relation to diet, hormones and other factors.
H. N. Munro, S. T. Jacob

20.392 ***Carbohydrate and Lipid Metabolism*** **(A)**
Prereq.: 20.33
Year: G (1) 2–0–4
Regulation of carbohydrate and lipid metabolism in the mammal. Roles of specific organs in the maintenance of energy balance. Fat transport in lipoproteins and its biological significance. *J. P. Flatt*

20.393 ***Vitamins in Metabolism*** **(A)**
Prereq.: 20.33
Year: G (2) 2–0–4
Advanced discussion of selected recent studies on the biochemical function, mechanism of action, and metabolism of the vitamins. Emphasis on fat-soluble vitamins, but interrelationships with the water-soluble vitamins also studied. Extensive student participation in the form of seminars and discussions on research publications.
G. Wolf

20.394 ***Mineral Metabolism*** **(A)**
Prereq.: 20.33
Year: G (1) 2–0–4
Minerals as components of metabolic systems, and their roles as enzyme cofactors and regulators of cellular processes. Consideration of calcification and electrolyte balance as processes that require and also participate in regulation. *S. A. Miller*

20.395 ***Advanced Nutrition and Physiological Chemistry*** **(A)**
Prereq.: 7.05, 20.301
Year: G (1 or 2) 2–0–4

20.396 ***Advanced Nutrition and Physiological Chemistry*** **(A)**
Prereq.: 7.05
Year: G (1 or 2) 2–0–4
Lectures and discussions of biochemical aspects of nutrition for advanced graduate students, one section being given each term. *Staff*

20.40 ***Selected Topics in Nutrition and Food Science*** **(A)**
Prereq.: 20.11, 20.30
Year: G (1 or 2) *Arr.*
Detailed discussion of selected topics of current interest. Class work in various fields of nutrition, food science and technology not covered by regular subjects of instruction.
Staff

20.41 ***Microbiology Laboratory***
(*Revised: Unit change*)
Prereq.: 7.05
Year: U (1 or 2) 2–6–4
Techniques for the isolation of bacteria, yeasts, molds, and viruses from natural sources such as food, water and air. Discussion and evaluation of methods for the morphological and metabolic characterization of such microorganisms, as well as how they interact in natural environments. *R. Davies, A. J. Sinskey*

20.43 ***Industrial Microbiology*** **(A)**
Prereq.: 7.21
Year: G (1) 3–6–4
Selected topics concerned with the use of microorganisms for the production of substances of industrial, medical or nutritional value, such as amino acids, antibiotics, vitamins and organic acids, with emphasis on metabolic regulation of and biochemical pathways leading to fermentation products. *A. L. Demain*

20.45 ***Epidemiology of Nutritional and Food-Borne Diseases*** **(A)**
Prereq.: 20.36, 20.46
Year: G (2) 2–2–4
Principles and practice of field epidemiology, medical ecology and modes of transmission: nutritional diseases such as pellagra and kwashiorkor; dental fluorosis and caries; food- and water-borne infectious diseases such as typhoid fever, bacillary dysentery, amebiasis and cholera; food poisoning from bacterial toxins and heavy metals, and intestinal parasitic infections. Prevention of enteric disease and control of epidemics. Synergism between infection and nutrition. Practical field techniques and research methods. (*Alternate years. Not offered 1971–72.*)
A. D. Rubenstein

20.46 ***Food Microbiology*** **(A)**
Prereq.: 7.05, 20.41
Year: G (2) 3–6–6
Qualitative and quantitative aspects of microbiology in relation to the behavior and detection of micro-organisms and microbial toxins in food systems. Evaluation of sublethal food processing techniques, i.e., freezing, drying, pasteurization, irradiation on recovery, growth and enumeration of microorganisms in foods. Metabolic repair processes that injured microorganisms undergo also considered. *A. J. Sinskey, R. Davies*

20.47 ***Biochemical Engineering*** **(A)**
Prereq.: 5.62 or 20.13J; 7.05 or 7.21
Year: G (2) 3–3–4
Interactions of chemical engineering, biochemistry and microbiology. Mathematical representation of microbial systems. Kinetics of growth, death and metabolism. Continuous fermentation. Transfer of gases in fermentation systems. Mixing and the measurement of mixing times. Product recovery. Laboratory experiments involving evaluation of mass transfer coefficients, operation of a pilot plant fermentor, computer simulation of fermentation systems, and other topics.
D. I. C. Wang, C. L. Cooney

20.48 ***The Mathematical Aspects of Ecology***
(*New*)
Prereq.: 18.02
Year: U (1) 3–0–6
A general survey of classical ecology with emphasis on those aspects which seem amenable to mathematical and statistical investigation. Intended to introduce the student to the diversity and complexity of ecological problems and the extent and limitations of current theory. Development of mathematical, statistical and computer techniques to handle various facets of the general problems discussed. Topics include: environmental description, single species populations, ecology of animal communities, food chains and webs, population dynamics, mechanisms and implications of evolution and human ecology and resource management. *W. M. Rand*

20.50 ***Food Biochemistry*** **(A)**
Prereq.: 7.05
Year: G (2) 3–0–6
Consideration of the biochemistry and physiology of plant and animal tissues used as foods, primary emphasis on enzyme-catalyzed reactions. Pathways for the biosynthesis and degradation of food constituents. Biochemistry and composition of the developing and maturing tissues. Postharvest and postmortem changes. Controlling these changes to achieve optimum food quality and maximum storage life. Utilization of enzymes in the food industry. *J. K. Palmer*

20.51 ***Food Chemistry*** **(A)**
Prereq.: 5.60; 20.11 or 20.38
Year: G (1) 3–0–6
Consideration will be given to the structure and properties of water in foods and its relationship to proteins, carbohydrates, lipids and their oxidation, non-enzymatic browning. *S. R. Tannenbaum*

20.52 ***Advanced Food Technology*** **(A)**
Prereq.: 20.13J, 20.51
Year: G (2) 3–0–6
Detailed consideration of selected food processing methods from the point of view of scientific and engineering principles. Colloidal and surface phenomena in processing of foods. Consideration of transport properties of foods in the design of concentration and dehydration processes. Physical and chemical changes occurring during and after food processing. *M. Karel*

20.57 ***Food Applications of Ionizing Radiations*** **(A)**
Prereq.: 8.04, 20.11
Year: G (1) 3–0–6
Theory and application of ionizing energy to the preservation of foods. Consideration of the basic effects of radiations on microorganisms and on compounds of biological importance. Dosimetry of intense beams of high-energy radiations. New developments in sources of ionizing energy; consideration of role of legislation from an international point of view as well as the effects of this on the potential uses of ionizing energy. (*Alternate years. Offered 1971–72.*) *S. A. Goldblith*

20.59 ***Food Toxicology*** **(A)**
Prereq.: 20.33, 20.63
Year: G (2) 3–0–6
Principles and problems in evaluating the wholesomeness and safety of foods, food components, additives, and contaminants. Consideration of selective toxicity, detoxication mechanisms, structure and biological activity; basic concepts and techniques of safety evaluation, and interpretation of biological data. *R. C. Shank*

20.591 ***Food Toxicology Laboratory*** **(A)**
Prereq.: 20.32, *20.59*, 20.63
Year: G (2) 1–6–2
Studies of acute and subacute toxicity; techniques of biological assay; and parameters of biological response. *R. C. Shank*

20.60 ***Research Programs in Nutrition and Food Science*** **(A)**
Prereq.: ——
Year: G (1) 2–0–2
Seminars, presented by individual departmental faculty members, on active and proposed research areas and specific research programs. Presentations of a general nature, including discussions of rationale and significance of programs in addition to detailed progress reports. *J. K. Palmer, W. M. Rand*

20.61 ***Seminar in Nutrition and Food Science*** **(A)**
Prereq.: ——
Year: G (1) 2–0–2

20.62 ***Seminar in Nutrition and Food Science*** **(A)**
Prereq.: ——
Year: G (2) 2–0–2
Opportunity for students to practice oral presentations, before an audience, on scientific topics of their own choice. Guidance and criticism with respect to speaking ability, use of speaking aids (blackboard, slides, etc.), and content of the presentation. The last presentation of the term in the format of a scientific meeting, with videotape recording to permit the student to analyze his own performance. *J. K. Palmer, W. M. Rand*

20.63 ***Systemic Physiology*** **(A)**
Prereq.: ——
Year: G (2) 3–0–6
Review of organ and system physiology in mammals, with particular reference to the human. Emphasis on systems and specific organs involved in maintenance of equilibrium with the external environment. Intended for providing a foundation for more specialized subjects in the physiology of higher organisms and in biomedical engineering. (*Open to advanced undergraduates and graduates from any department, by permission of instructors.*) *G. Schonfeld*

20.64 ***Comparative Histology*** **(A)**
Prereq.: 20.63
Year: G (1) 4–6–6
Study of microscopic and ultramicroscopic structure of cells, tissues and organs of laboratory animals. Relation of structure to function. (*Alternate years. Offered 1971–72.*) *C. E. Gilmore, P. M. Newberne*

20.65 ***Nutritional Pathology*** **(A)**
Prereq.: 20.64
Year: G (2) 3–6–6
Comprehensive study of gross and microscopic pathology of nutritional diseases of animals with evaluation and application of selected chemical, histochemical, and cytochemical methods as they apply to localization of enzymes, nucleic acids, amino acids, and other cellular constituents. (*Alternate years. Offered 1971–72.*) *P. M. Newberne*

20.651 ***Seminar in Comparative Pathology*** **(A)**
Prereq.: 20.65
Year: G (1) 3–0–3

20.652 ***Seminar in Comparative Pathology*** **(A)**
Prereq.: 20.65
Year: G (2) 3–0–3

20.653 ***Seminar in Comparative Pathology*** **(A)**
Prereq.: 20.65
Year: G (1) 3–0–3

20.654 ***Seminar in Comparative Pathology*** **(A)**
Prereq.: 20.65
Year: G (2) 3–0–3
Systematic study of disease problems common to various animal species and caused by viral, bacterial, fungal, and toxicological agents. Emphasis on background knowledge of and current areas of research on selected diseases. Comparative nutritional disease problems are emphasized in this seminar series and outside specialists in selected areas of comparative disease research are brought in at intervals during the semester.
P. M. Newberne, R. B. Wilson, C. E. Gilmore, A. Rogers

20.655 ***Introduction to Pathobiology***
(*New*)
Prereq.: ——
Year: G (2) 3–0–3
An introduction to animal histology and pathology for experimental biologists. Emphasis given to demonstration of gross appearance of organs and tissues, some familiarity with microscopic structure, and correlation of abnormal function and structure of cells, tissues, organs, and systems in a variety of experimental and spontaneous diseases. An introduction to effects of spontaneous disease on experimental procedures included.
R. B. Wilson, P. M. Newberne

20.66 ***Physiology of Transport*** **(A)**
(*Revised: Unit change*)
Prereq.: ——
Year: G (1) 4–0–8
A review of the physiological processes by which substances are transported within the human body and by which the body transports itself through the environment. The physiology of the cardiovascular system,

the lungs, and kidneys, and the musculoskeletal apparatus discussed in detail. Membrane transport, neurophysiology, and the control of smooth muscle contractions. *R. S. Lees*

20.68 *Food Marketing* (A)
Prereq.: ——
Year: G (2) 3–0–6
Examination of the distribution system through which food moves from the farm and range to the ultimate consumer. Emphasis on understanding critical problems faced by various members of the food distribution system: the farmer, the processor, the wholesaler, and the retailer. Use of the case method to develop analyses of key issues and possible solutions to marketing problems. Attention also on maladjustments in the food distribution system and the role of government in relationship to food marketing.
G. F. Bloom, S. A. Goldblith

20.71 *Research Problems* (A)
Prereq.: ——
Year: G (1) *Arr.*

20.72 *Research Problems* (A)
Prereq.: ——
Year: G (2) *Arr.*
Directed research in the field of nutrition and food science. *Staff*

20.75 *Food Distribution Crisis*
Prereq.: ——
Year: U (1) 3–0–6
The nature and urgency of national and international problems of population growth and food supply; the occurrence of malnutrition and its social consequences. Group discussion and formulation of specific recommendations in the areas covered. (*Juniors and seniors.*)
N. S. Scrimshaw

20.80 *Neuroendocrine Regulation and Communications* (A)
(*Revised: Unit change*)
Prereq.: 20.37
Year: G (2) 4–0–8
Study of the interaction of the nervous and endocrine systems, with emphasis on the role of both in the control of metabolism. Topics: components of systems which regulate the extracellular fluid; biologic communication systems; neurotransmitters; catecholamines; the anatomy and physiology of the neuro-endocrine transducers; the hypothalamus; the pineal; the adrenal; the effects of hormones on the brain; and the mechanisms of action of psychotropic drugs. (*Permission of instructor required for students who have not taken 20.37.*) *R. J. Wurtman*

20.81 *Clinical and Public Health Nutrition* (A)
Prereq.: 20.30
Year: G (S) 8–16–8
Given entirely in Guatemala. Seminar discussions of various nutritional diseases and programs combined with working visits to hospitals, public health clinics and other institutions concerned with nutrition problems. Three weeks of field work in various geographic regions for the nutritional evaluation of different population groups and two weeks of either residence in a rural health district for participation in multidisciplinary applied nutrition programs or completion of a special project. (*Restricted to suitably qualified physicians and dentists.*) *N. S. Scrimshaw*

20.83 *Topics in Engineering in Medicine* (A)
Prereq.: ——
Year: G (1, 2) 2–0–4
Discussion of topics in medical science and engineering solutions to medical problems. Emphasis on cardiovascular disease and biomedical data processing.
R. S. Lees

20.84 *Human Genetics* (A)
Prereq.: 7.01, 7.05
Year: G (2) 4–0–8
It includes chromosomal and Mendelian genetics, biochemical genetics, complex traits, inheritance and the environment, population genetics and a systematic survey of the biochemical lesions of inherited disease. (*This course is given in conjunction with the Harvard Medical School. Open to qualified students.*) *J. B. Stanbury*

20.85 *Research Management in the Food and Drug Industries* (A)
Prereq.: ——
Year: G (1 or 2) 2–0–2
Lectures devoted to research management problems peculiar to the food and drug industries and to managerial and technological problems encountered in the production of specific foods and food by-products. Governmental regulatory agencies and their relationship to modern food and drug industries. Consideration of research as a dominant force in modern society. Consideration of research audits, research management in small and large companies. *S. A. Goldblith*

20.88 *Special Topics in Oral Science* (A)
Prereq.: 20.30
Year: G (1) 2–0–4

20.89 *Special Topics in Oral Science* (A)
Prereq.: 20.30
Year: G (2) 2–0–4
Presentations of recent advances in oral science by staff, guest lecturers and students. *S. A. Miller*

20.91 *Experimental Statistics for the Biological Sciences I* (A)
Prereq.: 18.02
Year: G (1) 2–2–4
Designed to give investigators in life sciences a working knowledge of statistical procedures for interpretation of experimental data. Topics including: variation and statistical measures. Probability, frequency distributions and moments; sampling distributions, point and interval estimation, tests of significance. Basic concepts of statistical models and use of samples. Regression and correlation. Analysis of variance and covariance.
W. M. Rand

20.92 *Experimental Statistics for the Biological Sciences II* (A)
Prereq.: 20.91
Year: G (2) 2–2–4
Variance components. Theory of least squares. Elementary experimental design. Individual degrees of freedom, design of experiments repeated over time and place, factorial arrangements and incomplete block designs. *W. M. Rand*

21.
Humanities

21.011 *The Western Tradition: The Classical Heritage*
Prereq.: ——
Year: U (1) 3–0–6
Reading and discussion of literary and philosophical masterworks central to understanding the ideals and the problems of contemporary Western society. Major-

ity of texts of a literary nature with emphasis on the nature of civilization as the Western tradition has conceived it, its value and cost. Some of the authors to be read: Homer, Aeschylus, Sophocles, Plato, Aristotle, Virgil. *Staff*

21.012 *The Western Tradition: The European Heritage*
Prereq.: 21.011
Year: U (2) 3–0–6
Continuation of 21.011. Representative works from later periods of the Western tradition. Authors to be included: Dante, Shakespeare, Goethe, Dostoevsky, Freud; additional readings constituting a span of topics ranging chronologically from Christian Antiquity through the Renaissance and Enlightenment. *Staff*

21.013 *Self-Definition: Writing and Thinking*
Prereq.: ——
Year: U (1) 3–0–6
The discipline of writing as a way of exploring one's self and one's thought. Student projects include the keeping of a journal throughout the term, weekly writing for discussion, and occasional assigned exercises. Classes used to discover the effect of the writer's words on others. Emphasis placed on gaining facility and power in writing. *Staff*

21.014 *Self-Definition: Writing and Thinking*
Prereq.: 21.013
Year: U (2) 3–0–6
Continuation of 21.013. Exploration of themes that emerge from the writing of the first term. Possible directions for different sections: autobiographical and theoretical explorations of the sense of self; creative writing workshop; laboratory in group dynamics. *Staff*

21.017 *Culture and Society in America: The Rise of a Technological Civilization*
Prereq.: ——
Year: U (1) 3–0–6
An historical inquiry into the development of a technological civilization in America, focusing on ways in which Americans have thought about their society, about the relationship of the individual to society; and on conceptions of community, the ideal social order, and national destiny. Major changes in the structure and institutions of American society, and the meaning of such changes for community, the individual, social cohesion, liberty, equality, the distribution of power. Some effort made to account for the social forces and cultural values that lay behind American technological vigor and expansion. *Staff*

21.018 *Culture and Society in America: The Technological Society*
Prereq.: 21.017
Year: U (2) 3–0–6
Analysis of contemporary America as a technological civilization. The impact of technology on culture and politics, social structure, institutions, community, the family, the individual, and on freedom in America. Responses in thought, feeling and politics to the technological society. New defenses and modes of individual freedom and democracy. The development of countercultural thought and institutions, of social engineering and new forms of utopianism. Alternative futures for the technological society. *Staff*

21.019 *Three Major Texts: The Bible, Plato and Marx*
Prereq.: —
Year: U (1) 3–0–6
Examination of the religious foundations of Western civilization, concentrating upon the Holy Scriptures and such related Platonic dialogues as the *Euthyphro*, *Phaedo* and *Symposium* and employing a range of additional texts for commentary and contrasts. These include writings of the ancient Near East and classical Greece and selections from works of such subsequent writers as St. Augustine, St. Thomas Aquinas, Luther, Milton, Pascal, Kierkegaard, Nietzsche and Freud. *Staff*

21.020 *Three Major Texts: The Bible, Plato and Marx*
Prereq.: 21.019
Year: U (2) 3–0–6
Continuation of 21.019. Starting from a reading of Plato's *Republic* an examination of variety of secular attempts to set standards of human morality and political justice, focusing on Marx's critique of alternative positions and their relations, both contributory and critical, to Marxism. Pertinent conservative, liberal and radical thinkers include Aeschylus, Aristotle, Machiavelli, Rousseau, Burke, Kant, Hegel, and J. S. Mill. *Staff*

21.021 *The Western Tradition: The Classical Heritage*
(New)
Prereq.: ——
Year: U (1) 3–0–6

21.022 *The Western Tradition: The European Heritage*
(New)
Prereq.: 21.021
Year: U (2) 3–0–6
An alternative version of 21.011-21.012, with a larger consideration of non-literary texts and less extensive consideration of historical periods. Focus of study: the contrast between ideas of community, authority, responsibility, and heroism as they relate to the sense of personal destiny in Greek and Roman antiquity and the Judeo-Christian world. First term: authors studied include Homer, Hesiod, Aeschylus, Sophocles, Euripides, Thucydides, and Plato, and selections from the historical and prophetic literature of the Old Testament. Second term: examination of works by Aristotle, Virgil, Lucretius, St. Matthew, St. John, Augustine, Aquinas and Dante. *(Limited entollment.)* *Staff*

21.023 *The Western Tradition: The Classical Heritage*
(New)
Prereq.: ——
Year: U (1) 3–0–6

21.024 *The Western Tradition: The European Heritage*
(New)
Prereq.: 21.023
Year: U (2) 3–0–6
An alternative version of 21.011-21.012, with a larger consideration of non-literary texts and a less extensive consideration of historical periods. Focus of study: related ideals of community, authority and destiny in Christian and post-Christian Europe from the Renaissance to the nineteenth century. First term: authors studied include Machiavelli, Luther, Montaigne, Shakespeare, Rabelais, Molière, Galileo, and Hobbes. Second term: Milton, Pascal, Descartes, Swift, Rousseau, Goethe Darwin, Marx, Dostoyevsky, and Freud. *(Limited enrollment.)* *Staff*

21.025 *Identity and Purpose in Black America*
(New)
Prereq.: ——
Year: U (1) 3–0–6

21.026 *Identity and Purpose in Black America*
(New)
Prereq.: 21.025
Year: U (2) 3–0–6
An historical analysis of the issues arising from the conflicts between the promises of American democracy and

the hopes and needs of its Black minority. Consideration of the literary and political statements of Black community leaders as they address the problems of power, identity, social injustice, community, and purpose. The second term will focus on Black perceptions of Western civilization and the technological society as a context for understanding the forces which operate to create alternative cultural patterns and strategies designed to help the Black community achieve satisfactory political and social roles in American life. *Staff*

21.03 ***Approaches to Literature***
Prereq.: One first-year Humanities sequence
Year: U (1, 2) 3–0–6
Introduction to the varieties and possibilities of literary art. Particular emphases varying widely enough from section to section for the student to choose from a number of options. (*A statement of the instructor's approach and a reading list for each section announced before the start of the term.*) *Staff*

21.05 ***The Twentieth Century: Revolution and Totalitarianism***
Prereq.: One first-year Humanities sequence
Year: U (1, 2) 3–0–6
Introduction to history through the analysis of two complex twentieth-century phenomena: revolution (the Russian, Chinese, Cuban and Vietnamese Revolutions) and totalitarianism (Soviet and Chinese Communism, Nazi Germany). Historical analysis of the conditions that breed revolutions, the development of revolutionary ideologies, the roles of radical elites, the dynamics of revolutionary movements, and the characteristics of totalitarian movements and regimes. Study of various theories of revolution, including classical Marxism and its contemporary versions. Readings in primary sources, critical scholarly articles, and works of interpretation. *Staff*

21.051 ***Rationalism and Radicalism: The Dilemma of Liberal Society***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Historical examination of liberalism as a rationalizing and radicalizing force in Western society. Analysis of the progress and stalemate of liberalism as a political, social, and cultural phenomenon, with emphasis on the English Revolution of 1640–1660, the rise of the middle classes to power in nineteenth century Europe, and the liberal collapse and fascist successes of the 1920's and 1930's. Special attention to the use of sociological and psychological theory in historical explanation. *Staff*

21.052 ***The Dynamics of Imperialism***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (1, 2) 3–0–6
An exploration of various interpretations and theories leading toward a definition of imperialism. Examples characterizing historical epochs and the unique character pertaining to each, stressing the nexus between conquest, domination, and the response of colonized people to imperial domination. Comparative case studies cover an ancient example of "empire" (Rome or Greece) but primary emphasis on contemporary imperial theory and behavior in industrial modernizing societies such as Germany, the Soviet Union, Great Britain, and the United States. Case studies of anti-colonial movements may include India, China, Algeria, Vietnam, Czechoslovakia, and Cuba. Students explore in independent research projects a case study of their own choice, and concentration in the later part of the course toward integrating theory, practice, and the students' case studies into the creation of explanatory models which organize the data of the course and suggest alternative futures. (*Limited enrollment, fall term.*) *Staff*

21.053 ***Modern World History***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6

21.054 ***Modern World History***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Historical development of the modern world, stressing the growth of the U.S. as a member of a general western civilization; evolution of governmental, social, and economic organization, intellectual trends, and influence of science and technology; experience of the U.S. and other countries in dealing with related problems compared and contrasted. The first term covers the period from 1500 to 1870; the second term 1870 to the present. (*Limited enrollment.*) *Staff*

21.06 ***An Introduction to Anthropology***
Prereq.: One first-year Humanities sequence
Year: U (1, 2) 3–0–6
Study of a number of societies through the perspectives of multilinear evolution and cultural ecology, using the resources of archeology, linguistics, and cultural anthropology. Consideration of anthropological theory, the culturally-determined personal biases of anthropologists, and the social and political context of anthropological research. Case study method and the use of selected student field work projects. *Staff*

21.07 ***The Language of Music***
Prereq.: One first-year Humanities sequence
Year: U (1, 2) 3–0–6
A course designed to promote sensitivity to the language of music. Works to be studied comprise live and recorded performances selected from different historical periods. Consideration of fundamental structural principles, based on exposition of musical notation. Emphasis given to the changing relationships between the composer and his audience. *Staff*

21.08 ***Humanities Seminar***
(*Revised: Unit change*)
Prereq.: ——
Year: U (1) 3–0–9
Interdisciplinary seminar on selected topic. (*Open only to seniors in Course* XXI-A *and Course* XXI-B, *Program 1.*) *R. Lamson*

21.081 ***History Seminar***
Prereq.: ——
Year: U (1) 2–0–8
Seminar on selected topic in history. (*Open only to juniors or seniors in Course* XXI-B, *Program 2.*) ——

UNDERGRADUATE ELECTIVES

21.093 ***The Self and Social Behavior***
(*New*)
Prereq.: ——
Year: U (1, 2) 3–0–6
An approach to the classroom that derives from encounter group methods combined with theoretical and historical discussion of issues concerning human growth and identity, group behavior, and the socialization process. Analysis of the arguments over the relation of human instincts to culture. Some attention to the historical role of the family and the school in shaping individual personality and behavior. The portion of time given over to encounter group work will serve to bring the participants' own experience to bear on these matters. Readings drawn from several disciplines, including psychology, sociology, and literature. (*Enrollment limited to 15 students.*) *M. Miller*

21.095 *Writing Tutorial*
Prereq.: ——
Year: U (1, 2) *Arr.*
Non-credit tutorials for students who wish to increase the effectiveness of their writing. Conferences arranged with the instructor. *S. Kaye*

21.098 *The Cultural Boundary*
Prereq.: ——
Year: U (2) 2–0–4
Sampling of readings about non-Western cultures and societies in an effort to answer three questions: (1) how may an observer come to experience life in the same terms as an individual of a different culture? (2) how does an anthropologist go about studying situations foreign to his life experience? and (3) what is the relevance of anthropology for an understanding of our world? *M. Diskin*

SUBJECTS IN WRITING

21.10 *Scientific and Engineering Writing*
(*Revised: Unit change*)
Prereq.: ——
Year: U (1, 2) 2–0–7
Instruction basic to all types of communications that scientists and engineers are called upon to write, from abstracts to journal articles. Detailed analysis of the problems of conveying technical information to non-technical as well as to technical audiences. Term project involving a written paper on a technical or semi-technical subject and an oral presentation of the subject in class. *R. R. Rathbone*

21.101 *Writing Workshop*
Prereq.: ——
Year: U (1) 2–0–7
A workshop for those who want to write stories. Students examine each other's stories, in an attempt to find or create an audience for what they need to say. A few published stories furnish examples of how other writers have discovered and pleased their readers. (*Permission of instructor required.*) *J. S. Brown*

21.102 *The Writing of Fiction*
Prereq.: ——
Year: U (2) 2–0–7
Writing of fiction according to individual interests, supplemented by exercises in fictional techniques and critical reading of professional examples. Emphasis on analysis of students' manuscripts. (*Permission of instructor required.*) *S. Kaye, Adv. Sec.: C. T. Cole*

21.103 *The Writing of Poetry*
Prereq.: ——
Year: U (1, 2) 2–0–7
Writing of poetry according to individual interests, supplemented by exercises in various poetic forms and critical reading of professional examples. Emphasis in class on analysis of students' manuscripts. (*Permission of instructor required.*) *P. Cumming*

21.104 *Playwriting*
Prereq.: ——
Year: U (1) 2–0–7
Seminar on the writing of plays. Exercises in small scenes, followed by the writing of at least one short play by the individual student. Possible production in some sort of workshop, depending upon merit of work submitted; e.g., Dramashop or a local coffee house.
A. R. Gurney

21.105 *The Writing of Prose*
Prereq.: ——
Year: U (1) 2–0–7
Inquiry into, and experimentation with, the sources of material for prose writing, as well as the tactics for communicating the material to the reader. Each student whether unpracticed or accomplished at prose writing responsible for a substantial body of writing to be presented on a regular basis during the term. Three meetings with professional writers: one with a novelist, one with a journalist or essayist, and one with a writer having a particular specialty, such as science. Readings from imaginative literature, the mass media, and several special fields. Tapes, and the comparison of a movie with its script part of the inquiry. (*Permission of instructor required.*) *S. Kaye*

21.106 *Prose Writing*
(*New*)
Prereq.: ——
Year: U (2) 2–0–7
An exploration into the variety of purposes of prose, as defined by students' individual interests, and into the techniques by which these may be made real and compelling to readers. Discussion of students' writing will form the basis of the class, but professional writing where applicable will also be discussed. *P. Cumming*

LITERATURE

For other subjects in literature in addition to those given below, see Special Interdisciplinary Subjects (especially 21.953, Marx and Marxism, 21.954J, Workshop in Critical and Creative Experience, 21.997 and 21.998, American Values of the 1920's and 1930's, and 21.999, Group Behavior and the Cultural Process), subjects in writing, and subjects offered by the Department of Foreign Literatures and Linguistics.

21.11 *Literary Analysis*
Prereq.: One first-year Humanities sequence
Year: U (1, 2) 3–0–6
Subject matter of 21.03 presented as an upperclass Humanities elective. (*Open to those who have not taken 21.03.*) *Staff*

21.13 *The Epic*
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
The epic as expressive of the total range of moral and imaginative possibilities within a given culture. Readings in Homer, Virgil, The Bible, The *Chanson de Roland*, Dante, Milton, Wordsworth, James Joyce. *A. Kibel*

21.14 *The Bible: Form and Content*
(*New*)
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Close reading of selected Old and New Testament texts, focusing on the conceptual and literary form of religious discourse as evidence of specific — and changing — theological understanding, intellectual context, and audience-expectation. Special attention to the problems of "Hellenization" and "demythologizing." Comparison and contrast with appropriate Greek and Gnostic texts. *H. A. T. O. Reiche*

21.15 *Shakespeare*
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Reading and discussion of ten selected plays of Shakespeare, especially tragedy, in an effort to understand Shakespeare's work as dramatic and poetic expression of Renaissance and Elizabethan views of man. Study of the traditional and innovative qualities of Shakespeare's art and development in their relation to the theater and drama of his time and to later treatments in the modern theater and in films. Independent study of a contemporary of Shakespeare, Marlowe, Dekker, Jonson, or Webster; some exercises in criticism of current performances. *R. Lamson*

Descriptions

21.151 *Shakespearean Tragedy*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Study of Shakespeare's tragedies in the contexts of Shakespeare's total performance, the Elizabethan period and the traditions of tragedy from the Greeks to the present. *R. M. Koffler*

21.16 *Chaucer*
Prereq.: 21.03 or 21.11
Year: U (1) 3-0–6
Reading and discussion of *The Canterbury Tales* and *Troilus and Criseyde*. *R. Lamson*

21.17 *Literature of the English Renaissance*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Rise and development of English poetry and prose in the sixteenth and early seventeenth centuries, with some attention to the drama. Problems of artistic and social tradition and convention of the Renaissance and their relationship to English innovation and achievement. Reading and discussion of Marlowe, Sidney, Spenser, Shakespeare, Bacon, Jonson, Donne, Browne and other selected writers. (*Not offered 1971–72.*) *R. Lamson*

21.25 *Adventure in Fiction*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Examination of the value placed upon the fiction of adventure in modern literary culture. Readings in traditional narrative, such as the *Odyssey*, and *Gilgamesh* epic in an attempt to bring the traditional idea of adventure to bear upon the study of such writers as Poe, Melville, Conrad, T. E. Lawrence, Malraux, and Genet, who renew the stature of adventure as a literary subject matter. (*Not offered 1971–72.*) *P. Zweig*

21.251 *Readings in Modern English and American Poetry*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
The idea of modernity as an expression of the sense of crisis in the work of the early generation of moderns, Yeats, Pound and Eliot, and their influence upon subsequent moderns, such as Stevens, Roethke, Robert Lowell, John Berryman, Allen Ginsberg, W. S. Merwin.
B. Spacks

21.252J *How Is Poetry Made?*
(*New*)
(Same subject as 23.977J)
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Studies in comparative poetics. Insight into the poet's workshop. Authors and readers: their interrelation. The poet's treatment of sound and meaning: verse, imagery, theme. Poetic function of language. Changes and tradition. Examples drawn from English and other languages, but knowledge of other languages is not required. *K. Pomorska, W. O'Neil*

21.269 *Culture and Empire*
(*New*)
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
General consideration of the literature of empire with special emphasis on three topics: the "imperial idea" (empire from the point of view of the center), cultural imperialism, cultural relativism. Discussion in depth of the literature of the forming English empire of the eighteenth century and of its decay and discontents in the twentieth century. Readings include *The Aeneid*, Shakespeare, Swift, Pope, Defoe, Rousseau, Conrad, Forster, Orwell, H. James, Claude Levi-Strauss, Franz Fanon and two Latin American novelists. (*A reading knowledge of Spanish is welcome.*) *R. S. Leiken*

21.27 *Narrative Fiction*
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Studies in European Realism: An attempt to define the tradition of psychological realism in the novel as a unique fusion of comic plot and tragic conception of character. Works by Balzac, Stendhal, Flaubert, Dostoevsky, Tolstoy, Kafka, Camus and Malraux. (*Not offered 1971–72.*) *A. C. Kibel*

21.271 *Utopian Literature*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Study of the imagination of utopia in literature and political thought since the Renaissance. Consideration of modern utopian and anti-utopian fiction. Readings of works by Plato, Hobbes, More, Swift, Rousseau, Diderot, De Sade, Karl Marx, Lewis Carroll, Dostoevsky, Huxley and Freud. *A. C. Kibel*

21.272 *Narrative and the Novel*
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
An attempt to explain "the rise of the novel" in eighteenth century England showing how artistic tradition is modified by the social experience of industrialization. Comparison of "modern" and "traditional" narratives distinguishing those features which made the novel the characteristic literary product of capitalist society. Readings include modern historical interpretations. Also works by Milton, Pope, Fielding, Austen. (*Not offered 1971–72.*) *R. S. Leiken*

21.273 *Lyric Poetry: Practice and Theory*
(*New*)
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Reading lyrics, writing lyrics, and finding various ways of understanding the lyric as a literary genre and a human experience. Readings will include poems from different periods, on different topics and, where possible, in different languages. Some theoretical essays will be consulted. Writing will aim at gaining experience of the genre more than at perfecting personal expression. Students, therefore, will be expected to experiment with both forms and subject matter. (*Limited enrollment.*)
N. Z. Dworsky

21.274 *Literature and the Origins of American Empire*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Themes of territorial expansion, national character, and national purpose of an emerging industrial power as reflected and interpreted in major works of American literature, from James Fenimore Cooper to Norman Mailer: changing concepts of social order and heroic action. A course in the methods of literary imagination.
M. B. Folsom

21.276 *The Short Story*
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
The background of short narrative in parable, fable, folk tale, medieval *exempla*, anecdotes, jokes. Intense reading in the masters of the modern form: Gogol, Joyce, Chekhov, Hemingway, Kafka, Babel, Borges, the American southern writers, and others. Study of the techniques of compressed narration in propaganda, advertising, and the fictional film. Frequent short papers required. *C. T. Cole*

21.277 *The Politics of the Novel*
(*New*)
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
An attempt to understand the political implications of modern works of fiction: Dostoevsky's *The Possessed*, Flaubert's *A Sentimental Education*, James' *The Bostonians* or *The Princess Casimassima*, a novel by Conrad, Zamyatin's *We*, a novel by Victor Serge, and Malraux's *Man's Fate*. *E. Goodheart*

21.278 *Baudelaire, Mallarme, and Yeats*
(*New*)
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Explications de texte to reach the center of vision of each poet. An attempt to clarify how these three unique poetic minds share common themes and problems: the relationship of consciousness and nature, the role of language (or of poetic discourse) in this relationship, the dialectic of action and reflexion, and the place of the poet in the new, bourgeois, industrial world of 1848–1939. A reading knowledge of French will be required and an ability to read English well will be appreciated. Discussions will be in English. (*Limited enrollment. Permission of instructor required.*) *A. Berger*

21.28 *Theatre Arts: Elementary Stagecraft and Production Studies*
Prereq.: 21.03 or 21.11
Year: U (1, 2) 3–0–6
Introduction to the techniques of modern theatre as a means of realizing the thematic content of drama. Tutorial discussions and laboratory exercises in the theatre. Individual study arranged with the instructor in advance, dealing with such subjects as production methods, organizational structure of the theatre, and history of theatre development. *J. D. Everingham*

21.281 *Modern Drama*
(21.282) *Prereq.:* 21.03 or 21.11
Year: U (2) 3–0–6
Close reading of modern dramatists. Plays by Ibsen, Chekhov, Shaw, O'Neill, Wilder, Hellman, Williams, Miller, Ionesco, Beckett, Genet, and others. Approved practical projects in theatrical techniques accepted in lieu of term papers. (*Permission of instructor required.*)
J. D. Everingham

21.282 *Satire*
(*New*)
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
A look at the nature, problems, and accomplishments of selected satirical writing in English. Basic readings, as time permits, chosen from such authors as Chaucer, Jonson, Dryden, Swift, Pope, Byron, Morris, Butler, Shaw, Huxley, and contemporary writers and artists. Students may select any satirist, ancient, modern, or contemporary either in English, American, or foreign literature, art, drama, or film for individual study toward a major paper. (*Limited enrollment.*) *R. Lamson*

21.283 *Tragedy*
(*New*)
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Examination of a number of different works generally considered to have a tragic dimension, and of various theories on tragedy, in order to come to some conclusions about the problems and possibilities of tragedy in the twentieth century. Readings from Sophocles, The Book of Job, Ibsen, O'Neill, Beckett, and others, as well as from Aristotle and other critics. *A. R. Gurney, Jr.*

21.284 *Comedy*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
An examination of some problematic aspects of modern comedy. What, if any, are the limits of the comic? What role do cultural norms play in determining what is laughable? What is the function of "nonsense?" Authors studied include Jonson, Wycherley, Wilde, Carroll, Chekhov, Twain, Thurber, Perelman, Faulkner, and Beckett. Also readings in comic theory. (*Limited enrollment.*) *M. Brenner*

21.286 *The Sexual Order*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Analysis of some of the sexual myths at the heart of our culture; study of literature as the origin and vehicle of these myths. Three related implications of "sex" will be examined; individual identity, sexual behavior, and political power. Material drawn from popular culture and recent pamphlets will supplement readings from such authors as Virginia Woolf, Philip Roth, Sigmund Freud, Doris Lessing, Frederick Engels, Jane Austen, Eugene O'Neill, Colette, Mary Wollstonecraft, Gustave Flaubert and J. S. Mill. (*Permission of instructor required.*)
L. Robinson

21.29 *Dostoevsky, Tolstoi, Chekhov: Russia and the Modern Age*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Studies of artistic vision in modernizing Russia. Reading and analysis of *The Brothers Karamazov*, *The Possessed*, *Anna Karenina*, *The Death of Ivan Ilyich*, *The Seagull*, *The Three Sisters*, and shorter works by each of the three authors. Discussion with critical and biographical readings of the relation of artistic works to social and cultural processes. All works in English translation. (*Not offered 1971–72.*) *R. E. MacMaster*

21.302 *Chinese Literature*
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Reflection of Chinese culture in literature from earliest times to the present. Reading to understand the aims and possibilities of Chinese fiction and poetry and how they have been realized. Foundation for approaching Western literary traditions as local variations of world literature. (*21.951 desirable as preparation, but not required. Not offered 1971–72.*) *N. Sivin*

21.31 *Modern Fiction*
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
An introduction to the range of modern fiction through a study of mostly shorter works of major modern authors. The list includes: Diderot's *Rameau's Nephew*, Bronte's *Wuthering Heights*, Flaubert's *Madame Bovary*, Dostoevsky's *Notes from the Underground*, Conrad's *Heart of Darkness*, Mann's *Death in Venice*, Joyce's *The Dead* or *Portrait* (with perhaps passages from *Ulysses*). *E. Goodheart*

21.312 *The Return of the Repressed*
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
How can aesthetic ideas of freedom become negations of an actual status quo? Must fiction, or a controlled form of phantasy, be only an irresponsible mode of escapism? Or may certain works, seen in their proper historical perspective, constitute forms of struggle against repressive, prevailing social and political arrangements? Readings of 19th century texts from the perspecive of a still unresolved theoretical debate about real and ideal freedom. Readings include: Schiller, Freud, Marcuse, Rousseau, Stendhal, Nerval, Baudelaire, Flaubert. (*Not offered 1971–72.*) *A. Berger*

Descriptions

21.313 ***Major Authors: Friedrich Nietzsche***
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Work of a different author each term. May be repeated with permission of instructor in charge. Lectures designed to accompany an intensive reading of Nietzsche's principal works, primarily from the last period; the cultural situation of nineteenth century Germany, the significance of Wagner's music and Schopenhauer's metaphysics, biography of the author, his literary modes and the critique of academic reason, "placement" in relation to Marx and Kierkegaard, Heidegger's appropriation of his thought, etc. *J. McNees*

21.314 ***Major Authors: Charles Dickens***
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Work of a different author each term. May be repeated with permission of instructor in charge. Reading and discussion of the central body of Dickens' works, with emphasis on his novelistic achievements in contexts both social and artistic. Also some supplementary readings in biographical and critical materials. *T. R. Merritt*

21.315J ***Language and Its Structure***
(21.316J) (Same subject as 23.700J)
Prereq.: ——
Year: U (1) 3–0–6
An introduction to basic concepts and issues for the non-linguist. Production and physical properties of speech, phonetic and phonemic representations, deep and surface syntactic structures, language change, methods and goals of modern linguistic theories. *W. O'Neil, J. W. Harris*

21.316J ***History of the English Language*** **(A)**
(21.315J) (Same subject as 23.733J)
Prereq.: ——
Year: G (2) 3–0–9
Selected topics in the history of English syntax, morphology and phonology from Old English to the present, formulated within an attempt at a general theory of linguistic change. (*Some knowledge of Old and Middle English desirable.*) *W. O'Neil*

21.32 ***The Nineteenth Century: Aestheticism and Conscience***
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Study of an eclectic variety of writings — mainly English and American — illuminating a central issue in premodern literary culture: the opposition between notions of artistic autonomy and social morality, the important efforts to resolve that opposition. Reading list: novels, plays, poems, essays, histories, biographies, autobiographies, and miscellaneous pieces by such authors as Coleridge, Mill, Keats, Dickens, Browning, Thoreau, Mark Twain, Pater, Wilde, Henry James. (*Not offered 1971–72.*) *T. R. Merritt*

21.33 ***Popular Culture and Mass Media***
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Discussion of popular literature, mass circulation magazines, newspapers, television programs and commercials, and popular music, in order to develop a critical response to everyday cultural materials. Examination of their use for both art and propaganda; assessment of their potential for valid expression of popular consciousness as well as for social control and conditioning.
P. S. Donaldson

21.34 ***Literature and Propaganda***
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Analysis of propagandistic elements in literary and non-literary works, in order to understand the relationship between artistic quality and political or moral intention. Is the work only a means to a specific political end, or does it transcend its political purpose? To what extent does all literature, even "non-engaged" literature, consciously mean to persuade by projecting values and attitudes? General consideration of the use of language to manipulate, move or clarify. (*Not offered 1971–72.*)
S. Jhirad

21.35 ***Social Vision in Literary Art: Shaw, Lawrence, Faulkner***
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Reading in depth of three major writers, with emphasis on the varieties of social consciousness which affect dramatic and narrative form. Works to be read include: George Bernard Shaw's *Widower's Houses, Mrs. Warren's Profession, Man and Superman, Heartbreak House, Back to Methuselah;* D. H. Lawrence's *Sons and Lovers, Women in Love, The Plumed Serpent, St. Mawr, Lady Chatterley's Lover;* William Faulkner's *The Sound and the Fury, Absalom! Absalom!, Go Down Moses, The Hamlet.* *T. R. Merritt*

21.36 ***Women and Literature***
(*New*)
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
An examination of sex roles and stereotypes in literature by and about women. Male images of women from courtly love to Freud: *Roman de la Rose,* Baudelaire, Byron, Bellow, Mailer, Flaubert, and Cleaver. Woman's attempt at self-definition: Virginia Woolf, Kate Chopin, Sylvia Plath, Anne Sexton, and Doris Lessing. Selections from current poetry of the women's movement.
S. Jhirad

Special Seminars in Literature

(Work in the following subjects will be done in close association with the instructors. Each is open to all students with the permission of its instructor.)

21.381 ***Revolutionary Attitudes***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Reading and discussion of fiction, plays, memoirs and films by and about revolutionaries. Consideration of what has led certain people to commit themselves to overturning the society they live in, and trying to transform its human relations, its ways of feeling, thinking, and acting. Can we relate these transformations of consciousness to our own lives? Authors: Doris Lessing, André Malraux, Che Guevara, Victor Serge, Big Bill Haywood, Dostoyevsky, F. Douglass, George Jackson, and Paul Cowan. (*Permission of instructor required.*)
L. Kampf

21.383 ***The Idea of Culture***
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Examination of the idea of culture as it develops in literary argument, anthropological and sociological theory since the nineteenth century. Culture as "high culture," as a substitute for religion, as national culture, as an inherited power of order, as a principle of conscience. Readings in John Ruskin, Matthew Arnold, A. L. Kroeber, Richard Hoggart, T. S. Eliot, W. B. Yeats, Sigmund Freud, Claude Levi-Strauss, LeRoi Jones. (*Permission of instructor required. Not offered 1971–72.*) *A. C. Kibel*

21.384 ***Linguistics and Literary Study*** **(A)**
Prereq.: ——
Year: G (2) 3–0–9
Study of the formal properties of the language of literature. Consideration of the insight that linguistic theory gives into the development of a general theory of literature. (*Limited to 15 students. Undergraduates admitted only by permission of instructor. Not offered 1971–72.*)
W. O'Neil

21.385 ***Lyric and Discourse***
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Study of the relation between lyrical and discursive elements in both prose and verse. Discussion of essays, sermons, poems, letters, public addresses drawn mainly from 1750 to the present. Comparison of expressive and rhetorical functions, for exploration of the properties and capacities of different forms. Student criticism of each other's work as well as the regularly assigned material. (*Limited to ten students. Permission of instructor required. Not offered 1971–72.*) *T. R. Merritt*

21.386 ***Literature and Interpersonal Relationships***
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Literary works dealing with problems of interpersonal relationships as illustrations of ways of such problems arising in human situations, the sensitive writer's perception of such problems, his fitting them into his own world-view, and his acting them out in his literary works. Influence on the writer of his social environment; relevance to the student's own personal and social attitudes. Readings from Shakespeare, Swift, Ibsen, Dostoevsky, Lawrence, Doris Lessing, and some Romantic poets. (*Limited enrollment. Permission of instructor required.*) *A. R. Hawley*

21.387 ***Metaphor***
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Attempt to understand metaphor — figurative and tropological language. Exploration and testing of the hypothesis that we can learn about the relationship between thought and language by looking from as many points of view as possible — not merely the literary — at what happens when someone apprehends a metaphor he has not apprehended before. Instructor participitation by sharing and arbitrating the task, not imparting a body of knowledge. *P. H. Elbow*

21.391 ***Special Topics in Literature***
Prereq.: Any two subjects in literature
Year: U (1) *Arr.*
Open to qualified students who wish to pursue special studies or projects with members of the Literature Section. Students electing this subject must consult the Chairman of the Section. *Staff*

21.392 ***Special Topics in Literature***
Prereq.: Any two subjects in literature
Year: U (2) *Arr.*
Open to qualified students who wish to pursue special studies or projects with members of the Literature Section. Students electing this subject must consult the Chairman of the Section. *Staff*

21.393 ***Independent Study I***
Prereq.: Any two subjects in literature
Year: U (1) 3–0–6

21.394 ***Independent Study II***
Prereq.: Any two subjects in literature
Year: U (2) 3–0–6
For students concentrating in literature in Course XXI-B, Program 2. Designed to fulfill their requirement of independent reading. Decision on reading list by the student in consultation with his advisor on the basis of a general list. *Staff*

HISTORY

Economic-Technological

21.411 ***History of Engineering***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
History of the techniques and achievements in engineering from ancient times to about 1800. The goals, methods, and status of the engineer in Babylonia, Egypt, Greece, Rome, the Arabic world, the Middle Ages, and the Renaissance set against the background of the political, social, and economic conditions of the times. Study of the development of engineering as an integral part of the life of cultures different from our own to give perspective and background for studying and evaluating the position and contributions of the engineer in modern times. Extensive use of lantern slides. *R. S. Woodbury*

21.412 ***History of Engineering***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Study of the development of modern engineering from 1800 to about 1930. Presentation of engineering advance as an important factor among the economic and social changes which center around the Industrial Revolution. Concentration on those key aspects of greatest importance for future engineering development and for economic and social change — coal, steel, textiles, machinery, transportation, electric power, and others. Use of lantern slides. *R. S. Woodbury*

21.414J ***History of Materials***
(Same subject as 3.78J)
Prereq.: One first-year Humanities sequence
Year: U (2) 2–0–7
Study of man's knowledge of materials and attitude toward them in all ages from the discovery of ceramics to modern materials science. Materials as a bridge between art, science and engineering. Emphasis on use of original sources and artifacts. (*Not offered 1971–72.*) *C. S. Smith*

21.415 ***Technology and Economic Growth***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Growth of technology in the modern world in its relationship to economic and social change. Craft technology; industrialization — invention, origins of mass production and interchangeable parts, power sources, transportation, mechanization of agriculture, technology and large-scale enterprises, new industries. *R. S. Woodbury*

21.416 ***Science and Technology in the American Enlightenment***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
A study of American attitudes toward scientific achievement and technological improvement examined as deliberate goals of the men who made the American Revolution and founded the Republic. Examination of their actual achievement in science and in the formation of institutions related to science in the generation of such men as Jefferson and Franklin. Relationship of these conditions to the simultaneous introduction of the technology of the Industrial Revolution. *B. Hindle*

21.417 ***Science, Technology, and War in the American Experience***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Examination of reciprocal relationships between science and technology, and warfare and the military in their development and variety through the course of American history. Emphasis on patterns of military support of science and technology and on contributions from the scientific and technological communities to warfare and weaponry. Major periods examined: the American Revolution, the Civil War, and World War II. *B. Hindle*

Descriptions

21.421 ***Development of American Economic Institutions***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Topical study of the development of the American economy from 1800 to the present, concentrating on about four of the following topics: Alexander Hamilton; the early New England factory town; the plantation-slave economy; the westward movement; the American farm; the labor union; the automobile industry; the failure of an economy in the 1930's, and the New Deal.
L. S. Bryant

21.422 ***History of Transportation in the United States***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Study of new modes of transportation such as the canal, the steamship, the railroad, the automobile, and the airplane — their technical development, their effect on the American economy and society, and the evolution of new institutions for the management and control of the business of transportation. *L. S. Bryant*

21.423 ***History of the Automobile***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Development of the automobile and its impact on American economic and social institutions. Case study in the nature of technological development and in the social problems created by technological change.
L. S. Bryant

21.424 ***The Businessman in American History***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Study of the changing roles, images, and characterizations of businessmen in America from the colonial period to the present, with special emphasis on tensions between the traditional and innovative in practices, structure, perspectives and values. Readings in history, biography, fiction and critical and popular periodicals. (*Not offered 1971–72.*) *E. N. Hartley*

21.426 ***History of Technology in the United States***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
An introduction to the development of technology in the United States as interwoven with its economic and social background and influence. Representative topics: cotton, slavery, and Eli Whitney; interchangeable manufacture and the "American system"; McCormick and prairie agriculture; Oliver Evans and automation in grain milling; Samuel Colt and firearms; American machine tools; Howe, Singer, and the sewing machine; American shipbuilding — the clipper ship and the ironclad; petroleum — Drake and Rockefeller; the Wright Brothers and aviation; Ford and the automobile.
R. S. Woodbury

21.428J ***Economic Development, Political Structure, Imperialism, and Social Discontent in Low Income Countries***
(*New*)
(Same subject as 17.54J)
Prereq.: ——
Year: U (2) 3–0–6
A survey of the facts of social discontent in low income countries; critique of possible causes lying in economic status, political structure, and international relationships, and discussion of their social, political, and international implications. (*Open to graduates: graduates will write a term paper.*) *R. E. MacMaster, E. Hagen*

Social-Cultural

21.461 ***Revolution in Twentieth-Century Latin America***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Comparative historical analysis of the origins and development of Latin American revolutions in the 20th century. Emphasis upon nature and direction of social change attendant to revolution in Mexico, Guatemala, Argentina, Venezuela, Bolivia and Cuba. Additional topics: United States and Soviet diplomacy toward Latin America; revolutionary movements in contemporary Latin America including guerrila insurgency, peasant leagues, and military "Nasserism." (*Not offered 1971–72.*) *J. V. Kohl*

21.463 ***The Emergence of Modern Africa***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Examination of problems concerning the social and cultural, economic, and political development of tropical Africa from earliest times to the modern period. Interdisciplinary approach, with special emphasis on the findings of archaeology, ethnobotany, linguistics and ethnohistory. Emphasis on indigenous invention as well as the stimulus of contact with Arabia, the Orient, and Europe. The slave trade and the growth of Europe's awareness of Africa. (*Not offered 1971–72.*) *R. I. Rotberg*

21.473 ***Rome: Reality and Idea***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Rome from city-state to world-empire. Structure and function of public power in the "classical" republic. Reasons for, and mystique of, Rome's ascendancy: conservatism and improvisation as political ways of life. Revolutionary impact upon, and of, Greek political theory: the captive captor. The Roman revolution and its outcome: world-empire and peace. The unwritten constitution as reality and facade. The question of the "decline and fall": survey and assessment of rival views. The religious, economic, political, and social factors. Byzantium and the Roman legacy. Readings in Roman historians and poets and in secondary works such as Syme, Rostovtzeff, and Gibbon. *H. A. T. O. Reiche*

21.475 ***Culture and Society in Medieval Europe***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Interplay of intellect and society circa 284–1350 A.D. Role of Christian world view in orthodox and heretical manifestations studied against background of social change and political conflict. Topics discussed: continuity from late Roman to early medieval culture; mystic and rational currents in philosophy; Carolingian and Ottonian "rebirths"; idea of a Holy Roman Empire; meaning of scholasticism; and problem of disintegration of medieval life forms. Individuals discussed: Augustine, Bede, Alcuin, John of Salisbury, Aquinas, Eckhardt, and William of Ockham. Romanesque and Gothic art and Latin, Romance, and Germanic literatures surveyed. Concepts of "ancient," "medieval," and "modern" examined. (*Not offered 1971–72.*) *R. E. Herzstein*

21.476 ***The Italian Renaissance***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Comparative studies in the development of Italian society and its culture from the generation of Dante to that of Machiavelli, with principal emphasis on Florence and Venice. Reading drawn largely from documents and source materials written by merchants, lawyers and magistrates; artists, scholars and men of letters. (*Not offered 1971–72.*) *R. M. Douglas*

21.478 *The Northern Renaissance and the Reformation*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Historical change in the structure of society, the economic order and politics, studied in relation to various themes of complaint, protest and reform. Reading in the works of Thomas More, Machiavelli, Luther, Calvin, Rabelais, Montaigne, and Cervantes. *R. M. Douglas*

21.482 *Social Criticism and Social Science in America*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Study of the thought of the following social critics and social scientists (singling out two or three for detailed scrutiny) and of their place in the history of American social thought: Ward, Sumner, Veblen, Ross, Mead, Cooley, Park, Mills, Riesman, Goodman, Parsons, Merton, Lipset, Bell and others. The intellectual, social and institutional developments that shaped their work; the evolution and characteristics of sociology in the United States; ideas about the role of the social sciences in social planning and national life, and about the problem of objectivity in social analysis. Special attention to the work of C. Wright Mills and to the treatment of class and power in recent American social thought.
A. D. Kaledin

21.483 *Dissent and Reform in Twentieth-Century America*
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Study of the politics of reform, and of the social, psychological and ideological characteristics of reform movements in twentieth-century America. Topics included: the continuing current of "orthodox reform" (the Progressive movement, the New Deal and its latter-day versions); the populist movement; labor and reform; varieties of radical dissent (the socialist movement in the U.S., dissent on the right from the '30's to the John Birch Society, and on the left from the '30's to the "New Left"); black protest; women's reform movements; student-politics. Comparison with reform movements and dissent in other societies. (*Not offered 1971–72.*)
A. D. Kaledin

21.484J *Urban American History*
(Same subject as 11.561J)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6

21.485J *Urban American History*
(Same subject as 11.562J)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
A seminar on American urban history from roughly 1890 to present. Among the subjects considered: the concept of the "good" community, the nature of the ethnic ghetto, the decentralization of the American metropolis, the disintegration of the political machine, the professionalization of the police, the bureaucratization of the school, the character of the black ghetto, and the demand for community control. The first term devoted to reading and discussion; the second term devoted to research and writing. (*21.485J not offered 1971–72.*)
R. M. Fogelson

21.486 *Religion and American Culture*
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Explorations in the relationship between religion and secular culture in America, from the New England Puritans to the churches of the suburb and the ghetto. Particular attention paid to the role of the church, the sect and periodic "awakenings" in social organization, control, protest and innovation. (*Not offered 1971–72.*)
S. M. Blumin

21.488 *The City in American History*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
An examination of the process of urbanization in America from the colonial period to the present. Emphasis on the development of urban forms, institutions and life styles, as well as the impact of cities on non-urban areas and on the nation as a whole. Theoretical readings in urbanism, urbanization and community and a detailed consideration of the "eclipse of community" and of the emergence of an urban-dominated society and culture. (*Not offered 1971–72.*) *S. M. Blumin*

21.489 *The Family in Technological Society*
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Focus on the family as a changing institution in Western technological society. Special attention to various theories of family life and structure and to the possible future of the family. Analysis of various contemporary approaches to family re-organization (communes, family therapy, etc.). In addition, focus upon students own families as historical artifacts and research on the structure and development of their family lives. (*Permission of instructor required.*) *D. H. Bell*

Intellectual-Scientific

21.514 *Society and Culture in the Eighteenth Century*
(*New*)
Prereq.: One First-year Humanities sequence
Year: U (2) 3–0–6
An examination of the intellectual history of the eighteenth century within a social framework. The contributions of major Enlightenment thinkers to the changing pattern of social relations in the period, and to the changing role of the intellectual. Primary reading in the work of figures such as Voltaire, Diderot, Rousseau and Hume, along with analyses of class structure and social life characteristic of the period. *L. Wurgaft*

21.515 *Intellectual History of Modern Europe*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Intellectual history of the period from 1760 to the present, focusing on political and social thought, but in terms of the interplay of ideas from different fields, and of ideas and events. Consideration of such topics as romanticism, industrialism, and socialism; the increase in awareness of the self; the rise of historicism; the nature of ideology; the concepts of classes, masses, and races; and the nature of imperialist and totalitarian thought. Presentation focused, wherever possible, upon important individuals who epitomize a way of thinking and feeling. (*Not offered 1971–72.*) *B. Mazlish*

21.517 *Russia: Orthodoxy, Autocracy, and Rebellion*
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Comparative historical analysis of Russian radical social thought (communist anarchism, populism, socialism, utopianism in general) and action before the advent of Bolshevism. Analysis of social structures, historical experiences, religious and political traditions in Russia, in an effort to discover reasons for the relative prominence of radicalism in modern Russian as compared to modern Western thought. Study of such thinkers as Herzen, Chernyshevsky, Bakunin, Lavrov, Tkachev, Nechaiev and of revolutionary circles and conspiracies inspired by them. Study of young Lenin and his relation to the revolutionary tradition. *R. E. MacMaster*

21.518 ***Anarchism***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Anarchist and Anarcho-Syndicalist movements of the nineteenth and twentieth centuries, their philosophic bases, their opposition to certain societies and governments, their attempts at establishing communities and organizations, their methods of obtaining their goals, their provocation of reactions, within both rural and urban settings. Readings from the classics of anarchism and the histories of anarchist movements in Europe and America. *W. B. Watson*

21.522 ***Marx, Darwin, and Freud***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Historical and critical study, in depth, of three attempts to investigate the natural and cultural development of man and society, treated as a problem in intellectual history, history and philosophy of the cultural sciences, and social thought. *B. Mazlish*

21.523 ***Post-Freudian Social Thought***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Analysis of the development and transformation of Freudian theory in the social thought of the twentieth century. Consideration of topics such as the socialization of psychoanalytic theory; the union of phenomenology and psychoanalytic theory in existential analysis; the attempted synthesis of Marx and Freud in radical social thought. Study of theorists such as Fromm, Reich, Sartre, Erikson, Marcuse and Laing. (*Not offered 1971–72.*) *L. D. Wurgaft*

21.524 ***History and Psychoanalysis***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Attempt to inquire into the psychological, especially the psychoanalytic, aspect of historical events and persons. First part: examination of various theories and techniques that have already been employed by historians and psychologists; e.g., readings in Freud, Erikson, etc. Second part: reports by members of the class on their own attempts to study an event or person in psychohistorical terms. (*Limited enrollment.*) *B. Mazlish*

21.526 ***Politics of the Self: Conceptions of Man and Society in American Social Science***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
An intellectual history of American social science dealing with a variety of "schools" (behaviorist, psychoanalytic, interactionist, etc.), particularly as they address themselves to the problems of the relationship between the individual self and society. Special consideration given to the political dimension of these social theories. Among those considered: C. H. Cooley, G. H. Mead, John Dewey, J. B. Watson, Ruth Benedict, Erich Fromm, Erik Erikson, Talcott Parsons, and C. Wright Mills.
M. J. Cohen

21.531 ***American Intellectual History***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Study of important case specimens in the dialogue between "conservatives" and "liberals" from the Founding Fathers to the Radical Right and New Left. Seminar-type discussion of the role of major figures such as Jefferson, Calhoun, Emerson, Sumner, and Veblen and of major forces such as industrialization, urbanization and immigration in the shaping of American ideas and values. *E. N. Hartley*

21.532 ***American Ideas and Institutions***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Historical study of the development of a free, tolerant, and pluralistic society in the United States. Nineteenth-century dissenters and utopians, especially the Transcendentalists and the Mormons. The tradition of civil liberties in America, and the use of the Constitution to promote freedom and tolerance. Pragmatism (Peirce James, Dewey, and Holmes) as a peculiarly American rationale for individualism, pluralism, and social reform. (*Not offered 1971–72.*) *L. S. Bryant*

21.533 ***American Constitutional History***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Historical study of the evolution of constitutional law and institutions in the United States, and their adaptation to social reform in the 1930's and the extension of civil liberties since 1940. *L. S. Bryant*

Political — Diplomatic

21.541 ***The American Revolution***
Prereq.: 17.02 or 21.05 or 21.051
Year: U (1) 3–0–6
Analysis of the social, political and ideological roots of the American Revolution; of the revolutionary movement itself; and of the formation of the new nation and its Constitution. Consideration of the changing image of the Revolution throughout our history, from accounts written by revolutionary partisans to the most recent interpretations. Comparison of the American with other major Revolutions. *A. D. Kaledin*

21.542J ***Political Ideas and Industrial Society***
(*New*)
(Same subject as 17.12J)
Prereq.: 17.02
Year: U (2) 3–0–6
Identification of certain fundamental problems of industrial society through readings of selected nineteenth and twentieth century political and social theorists. Use of economic and historical materials in an attempt to relate political ideas to the problems raised by industrialism.
B. Mazlish, S. Berger

21.543 ***China, Japan, and the West***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Relations of the West with China and Japan and the revolutionary ferment set up in the Far East by these contacts. Study of the traditional cultures of China and Japan in their geographic settings. Emphasis on tracing and seeking to explain the processes by which the self-sufficiency and isolation of China and Japan were broken down; development of resulting cultural changes, both planned and spontaneous. *T. H. D. Mahoney*

21.545 ***War and the Military Institutions of the Modern State***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Examination of the evolution of military institutions of the modern state in the light of the changing forms and modes of war since the eighteenth century. Stress on the interacting relationship between the military institutions of a state and its political institutions and their effect on civil society. (*Not offered 1971–72.*)
D. B. Ralston

21.546 ***The Export of the European Army***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
The introduction of European military institutions and ideas into the non-European world since 1700. A

consideration of the role of the European-style army as a prime agent of "modernization" within traditional society. Cases to be examined include Russia under Peter the Great, the Ottoman Empire in the nineteenth century, and Japan during the Meiji Restoration.
D. B. Ralston

21.548 *Vienna and Versailles*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Two modern attempts to construct an enduring peace for Europe and the world following, respectively, the Wars of the French Revolution and Napoleon and World War I. Comparison of the ideas, institutions, and personalities dominating the architects of Vienna with their counterparts a century later at Versailles. (*Not offered 1971–72.*) *T. H. D. Mahoney*

21.549 *Comparative Revolutions*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Inquiry into the historical phenomenon, revolution, treated as a major form of social change. Approach primarily analytic and comparative, rather than narrative; emphasis, however, on viewing revolution in a historical perspective. Among revolutions studied: the Puritan, American, French, Russian, Chinese, and various Middle East and Latin-American examples. Each student chooses either one revolution or feature of a revolution (e.g., role of the army, cities, women, international setting, etc.) for his major area of research, to be discussed in class. (*Limited enrollment.*) *B. Mazlish*

21.551J *Nationalism in Africa*
(Same subject as 17.55J)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Examination of the ideological, political, and economic bases of imperialism, colonialism and nationalism; the partition of Africa, the nature of alien rule, and the response of Africans thereto during the nineteenth and twentieth centuries. *R. I. Rotberg*

21.552 *The Soviet Union: An Industrial Society in Historical Perspective*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Comparative historical analysis of the relationships between totalitarianism and modernization in post-revolutionary Russia. Study in depth of the physical and ideological setting, the rise of Stalin, collectivization and industrialization, the terror and the purges, the process of de-Stalinization under Khrushchev and his successors, the transition from developing to industrial society, contemporary movements of dissent among intellectuals, religious groups, and nationalities. Attention to the problem of evaluating the changing Soviet Union in the light of recent developments there and in other Communist regimes, especially the Yugoslav and the Chinese. *R. E. MacMaster*

21.553 *The Rise of European Socialism 1864-1914*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Investigation of European socialism as it developed in theory and practice prior to 1914. Socialist theory; primary attention given to Marxism and the revisionist and radical challenges during the era of the Second International. Practice; focus on the formation and growth of socialist political parties and trade unions in Germany, France, England, and Russia. (*Not offered 1971–72.*)
D. S. White

21.554 *Spanish Civil War, 1936-39*
Prereq.: 17.02 or 21.05 or 21.051
Year: U (1) 3–0–6
Examination of the eruption of conflicts in Spanish society — between leftist and rightist political groups, civil and military authorities, intellectuals and clerics, workers and capitalists, peasants and landowners — into civil war, almost immediately provoking a world-wide response. Examination of the consequences of the Civil War for Spain and the rest of Europe in light of political, social, and economic issues selected by students and the instructor. *W. B. Watson*

21.555 *Socialism and Communism in Europe 1917-1941*
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
The European left in passage from years of revolutionary opportunity to decades of division and reversal. Socialist and Communist movements considered against the backdrop of an era that upset their hopes and expectations. Topics include: the origins and consequences of the Communist-Socialist split; theoretical attempts to renew and transcend Marxism; responses on the left to economic depression and fascism; the dilemmas of Socialists and Communits in power. *D. S. White*

21.556 *Soviet-American Diplomacy*
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Study of the foreign policies and diplomatic interaction of the two powers beginning with nineteenth century patterns of Tsarist and American diplomacy. Case studies which permit examination of the origins of Bolshevik diplomacy with a view toward continuity and change; the formation of America's stance on Soviet Russia; parallels between the two societies during the interwar period: isolationism, messianism, and the drive for security; the themes of conflict and cooperation in World War II, followed by the "Cold War" and the bipolarization of Europe; and the emergence of a new diplomacy. Emphasis on a comparison of the two nations, their parallel problems and instances of direct confrontation. (*Not offered 1971–72.*) *D. S. Clemens*

21.558 *Reconstruction of Europe, 1945-65*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
The Marshall Plan, the Iron Curtain, NATO, the Fourth and Fifth Republics, Italy, Germany, Great Britain. Towards a United States of Europe: the New Technicians; the Common Market; EFTA; Euratom.
T. H. D. Mahoney

21.559 *Cold War Seminar*
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
An analysis of the contemporary period from an historical perspective emphasizing the agents of change. Covering World War II, the postwar global bi-polarization, emergence of a "third world," containment and revolution, and the interaction of nations in the context of economic, political, and social change with in-depth case studies. Reading, discussion, presentations by class members of independent research supplementary to lectures. *D. S. Clemens*

21.574 *Nineteenth Century European Liberalism: Its Decline and Transformation*
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Examination of nineteenth century European liberalism as it was embodied in the political institutions and politi-

cal practices of such states as Great Britain, France, Germany, Italy, and Austria-Hungary. Origins of the liberal ideology, and its underlying assumptions about man and society. Forces leading either to its breakdown or transformation in the decades prior to World War I. (*Not offered 1971–72.*) *D. B. Ralston*

21.576 ***Varieties of Fascism: Origins and Comparative Development in Germany and France, 1900-1945***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Study of a major modern theme on both the intellectual and sociopolitical levels, using the comparative method. Fascism in France and Germany as a study in comparative modernization, viewed in part as a response to economic and social change in the period 1870–1945. Focus on the quasi-failure of fascism in France and its success in Germany after 1932, with this central theme posed as a basic question. *R. E. Herzstein*

21.578J ***Research Seminar in Imperialism and Colonialism*** **(A)**
(*New*)
(Same subject as 17.893J)
Prereq.: One graduate subject in Comparative Politics or International Politics
Year: G (1) 3–0–6
Topics in the economic, social, and cultural bases of imperialism and colonialism, its theory and practice. (*Open to undergraduates by permission of instructor only. Not offered 1971–72.*) *R. I. Rotberg*

21.579J ***Race Relations and Politics in the Caribbean*** **(A)**
(*New*)
(Same subject as 17.782J)
Prereq.: —
Year: G (2) 3–0–6
Comparative study of the role of color and race in the politics of the Caribbean. Attention to problems of modernization and leadership in French, Dutch, and English speaking areas. (*Open to advanced undergraduates.*) *R. I. Rotberg*

21.581 ***Special Topics in History***
Prereq.: Any two subjects in history
Year: U (1) *Arr.*
Topics in history not included in other subjects. Students electing this subject must consult the Chairman of the Section. *Staff*

21.582 ***Special Topics in History***
Prereq.: Any two subjects in history
Year: U (2) *Arr.*
Topics in history not included in other subjects. Students electing this subject must consult the Chairman of the Section. *Staff*

ANTHROPOLOGY

21.621 ***Cultures and Societies of Modern Mexico***
(21.594) *Prereq.:* 21.06
Year: U (1) 3–0–6
A consideration of post-Conquest social dynamics of the Mesoamerican population. Adaptive responses to Spanish colonialism such as assimilation, transculturation and avoidance. The role of key institutions such as the Church, political administration and education. Being Indian in Mexico and a review of pertinent national legislation. *M. Diskin*

21.642 ***Archeology of Technology***
(21.596) *Prereq.:* 21.06
Year: U (1) 3–0–6
The role of technology in understanding the ancient cultures of the Mediterranean and Near East. How and why technology must be examined to understand the evolution and differentiation of cultures. The interrelationship of man with his material environment: how he exploits it; how he organizes himself to deal with it; what institutions arise from this relationship, etc. Specific discussion of stone, ceramic, metallurgical and building technologies in various areas and periods, using artifacts and laboratory examinations of some specimens. (*Not offered 1971–72.*) *A. R. Steinberg*

21.643 ***Comparative Ancient Technologies***
(*New*)
Prereq.: 21.06
Year: U (2) 3–0–6
Technological systems of ancient, complex societies studied through artifactual materials, archaeological excavations, and historical records. Comparison of systems in their entirety or in aspects, such as ceramic technology, metallurgy, architecture, communication, transportation and waterways. Study of particular technological developments, cultural forces that govern development, the extent to which technologies are independent of societal settings, the nature of technological change. Examples from ancient China, Mesopotamia, and Peru. Some laboratory work to be arranged by individual students. *H. Lechtman*

21.651 ***Archeology of Urbanization***
(21.595) *Prereq.:* 21.06
Year: U (1) 3–0–6
A study of the rise of civilization in the ancient Near East and Mesoamerica using cross-cultural comparisons of the relationships between political authority, technology, economic and social structures. Readings combine original texts and archeological reports, also work in local museums. *A. R. Steinberg*

21.671 ***American Indian Policy***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
A study of the development of the policy toward the American Indians from colonial times to the present, with an attempt to determine the assumptions upon which this policy was and is based. An investigation of the way in which this policy has been administered by government officials, and an examination of its present-day effects on the life style of an Indian community. *H. Matthews*

21.681 ***Economic Anthropology***
(21.593) *Prereq.:* 21.06
Year: U (2) 3–0–6
Economic aspects of cultures and society. Modes of exchange, distribution, and production in non-monetized societies. Consideration of prestation, barter, and peasant markets as mechanisms of social articulation. Examples from New Guinea, Malaya, Mexico, and Africa. The notions of scarcity and maximization examined for their universality. The dual economy debate and economic development discussed. *M. Diskin*

21.682 ***Archeological Theory and Methods***
(*New*)
Prereq.: 21.06
Year: U (2) 3–0–6
An examination of how archeology can serve to elucidate cultural processes, culture history and past ways of life. Discussion centers on various theoretical approaches to archeological problems and the new techniques that are being used to solve some of these problems as archeology gradually evolves from mere treasure-hunting to a science with its own theory and methodology. *A. R. Steinberg*

21.683 ***Language and Culture***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
An introduction to the study of those aspects of language which have been of special interest to anthropologists and sociologists. A survey of the concerns of anthropological linguistics with particular emphasis on their implications for the study of language itself. An examination of a particular language in relation to various aspects of its cultural and social setting and to the intellectual life of its speakers. *K. Hale*

21.684 ***Peasant Society***
(21.592) *Prereq.:* 21.06
Year: U (2) 3–0–6
Definition of the peasant as a social type; consideration of so-called centrifugal-centripetal forces that help shape a given society. Historical factors and economic links between the peasantry and modern society. Cultural, historical and personality factors in economic development. The role of the peasantry in social change. (*Not offered 1971–72.*) *M. Diskin*

21.698 ***Special Topics in Anthropology***
(*New*)
Prereq.: Any two subjects in Anthropology
Year: U (1) *Arr.*
Topics in anthropology not included in other subjects. Students electing this subject must consult the Chairman of the History Section. *Staff*

21.699 ***Special Topics in Anthropology***
(*New*)
Prereq.: Any two subjects in Anthropology
Year: U (2) *Arr.*
Topics in anthropology not included in other subjects. Students electing this subject must consult the Chairman of the History Section. *Staff*

MUSIC

21.81 ***The Symphony***
Prereq.: 21.07
Year: U (2) 3–0–6
The evolution of symphonic forms from the Baroque to the twentieth century. Special attention focused on works of Haydn, Mozart, and Beethoven. Recordings and opportunities to hear live performances will be augmented by class discussions. *K. Liepmann*

21.821 ***Music Theory I***
Prereq.: 21.07
Year: U (1, 2) 3–0–6
Study of harmony and counterpoint as developed in the period of tonal music. Readings, weekly exercises and writing assignments, and analysis of the music of this period. *Staff*

21.822 ***Music Theory II***
Prereq.: 21.821
Year: U (1, 2) 3–0–6
Continuation of the work initiated in Music Theory I. Study and the construction of larger musical phrases and forms and the harmonic and contrapuntal principles upon which they depend. Readings, weekly exercises and writing assignments, and analysis of music. *Staff*

21.823 ***Music Theory III***
Prereq.: 21.822
Year: U (1) 3–0–6
Study of the techniques of counterpoint and writing of inventions, fugues, and other contrapuntal forms Readings, weekly exercises and writing assignments. *G. Tucker*

21.824 ***Music Theory IV***
Prereq.: 21.822
Year: U (2) 3–0–6
Study of the techniques of composition in extending contrapuntal and larger homophonic forms, such as variation and sonata form. Readings, analyses and compositional assignments. *G. Tucker*

21.825 ***Orchestration***
Prereq.: 21.822
Year: U (2) 3–0–6
An examination of the construction and techniques of orchestral instruments. Graded exercises in instrumentation for strings, woodwinds, brass — separately and subsequently in combination. Deliberate imitative orchestration of selected passages from compositions with the composers' orchestral technique. *J. Cook*

21.826 ***Problems and Techniques of Music Research***
Prereq.: 21.822
Year: U (1, 2) 3–0–6
Studies in the structure of music and theories of music, with emphasis upon the use of the computer. Representation of music notation for computer input, appropriate programming languages and data-structures, and the development of relevant models. Readings, papers, discussions, research projects. (*Permission of instructor required.*) *Staff*

21.827 ***Analysis of Musical Structure***
Prereq.: 21.822
Year: U (1) 3–0–6
Consideration of differing concepts of musical structure and formal organization, viewed in historical perspective. Study of generalized formal models and the unique formal aspects of specific works. Study of scores, listening to recordings and readings. *J. Harbison*

21.83 ***Music in the Middle Ages***
Prereq.: 21.07
Year: U (1) 3–0–6
The development of sacred and secular monody and of polyphonic music from its beginnings to the death of Dunstable. Required reading and listening assignments. Some course members may prepare a concert from repertory studied in class. *R.S. Freeman*

21.831 ***Music in the Renaissance***
(*New*)
Prereq.: 21.07
Year: U (1) 3–0–6
A survey of musical developments from about 1450 to about 1600, dealing with vocal music of the period, the formulation of independent instrumental styles, the rise of the harmonic principle, and the beginnings of dramatic music. Required reading and listening assignments. A concert from repertory studied in class. (*Not offered 1971–72.*) *R. S. Freeman*

21.84 ***Music in the Baroque Period***
Prereq.: 21.07
Year: U (2) 3–0–6
A survey of the principal developments in musical style from about 1600 to about 1750. Works for consideration in weekly discussion sessions drawn from the music of Monteverdi, Carissimi, Schutz, Purcell, Alessandro Scarlatti, Vivaldi, Couperin, Handel, and J. S. Bach. Required reading and listening assignments. (*Not offered 1971–72.*) *R. S. Freeman*

21.841 *J. S. Bach*
(*New*)
Prereq.: 21.07
Year: U (2) 3–0–6
An examination of representative vocal, instrumental, and chamber works, considered in relation to the intellectual and social life of the early eighteenth century. Required reading and listening assignments.
R. S. Freeman

21.85 *Music in the Classic Period*
Prereq.: 21.07
Year: U (1) 3–0–6
A survey of the principal developments in musical style during the end of the eighteenth century. Works for consideration in weekly discussion sessions drawn from the music of Pergolesi, C. P. E. Bach, Gluck, Haydn, Mozart and Beethoven. Required reading and listening assignments. (*Not offered 1971–72.*) *J. L. Buttrick*

21.851 *Mozart*
(*New*)
Prereq.: 21.07
Year: U (1) 3–0–6
An examination of representative vocal, instrumental, and chamber works, considered in relation to the intellectual and social life of the end of the eighteenth century. Required reading and listening assignments.
J. L. Buttrick

21.86 *Music in the Romantic Period*
Prereq.: 21.07
Year: U (2) 3–0–6
A survey of the principal developments in musical style during the nineteenth century. Works for consideration in weekly class discussions drawn from the music of Beethoven, Schubert, Schumann, Brahms, Berlioz, Chopin, Liszt, Wagner, Verdi, Richard Strauss, and Mahler. Required reading and listening assignments.
J. L. Buttrick

21.861 *Beethoven*
Prereq.: 21.07
Year: U (2) 3–0–6
A study of selected works, tracing the chronological development of Beethoven's style. Special attention given to the piano sonatas. (*Not offered 1971–72.*)
J. L. Buttrick

21.871 *Twentieth-Century Music*
Prereq.: 21.822
Year: U (1) 3–0–6
Study of principal works by masters of the twentieth century. Tradition and innovation as exemplified in the music of Stravinsky, Bartok, Hindemith, Copland, Ives, Prokofieff, and other composers. The interrelationship of art music, folk music, and popular music. Concerts, recordings, and discussion. *G. Tucker*

21.872 *Twentieth-Century Music: Schoenberg, Berg and Webern*
Prereq.: 21.822
Year: U (2) 3–0–6
Study of the principal works of Schoenberg, Berg and Webern, and of other dodecaphonic compositions. Concerts of representative solo and chamber music. Study of electronic and other experimental music. *Staff*

21.88 *The Opera*
Prereq.: 21.07
Year: U (2) 3–0–6
Study of the nature and development of the music drama. Illustrations at the piano as well as from recordings. As far as possible, special attention given to current productions of opera in the Boston area. *J. Cook*

21.881 *Seminar in Music*
Prereq.: 21.07
Year: U(1) 3–0–6
Varying topics from year to year. Topic for fall 1971: The Beethoven String Quartets. (*Permission of instructor required.*) *K. Liepmann*

21.882 *Seminar in Music*
Prereq.: 21.07
Year: U (2) 3–0–6
Varying topics from year to year. Topic for 1972: Studies in composition. *G. Tucker*

21.883 *Non-Western Music*
(*New*)
Prereq.: 21.07
Year: U (2) 3–0–6
An introduction to musical cultures independent of the European tradition. A survey of selected areas of Asia, Africa, and the New World, with some consideration of methodology. *D. Sur*

21.891 *Special Topics in Music*
Prereq.: Any two subjects in Music
Year: U (1) *Arr.*
Open to qualified students who wish to pursue special studies or projects with members of the Music Section. Students electing this subject must consult the Chairman of the Section. *Staff*

21.892 *Special Topics in Music*
Prereq.: Any two subjects in Music
Year: U (2) *Arr.*
Open to qualified students who wish to pursue special studies or projects with members of the Music Section. Students electing this subject must consult the Chairman of the Section. *Staff*

SPECIAL INTERDISCIPLINARY SUBJECTS

21.901 *Special Topics in Interdisciplinary Studies*
Prereq.: Any two subjects in Humanities
Year: U (1) *Arr.*
Special topics involving interdisciplinary study sponsored by members of the Department of Humanities or Institute faculty. Subjects varying from year to year. *Staff*

21.902 *Special Topics in Interdisciplinary Studies*
Prereq.: Any two subjects in Humanities
Year: U (2) *Arr.*
Special topics involving interdisciplinary study sponsored by members of the Department of Humanities or Institute faculty. Subjects varying from year to year.
Staff

21.941J *Seminar in Technology and Society: Ethical and Social Issues in Bio-Medicine*
(*New*)
(Same subject as 7.09J)
Prereq.: One first-year Humanities sequence
Year: U (1) 3–3–6
Examination, using case studies, of the ethical and social implications of the development and application of biomedical science and technology. Consideration of the following issues: experimentation with human subjects, death and organ transplantation, women and medicine, behavior control, mental health and illness, genetic engineering, allocation of resources. Laboratory work in psycho-socio research and clinical observation.
R. Wertz, S. Leff, F. Ausubel

21.948 ***Poetic and Scientific Discourse in Classical Literature*** (21.95)
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Myth and logic as differential languages for, and perspectives upon, reality. Special emphasis on the transition from one to the other. Readings in Solon, Pindar, Simonides; in philosophical poets like Parmenides, Empedocles, Lucretius; and in Plato and Aristotle on the truth-value of art. *H. A. T. O. Reiche*

21.949 ***Classical Philosophy: Cosmology and Ethics*** (21.613)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Selected readings in the pre-Socratics; in Plato and Aristotle; or in Hellenistic and later thought: Stoicism — Lucretius, Epictetus, and Marcus Aurelius; Epicureanism — Epicurus and Lucretius; Neo-Platonism — Plotinus and the critical encounter with early Christianity in theologians like Origen and Augustine; the development of the Logos-concept. *H. A. T. O. Reiche*

21.951 ***Introduction to the Far East***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Interdisciplinary approach to the classical civilizations of China and her immediate neighbors — especially Japan — from earliest times until the mid-nineteenth century. General survey of culture with emphasis determined by students' interests. Recommended, but not required, preparation for other subjects concerned with the Far East. (*Not offered 1971–72.*) *N. Sivin*

21.952 ***Seminar in Chinese Culture***
Prereq.: ——
Year: U (2) 3–0–6
A group of related problems in traditional Chinese history, literature, philosophy, science, or comparative studies chosen on the basis of participant's interests, and investigated by small groups or individuals. Needed: A basic acquaintance with Far Eastern culture through courses, reading, or experience. (*Permission of instructor required. Not offered 1971–72.*) *N. Sivin*

21.953 ***Marx and Marxism***
(*New*)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
A discussion of Marxist theories of revolution, their relationship to today's world and to the study of society, psychology, and the arts. Reading from the works of Marx, Engels, Luxemburg, Lenin, Gramsci, Mao Tse-tung, Lukacs, Gorz, Mandel, Althusser, Marcuse. (*Limited enrollment. Permission of instructor required.*) *L. Kampf*

21.954J ***Workshop in Critical and Creative Experience***
(*New*)
(Same subject as 4.099J)
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Inquiry into the social and cultural bases of perception and into the connection between aesthetic experience and the emotions. The emphasis on encountering visual images, especially photographic ones, as a mode of self-expression. Development of a critical approach grounded in experience of the image rather than opinions about it. Application of gestalt and encounter group techniques to discover the feelings, preconceptions, and roles that block openness to the interpersonal and cultural environment. (*Limited enrollment.*) *M. Miller, M. White*

21.955 ***Chinese Science and Natural Philosophy*** (21.512)
Prereq.: Any two-year Humanities sequence
Year: U (2) 3–0–6
Study of theoretical approaches to nature, mainly before Scientific Revolution, in order to provide basis for thinking comparatively about which aspects of science are universal and which are local peculiarities. Emphasis distributed between the internal strategies and content of science, its place in and mutual influence upon social groupings and social change, and the role of natural philosophy in culture (seen through art, literature, religion, etc.). Introductory orientations as well as work by small groups of students in areas which concern them. 21.951 desirable preparation but not required. (*Not offered 1971–72.*) *N. Sivin*

21.956 ***Seminar on the American University***
Prereq.: One first-year Humanities sequence
Year: U (2) 2–0–7
Analysis of the historical development and present condition of the American university (and college), focusing on several current problems: educational reform; the professionalization of intellect and its consequences; student protest; authority and democracy in the university; the role of the university in society; possibilities for the future. (*Limited enrollment.*) *A. D. Kaledin*

21.958 ***Education and Society I***
Prereq.: ——
Year: U (1) 3–0–6
Selected topics in the politics, economics, and sociology of American education as these intersect with or determine philosophies of education. Emphasis on the contemporary setting. *W. O'Neil*

21.959 ***Education and Society II***
Prereq.: ——
Year: U (2) 3–0–6
Continuation of 21.958. Precise focus of study to be worked out among the instructors and students. (*Permission of instructor required.*) *W. O'Neil*

21.961 ***Seminar on Technology and Society***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Examination of the rhetoric of the "technological sublime" in regard to railroads, electricity, chemistry and computers, or how new technologies have promised to fulfill the American dream; how this rhetoric has been criticized. *R. W. Wertz*

21.963 ***Technology, Values and Social Choice***
Prereq.: ——
Year: U (2) 3–2–5
Engineering, economic, psychological and ethical problems of optimizing design of technological systems. Theory of subjective utility and probability as applied to social welfare. Information value. Cooperative and competitive games. Philosophical considerations of justice. Laboratory experiments in quantitative assessment of worth. Possibilities for using computers in pooling individual values and deriving trading relations to determine social choice. (*Permission of instructor required.*) *T. B. Sheridan*

21.967 ***Seminar in Urban Education***
Prereq.: One first-year Humanities sequence
Year: U (1) 3–0–6
Evaluation of the "Tutoring Plus" program in the light of current general theories of education. Examination of social and political implications of education among different economic groups. (*Not offered 1971–72.*) *W. O'Neil*

21.968 ***Seminar in Urban Education***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Discussion of developing an experimental school in Cambridge involving parents of neighborhood and tutors. (*Not offered 1971–72.*) *W. O'Neil*

21.971 ***Black Literature in America***
Prereq.: ——
Year: U (1) 3–0–6
Black culture from past to present; poetry, prose and plays. Authors to be read: Dunbar, Baldwin, Wright, LeRoi Jones, Cleaver, and Ellison. Examination of connections between culture, politics and economics. Analysis of Black cultural institutions, along with Black proposals for the future. Special attention given to historical antecedents of the new Black Renaissance. *F. Barbour*

21.972 ***Black Literature II***
Prereq.: 21.971
Year: U (2) 3–0–6
Continuation of the first semester with an in-depth look at some of the authors already studied. Special emphasis on vision as a metaphor in the works of black authors. Course will lead to a creative project by the student inspired by the material covered. Authors to be read include Johnson, Wright, Baldwin, Demby, and Bontemps. *F. Barbour*

21.973 ***The Philosophy and Critique of the Black Movement***
Prereq.: ——
Year: U (1) 3–0–6
Analysis of the "Black Revolution" in the United States. Examination of the theoretical and practical options available to the Black movement, given in the context of the Black past, present, and future. Special attention devoted to historical events and conditions which have developed ideological conflict. Relation of current events to the Black movement. *H. Henry, Jr.*

21.995 ***Intellectuals and Social Change***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
The role and responsibility of individuals who challenge the assumptions of the established political and social order, and who are concerned with ideas and their consequences. Discussion of current issues that have given rise to action and protest, in particular: American foreign policy, the problem of poverty, the Negro revolution, the role of university students. Questions of individual commitment, and the available alternatives for action. Historical background, with emphasis on socialist, anarchist, and liberal responses to recurrent problems which have faced the committed individual since the Enlightenment and Industrial Revolution. Study of the conditioning of these responses by the relation of intellectuals to established institutions such as government and the universities. Individual research on topics of particular current significance. (*Not offered 1971–72.*)
N. A. Chomsky, L. Kampf

21.997 ***American Values of the 1920's***
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Examination of literature, art and certain events of the period between World War I (1919) and the Great Crash (1929). Some works of: Anderson, Fitzgerald, Lewis, Hemingway, Eliot, Mencken, O'Neill, Benet, Sandburg. Consideration of magazines of the Right, Left and Center — "Best Sellers" — Popular Art, Music, Films — creative activity in Greenwich Village and Harlem — The Revolution in Manners and Morals — Prohibition — The Scopes Trial — Sacco and Vanzetti — the Big Bull Market — The Great Crash. *T. Wood*

21.998 ***American Values of the 1930's***
Prereq.: 21.03 or 21.11
Year: U (2) 3–0–6
Examination of literature, art and certain events of the period between the Great Crash (1929) and World War II (1941). Some works of: Fitzgerald, Hemingway, Lewis, Wolfe, Dos Passos, Farrell, Steinbeck, Odets, Wright. Consideration of: the Great Crash — the New Deal — Writers on the Left — the Group Theater — Government and the Arts — Folklore in an Industrial Society — Strong Men on the Right — Preludes to World War II. *T. Wood*

21.999 ***Group Behavior and the Cultural Process***
Prereq.: One first-year Humanities sequence
Year: U (2) 3–0–6
Encounter group techniques used to explore human relations arising from classroom interaction. The encounter group will provide the basis for theoretical discussions of the relationships between the general norms and values of American culture and various modes of interpersonal behavior. Readings chosen from humanistic psychology, social psychology, and cultural criticism. (*Permission of instructor required. Not offered 1971–72.*)
M. V. Miller

22.
Nuclear Engineering

Introductory Subjects

22.01 ***Introduction to Nuclear Reactor Engineering***
Prereq.: 8.01, 18.02
Year: U (1) 3–0–9
Introduction to the basic scientific and engineering principles underlying the production of useful energy from nuclear fission. Neutron diffusion in, and interaction with, materials. Characteristics of the fission process and their influence upon the reactor physics and engineering design of an integrated nuclear power plant.
N. C. Rasmussen

22.02 ***Elementary Nuclear Physics***
Prereq.: 8.02, 18.03
Year: G (1) 2–0–4
Introduction to aspects of modern physics important in nuclear engineering; atomic structure, atomic radiations and X rays; nuclear structure, radioactivity, nuclear reactions, and the fission process. (*Not offered 1971–72.*)

22.09 ***Basic Electronic Instrumentation Laboratory***
Prereq.: ——
Year: G (S) 1–5–2
For engineering research students with little or no background in electronics, who need a working knowledge of electronic devices and circuits. Basic laws and electronic principles, basic circuits and components, servo systems, operational amplifiers, feedback control, digital circuits and logic and other devices, using both tube and transistor circuitry. *Staff*

Nuclear Physics

22.111 ***Nuclear Physics for Engineers I*** **(A)**
Prereq.: 8.272 or 22.02
Year: G (1) 3–0–9
Nuclear phenomena, for advanced students not majoring in physics. Stationary states of nuclei: nuclear charge, radius, mass, moments, parity, and statistics. Barrier transmission; radioactive transitions; alpha, beta, and gamma decay. Binding energy, nuclear forces, and nuclear models. *I. Kaplan*

22.112 ***Nuclear Physics for Engineers II*** **(A)**
Prereq.: 22.111
Year: G (2) 3–0–9
Continuation of 22.111. Nuclear dynamics: energetics and cross sections for nuclear reactions, scattering, and fission. Passage of charged particles through matter: ionization, scattering, and radiative losses. Interaction of neutrons and gamma rays with matter. *I. Kaplan*

Nuclear Reactor Physics

22.211 ***Nuclear Reactor Physics I*** **(A)**
Prereq.: 8.272 or 22.02; *18.076*
Year: G (1, 2) 3–0–9
Introduction to the problems of fission reactor physics; nuclear reactions induced by neutrons; nuclear fission; slowing down of neutrons in infinite media; diffusion theory; two group theory. Emphasis on the nuclear physical bases of reactor design and their relation to reactor engineering problems.
E. P. Gyftopoulos, M. J. Driscoll

22.212 ***Nuclear Reactor Physics II*** **(A)**
Prereq.: 22.211
Year: G (2) 3–0–9
Problems relating to the operation of nuclear reactors at power including multigroup theory, heterogeneous reactors, control rods, poisons, time dependent phenomena, temperature effects and elementary transport theory. Emphasis on applying reactor theory to actual reactor systems. *N. C. Rasmussen*

22.213 ***Nuclear Reactor Physics III*** **(A)**
Prereq.: 22.212
Year: G (1) 3–0–9
Review of current methods for predicting neutron behavior in complex geometrical and material configurations. Systematic few-group procedures; blackness theory for control rods; cell theory; flux synthesis techniques.
A. F. Henry

22.22 ***Nuclear Reactor Kinetics*** **(A)**
Prereq.: 22.212
Year: G (2) 3–0–9
Dynamic behavior of neutrons in a reactor. Point kinetics formalism, physical significance of parameters appearing in point kinetics equation and analysis of methods for measuring ratios of these parameters. Dynamic behavior when space and time are not separable. Direct finite space-time difference approach; nodal methods and the application of orthogonal and non-orthogonal modes; flux synthesis schemes. Analysis of spatial xenon transients and reactor power transients involving feedback. (*Alternate years. Offered 1971–72.*) *A. F. Henry*

22.23 ***Nuclear Plant Control*** **(A)**
Prereq.: 6.214 or 6.601; 22.211
Year: G (2) 3–0–9
Nuclear reactor kinetics, thermal dynamics, inherent feedback loops, external control loops, transient and steady-state performance of nuclear reactors. Pile statistics, pile oscillation tests. Dynamics of nuclear plants, analog and digital methods of analysis of nuclear systems. Analysis of non-linear nuclear plant dynamics, development of boundedness and stability criteria for non-linear systems. Synthesis of control systems. (*Alternate years. Not offered 1971–72.*) *E. P. Gyftopoulos*

22.29 ***Nuclear Measurements Laboratory*** **(A)**
Prereq.: 22.211
Year: G (1) 2–6–4
Properties of the particles and radiations resulting from the fission process. Principles underlying instrumental methods for detection and energy determination of gamma rays, neutrons and charged particles. Applications to experimental reactor physics, health physics and reactor technology. Laboratory experiments on scintillation, gas filled and semiconductor detectors; nuclear electronics such as pulse amplifiers, multichannel analyzers and coincidence techniques; and basic applications such as subcritical assembly measurements, gamma attenuation, and pulsed neutron techniques. *S. H. Chen*

Nuclear Reactor Engineering

22.311 ***Engineering Principles for Nuclear Engineers***
Prereq.: ——
Year: G (1) 3–0–9
Fundamentals of engineering thermodynamics, fluid flow, heat transfer and strength of materials. Introductory subject for graduate students without previous engineering background. Applications to fission, fusion, and radioisotopic power systems. *M. W. Golay*

22.312 ***Engineering of Nuclear Reactors*** **(A)**
Prereq.: 22.311, *22.211*
Year: G (1, 2) 3–0–9
Engineering principles of nuclear reactors with emphasis on applications in central station power reactors. Power plant thermodynamics; energy production and distribution in reactors; incompressible and 2-phase fluid flow, heat transfer by conduction, convection, boiling; mechanical design and analysis. *N. E. Todreas*

22.313 ***Advanced Engineering of Nuclear Reactors*** **(A)**
Prereq.: 22.212, 22.312
Year: G (2) 3–0–9
Advanced topics in nuclear engineering with emphasis on central station and advanced power reactors. Thermal design methods; analytic engineering evaluation of transients and engineering safeguards; liquid metal flow and heat transfer; flow and heat transfer with compressible gases with application to space nuclear propulsion concepts; environmental effects of nuclear power.
N. E. Todreas

22.32 ***Nuclear Power Reactors*** **(A)**
Prereq.: 22.212, 22.312
Year: G (1) 3–0–9
A survey of the reactor engineering and reactor physics aspects of nuclear power reactors. Current designs of both thermal and fast reactor systems including light and heavy water reactors, molten salt breeder reactors, high temperature gas cooled reactors, liquid metal and gas cooled fast breeder reactors. Stationary power units, mobile units, and propulsion systems. Limiting factors for the safe design and operations; potential for future improvements. *D. D. Lanning*

22.33 ***Nuclear Reactor Design*** **(A)**
Prereq.: 22.212, 22.312
Year: G (1) 2–6–10
Group design project involving a complete nuclear power plant, integrating the requirements of reactor physics, control, heat transfer, safety, materials, power production, fuel cycle management and economic optimization. Provides the student with the opportunity to synthesize knowledge acquired in previous subjects and apply it to practical problems of current interest in the reactor design field. *M. J. Driscoll*

22.34 ***Economics of Nuclear Power*** **(A)**
(Revised: Unit change)
Prereq.: 22.311
Year: G (2) 3–0–9
Principles of engineering economics, with applications to nuclear power systems. Capital and operating costs of nuclear power plants. Economics of the nuclear fuel cycle. Uranium resources, requirements and costs. Breeder reactor economics. Economic comparison of nuclear and fossil-fueled plants. *M. Benedict*

22.35 ***Nuclear Fuel Management*** **(A)**
Prereq.: 22.212
Year: G (2) 3–0–9
Characterization of the space-time history of nuclear fuels and the effects upon fuel costs. Physical and material constraints upon fuels and their effects on fuel management policies. Methods of analysis for the optimization of fuel costs. Qualitative description of current methods of management and areas of future development. *E. A. Mason*

22.36J ***Two-Phase Flow and Boiling Heat Transfer*** **(A)**
(Same subject as 2.57J)
Prereq.: 22.312
Year: G (2) 3–0–9
Phase change in bulk stagnant systems. Kinematics and dynamics of adiabatic two-phase flow. Dynamics and thermodynamics of forced-convection two-phase flow with boiling and/or evaporation. Thermal and hydrodynamic stability of two-phase flows. Associated topics, such as condensation and atomization. Both water and liquid metal applications considered under each topic where data exists.
N. E. Todreas, W. M. Rohsenow

22.39 ***Nuclear Reactor Operations*** **(A)**
Prereq.: 22.211, *22.212, 22.312,* 22.29
Year: G (2) 3–5–4
Practical experience in operating power and research reactors. Reactor startup criticality considerations; control and instrumentation; refueling and fuel reprocessing from reactor operational view; review of reactor safety and regulation including past accident experience, preparation of safety analysis reports, reactor licensing, technical specifications. The M.I.T. Research Reactor is utilized for operational training and individual investigation of reactor operational projects.
D. D. Lanning, J. W. Gosnell

Numerical and Mathematical Methods

22.41 ***Mathematical Methods of Reactor Analysis*** **(A)**
Prereq.: 18.076, 22.212
Year: G (2) 3–0–9
Mathematical methods for the solution of neutron transport problems: Monte Carlo methods, Case's method, the moments method, discrete ordinates method. Variational and weighted residual methods as applied to reactor theory problems and their use in developing energy group diffusion theory, perturbation theory and flux synthesis procedures. *S. Yip*

22.42 ***Numerical Methods of Reactor Analysis*** **(A)**
Prereq.: 22.211
Year: G (1) 3–0–9
Applications of digital computers to nuclear engineering topics. Review of specific mathematical techniques for solving engineering problems including matrix algebra, finite difference equations, and numerical solution of equations. Special topics such as multigroup diffusion methods. *K. F. Hansen*

22.43 ***Advanced Methods of Reactor Analysis*** **(A)**
Prereq.: 22.42
Year: G (2) 3–0–9
Advanced numerical treatment of problems in reactor criticality and transient behavior. Transport analysis by spherical harmonic and discrete ordinates methods. Reactor kinetics analysis by direct numerical integration and approximate techniques such as modal and nodal methods. *(Alternate years. Offered 1971–72.)*
K. F. Hansen

Applied Radiation Physics

22.51 ***Interaction of Radiations with Matter*** **(A)**
Prereq.: 8.321, 22.112
Year: G (1) 3–0–9
Basic principles of interaction of electromagnetic radiations and charged particles with matter. Introduction to classical electrodynamics, quantum theory of radiation fields, and time dependent perturbation theory. Emphasis will be on the development of fundamental cross sections describing the interactions of light, X-ray, γ-ray and charged particles with atomic systems. Applications include: emission and absorption of light; theory of line width; Rayleigh, Brillouin and Raman scattering; laser spectroscopy; X-ray scattering; photoelectric effect; Compton effect; Bremsstrahlung; pair production; atomic collisions in Born and impulse approximations; collisions of fast electrons and massive charged particles with atoms. *S. Yip*

22.52 ***Neutron Physics and Applications*** **(A)**
Prereq.: 22.111
Year: G (2) 3–0–9
Basic principles of neutron interaction with nuclei in matter. Applications to cross section calculation for reactor design and to scattering experiments for the study of material properties. Fast neutron cross sections, resonance absorption, neutron thermalization, general properties of inelastic scattering of thermal and cold neutrons in liquids and solids, and analysis of current experiments. *S. H. Chen*

22.53 ***Radiation Engineering*** **(A)**
Prereq.: 22.02 or 22.111
Year: G (2) 4–0–8
Principles and practice of the engineering application of radiation and radioisotopes. Radiation sources and machines, radiation interactions, dosimetry and shielding, and radiation detection. Additional topics selected from tracer application, radiation gauging, x-ray analysis, radiation preservation and processing, radioisotope power sources, and medical and biological application of radiation and radioisotopes. *G. L. Brownell*

22.54 ***Radiation Shielding*** **(A)**
Prereq.: 22.112, 22.311
Year: G (2) 3–0–6
Shielding of nuclear reactors, accelerators and space vehicles. Interaction of neutrons, γ-rays and charged particles in thick shields. Emphasis on the engineering aspects of shield design including shielding material, voids and ducts, heat removal, and a description of shield design codes. *(Alternate years. Not offered 1971–72.)*
N. C. Rasmussen

22.55 ***Biological Effects of Nuclear Radiation*** **(A)**
Prereq.: 22.02 or 22.112
Year: G (1) 3–0–6
Review of interactions of nuclear radiations with matter and the effects of energy absorbed from nuclear radiation on simple and complex chemical systems, various organisms, and living tissue. Theories of the action of radiations on living matter, and considerations of various factors which affect the biological response, such as time and type of radiation. Theory and practice of radiation

dosimetry with special reference to practical applications. Discussion of biological and physical bases for safety standards. (*Alternate years. Not offered 1971–72.*)

G. L. Brownell

22.58J *Quantum Thermodynamics* (A)
(Same subject as 2.47J)
Prereq.: 2.403, 2.461, 8.04
Year: G (2) 3–0–9

Theory of quantum thermodynamics derived from the general postulates of quantum mechanics and the second law. Definitions of state, changes of state described by unitary transformations in time, equilibrium state, stable state, and reversible processes. Definition and determination of available work and entropy for all systems and all states. Nature of irreversibility and its relation to field theory. Derivation of the general canonical distribution. Applications to bosons and fermions, and to ideal and perfect substances in stable states. Applications to general rate processes and to linear irreversible processes in gaseous, liquid, and solid phases. *E. P. Gyftopoulos, G. N. Hatsopoulos*

Plasmas and Controlled Fusion

22.611 *Plasmas and Controlled Fusion I* (A)
Prereq.: 8.03; 8.05 or 22.02
Year: G (1) 3–0–9

Survey of the means of obtaining energy from fusion reactions. Energy resources. Atomic and electronic collision phenomena, and transport and electromagnetic theory applicable to confined plasmas. Methods of producing and heating plasmas. Electromagnetic methods of confinement. Material and energy loss processes. Energy balances. Recent experiments. Diagnostics. *D. J. Rose*

22.612 *Plasmas and Controlled Fusion II* (A)
Prereq.: 8.261 or 22.611; 8.311
Year: G (2) 3–0–9

Topics in plasma dynamics of current interest in thermonuclear research, such as: conductivity of highly ionized plasma; radiation losses; wave propagation; magnetic field structures; instabilities; dynamics of a thermonuclear system; critical review of confinement schemes; advanced diagnostic techniques; recent experiments.

R. A. Blanken

22.62 *Thermonuclear Reactor Design* (A)
Prereq.: 22.311, 22.611
Year: G (1) 3–0–6

Systems analysis and design of controlled thermonuclear reactors. Study of the need for new energy sources, critical survey of possible approaches to the generation of thermonuclear power, development of criteria for CTR feasibility on basis of economic and technical considerations, study of blanket neutronics and fuel breeding ratios, design of prototype CTR power plant, possibilities of fission-fusion symbiosis. *L. M. Lidsky*

22.63 *Engineering Physics of Plasma and Particle Devices* (A)
Prereq.: 6.03 or *22.611*
Year: G (1) 3–0–6

Principles of accelerators and thermonuclear research devices, including vacuum systems, magnets, acceleration methods, ion sources, targets, lasers, and laser diagnostics. Examples from recent practice.

R. A. Blanken

22.64J *Plasma Kinetic Theory* (A)
(Same subject as 8.621J)
Prereq.: 8.611 or 16.59
Year: G (1) 3–0–9

Content varying from year to year. Typical subjects: the linearized Vlasov equation, Fokker-Planck and diffusion approximations for the average distribution function, autocorrelation functions, resonant and non-resonant diffusion, free energy, energy and momentum conservation, resonant wave coupling, non-linear Landau damping, strong turbulence theories. Selected applications to enhanced diffusion, stochastic acceleration, turbulent resistivity, shock waves, radio emission.

T. H. Dupree

22.65J *Advanced Topics in Plasma Kinetic Theory* (A)
(Same subject as 16.58J)
Prereq.: 16.59, 22.64J
Year: G (2) 3–0–9

Varying content including topics of current interest. Typical subjects: theories of collective phenomena such as linear instability and non-linear saturation mechanisms in plasma, particularly in regimes described by the Vlasov-Maxwell equations. Effects of wave-particle resonance; trapping and scattering of particles by waves. Linear theory of instabilities in inhomogeneous plasmas. Reflection and eigenmode problems in bounded systems. Diffusion phenomena and anomolous resistivity associated with wave-particle interaction. Discussion of experiments. *T. H. Dupree, J. E. McCune*

22.69 *Plasma Laboratory* (A)
Prereq.: 8.261 or 22.611 or 22.63
Year: G (2) 1–4–4

Introduction to the advanced experimental techniques needed for research in plasma physics and useful in experimental atomic and nuclear physics. Laboratory work on vacuum systems, plasma generation and diagnostics, physics of ionized gases, ion sources and beam optics, cryogenics, magnetic field generation, and other topics of current interest; brief lectures and literature references to elucidate the physical bases of the laboratory work. *L. M. Lidsky*

Nuclear Materials

22.71 *Metallurgy for Nuclear Engineers* (A)
Prereq.: ——
Year: G (1) 3–0–9

Crystallography and microstructure of engineering materials. Elastic and plastic properties of metals and relation of mechanical properties to metallurgical structure. Phase relations in metals; phase transformations and diffusion kinetics. Corrosion and oxidation. Effects of radiation on mechanical properties. Emphasis throughout is on materials used in nuclear reactor systems — structural alloys, fuels, moderators, and control materials.

A. L. Bement

22.72J *Nuclear Fuels* (A)
(Same subject as 3.72J)
Prereq.: 3.13 or 3.14 or 22.71
Year: G (2) 3–0–9

Behavior of nuclear fuels and fuel element cladding materials in reactor cores. Experimental observations and theory of radiation damage to metals and ceramics of practical interest. Processes for fabricating fuel elements and fuel assemblies; fuel fabrication costs. Recent developments of advanced reactor core materials.

A. L. Bement

22.73J *Radiation Effects in Crystalline Solids* (A)
(Same subject as 3.721J)
Prereq.: 3.13 or 3.14 or 22.71
Year: G (2) 3–0–9

Theory of atomic displacements, cascades, and spike phenomena produced in crystalline solids by high energy radiation bombardment. Defect interaction with structural imperfections and impurities and the kinetics of defect mobility and recovery. Relationships between radiation-induced defect states and physical and mechanical properties. Discussion of radiation damage experiments of technological importance and basic experiments designed to advance the theory of radiation effects in crystalline solids. *A. L. Bement*

22.76 ***Nuclear Chemical Engineering*** **(A)**
Prereq.: 10.12
Year: G (1) 3–0–9
Applications of chemical engineering to the processing of materials for and from nuclear reactors. Fuel cycles for nuclear reactors; chemistry of uranium, plutonium and fission products; refining of uranium; production of materials for nuclear reactors; separation of products of nuclear reactors; inorganic solvent extraction as applied to nuclear reactor materials; management of radioactive wastes; processes for isotope separation; and theory of isotope separation. (*Alternate years. Offered 1971–72.*)
M. Benedict

General

22.90 ***Special Problems in Nuclear Engineering*** **(A)**
Prereq.: ——
Year: G (1, 2) *Arr.*
For graduate and advanced undergraduate students who wish to carry out a one-term project of a theoretical or experimental nature in the nuclear engineering field in close cooperation with individual staff members. Arrangement of topic and hours to fit student requirements.
E. A. Mason

22.911 ***Seminar in Nuclear Engineering*** **(A)**
Prereq.: ——
Year: G (1) 2–0–1
22.912 ***Seminar in Nuclear Engineering*** **(A)**
Prereq.: ——
Year: G (2) 2–0–1
For graduate students engaged in doctoral theses.
E. A. Mason

23.

Foreign Literatures and Linguistics

23.011 ***The Greek Tradition***
Prereq.: ——
Year: U (1) 3–0–6
Study of the foundations of Western civilization through selected masterworks of Greek literature and post-Renaissance adaptations of them. Among the authors studied: Aeschylus, Sophocles, Euripides, Aristophanes, Aristotle, Plato, Racine, Molière, Giraudoux, O'Neill, Sartre, Anouilh, Cocteau. Readings, lectures, and discussion in French. Tests and essays in English. (*Restricted to students with an adequate background in French.*)
R. E. Jones

23.021 ***The Judaeo-Christian Tradition***
Prereq.: 23.011
Year: U (2) 3–0–6
Study of the foundations of Western civilization through selected works of the Hebrew and Christian Bibles: e.g., Genesis, Job, various of the historical and prophetic books, the Gospels, and various epistles. Adaptations of Biblical subjects by modern authors also read: e.g., Milton, Hugo, MacLeish, Wilder, Baudelaire, Vigny. Readings, lectures, and discussion in French. Tests and essays in English. (*Restricted to students with an adequate background in French.*)
R. E. Jones

23.031 ***The Nature of Literature***
Prereq.: 23.051
Year: U (2) 3–0–6
Training in background, internal, and comparative analysis of modern poems (by Eliot, Yeats, St. John Perse), plays (by Giraudoux, Sartre, O'Neill), and novels (by Camus, Malraux, Faulkner). Readings in French and English. Lectures and discussion in French. Tests and essays in English. (*Restricted to students with an adequate background in French.*)
M. G. Kaufman

23.051 ***The French Enlightenment***
Prereq.: 23.021
Year: U (1) 3–0–6
Training in the elements of historical method through analysis of major developments in the French Enlightenment. Focus on political, economic, and social phenomena. Some attention to cultural manifestations as well. Readings in primary sources and works of interpretation. Lectures, discussion, and readings in French. Tests and essays in English. (*Restricted to students with an adequate background in French.*)
W. F. Bottiglia

23.11 ***Elementary German I***
Prereq.: ——
Year: U (1, 2) 4–0–8
Basic principles of the German language. Fundamentals of pronunciation, intonation, and grammar. Acquisition of basic vocabulary. Laboratory exercises to further comprehension and oral expression. Reading of simple texts, practice in writing.
Staff

23.12 ***Elementary German II***
Prereq.: 23.11
Year: U (2) 4–0–8
Continued practice in pronunciation and intonation. Extension of vocabulary for both conversational and literary purposes. Review and extension of basic grammar. Practice in writing short essays. Introduction to the history and culture of German-speaking countries. Conducted partly in German.
Staff

23.13 ***Intermediate German***
Prereq.: 23.12
Year: U (1) 4–0–8
Intensive review of general linguistic forms and idiomatic structures, with emphasis on literary usage. Readings designed to broaden acquaintance with German thought and culture. Class discussion and essays on the reading material. Conducted in German.
G. E. Nelson

23.14 ***Advanced German***
Prereq.: 23.13
Year: U (1, 2) 4–0–8
Extensive practice in reading, writing, and speaking German. Readings in narrative prose, drama, and poetry as an introduction to German literature and in relation to historical and cultural developments. Oral and written analyses of texts. Conducted in German.
G. E. Nelson

23.141 ***Introduction to German Poetry***
Prereq.: 23.14
Year: U (1) 3–0–6
Ways and modes of coming to grips with poetry. Metaphoric analysis. Detailed interpretation, by various methods, of representative poems written since 1600. Comparative viewing of the mutations of German poetry since 1600: in theme and technique, in the lyrical sensibility and in the metaphoric imagination. Readings and instruction in German. Discussion in English and German. Papers in English.
M. Dyck

23.142 *German Civilization*
Prereq.: 23.14
Year: U (2) 3–0–6
Readings in some pivotal phases of German *Kulturgeschichte*. Conducted in German primarily through conversation. *G. E. Nelson*

23.15 *Goethe's Poetry*
Prereq.: 23.141
Year: U (2) 3–0–6
An intensive analysis of representative poems from Goethe's entire career. Supplementary readings in Goethe's thought. Instruction in German. Discussion and papers in English or German. *M. Dyck*

23.16 *German Romanticism*
(Revised: Content change)
Prereq.: 23.14
Year: U (1) 3–0–6
A fourfold inquiry into German Romanticism: (1) as the literary movement centering about 1800 (Novalis, Friedrich Schlegel, Tieck, Brentano, Eichendorff, Hoffmann); (2) as part of the larger European trend of romanticism during the period; (3) as manifested in cognate domains (music and painting, science and religion, philosophy and political thought); (4) as a peculiar configuration of ideas and ideals, forms and fantasies persisting through the ages in the German-speaking countries. Instruction and readings in German. Discussion and papers in English or German. *M. Dyck*

23.171 *Spoken German I*
Prereq.: ——
Year: G (1) 4–0–8
Introduction to speaking and understanding German. No previous knowledge of German required. Primary emphasis on rapid acquisition of essentials for effective communication in practical situations. Practice in reading. Full use made of language laboratory. *(Open to graduate students only. No credit given.)* *R. H. Briggs*

23.172 *Spoken German II*
Prereq.: 23.171
Year: G (2) 4–0–8
Continued training in speaking and understanding German. Increased practice in reading. Continued use of language laboratory. *(Open to graduate students only. No credit given.)* *R. H. Briggs*

23.173 *German Reading I*
Prereq.: ——
Year: G (1) 4–0–8
Introduction to the reading of German. No previous knowledge of German required. Intensive study of grammar. Practice in reading simple materials. *(Open to graduate students only. No credit given.)* *P. B. Bon*

23.174 *German Reading II*
Prereq.: 23.173
Year: G (2) 4–0–8
Reading of varied materials of intermediate difficulty, both general and technical. Continued study of grammar. *(Open to graduate students only. No credit given.)* *P. B. Bon*

23.19 *Goethe's "Faust"*
Prereq.: 23.141
Year: U (2) 3–0–6
An intensive analysis of both parts of *Faust*. Instruction in German. Discussion and papers in English or German. *(Not offered 1971–72.)* *M. Dyck*

23.20 *Seminar in German Poetry*
Prereq.: 23.141
Year: U (2) 3–0–6
Deep study of one poet. Instruction in German. Discussion and papers in English or German. *(Not offered 1971–72.)* *M. Dyck*

23.21 *Modern German Drama*
(Revised: Content change)
Prereq.: 23.14
Year: U (2) 3–0–6
Life and art on and off the stage as dramatized in the continual interplay and counterplay of "progressing" modernity and experimentation and "regressing" classicism and "obsolescence." The underlying kernel of human concerns and values in the shifting costume of drama. A dozen plays will be chosen: from the classical period (Lessing, Goethe, Schiller, Kleist), the "early modern" Büchner, from the "moderns proper" (Wedekind, Hauptmann, Kaiser, Brecht) and the "ultramoderns" (Frisch, Dürrenmatt, Weiss, Hochhuth). Readings and instruction in German. Discussion and papers in English or German. *M. Dyck*

23.22 *Modern German Fiction*
Prereq.: 23.14
Year: U (2) 3–0–6
Critical reading and discussion of examples of modern German prose fiction, with emphasis on Mann and Kafka. Instruction in German. Discussion and papers in English or German. *(Not offered 1971–72.)* *M. Dyck*

23.35 *Spanish Drama*
Prereq.: 23.41
Year: U (1) 3–0–6
Reading and discussion of works by Lope de Vega, Cervantes, Tirso de Molina, Ruiz de Alarcón, Calderón de la Barca, Rojas Zorilla, Moratín, Duque de Rivas. Conducted in Spanish. *(Limited enrollment. Not offered 1971–72.)* *J. W. Harris*

23.36 *Twentieth-Century Spanish Literature*
Prereq.: 23.41
Year: U (2) 3–0–6
Study of philosophical works by Unamuno, Ortega y Gasset. Reading and discussion of literary prose works by Azorín, Pío Baroja, Valle-Inclan, and others. Conducted in Spanish. *(Limited enrollment. Not offered 1971–72.)* *J. W. Harris*

23.371 *Spoken Spanish I*
Prereq.: ——
Year: G (1) 4–0–8
Introduction to speaking and understanding Spanish. No previous knowledge of Spanish required. Primary emphasis on rapid acquisition of essentials for effective communication in practical situations. Practice in reading. Full use made of language laboratory. *(Open to graduate students only. No credit given.)* *I. A. Bordelois*

23.372 *Spoken Spanish II*
Prereq.: 23.371
Year: G (2) 4–0–8
Continued training in speaking and understanding Spanish. Increased practice in reading. Continued use of language laboratory. *(Open to graduate students only. No credit given.)* *J. W. Harris*

23.41 *Introduction to Spanish Literature*
Prereq.: ——
Year: U (1) 3–0–6
Detailed study of poems, plays, and prose works by such writers as Arreola, Baroja, Casona, Guzmán, and Neruda. Emphasis on control of grammar and rapid acquisition of vocabulary, leading to the ability to read standard works with immediate comprehension and pleasure. Conducted largely in Spanish. *J. W. Harris*

23.42 *Masterpieces of Spanish Literature*
Prereq.: 23.41
Year: U (2) 3–0–6
Careful study of unabridged works of recognized masters in various genres, largely contemporary and largely Latin

American, such as Arciniegas, Borges, García Lorca, Mistral, Romero, and Paz. Conducted in Spanish.
J. W. Harris

23.51 *Elementary French I*
Prereq.: ——
Year: U (1, 2) 4–0–8
Necessary foundation for French language and literature. Training in pronunciation and intonation with the aid of mechanical devices, and in elementary grammar; practice in hearing and speaking French; acquisition of useful vocabulary; reading of varied matter.
S. B. Greenfield

23.52 *Elementary French II*
Prereq.: 23.51
Year: U (2) 4–0–8
Continued training in the speaking and listening skills with the aid of mechanical devices. Completion of elementary grammar. Practice in reading to increase vocabulary and to develop some appreciation of French literature and civilization. *S. B. Greenfield*

23.53 *Intermediate French*
Prereq.: 23.52
Year: U (1, 2) 4–0–8
Practice in spoken French to develop fluency in everyday conversation; also in written French to increase accuracy. Grammar review; reading of varied matter. Mechanical devices used for improving pronunciation and intonation. *S. B. Greenfield*

23.54 *Advanced French*
(Revised: Content change)
Prereq.: 23.53
Year: U (1, 2) 4–0–8
Transition subject to prepare students for advanced work in French literature. Readings include such modern authors as Sartre, Camus, Mauriac, Gide, and Anouilh. Conducted in French. Pronunciation drills in language laboratory and frequent essays in French provide opportunity for developing accuracy in the speaking and writing skills. *M. G. Kaufman*

23.541 *French Civilization I*
(New)
Prereq.: 23.54
Year: U (1) 3–0–6
Study of French civilization from its beginnings to the French Revolution. Coordination of political, economic, and social background with literature and the arts. Conducted in French. *S. B. Greenfield*

23.543 *French Civilization II*
Prereq.: 23.54
Year: U (1) 3–0–6
Continuation of French Civilization I, extending from the French Revolution to the present. Coordination of political, economic, and social background with literature and the arts. Conducted in French. *(Not offered 1971–72.)* *S. B. Greenfield*

23.571 *Spoken French I*
Prereq.: ——
Year: G (1) 4–0–8
Introduction to speaking and understanding French. No previous knowledge of French required. Primary emphasis on rapid acquisition of essentials for effective communication in practical situations. Practice in reading. Full use made of language laboratory. *(Open to graduate students only. No credit given.)* *I. Ricardo*

23.572 *Spoken French II*
Prereq.: 23.571
Year: G (2) 4–0–8
Continued training in speaking and understanding French. Increased practice in reading. Continued use of language laboratory. *(Open to graduate students only. No credit given.)* *I. Ricardo*

23.573 *French Reading I*
Prereq.: ——
Year: G (1) 4–0–8
Introduction to the reading of French. No previous knowledge of French required. Intensive study of grammar. Practice in reading simple materials. *(Open to graduate students only. No credit given.)* *M. Bukal*

23.574 *French Reading II*
Prereq.: 23.573
Year: G (2) 4–0–8
Reading of varied materials of intermediate difficulty, both general and technical. Continued study of grammar. *(Open to graduate students only. No credit given.)* *M. Bukal*

23.58 *Seminar on Voltaire*
Prereq.: 23.54
Year: U (2) 3–0–6
Concentrated study of Voltaire's thought and art. Conducted in French. *(Not offered 1971–72.)* *I. Ricardo*

23.61 *Contemporary French Drama*
Prereq.: 23.54
Year: U (1) 3–0–6
Study of major authors and movements in French drama since 1920: Lenormand, Giraudoux, Anouilh, Montherlant, Claudel, Artaud, Ionesco, Beckett, Genet, Surrealism, Existentialism, etc. Conducted in French.
R. E. Jones

23.62 *French Romanticism*
Prereq.: 23.54
Year: U (2) 3–0–6
Inclusive study of French literature from 1800 to 1860, with emphasis on the poetry of Hugo, Vigny, Musset, Lamartine, Nerval, and Gautier, the novels of Stendhal and Balzac, and the Romantic theatre. Also, examination of the allied arts of music and painting. Conducted in French. *R. E. Jones*

23.631 *French Prose Fiction III*
(New)
Prereq.: 23.54
Year: U (1) 3–0–6
Continuation of French Prose Fiction II, concentrating on the twentieth century. Works by such authors as Gide, Proust, Malraux, Sartre, Camus, Mauriac, and Robe-Grillet. Conducted in French. *(Not offered 1971–72.)* *R. E. Jones*

23.632 *French Prose Fiction I*
(New)
Prereq.: 23.54
Year: U (2) 3–0–6
Intensive study of selected novels and philosophic tales against their cultural background, ranging from *La Princesse de Cleves* (1678) to *Adolphe* (1816), and featuring works by such authors as Lesage, Prevost, Marivaux, Voltaire, Diderot, Rousseau, Laclos, and Chateaubriand. Conducted in French. *I. Ricardo*

23.634 *French Prose Fiction II*
(New)
Prereq.: 23.54
Year: U (2) 3–0–6
Continuation of French Prose Fiction I, extending through the nineteenth century, and focusing on Romanticism, Realism, Naturalism, and Symbolism. Works by such authors as Hugo, Balzac, Stendhal, Flaubert, Daudet, Zola, and Alain-Fournier. Conducted in French. *(Not offered 1971–72.)* *W. F. Bottiglia*

23.64 *Seminar in French Literature*
Prereq.: 23.54
Year: U (1) 3–0–6
Detailed study of three authors concerned with moral issues: La Rochefoucauld, Pascal, Gide. Conducted in French. *M. G. Kaufman*

23.65 *Classical French Drama*
Prereq.: 23.54
Year: U (1) 3–0–6
Concentrated study of selected plays by Corneille, Racine, and Molière, and of Boileau's *Art poétique*. Conducted in French. (*Not offered 1971–72.*) *M. G. Kaufman*

23.66 *Modern French Poetry*
Prereq.: 23.54
Year: U (2) 3–0–6
Detailed analyses of poetry by Nerval, Baudelaire, Rimbaud, Mallarmé, Apollinaire, and the Surrealists. Special attention to the prose poem. Conducted in French. (*Not offered 1971–72.*) *R. E. Jones*

23.700J *Language and Its Structure*
(Same subject as 21.315J)
Prereq.: ——
Year: U (1) 3–0–6
An introduction to basic concepts and issues for the non-linguist. Production and physical properties of speech, phonetic and phonemic representations, deep and surface syntactic structures, language change, methods and goals of modern linguistic theories.
J. W. Harris, W. O'Neil

23.701 *Crucial Problems in Linguistics*
Prereq.: ——
Year: G (1) 2–0–7
The Moscow school — Fortunatov, Trubetzkoy, further stages — and its place in world linguistics. (*Not offered 1971–72.*) *R. Jakobson*

23.704 *Linguistics and Poetics*
Prereq.: ——
Year: G (2) 2–0–7
Poetic function in relation to the other functions of language; linguistic analysis of verbal art; verse and prose. Sound and meaning. Parallelism, versification, rhyme and alliteration; grammar of poetry; tropes and figures. (*Not offered 1971–72.*) *R. Jakobson*

23.705 *Seminar on Poetic Form*
Prereq.: ——
Year: G (1) *Arr.*
Study of the organization of linguistic elements in metrical verse. *M. Halle, R. P. V. Kiparsky*

23.711 *Special Problems in Language and Literature*
Prereq.: ——
Year: G (1) *Arr.*

23.712 *Special Problems in Language and Literature*
Prereq.: ——
Year: G (2) *Arr.*
Advanced work in literature or linguistics for unusually well-prepared students. Offered by members of staff in their special fields. *Staff*

23.721 *Semantics* (A)
Prereq.: ——
Year: G (1) 3–0–9
Characterization of the form of a semantic theory for natural languages, within the framework of the transformational theory of grammar. Topics: the explanatory goals of semantic theory, the representations of propositions within grammars, presupposition, analyticity and other forms of linguistic truth, the logic of questions, referential opacity, temporal relations, the converse relation, the distinction between syntactic and semantic representation, deep structure and its interpretation, surface structure and its interpretation. An examination of aspects of linguistic communication that fall outside grammatical theory (e.g., Grice's theory of conversational implicature). (*Primarily for graduate students in philosophy and linguistics; others admitted only by permission of instructor.*) *J. J. Katz*

23.731 *Linguistic Structures: Romance* (A)
(*New*)
Prereq.: 23.751, 23.761
Year: G (2) 3–0–9
Topics in the syntax, phonology and morphology of the Romance languages, with emphasis on the application of modern theory to classical problems of Romance linguistics and the implications of data drawn from the Romance languages for general linguistic theory. (*Some knowledge of a Romance language is required.*)
K. L. Hale, J. W. Harris, D. M. Perlmutter

23.732 *Structure of Spanish* (A)
Prereq.: 23.751, 23.762
Year: G (2) 3–0–9
Survey of the syntax, morphology and phonology of contemporary literary Spanish, with emphasis on the application of modern theory to classical problems of Spanish linguistics. (*Adequate knowledge of Spanish required. Not offered 1971–72.*) *K. L. Hale, J. W. Harris*

23.733J *History of the English Language*
(*Same subject as 21.316J*)
Prereq.: ——
Year: G (2) 3–0–9
Selected topics in the history of English syntax, morphology and phonology from Old English to the present, formulated within an attempt at a general theory of linguistic change. (*Some knowledge of Old and Middle English desirable.*) *W. O'Neil*

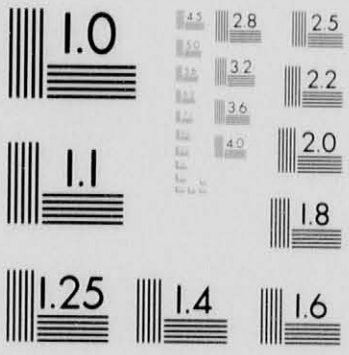
23.734 *Structure of Russian* (A)
Prereq.: 23.751, 23.762
Year: G (2) 3–0–6
Survey of the syntax, morphology and phonology of contemporary literary Russian, with emphasis on the application of modern theory to classical problems of Slavic linguistics. Consideration of the relevant dialectological and historical evidence. (*Adequate knowledge of Russian required. Not offered 1971–72.*)
M. Halle, D. M. Perlmutter

23.736 *Structure of German* (A)
Prereq.: 23.751, 23.762
Year: G (2) 3–0–9
Survey of the syntax, morphology and phonology of contemporary literary German, with emphasis on the application of modern theory to classical problems of Germanic linguistics. Consideration of the relevant historical evidence. (*Adequate knowledge of German required. Not offered 1971–72.*)
R. P. V. Kiparsky, J. R. Ross

23.737 *Introduction to Sanskrit*
Prereq.: ——
Year: G (1) 3–0–9
Brief review of writing system, phonology, morphology, and syntax of the language. (*Not offered 1971–72.*)
R. P. V. Kiparsky

23.741 *Topics in the Grammar of a Non-Indo-European Language*
Prereq.: 23.751
Year: G (1) 3–0–6

23.742 *Topics in the Grammar of a Non-Indo-European Language*
Prereq.: 23.751
Year: G (2) 3–0–6
Detailed examination of the grammar of a language whose structure is significantly different from English,



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with special emphasis on problems of interest in the study of linguistic universals. Course assistance by a native speaker of the language, when possible. *K. L. Hale*

23.751 *Introduction to Linguistics I: Syntax*
Prereq.: ——
Year: G (1) 6–0–18
Introduction to the process of formulating and testing hypotheses to account for syntactic data in natural languages. Emphasis on the role of metatheory in choosing between competing hypotheses. Grounding in basic syntactic processes: deep and surface structure, phrase structure and transformational rules, recursive mechanisms, rule ordering, and the transformational cycle. Data is drawn primarily from English.
D. M. Perlmutter

23.752 *Introduction to Linguistics III: Theory of Grammar*
Prereq.: 23.751
Year: G (2) 3–0–9
Elementary transformations and derived constituent structure. Rule government. Variables. Identity. Indexing. The abstract nature of underlying structures.
G. H. Matthews

23.753 *Advanced Grammar I* (A)
Prereq.: 23.752
Year: G (1) 3–0–9

23.754 *Advanced Grammar II* (A)
Prereq.: 23.752
Year: G (2) 3–0–9
Selected topics in phonology, syntax, and semantics.
J. R. Ross

23.755 *Linguistic Structure*
Prereq.: 23.752
Year: G (1) 3–0–9
The empirical requirements for a theory of linguistic structure that will encompass and account for linguistic competence and the ability to use and acquire it. Study of aspects of English syntax, semantics, and phonology insofar as they furnish critical tests for such a theory. Systematic presentation of a theory of linguistic structure, its abstract properties and range of empirical adequacy. Explanatory models in linguistics; their implications concerning the nature of cognitive processes. (*Not offered 1971–72.*) *N. A. Chomsky*

23.756 *Introduction to Linguistics IV: Universal Grammar*
(*New*)
Prereq.: 23.751
Year: G (2) 3–0–9
The nature of linguistic universals, which make it possible for languages to differ and place limits on these differences. Study of selected problem areas which show how data from particular languages contributes to the development of a strong theory of universal grammar and how such a theory dictates solutions to traditional problems in the syntax of particular languages. *D. M. Perlmutter*

23.757 *Seminar on Universal Grammar* (A)
Prereq.: 23.752
Year: G (1) 3–0–9
Study of grammatical problems in several languages with a view towards achieving a sharper characterization of certain universal features of grammatical structure. (*Not offered 1971–72.*) *G. H. Matthews*

23.759 *Workshop in Syntax*
Prereq.: ——
Year: G (1) 3–0–9
An intensive group tutorial/seminar for discussion of research being conducted by participants. No auditors will be allowed. (*Permission of instructor required.*) *J. R. Ross*

23.761 *Introduction to Linguistics II: Phonology*
Prereq.: ——
Year: G (2) 3–0–5
Aims and principles of a scientific description of the phonic aspect of language. The mechanism and acoustics of speech. Distinctive features as the descriptive framework. The phoneme. The phonemic system of a language. The interrelations between phonology and other linguistic levels. Some problems of historical phonology. Practical exercises. *M. Halle*

23.762 *Advanced Phonology* (A)
Prereq.: 23.761
Year: G (2) 3–0–9
The interrelation of syntactic, morphological and phonological phenomena in the English language. The phonological system and the structure of phonemes.
J. R. Ross, R. P. V. Kiparsky

23.766J *Laboratory on the Physiology, Acoustics and Perception of Speech* (A)
(Same subject as 6.694J)
Prereq.: ——
Year: G (1) 0–6–6
Experimental investigations of speech processes. Topics include (a) interpretation of x-ray motion pictures, (b) measurement of pressure and volume velocity, (c) computer-aided waveform analysis and spectral analysis of speech, (d) synthesis of speech with an articulatory model and with a terminal analog model, (e) identification and discrimination of speech-like sounds, (f) the perceptual reality of phonetic features, and other topics. (*Recommended prerequisites: engineering and science students, 6.41 linguistics students, mathematical background equivalent to 6.01 or 18.03. Others admitted by permission of instructor.*)
M. Halle, D. H. Klatt

23.768J *Speech Communication* (A)
(Same subject as 6.691J)
Prereq.: ——
Year: G (2) 3–0–9
Survey of structural properties of natural languages with special emphasis on the sound pattern. Survey of physiology of speech production, articulatory phonetics. Acoustical theory of speech production: the vocal tract as a generator of acoustical signals; acoustical correlates of vocal-tract configurations, both stationary and dynamic; acoustical and articulatory descriptions of phonetic features. Perception of speech: the auditory capabilities of man; evidence for perceptual correlates of phonetic categories. Mechanical recognition and generation of speech. (*Recommended prerequisites: engineering and science students, 6.41; linguistics students, mathematical background equivalent to 6.05 or 18.05. Others admitted by permission of instructor.*) *M. Halle, K. N. Stevens*

23.769 *Workshop in Phonology*
Prereq.: ——
Year: G (1) 3–0–9
An intensive group tutorial/seminar for discussion of research being conducted by participants. No auditors will be allowed. (*Permission of instructor required.*)
R. P. V. Kiparsky

23.771 *Mathematical Backgrounds for Communication Sciences*
Prereq.: ——
Year: G (1) 3–0–9
Fundamentals of discrete mathematics for non-mathematicians. Introduction to various topics in set theory and foundations, logic and formal systems, modern algebra, theory of automata and computability.
G. H. Matthews

23.772 *Mathematical Models in Linguistics*
Prereq.: 23.771
Year: G (2) 3–0–9
Study of mathematical models that relate to linguistic competence and performance. Formal properties of grammatical systems. Grammars of natural and artificial languages. Models for the speaker and hearer that incorporate representations of his knowledge of the language. Probabilistic models for the user. Stress on interconnections of theory of grammar and theory of automata, and implications for the study of human cognitive processes wherever possible. (*Not offered 1971–72.*)
G. H. Matthews

23.782 *Linguistic Change* (A)
Prereq.: 23.751, 23.761
Year: G (2) 3–0–9
Review of instances of change in phonology, morphology, and syntax. Examples to be drawn from various language families, Indo-European, as well as others. An attempt to develop a general theory of linguistic change.
G. H. Matthews, R. P. V. Kiparsky, K. L. Hale

23.784 *Indo-European* (A)
Prereq.: 23.782
Year: G (2) 3–0–9
Selected topics in the grammar of Indo-European. (*Not offered 1971–72.*)
R. P. V. Kiparsky

23.786 *Seminar on the Linguist in Society*
Prereq.: ——
Year: G (2) 1–0–5
Discussion of role and responsibility of the linguist qua linguist. Nature of linguistics as a tool and as a discipline in modern society. Moral decisions the linguist must be prepared to make concerning how his special knowledge and research is to be used both by himself and by others. Kinds of situations that arise which call upon him to make such decisions, and the relationship between these decisions and his responsibility as a member of society.
G. H. Matthews

23.792 *Survey of General Linguistics I* (A)
Prereq.: 23.751, 23.761
Year: G (2) 3–0–9
An expository and critical survey of modern structural linguistics. The work of Boas, Sapir, Bloomfield, the Prague Circle, and other developments in general linguistics during the past half-century. Contemporary trends and their immediate backgrounds.
R. P. V. Kiparsky

23.796 *Survey of General Linguistics II* (A)
Prereq.: ——
Year: G (2) 3–0–9
Concepts of language as they have arisen in linguistics, psychology, and philosophy studied against the background of developments in science and philosophy. Emphasis on the nineteenth and twentieth centuries, with stress on contemporary relevance. (*Not offered 1971–72.*)
N. A. Chomsky, S. Bromberger

23.87 *Dante I*
Prereq.: ——
Year: U (1) 3–0–6
Intensive literary analysis of the *Inferno* in the original, after preliminary training in fundamentals of Italian grammar and pronunciation. Designed for students with no previous knowledge of Italian. (*Not offered 1971–72.*)
W. F. Bottiglia

23.88 *Dante II*
Prereq.: 23.87
Year: U (2) 3–0–6
Continuation of 23.87. Intensive literary analysis of the *Purgatorio* and the *Paradiso* in the original. (*Not offered 1971–72.*)
W. F. Bottiglia

23.91 *Elementary Russian I*
Prereq.: —
Year: U (1) 4–0–8
Basic grammar and practice in the elements of Russian. Emphasis on learning to speak and understand as a prerequisite for effective communication in Russian and as a basis for learning reading and writing skills.
R. Channon

23.92 *Elementary Russian II*
Prereq.: 23.91
Year: U (2) 4–0–8
Continuation of 23.91. Additional practice and further work on points of grammar. The main emphasis will continue to be on speaking and understanding, but the transition to greater emphasis on reading and writing will begin in the second part of the term.
R. Channon

23.922 *Elementary Russian Review*
Prereq.: ——
Year: U (2) 4–0–8
Brief review of the grammar of 23.91, followed by the bulk of the material of 23.92. Designed for students with incomplete previous preparation in Russian and for those whose study of Russian is discontinuous. Students may register for 23.93 upon successful completion of 23.922. (*Admission only by permission of instructor.*)
R. Channon

23.93 *Intermediate Russian*
Prereq.: 23.92 or 23.922
Year: U (1) 4–0–8
Reading and discussion of short stories, poems and historical texts. Review of Russian grammar with the help of written exercises. Building independence of the dictionary by means of systematic study of word formation.
C. V. Chvany

23.94 *Advanced Russian*
Prereq.: 23.93
Year: U (1, 2) 4–0–8
Study of more complex problems of morphology and syntax, with a view to improving the student's facility in oral and written expression. Reading of literary and expository prose. Aural comprehension developed through brief lectures on Russian and Soviet culture.
M. Z. Freeman, C. V. Chvany

23.951 *Russian Civilization*
(23.95) *Prereq.:* 23.94
Year: U (1) 4–0–8
Readings in Russian history and civilization based on original texts drawn from literature dealing with historical and cultural problems. Work on advanced grammar and style. Frequent oral and written reports and compositions. Conducted in Russian.
M. Z. Freeman

23.971 *Spoken Russian I*
Prereq.: ——
Year: G (1) 4–0–8
Introduction to speaking and understanding Russian. No previous knowledge of Russian required. Primary emphasis on rapid acquisition of essentials for effective communication and as a basis for later building of reading and writing skills. (*Open to graduate students only. No credit given.*)
R. Channon

23.972 *Spoken Russian II*
Prereq.: 23.971
Year: G (2) 4–0–8
Continued training in speaking and understanding Russian. Introduction to and practice in reading scholarly prose. (*Open to graduate students only. No credit given.*)
R. Channon

23.973 *Russian Reading I*
Prereq.: ——
Year: G (1) 4–0–8
Introduction to the reading of Russian. No previous knowledge of Russian required. Intensive study of grammar. Practice in reading simple materials. (*Open to graduate students only. No credit given.*) *M. Schecter*

23.974 *Russian Reading II*
Prereq.: 23.973
Year: G (2) 4–0–8
Reading of varied materials of intermediate difficulty, both general and technical. Continued study of grammar. (*Open to graduate students only. No credit given.*) *M. Schecter*

23.975 *The Art of Story-Telling in Russian Literature*
(*New*)
Prereq.: 21.03 or 21.11 or 23.94
Year: U (1) 3–0–6
This subject will explore the innovative way in which some nineteenth and twentieth century Russian authors approached the problem of story-telling. The kind of narrator who tells the story, the kind of material he relates, his credibility and consistency as an informant, and his relation to the author are all aspects of narration that will be analyzed. Authors whose works are of special interest in this regard will be considered: Turgenev, Leskov, and Chekhov from the nineteenth century; Nabokov, Zoshchenko, and Bulgakov from the twentieth. For purposes of comparison such non-Russian writers as Henry James ("The Turn of the Screw") and Ford Maddox Ford ("The Good Soldier") will be read. Readings in English, conducted in English. *K. T. O'Connor*

23.976 *Chekhov as Prose Writer*
(*New*)
Prereq.: 21.03 or 21.11 or 23.94
Year: U (2) 3–0–6
After detailed analysis and discussion of several of Chekhov's masterpieces in the short story genre, an attempt will be made to characterize the peculiar nature of his versatility as an artist and also to evaluate his claim to pre-eminence in nineteenth century Russian fiction, along with Dostoyevsky and Tolstoy. Stories to be read will include: "The Name-Day Party," "A Boring Story," "The Black Monk," "Ward No. 6," "The Grasshopper," "A Woman's Kingdom," and "Gusev." Readings in English, conducted in English. *K. T. O'Connor*

23.977J *How Is Poetry Made?*
(*New*)
(Same subject as 21.252J)
Prereq.: 21.03 or 21.11
Year: U (1) 3–0–6
Studies in comparative poetics. Insight into the poet's workshop. Authors and readers: their interrelation. The poet's treatment of sound and meaning: verse, imagery, theme. Poetic function of language. Changes and tradition. Examples drawn from English and other languages, but knowledge of other languages is not required. *K. Pomorska, W. O'Neil*

23.980 *Introduction to Russian Literature*
(23.96) (*Revised: Content change*)
Prereq.: 23.94
Year: U (2) 3–0–6
The subject has a double aim; on the one hand, to introduce the elements of composition and stylistics; on the other, to acquaint the student with the foundations of modern Russian literature through the most important and characteristic works of Pushkin, in verse and in prose — "Evgenij Onegin" and "Povesti Belkina." Critical method and literary terminology are introduced, as the texts are analyzed both historically and structurally. Conducted in Russian. *K. Pomorska*

23.981 *Modern Russian Poetry*
(*Revised: Content change*)
Prereq.: 23.94
Year: U (1) 3–0–6
Russian Symbolism as represented by K. Balmont, A. Blok, and others. Post-Symbolist poetry: Acmeism and Futurism as illustrated by Akhmatova, Gumilev, Majakovskij, and Khlebnikov. Study of the theory of these movements and analysis of texts. Lectures and readings in Russian. Discussion and papers in Russian or English, depending on individual ability. (*Not offered 1971–72.*) *K. Pomorska*

23.982 *Seminar on Pushkin and Russian Romanticism*
(*Revised: Content change*)
Prereq.: 23.94
Year: U (1) 3–0–6
Central problems of European and Russian Romanticism studied through Pushkin's poetry and prose. Analysis of selected short poems, major long poems ("Cygany," "Poltava," "Mednyj Vsadnik"), fairy tales ("Zolotoj Petushok"), dramatic works ("Kamennyj gost"), and parallel prose pieces ("Egipetskie Nochi"). Related works by other Romantics (Lermontov, Tjutchev) included. Lectures and readings in Russian. Discussion and papers in Russian or English, depending on individual ability. (*Not offered 1971–72.*) *K. Pomorska*

23.983 *Studies in Russian Prose: Gogol*
(*Revised: Content change*)
Prereq.: 23.94
Year: U (1) 3–0–6
Concentrated study of Gogol as the most original among Russian and European writers of the first half of the nineteenth century. Grotesque and absurd as well as folkloric elements in Gogol's prose. Gogol's relation to E. T. A. Hoffmann and L. Sterne. Works analyzed: "Vechera na khutore," "Mirgorod," "Peterburgskie povesti," "Mertvye dushi," "Revizor," "Zhenitba." Lectures and readings in Russian. Discussion and papers in Russian or English, depending on individual ability. *K. Pomorska*

23.985 *Selected Problems in Soviet Literature*
(23.984) (*Revised: Content change*)
Prereq.: 23.94
Year: U (1) 3–0–6
Study of prose works from the twenties, the "Golden Age" of Soviet literature, by writers such as young Pasternak, Pilnjak, Babel, Zamjatin, and Zoshchenko. Prose and poetry of the post-Stalin period, drawn from works of such writers as Ehrenburg, Panova, Solzhenicyn, and Okudzhava. Lectures and readings in Russian. Discussion and papers in Russian or English, depending on individual ability. (*Not offered 1971–72.*) *K. Pomorska*

23.992 *Gogol and Literary Methodology in Russia*
Prereq.: 21.03 or 21.11 or 23.94
Year: U (2) 3–0–6
Gogol's writings as approached by sociological criticism (Belinskij, Chernyshevskij), by the Symbolists, by the Formalist school; the biographical and psychological approach; the impact of Husserl's phenomenology in Russia at the beginning of the twentieth century. Readings in English, conducted in English. *K. Pomorska*

23.993 ***Tolstoi's "War and Peace"***
Prereq.: 21.03 or 21.11 or 23.94
Year: U (1) 3–0–6
Intensive study of *War and Peace* both as an historical novel and as a literary structure. Readings in English, conducted in English. (*Not offered 1971–72.*) *K. Pomorska*

23.994 ***Mayakovsky and Pasternak***
Prereq.: 21.03 or 21.11 or 23.94
Year: U (2) 3–0–6
Consideration of twentieth century literary movements, like Futurism and Constructivism, through a study of both the poetry and prose of Russia's greatest contemporary poets. Readings in English, conducted in English. (*Not offered 1971–72.*) *K. Pomorska*

23.995 ***The Prose of A. Solzhenicyn***
(*New*)
Prereq.: 21.03 or 21.11 or 23.94
Year: U (1) 3–0–6
Solzhenicyn both as a cultural bridge between the nineteenth century tradition of Russian classical realism, and as a moral challenge to the ideological and political dilemmas of our time. Problems of freedom and totalitarianism in a universal modern context as expressed in: "One Day in the Life of Ivan Denisovich," "Cancer Ward," and "First Circle." Readings in English, conducted in English. *K. Pomorska*

23.996 ***The Russian Short Story***
Prereq.: 21.03 or 21.11 or 23.94
Year: U (2) 3–0–6
Tradition and novelty in Russian short story of the nineteenth century. Intensive analysis of works by Karamzin, Pušhkin, Lermontov, Gogol, Turgenev, Tolstoi, Dostoevskij, and Chekhov. Readings in English, conducted in English. (*Not offered 1971–72.*) *K. Pomorska*

23.997 ***Nineteenth Century Russian Literature***
Prereq.: 21.03 or 21.11 or 23.94
Year: U (1) 3–0–6
Selected masterpieces of nineteenth century Russian literature, analyzed against their historical and cultural background. Readings in English, conducted in English. (*Not offered 1971-72.*) *K. T. O'Connor*

23.998 ***Dostoevskij***
Prereq.: 21.03 or 21.11 or 23.94
Year: U (2) 3–0–6
Intensive analysis of *Crime and Punishment*, *The Idiot*, and *The Brothers Karamazov*. Readings in English, conducted in English. (*Not offered 1971–72.*) *K. T. O'Connor*

23.999 ***Revolution and War in Contemporary Russian and Polish Literature***
(*New*)
Prereq.: 21.03 or 21.11 or 23.94
Year: U (2) 3–0–6
Various concepts and various images of war, as related to the national experience, historical moment, philosophy, and literary tradition. The range extends from such Russian writers as A. Belyj, through D. Furmanov, M. Sholokhov, and B. Okudzhava, to such Polish writers as L. Buczkowski and T. Konwicki. Readings in English, conducted in English. (*Not offered 1971–72.*)
K. Pomorska

24.

Philosophy

24.01 ***Contemporary Moral Issues***
(21.015) *Prereq.:* ——
Year: U (1) 3–0–6
Examination of moral controversies arising out of contemporary experience such as the limits of personal responsibility in a mass society, the sanctity of human life and the conditions under which taking it are justified, interference with a person's liberty for his own welfare, and civil disobedience. Readings drawn from contemporary and classical sources alike — philosophers, novelists, theologians and jurists. Works supplemented by lectures and films. *Staff*

24.02 ***Contemporary Moral Issues***
(21.016) *Prereq.:* 24.01
Year: U (2) 3–0–6
Examination of philosophical theories about controversies like those discussed during the first term. Questions to be discussed regarding these theories: Are moral judgments true or false? Is morality relative to a society? Are there universally valid ethical principles? What role should intuition play? Or conscience? Readings from philosophical texts, classical and contemporary, and from relevant studies in cultural anthropology, sociology and jurisprudence. *Staff*

24.11 ***Philosophy: Classic and Contemporary***
(21.04) *Prereq.:* One first-year Humanities sequence
Year: U (1, 2) 3–0–6
Problems of knowledge, moral choice, reality, and the existence of God. The nature of philosophical inquiry exemplified through the analysis of great texts. *Staff*

24.201 ***History of Philosophy I***
(21.611) *Prereq.:* 24.11
Year: U (1) 3–0–6
Survey of ancient philosophic thought. Emphasis on Plato and Aristotle. *B. A. Brody*

24.202 ***History of Philosophy II***
(21.612) *Prereq.:* 24.11
Year: U (2) 3–0–6
Philosophic thought from the Renaissance through the Enlightenment. Emphasis on Descartes, Locke, and Hume. *R. L. Cartwright*

24.211 ***Theory of Knowledge***
(21.647) *Prereq.:* 24.11
Year: U (1) 3–0–6
Study of problems concerning our concept of knowledge, our knowledge of the past, our knowledge of the thoughts and feelings of ourselves and others, and our knowledge of the existence and properties of physical objects in our immediate environment. *M. A. Levensky*

24.221 ***Metaphysics***
(21.677) *Prereq.:* 24.11
Year: U (1) 3–0–6
Problems involved in basic metaphysical concepts; substance, essence, existence, universality, causality, and spatio-temporality. Classical and contemporary analysis of these concepts. (*Not offered 1971–72.*) *B. A. Brody*

24.231 ***Ethics***
(21.644) *Prereq.:* 24.11
Year: U (2) 3–0–6
Systematic study of some central problems in ethics, such as the relation between fact and value, the nature of obligation, the relevance to moral evaluation of pleasure, desire, intention, etc. *J. J. Thomson*

Descriptions

24.232 *Liberty and Equality*
(New)
Prereq.: 24.11
Year: U (1) 3–0–6
An examination of the nature of liberty and equality and the principles which govern their application.
G. Dworkin

24.241 *Symbolic Logic*
(21.641) *Prereq.:* One first-year Humanities sequence
Year: U (1) 3–0–6
Introduction to the aims and techniques of formal logic. The logic of truth-functions and quantifiers. Formal systems: consistency and completeness. The decision-problem for a formal system. Applications of formal logic, the place of logic in philosophy. *J. F. Thomson*

24.251 *Philosophy of Science*
(21.712) *Prereq.:* 24.11
Year: U (1) 3–0–6
Discussion of problems concerning the principles and methods of scientific activity, and their possible philosophical justifications. Analysis of hypothesis formation, testing, and choice. Role of induction, probability, simplicity, utility, and their difficulties. Character of scientific explanation and concept formation. Relation of observations to laws, theories, models, and the ontology of physical reality. Status of reductionism, unity of science, causality, and determinism. *(Not offered 1971–72.)* *J. C. Graves*

24.261 *Natural Theology*
(New)
Prereq.: 24.11
Year: U (2) 3–0–6
An examination of such issues as: Is there any reason to believe that God exists? Can predicates normally applicable to human beings be meaningfully applied to God? Can God's fore knowledge be reconciled with the existence of free will and God's providence with the existence of evil? Is it meaningful to believe in the immortality of the soul and the resurrection of the body? The readings drawn from medieval theologians, eighteenth century philosophers, and recent writers in the analytic tradition. *B. A. Brody*

24.271 *Phenomenology*
(21.645) *Prereq.:* 24.11
Year: U (2) 3–0–6
A study of Husserl and Heidegger. Their procedure with certain problems of "world" and relevance. Comparison of their procedure with Wittgenstein's. *(Enrollment limited.)* *D. M. Levin*

24.272 *Existentialism*
(21.646) *Prereq.:* 24.11
Year: U (1) 3–0–6
Consideration of certain related problems in the works of Kierkegaard, Nietzsche, Sartre and Merleau-Ponty.
D. M. Levin

24.291 *Philosophy Seminar*
(21.082) *(Revised: Unit change)*
Prereq.: ——
Year: U (2) 2–0–7
Seminar on selected topics in philosophy. *(Open only to juniors or seniors in Course XXIV.)* *G. B. Dworkin*

24.292 *Special Topics in Philosophy*
(21.791) *Prereq.:* Any two subjects in philosophy
Year: U (1) *Arr.*
Open to qualified students who wish to pursue special studies or projects. Students electing this subject must consult the Chairman. *Staff*

24.293 *Special Topics in Philosophy*
(21.792) *Prereq.:* Any two subjects in philosophy
Year: U (2) *Arr.*
Open to qualified students who wish to pursue special studies or projects. Students electing this subject must consult the Chairman. *Staff*

24.301 *Introduction to Moral and Social Philosophy*
(21.092)
Prereq.: ——
Year: U (2) 2–0–4
Exploratory study of moral problems as occurring in concrete human situations. Readings from recent work on aggression, love, and in general the spectrum of social feelings. *(Not offered 1971–72.)* *I. Singer*

24.302 *Modern Social Theory*
(21.618) *Prereq.:* One first-year Humanities sequence
Year: U (1) 3–0–6
An exploration of significant themes and figures in the development of modern theories of society, especially industrial society. Beginning the course, a study of Marx and Marxism and other theories, e.g., Weber, Durkheim, Pareto, Galbraith, Parsons, Dahl, Marcuse, etc. studied as responses, critiques, and modifications of the Marxist analysis. ——

24.311 *Philosophy of Education*
(New)
Prereq.: ——
Year: U (2) 3–0–6
An investigation of some theories of education and the assumptions, presumptions, attitudes, feelings, values, discoveries, facts, hopes, fears, wishes and guesses that surround them. Readings from Plato, Aquinas, Rousseau, Dewey, Earl Kelly, Carl Rogers, Jerome Bruner. John Holt, George Dennison and from things that we write ourselves. *M. A. Levensky*

24.321 *Philosophy of the Arts*
(21.671) *Prereq.:* One first-year Humanities sequence
Year: U (2) 3–0–6
An inquiry into philosophical questions concerning aesthetic experience and the connections between aesthetic experience and the nature, meaning and value of particular works of art. *M. A. Levensky*

24.322 *Philosophy in Literature*
(21.672) *Prereq.:* One first-year Humanities sequence
Year: U (1) 3–0–6
Philosophical concepts as an aesthetic component in literature. Works of Romantic and Existentialist literature analyzed in relation to problems about love, hatred, despair, etc. *(Not offered 1971–72.)* *I. Singer*

24.331 *Classics in the Philosophy of Science*
(New)
Prereq.: ——
Year: U (2) 3–0–6
The course addresses itself to some of the major writings by philosophers and by scientists concerned with the task of elucidating the nature, goals, structure, methods, and limitations of the natural sciences. The actual authors chosen determined to some extent by the interests of the class but the emphasis put (at least initially) on works by Mach, Poincare, Duhem, Meyerson, Campbell, and other recent but not contemporary writers whose views have shaped those of many contemporary scientists.
S. Bromberger

24.332 *Tradition and Innovation in Twentieth Century Physics*
(21.992)
Prereq.: 8.02
Year: U (2) 3–0–6
Evolution of the new ideas of twentieth century physics, especially in relativity and quantum mechanics. Value of such notions as paradigm, model, and ideal of natural

order in understanding the dynamics of scientific growth and revolutions. Relative importance of individual genius, tradition, and formal methodological rules. Interactions of physics with the philosophy of science. Features unique to the twentieth century. *(Not offered 1971–72.)* *J. C. Graves*

24.341 *Philosophical Anthropology*
(21.668) *Prereq.:* One first-year Humanities sequence
Year: U (1) 3–0–6
Philosophical reflection on the nature of man: meaning of being a human being, living a human life. Cross-cultural perspectives, findings of the behavioral sciences, and insights from the history of philosophy. Laboratory attempts, through encounter group exercises, for affecting the climate of learning and providing experiential bases for themes considered. *(Limited enrollment. Advance permission of instructor required.)* *H. C. Smith*

24.351 *Religious Philosophy in the West*
(21.692) *Prereq.:* One first-year Humanities sequence
Year: U (1) 3–0–6
An examination of the conceptual components of Judaism, Christianity, and Islam. Principal historical developments and the contemporary scene. *(Not offered 1971–72.)* *H. C. Smith*

24.352 *Philosophies and Religions of Asia*
(21.691) *Prereq.:* One first-year Humanities sequence
Year: U (1) 3–0–6
Exploration of the distinctive perspectives of India and the Orient on the nature of the universe, the goal of human life, and the means by which this goal is to be achieved. Reading and discussion on the basic texts of Hinduism, Buddhism, Confucianism, Taoism and Japanese Zen; lectures on historical background.
H. C. Smith

24.353 *Contemporary Philosophy and Theology*
(21.96) *Prereq.:* 21.019, 21.020; or one subject in philosophy
Year: U (2) 3–0–6
Study of contemporary theological and philosophical though concerning the concept of God, the knowledge of God, language about God and the existence of God. Examination of the theology of Paul Tillich (part 1) in the light of selected writings, critical and constructive, of British and American philosophers (part 2) together with a consideration of new directions in contemporary religious thought (part 3). *W. R. Crout*

24.401 *Plato's Later Dialogues* (A)
(21.64) *Prereq.:* ——
Year: G (2) 3–0–9
Study of Plato's writings after the *Republic* on linguistics, epistemology and metaphysics. Special attention given to the place and character of the theory of forms in Plato's later thought on these subjects. ——

24.403 *Aristotle* (A)
(21.649) *Prereq.:* ——
Year: G (2) 3–0–9
A study of some of Aristotle's most important works on metaphysics and logic. *(Not offered 1971–72.)* ——

24.411 *The British Empiricists* (A)
(21.657) *Prereq.:* ——
Year: G (2) 3–0–9
Selected topics in the history of British Empiricism. *(Not offered 1971–72.)* *B. A. Brody, S. Bromberger*

24.413 *The Continental Rationalists* (A)
(21.661) *Prereq.:* ——
Year: G (1) 3–0–9
Studies in the writings of Descartes, Spinoza, and Leibniz. *(Not offered 1971–72.)* *R. L. Cartwright*

24.415 *Kant* (A)
(21.658) *Prereq.:* ——
Year: G (1) 3–0–9
Critical examination of the logical, epistemological, and metaphysical doctrines of Kant. Main text: *The Critique of Pure Reason.* Some attention to his views in the *Prolegomena*, the *Inaugural Dissertation*, and some of his early writings. *B. A. Brody*

24.421 *Background of Contemporary Philosophy* (A)
(21.665) *Prereq.:* ——
Year: G (1) 3–0–9
Frege; the early philosophies of Moore and Russell, and associated continental movements; logical atomism. *(Not offered 1971–72.)* *R. L. Cartwright*

24.501 *Problems in Metaphysics* (A)
(21.678) *Prereq.:* —
Year: G (1) 3–0–9
Metaphysical problems centering around concepts such as existence, substance, attribute, relation, identity, and change. Readings from both classical and contemporary sources. *R. L. Cartwright*

24.511 *Problems of Knowledge* (A)
(21.659) *Prereq.:* —
Year: G (2) 3–0–9
Study of problems concerning the foundation of knowledge, with special attention to our concepts of evidence, belief, doubt, knowledge, certainty and philosophy. *(Not offered 1971–72.)* *G. Boolos*

24.521 *Philosophy of Mind* (A)
(21.716) *Prereq.:* —
Year: G (1) 3–0–9
Some concepts and problems in the philosophy of mind, such as the relations between minds and bodies, sensation and feeling, thinking and perceiving. *J. A. Fodor*

24.525 *Problems in the Theory of Action* (A)
(21.653) *Prereq.:* ——
Year: G (2) 3–0–9
The nature of human action. Problems regarding the description of an act and its consequences. Identity-conditions for acts. Intention. Explanation of actions by appeal to motives, reasons, and causes. The logical form of action sentences. Readings from selected texts and current journals. *J. J. Thomson*

24.531 *Philosophy of Religion* (A)
(21.693) *Prereq.:* ——
Year: G (1) 3–0–9
Emphasis on phenomenology's contribution to the field. The nature and function of religion; religious symbolism; the problem of evil; God, transcendence, salvation, faith, hope, guilt; death. *(Not offered 1971–72.)* *H. C. Smith*

24.601 *Moral Philosophy* (A)
(21.651) *Prereq.:* ——
Year: G (1) 3–0–9
Systematic study of some problems of moral philosophy. Special attention to the justification of moral evaluation of actions and the relevance to this of intentions, motives, and consequences. Readings chiefly from contemporary sources. *J. J. Thomson*

24.605 *Responsibility in Law and Morality* (A)
(21.654) *Prereq.:* ——
Year: G (1) 3–0–9
Examination of concepts such as purpose, causation, act and omission and their bearing on issues of responsibility in law and morality. *(Not offered 1971–72.)* *G. B. Dworkin*

Descriptions

24.611 *Topics in Political Philosophy* (A)
(21.666) *Prereq.:* ——
Year: G (2) 3–0–9
The political theory of capitalism and socialism. A study of the political theories involved in the theory and practice of capitalist and socialist systems. Special attention to the moral considerations involved. ——

24.621 *Aesthetics* (A)
(21.639) *Prereq.:* ——
Year: G (1) 3–0–9
Philosophical problems related to the history and theory of art. The nature and philosophical significance of our aesthetic experience. Particular works of art — poems, photographs, musical compositions, films — will be experienced and studied and a small part of the philosophical literature on aesthetic experience will be examined in detail. (*Not offered 1971–72.*) *M. A. Levensky*

24.701 *Topics in Logic* (A)
(21.674) *Prereq.:* 24.241
Year: G (2) 3–0–9
Soundness, completeness and compactness of first-order logic, Löwenheim-Skolem theorems, Craig interpolation lemma. Beth definability theorem, decidability of monadic logic with identity. Turing machines, recursive functions and their definitions, Gödel incompleteness theorems and extensions, undecidability of dyadic logic, Tarski's theorem, nonstandard models of arithmetic. *J. F. Thomson*

24.703 *Set Theory* (A)
(21.648) *Prereq.:* 24.241
Year: G (2) 3–0–9
Zermelo-Fraenkel set theory. Topics include: the paradoxes and their resolutions, relations, functions, orderings, ordinals, the "reduction" of arithmetic to set theory, types and the general structure of the universe of set theory, cardinals, orders of infinity, the continuum question, König's theorem, the concept of truth, the Löwenheim-Skolem theorem, the reflection principle, measurable and inaccessible cardinals. *G. Boolos*

24.705 *Modal Logic* (A)
(21.675) *Prereq.:* 24.241
Year: G (1) 3–0–9
Systems of modal logic. Completeness and consistency problems. Models for such systems. Quantified modal logic. Relations with intuitionistic logic. Emphasis largely formal, but some attention paid (if time permits) to philosophical issues. (*Not offered 1971–72.*)
G. Boolos, J. F. Thomson

24.711 *Philosophy of Logic* (A)
(21.642) *Prereq.:* ——
Year: G (1) 3–0–9
Relations between logical operators and their ordinary language counterparts; questions about logical form, logical truth, analyticity, reference, presupposition, and "ontological commitment;" times and tenses; problems about modality and identity. (*Not offered 1971–72.*)
G. Boolos

24.721 *Philosophy of Language* (A)
(21.724) *Prereq.:* ——
Year: G (2) 3–0–9
Study of recent philosophical movements concerned with a linguistic treatment of traditional philosophical problems; in particular, logical positivism and ordinary language philosophy. Consideration of certain philosophical problems within the framework of transformational theory of grammar, e.g., the problem of innate knowledge, analyticity, categories, logical form, and speech acts. *J. J. Katz*

24.723 *Semantics*
(21.721) *Prereq.:* ——
Year: G (1) 3–0–9
Characterization of the form of a semantic theory for natural languages within the framework of the transformational theory of grammar. Topics: the explanatory goals of semantic theory, the representation of propositions within grammars, presupposition, analyticity and other forms of linguistic truth, the logic of questions, referential opacity, temporal relations, the converse relation, the distinction between syntactic and semantic representation, deep structure and its interpretation, surface structure and its interpretation, and an examination of aspects of linguistic communication that fall outside grammatical theory (e.g., Grice's theory of conversational implicature.) *J. J. Katz*

24.727 *Logic and Language* (A)
(21.673) *Prereq.:* ——
Year: G (2) 3–0–9
Logic and language: an investigation of the relation between the syntactic and semantic representations of natural language sentences, provided by generative grammars and the formal representations provided by standard logical theories. Some, at least, of the following topics: quantifiers, opaque contexts, specificity, tense, connectives, modal operators, the notion of "logical form," "generative" and "interpretive" accounts of sentences, definitions. Acquaintance with the standard works in generative syntax and analytic philosophy of language will be presupposed. *J. A. Fodor*

24.801 *Philosophy of Mathematics* (A)
(21.714) *Prereq.:* ——
Year: G (1) 3–0–9
Examination of major philosophies of mathematics — logicism, formalism, intuitionism — on the nature of mathematical proof, existence of mathematical entities, and related issues. (*It is strongly recommended that students have taken 24.241 or equivalent.*) *G. Boolos*

24.811 *Philosophy of Physics* (A)
(21.715) *Prereq.:* 8.04
Year: G (2) 3–0–9
Discussion of philosophical problems concerning the foundations of classical mechanics, special relativity, general relativity, and quantum mechanics. Special consideration of such basic concepts as space, time, and causality. Analysis of both standard and non-orthodox accounts, and emphasis on the ontologies that emerge from these theories. (*Undergraduates admitted by consent of instructor. Not offered 1971–72.*) *J. C. Graves*

24.821 *Philosophy and the Life Sciences* (A)
(21.663) *Prereq.:* ——
Year: G (2) 3–0–9
Selected concepts and empirical findings in the life sciences examined for their possible relevance to various problems of philosophy: e.g., current psychiatric and ethological theories about innate behavior studied in their relation to philosophical questions about human sexuality, aggression, and the nature of instinct. (*Not offered 1971–72.*) *I. Singer*

24.851 *Problems of Explanation and Theory Formation* (A)
(21.656) *Prereq.:* ——
Year: G (2) 3–0–9
Problems about the nature of explanation, the evaluation of competing explanations, and the relation of observation to theory. *S. Bromberger*

24.853 *Induction* (A)
(New)
Prereq.: ——
Year: G (1) 3–0–9
The classical problem of induction: attempts to solve or dissolve it; recent work on inductive logic and on the philosophy of probability. *J. F. Thomson*

24.901 *Graduate Seminar* (A)
(21.781) *Prereq.:* ——
Year: G (1) *Arr.*
Seminar in the teaching of philosophy. (*Permission of instructor required.*) *S. Bromberger*

24.911 *Graduate Seminar* (A)
(21.782) *Prereq.:* ——
Year: G (2) *Arr.*
A graduate proseminar in which students present original work. (*Second- and third-year graduate students in philosophy must attend unless explicitly excused. First-year graduate students in philosophy are invited to participate.*) *Staff*

24.921 *Special Advanced Topics in Philosophy*
(21.793) **(A)**
Prereq.: ——
Year: G (1) *Arr.*
Open to qualified graduate students in philosophy who wish to pursue special studies or projects. *Staff*

24.922 *Special Advanced Topics in Philosophy*
(21.794) **(A)**
Prereq.: ——
Year: G (2) *Arr.*
Open to qualified graduate students in philosophy who wish to pursue special studies or projects. *Staff*

AS
Aerospace Studies

AS11 *U.S. Military Forces*
(Revised: Unit change)
Prereq.: ——
Year: U (1) 1–0–1
Examination of the role of U.S. military forces in the contemporary world, with particular attention to the United States Air Force, its doctrine, organization and mission. *R. H. Grenier*

AS111 *Corps Training*
Prereq.: ——
Year: U (1) 0–1–0

AS121 *Corps Training*
Prereq.: AS111
Year: U (2) 0–1–0
Introduction to customs and traditions, courtesies, and drill procedures in the Air Force through seminars and guest speakers. *Staff*

AS21 *Introduction to Defense Policy*
(New)
Prereq.: AS11
Year: U (2) 1–0–1
Study and analysis of the organization and functions of the Department of Defense and the role of the military in U.S. national policies. *R. H. Grenier*

AS211 *Corps Training*
(New)
Prereq.: AS121
Year: U (1) 0–1–0

AS221 *Corps Training*
(New)
Prereq.: AS211
Year: U (2) 0–1–0
Analysis of the employment of Air Force resources. Emphasis on the opportunities and environment in Air Force life. Continued development of ability to give information and direction to other students in drill procedure. Preparation for attendance at Field Training. *Staff*

AS31 *Seminar in Growth and Development of Aerospace Power*
(Revised: Unit change)
Prereq.: AS21
Year: U (1) 3–0–3
Focuses on the development of air power and aerospace power including doctrine, technology, organization and the utilization of manned and unmanned aircraft and space vehicles. Emphasis on current and projected technology with an introduction into the history of aerospace power. (*Six weeks of field training is an acceptable prerequisite for AS31 in lieu of AS21.*) *D. B. Foisy*

AS311 *Corps Training*
Prereq.: AS221
Year: U (1) 0–1–0

AS321 *Corps Training*
Prereq.: AS311
Year: U (2) 0–1–0
Supervisory practice and exercise of leadership functions in controlling and improving the activities of the cadet corps. Development of leadership potential in a practical, supervised training laboratory, which typically includes field trips to Air Force installations. *Staff*

AS41 *Seminar in Air Force Leadership*
(Revised: Unit change)
Prereq.: AS31
Year: U (1) 3–0–3
Theory and application of general concepts of leadership to Air Force situations. Includes a study of professionalism, the variables affecting leadership, the Military Justice System and interactional approaches to leadership. Emphasis on the communicative process. *Staff*

AS411 *Corps Training*
Prereq.: AS321
Year: U (1) 0–1–0

AS421 *Corps Training*
Prereq.: AS411
Year: U (2) 0–1–0
Exercise of management functions in planning, supervising and directing cadet corps activities. Acquire proficiency in military leadership skills. Preparation for professional duties. *Staff*

AS42 *Seminar in Management Principles*
(Revised: Unit change)
Prereq.: AS41
Year: U (1) 3–0–3
General theory and practice of management with special reference to Air Force application. Introduction to information systems, quantitative approaches to decision-making and resource control techniques. *Staff*

AS421 *See above following* AS411.

MS

Military Science

MS11 ***Military Organization, Tactics, and Communication***
Prereq.: ——
Year: U (1, 2) 2–0–1
Introduction to the U.S. Army through a discussion of military organization, fundamentals of tactics, and communications. *Staff*

MS111 ***Leadership Development***
Prereq.: ——
Year: U (1) 0–1–0
Fundamental development of leadership abilities and military skills through practical exercises. *Staff*

MS121 ***United States Military History***
Prereq.: MS 111
Year: U (2) 0–1–0
Discussion of the historical development of the U.S. Army. *Staff*

MS21 ***Principles of Leadership***
Prereq.: ——
Year: U (1, 2) 2–0–1
A discussion of the study of military leadership centered around the role of the military leader at the lower echelons of the command structure. The principles and techniques of military leadership are discussed and applied through practical work. *Staff*

MS211 ***Leadership Development***
Prereq.: MS 121
Year: U (1) 0–1–0
Continued development of leadership abilities and military skills through practical application. *Staff*

MS221 ***Leadership Development***
Prereq.: MS211
Year: U (2) 0–1–0
Continuation of MS211. *Staff*

MS31 ***Principles of Military Management, Operations, and Logistics***
Prereq.: ——
Year: U (1, 2) 2–0–1
Principles and techniques of military operations, management, organization, and logistics emphasizing effective and economical utilization of men and material. *Staff*

MS311 ***Leadership Development***
Prereq.: MS 221
Year: U (1) 0–1–0
Advanced development of leadership abilities through problem solving process. Also, a detailed discussion of the roles of the branches of the Army. *Staff*

MS321 ***Leadership Development***
Prereq.: MS 311
Year: U (2) 0–1–0
Continuation of MS311. *Staff*

MS41 ***Principles and Applications of Military Law and Administration***
Prereq.: ——
Year: U (1, 2) 2–0–1
Study and application of junior officer's leadership role in the military environment; with detailed discussion of his role in military law and unit administration. *Staff*

MS411 ***Leadership Development***
Prereq.: MS321
Year: U (1) 0–1–0
Method of instruction and application of teaching principles. Organization and implementation of the leadership development program. *Staff*

MS421 ***Leadership Development***
Prereq.: MS411
Year: U (2) 0–1–0
Continuation of MS411; customs and traditions of the service; precommissioning orientation. *Staff*

NS

Naval Science

NS11 ***Naval Organization and History***
Prereq.: ——
Year: U (1) 0–2–0
Fundamentals of naval organization and the historical development of seapower and naval tactics. This course is directed toward introducing military concepts and structure and includes a discussion of customs and traditions. *Staff*

NS12 ***Naval Engineering***
Prereq.: ——
Year: U (2) 0–3–0
Lecture series on technological fundamentals of applied and planned Naval Engineering Systems. *Staff*

NS21 ***Naval Weapons Systems***
Prereq.: ——
Year: U (1) 0–3–0
Lecture series on components, design and employment of modern Naval Weapons Systems. *Staff*

NS22 ***Seapower and Maritime Affairs***
Prereq.: ——
Year: U (2) 0–2–0
Seminar series to stimulate and develop an interest in and awareness of current problems affecting Naval and Maritime development. Topics discussed cover a wide spectrum of issues including oceanography, the Merchant Marine, naval strategy and the Vietnam War. *Staff*

NS31 ***Naval Operations and Navigation***
Prereq.: ——
Year: U (1) 0–2–0
Study of the tactical and planning considerations relative to the employment of naval forces and an introduction to the principles of navigation. *Staff*

NS32 ***Naval Operations and Navigation Laboratory***
Prereq.: ——
Year: U (2) 0–3–0
Pre-cruise preparation in applied aspects of ship operations, including navigation, maneuvering board and watch-standing. *Staff*

NS41 ***Defense Management***
Prereq.: ——
Year: U (1) 0–2–0
Management principles and techniques as employed within the Defense establishment. Topics include Systems Analysis, Budget Formulation, and the Resources Management Concept. *Staff*

NS42 ***Naval Management***
Prereq.: ——
Year: U (2) 0–3–0
Management principles and techniques as employed within the Naval Establishment. Areas covered include Shipyard and Shipboard Organization and Management, Material and Project Management, and Naval Information Systems. *Staff*

NS51J ***Water, Air and Interface Vehicles***
(*Revised: Unit change*)
(Same subject as 13.64J)
Prereq.: ——
Year: U (2) 2–0–6
The competitive position of diverse water, air and interface vehicles in the world today determined from basic engineering principles. Development of the concepts of buoyancy, hydrodynamic life, hydrodynamic drag, propulsor thrust and scaling laws as applied to surface ships, deep submersibles, dirigibles, airplanes, hydrofoil craft, planing craft and air-cushion vehicles. Comparison of the most significant performance criteria among these different vehicle types as well as evaluation of the effect of vehicle size, and speed and fluid density on these performance criteria. *P. Mandel, W. R. Porter*

SEM

Undergraduate Seminar

SEM11 ***Undergraduate Seminar***
Prereq.: ——
Year: U (1, 2) 0–6–0
SEM12 ***Undergraduate Seminar***
Prereq.: ——
Year: U (1, 2) 0–6–0
Seminar and/or research work for undergraduates in a small group under leadership of a staff member. A description of seminars and research projects offered is published each term. Application for all seminars is made to the Undergraduate Seminar Office, Room 7-105. *Staff*

SEM211 ***Undergraduate Teaching Seminar***
Prereq.: ——
Year: U (1, 2) 2–5–5
Student teaching program in cooperation with the Cambridge School System providing opportunity to teach at the high school level in the areas of science, mathematics, English, or social studies. Concurrent seminars at M.I.T. allowing discussion of situations arising from the teaching experience and providing a systematic review of educational theories. Outside lecturers participating. Acceptance to the program at the discretion of the Instructor and the Headmaster of the Cambridge high school involved. *L. Menand, J. McIntyre*

SEM212 ***Undergraduate Teaching Seminar***
Prereq.: ——
Year: U (1, 2) 2–0–10
Seminar oriented towards research in particular issues arising from SEM211 but without simultaneous teaching. Topics ranging from preparation for SEM211 to analysis of particular issues arising from work in SEM211. *L. Menand, J. McIntyre*

SEM311 ***Undergraduate Teaching Seminar***
Prereq.: ——
Year: U (1) *Arr.*
Teaching assistant program in the Experimental Study Group, providing opportunity to instruct M.I.T. freshman (under faculty supervision) in learning skills and facts relevant to mathematics, physics, chemistry, humanities, engineering, and computer science. Cooperation with M.I.T. faculty members in leading seminars and discussion groups. Acceptance to the Program by decision of the M.I.T. faculty member in charge of the particular area in the Experimental Study Group. *G. E. Valley*

SEM312 ***Undergraduate Teaching Seminar***
Prereq.: ——
Year: U (2) *Arr.*
Continuation of SEM311. *G. E. Valley*

SEM41 ***Undergraduate Policy Seminar***
Prereq.: ——
Year: U (1, 2) *Arr.*
SEM42 ***Undergraduate Policy Seminar***
Prereq.: ——
Year: U (1, 2) *Arr.*
Analysis of the application of multidisciplinary techniques to current social and national problems to enhance the relevance of a technical education to contemporary life. (*Enrollment limited to 20 students and permission of the instructor.*) *C. L. Wilson*

SPS

Special Studies

SPS1 ***Special Summer Program***
Prereq.: ——
Year: U (S) *Arr.*
Program intended to assist freshmen in developing and sharpening their knowledge and facility with those concepts, techniques and skills, primarily mathematical and verbal, that are essential for a successful academic performance in the freshman year, to enable them to develop gradually individual styles, study habits and discipline that will lead smoothly into the first year's mode of operation, expectations and quality and quantity of workload, and to introduce the students to M.I.T. and its surrounding community under conditions somewhat moderated from those that characterize the fall and spring academic terms. The program consists of two areas: humanities, dealing with the issues of society and self-identity through the reading, writing, evaluation and discussion of novels, autobiographies, essays and critical articles; combined physics and mathematics, which will review and expand upon high school level physics, algebra, geometry, and trigonometry, and will introduce, where possible, Newtonian mechanics, electricity, magnetism, functions, limits, differentiation and integration as taught in 8.011 and 18.011. Credit will be arranged. (*Enrollment by invitation of the Admissions Office.*) *P. E. Gray*

SPS11 ***Experimental Study Group***
Prereq.: ——
Year: U (1) *Arr.*
Special program for a limited number of freshmen who prefer independent study and are willing to accept the attendant risks.

SPS12 ***Experimental Study Group***
Prereq.: ——
Year: U (2) *Arr.*
Continuation of SPS11. *G. E. Valley*

Descriptions

SPS13 ***Unified Science Study Program***
Prereq.: ——
Year: U (1) *Arr.*

SPS14 ***Unified Science Study Program***
Prereq.: ——
Year: U (2) *Arr.*

Interdisciplinary problem-oriented freshman program which provides students with the opportunity to choose and investigate topics and problems with the guidance of staff members in the various sciences and humanities. This full-time program permits many different modes, paces, and areas of study and should be useful to the student who has not narrowed his interest to a specific discipline or career. *J. R. Zacharias*

SPS21 ***Experimental Study Group***
Prereq.: SPS12
Year: U (1) *Arr.*

Special program for members of the Class of 1974 who participated in SPS11 and SPS12 their freshman year. Continuation of SPS12. *G. E. Valley*

SPS22 ***Experimental Study Group***
Prereq.: SPS21
Year: U (2) *Arr.*

Continuation of SPS21. *G. E. Valley*

SPS23 ***Unified Science Study Program***
Prereq.: ——
Year: U (1) *Arr.*

SPS24 ***Unified Science Study Program***
Prereq.: ——
Year: U (2) *Arr.*

Interdisciplinary problem-oriented sophomore program which provides students with the opportunity to choose and investigate topics and problems with the guidance of staff members in the various sciences and humanities. This full-time program permits many different modes, paces, and areas of study and should be useful to the student who has not narrowed his interest to a specific discipline or career. *J. R. Zacharias*

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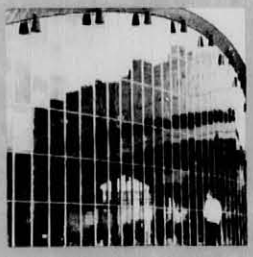
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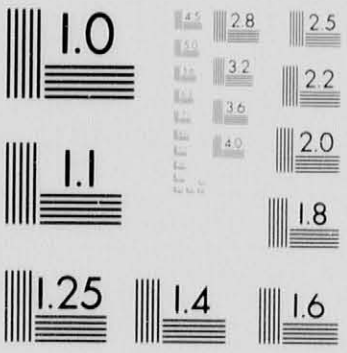













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