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Massachusetts Institute of Technology



REPORTS

OF THE

PRESIDENT, SECRETARY,

AND

DEPARTMENTS.

1871-72.

BOSTON:
PRESS OF A. A. KINGMAN.
1872.

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MASSACHUSETTS INSTITUTE

OF

TECHNOLOGY.

PRESIDENT'S REPORT.

To the Corporation of the Institute.

GENTLEMEN :—Your attention is respectfully invited to the accompanying reports, as carefully prepared statements of the condition of the departments to which they relate, and leaving but little to be said in addition.

Since the report of the department of Mining and Metallurgy was put in type, Mr. Samuel Bachelder, of Cambridge, has presented to the Institute his very ingenious dynamometer, which accurately weighs all the power transmitted through it. This will enable the department to keep an exact record of all the power used in the mining and metallurgical laboratory in running all or any of the machines in use. We have also received a Blake crusher, size 3' by 5', and a 12 inch Whelpley and Storer dry pulverizer. The new smelting and blast furnaces have been fully designed by Prof. Ordway, and their construction begun.

Our thanks are due to H. J. Booth & Co., of the Union Iron Works, San Francisco, California, for a very large and generous reduction in the price of the machinery furnished by them; and it is but justice to I. M. Scott, Esq., of that firm,

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who designed and built the five-stamp battery now in our laboratory, expressly for the Institute, to say that it is complete in all its parts, and gives entire satisfaction. Our thanks are also due to Col. J. J. Storer, for a large reduction in the price of his pulverizer.

Prof. Henck and a party of fifteen students in the department of Civil Engineering left Boston, on Thursday, the 6th of June, for the purpose of making a systematic study of the great railroad bridges over the Hudson, Ohio, Mississippi and Missouri rivers. On the way out each bridge will be examined by the whole party under Prof. Henck's direction, and a particular bridge assigned to each student, which he will be required to study in greater detail on his return; obtaining sketches and measurements of foundations and superstructure, and all the data for making a full report, accompanied with drawings of plan, elevation, sections, and all details necessary for the construction. We hope to do this summer for bridge construction, what was done the last for Mining Engineering and Metallurgy. It is proposed, hereafter, to make bridge construction a very important element in the course, and to this end it is earnestly recommended that models of all the important types of American bridges be supplied to the department as soon as possible.

We are well supplied with excellent field instruments, and the number is increased as fast as needed; but we have been, and still are, dependent upon the kindness of Prof. Peirce, Sup't. of the Coast Survey, for the use of a base-line measure, and a large altitude and azimuth instrument for triangulation, and for obtaining astronomical data for positions. It is most convenient for the department to use these instruments at the time when the subjects properly come in the course, and not when they can be best spared, if at all, by the Survey; and on this account it is very desirable that they be added to the collections of the department.

The work in the department of Drawing, both free-hand and mechanical, has upon the whole, been well maintained. Mr.

Schubert was absent last year for the purpose of study, and the break in the free-hand work, thus caused, has not been fully made up during the session just ended; but it is already evident that the department will be a great gainer in the end by the increased knowledge and appliances for instruction, which Mr. Schubert brought back as the fruit of his year's study in the celebrated art school of Nuremberg. The work in Descriptive Geometry and Stereotomy and the corresponding courses in Mechanical Drawing, will hereafter be under the same direction during the whole four years, which is expected to result in an improvement.

I am authorized by Hon. John Amory Lowell to announce that it is his intention to establish courses of instruction in the Institute in Désignant as applied to the Industrial Arts.

These courses will be duly announced.

The Faculty of the School of the Institute has been increased during the past year by the appointment of Thomas Sterry Hunt as Professor of Geology, George H. Howison as Professor of Logic and the Philosophy of Science, and S. Edward Warren, as Professor of Descriptive Geometry, Stereotomy and Drawing. These gentlemen, eminent in their respective departments, will enter upon their duties with the new year.

At the recent entrance examinations, held June 3, and the following days, sixty-four applicants were admitted, sixty-two to the first year's class, and two to the second; an increase of thirteen over the corresponding examinations of last year. If the same proportional increase shall hold at the fall examinations the new class will largely exceed one hundred, and we shall be obliged to consider the question of a new building to meet the growing demands for space in which to properly carry on our work.

It gives me the greatest pleasure to be able to say that the most friendly and cordial relations continue to prevail between teachers and students, and that the past year's work in all departments has been of the most satisfactory character.

In accordance with your vote, the following brief sketch is appended for those who are interested in the origin and progress of the Institute in its several departments.

In the years 1858 and 59, an association of gentlemen residing in and near Boston, interested in the professional applications of science, and in the practical and fine arts, conceived the idea of securing the proper site on which to erect, in close proximity, such buildings as might be suitable and necessary for the purpose of the museums and collections of the Natural History Society, the Horticultural Society, and such others as might be formed representing the Industrial and Fine Arts, so as by their union and coöperation to constitute a comprehensive Museum, or Conservatory of Arts and Sciences.

With this view, after organizing as a "Committee of Associated Institutions," Hon. Marshall P. Wilder, Chairman, and Dr. Samuel Kneeland, Secretary, they petitioned the Legislature for a grant of land on the Back Bay, on which to erect buildings suitable for the proposed purposes.

At about the same time, Mr. William E. Baker had also suggested the desirableness of building up in some convenient location in Boston a Conservatory of Arts, and published some numbers of a Journal in advocacy and aid of the idea.

The time, however, seemed not yet to have come; the Legislature refused to make the grant of land, but the Committee, instead of being disheartened, redoubled their efforts.

About this time the matter was brought to the attention of Prof. William B. Rogers, whose deep interest in such subjects, and whose ability to aid in devising and consummating the proper plans to secure the desired ends, were well known. He prepared a memorial to the Legislature of 1860, which was adopted by the Committee. In this memorial we find the first suggestion of a School of Applied Science, in the plea for the early establishment of a "Comprehensive Polytechnic College," furnishing a "complete system of industrial education supplementary to the general training of the other institutions,

and fitted to equip its students with every scientific and technical principle applicable to the industrial pursuits of the age."

This, like the previous effort, failed to secure the favor of the Legislature, but it attracted attention to the growing importance of practical education, and led the way to the more definite scheme of organization which was developed in a Report by Prof. Rogers, and adopted by the Committee in the autumn of 1860. This Report, entitled "Objects and Plan of an Institute of Technology; including a Society of Arts, a Museum of Arts, and a School of Industrial Science," was read at a meeting of gentlemen interested in the establishment of an Institute of Technology, held at the rooms of the Board of Trade, October 5, 1860, and, on vote, was approved, and its publication recommended. The wide circulation of this able report, accompanied by an appeal to the public for coöperation and support, led to the calling of a meeting on Jan. 11, 1861, at Mercantile Hall, Summer St., "for the purpose of adopting measures preliminary to the organization of the Institute, and in furtherance of a petition to the Legislature for a charter, and a portion of the Back Bay lands."

The number of subscribers at this time amounted to 209.

The meeting was held at the appointed time; and after an exposition, by the Chairman, of the previous action and future purposes of the Committee, and interesting addresses by Prof. Peirce, Rev. Dr. Gannett, and others, in behalf of the Institute, a preliminary organization was established by adopting the following form of association, to which the names of those present were affixed: —

"We the subscribers, feeling a deep interest in promoting the Industrial Arts and Sciences as well as Practical Education, heartily approve the objects and plan of an Institute of Technology, embracing a Society of Arts, a Museum of Arts, and a School of Industrial Science, as set forth in the Report of the Committee; and we hereby associate ourselves for the purpose of endeavoring to organize and establish in the city of Boston such an Institution, under the title of 'The Massachusetts Institute of Technology,' whensoever we may be legally empowered and properly prepared to carry these objects into effect."

The following resolutions were then adopted:—

“*Resolved*, That a Committee of twenty, with power to increase their number, be appointed to represent the interests and objects of the Association, and to act generally in its behalf, until it shall be legally incorporated and regularly organized under the title, and according to the purposes, of the Massachusetts Institute of Technology.

“*Resolved*, That said Committee be instructed to use its best efforts, in co-operation with the Committee of Associated Institutions of Science and Arts, to obtain from the Legislature an Act of Incorporation of the Institute, and secure a grant of land on the Back Bay for its use, and for that of other institutions devoted to the Practical Sciences.

“*Resolved, further*, That this Committee be requested to frame a Constitution and By-laws for the government of said Institute in its several departments, and to submit the same to the consideration of this Association, whenever we may be in readiness, and properly empowered, to organize formally as the Institute of Technology.”

Subsequently, on motion, the Chairman of the meeting was added to the Committee, to act as its Chairman.

The members of this Committee are as follows:—

W. B. ROGERS, *Chairman*.

J. M. BEEBE.

E. S. TOBEY.

S. H. GOOKIN.

E. B. BIGELOW.

M. D. ROSS.

J. D. PHILBRICK.

F. H. STORER.

J. D. RUNKLE.

C. H. DALTON.

E. C. CABOT.

J. B. FRANCIS.

J. C. HOADLEY.

M. P. WILDER.

C. L. FLINT.

THOS. RICE.

JOHN CHASE.

J. P. ROBINSON.

F. W. LINCOLN, Jun.

THOS. ASPINWALL.

J. A. DUPEE.

This Committee, in coöperation with the Committee of Associated Institutions of Science and Arts, again applied to the Legislature for a charter and land, which was granted in an act approved April 10, 1861. This act made “William B. Rogers [and others named] a body corporate, by the name of the Massachusetts Institute of Technology, for the purpose of instituting and maintaining a Society of Arts, a Museum of Arts, and a School of Industrial Science, and aiding generally, by suitable means, the advancement, development and practical application of science in connection with arts, agriculture, manufactures and commerce.”

It also granted one square of land bounded on the east and west by Berkeley and Clarendon Streets, and on the north and

south by Newbury and Boylston Streets, the easterly one-third to the Boston Society of Natural History, and the remaining two-thirds to the Institute of Technology, with the condition that neither corporation should cover more than one-third of the land granted to it with buildings.

The Institute was formally organized under the charter, April 8th, 1862, by the election of William B. Rogers, President; John A. Lowell, Jacob Bigelow, Marshall P. Wilder and John Chase, Vice-Presidents; Thomas H. Webb, Secretary; Charles H. Dalton, Treasurer; and through the liberality of some gentlemen interested in the undertaking, sufficient funds were immediately raised to begin operations.

The first meeting of the Society of Arts was held December 17, 1862. Since that time it has continued to hold two meetings a month during the successive sessions; the 146th meeting having been held May 23, 1872. At these meetings are presented communications on various subjects of applied science, with the exhibition of machines and apparatus illustrating important inventions in the mechanic arts.

By an Act of the General Court of Massachusetts, approved April 27, 1863, the Institute receives from the State "one-third part of the annual interest or income which may be received from the fund created under, and by virtue of, the 130th chapter of the Acts of the 37th Congress, at the second session thereof, approved July 2, 1862. . . . Said Institute of Technology, in addition to the objects set forth in its Act of incorporation, shall provide for instruction in military tactics."

A report by Prof. Rogers, on the "Scope and Plan of the School of Industrial Science of the Massachusetts Institute of Technology," was submitted to the Government by the Committee on the School of Industrial Science, and adopted May 30, 1864. This elaborate and carefully considered scheme forms the basis of the instruction in all departments, with only such changes and additions in the details of the organization and equipment of the laboratories as time and experience could alone determine.

The School was opened with temporary accommodations in Mercantile Library Building, Summer Street, in Feb., 1865, with a class of 27 students. The successive catalogues show the following summaries: 1865-6, 72; 1866-7, 137; 1867-8, 167; 1868-9, 172; 1869-70, 206; 1870-71, 224; 1871-72, 264.

Besides the systematic day courses the Institute proposed as a part of its work "to provide evening instruction for persons of either sex, who, being unable to study during the day desire to avail themselves of systematic evening lessons or lectures." Before this part of the school was opened, the following letter was received:—

BOSTON, Oct. 26, 1865.

DEAR SIR:—

I propose to institute evening courses of instruction, to be opened gratuitously to the public, under such regulations as may be deemed advisable.

It has occurred to me that these courses might with advantage be delivered in the first instance under the supervision of the Massachusetts Institute of Technology, and by their professors; the programme of course to be acceptable to me.

I shall devote to this purpose \$3,000 a year, to be divided among the teachers in proportion to the time devoted by each.

If such an arrangement would be acceptable to the Government, I shall be happy to confer with you upon the subject.

Yours respectfully,
 (Signed) JOHN AMORY LOWELL,
Trustee Lowell Fund.

PROF. W. B. ROGERS,
President Mass. Inst. Tech.

The proposal of Mr. Lowell was gratefully accepted by the Government, and this important department of the school has since continued to be conducted with the approval of Mr. Lowell, and at the expense of the Lowell Fund.

Among the largest benefactors have been William J. Walker, Ralph Huntington, James Hayward, and William Powell Mason, deceased, and Nathaniel Thayer and John Amory Lowell. The following statement will show the amount of cash gifts which the Institute has thus far received.

In 1862, \$3,000; 1863, \$175,610; 1864, \$3,000; 1865, \$132,761; 1866, \$30,700; 1867, \$58,000; 1868, \$76,800; 1869, \$4,000; 1870, \$24,415; 1871, \$63,500; 1872, thus far \$3,300. Total, \$575,086.

Respectfully submitted,

J. D. RUNKLE.

SECRETARY'S REPORT

FOR THE YEAR MAY 1871—MAY 1872.

In conformity with article 16, section 4, of the By-Laws of the Corporation, I herewith present the Annual Report of the Transactions and condition of the Institute for the tenth year 1871-1872.

There have been held during the year fourteen meetings of the Society of Arts. The meetings have been generally well attended, and communications have been made on the following subjects:—

Nov. 9, 1871. President Runkle gave an account of the Institute expedition to Colorado and Utah during the summer, for the observation of the mines and mining processes. The party consisted of five professors and fifteen students. The expedition was in every way a success, both in giving the students valuable information and in securing for the Institute a large supply of ores from many localities.

Nov. 23. Prof. Richards gave an account of an expedition to Wyoming and the Laramie Plains, illustrated by a series of ores from the mining regions of Missouri, Colorado, and Utah.

Mr. Wm. E. Hoyt gave a description of several European bridges of modern construction, illustrated by black-board drawings and a set of models belonging to the Department of Civil Engineering in the Institute.

Prof. Pickering explained the methods of teaching physical manipulation in the Physical Laboratory as regards the engineering course, and with special reference to bridges.

Prof. Watson exhibited a modification of the endless screw, by which the wheel is made the driver and the screw the follower — a very convenient form for obtaining considerable speed.

Dr. Samuel Gregg exhibited and explained a model of a system of ventilation, devised by himself, by which he claimed that a free ventilation can be obtained in cold weather without loss of heat.

Prof. Watson exhibited and described, by means of the calcium light, Prof. Faber's Speaking Machine, then on exhibition in Boston.

Dec. 24, 1871. The Secretary gave an account, from personal observation, of the way in which the bed of the Mississippi river, in the upper part of its course, is gradually filling up from the sediment carried in from newly cultivated fields in Minnesota and Wisconsin — and of the diminished rainfall from the destruction of forests — seriously interfering with the navigation of the river.

Prof. Cross made a communication upon the methods employed in illustrating the lectures on physics, by means of photographs projected on a screen.

The Secretary announced the donation to the Institute, by Thomas Gaffield, Esq., of two large and handsomely framed oil paintings, representing the manufacture of plate and of cylinder glass.

Dec. 28. Mr. Langley described a spliced joint for uniting rails — an automatic road-maker — and a working model of a machine for coiling wire to be used for inside support for rubber hose and for making all kinds of wire springs.

Mr. J. A. H. Ellis gave a description of his process of utilising the heat in exhaust steam to produce power in a second and connected boiler, by the use of bisulphide of carbon, a volatile liquid boiling at 110° Fahr., and at the temperature of exhaust steam giving a pressure of 65 lbs. to the inch.

Jan. 11, 1872. Dr. Sternberg, U. S. A., exhibited in operation and explained an electro-magnetic apparatus of his invention, the object of which is the automatic regulation of temperature, wherever artificial heat is employed and an equable temperature desirable.

Mr. James Hamblet, Jr., made a communication on electric clocks and the telegraphic distribution of time.

Jan. 25. Dr. Van Zandt, of California, exhibited in operation and explained an apparatus devised by himself for lighting and extinguishing street gas lamps by electricity.

Prof. Watson made a communication, illustrated by diagrams, on the ther engine. He also exhibited some models and drawings, the work of the students in the department of Stereotomy.

Feb. 8. Mr. E. H. Hewins read a communication, illustrated by the calcium light, on European and American bridges compared.

Prof. Watson made some observations on the history of ancient bridges.

Prof. Pickering exhibited specimens of so-called "mineral wool," made by blowing high-pressure steam through melted slag; this is well adapted for steam packings and similar purposes, being incombustible and a non-conductor of heat. He also showed a plate of glass on which an engraving had been cut by the sand blast; and called attention to various methods of photographic engraving, some of which promise to revolutionize the art of book-illustrations.

Mr. J. F. H. Markoe exhibited an improved achromatic stereoscope, from London, adjustable for all kinds of focal distances, and for each eye separately.

Feb. 22. Prof. Watson read a paper, illustrated by diagrams and models, on the history, construction, and recent improvements of turbine water wheels, accompanied by an account of some recent experiments to test their efficiency.

Prof. Richards made a communication, illustrated by the apparatus, on Gifford's Injector as a substitute for Bunsen's filter pump.

March 14. Mr. S. Dana Hayes read a paper, illustrated by experiments and specimens, on the "History and Manufacture of Petroleum Products."

March 28. Mr. McMurtrie explained by the aid of diagrams on the blackboard, the Blanchard boiler — in which the water space is divided by horizontal diaphragms into three nearly separate compartments, communicating only by small openings. He compared this boiler with other horizontal tubular boilers in Portland, Me., — stating that on a competitive trial a great advantage is claimed for it on the point of economy in fuel.

Prof. Richards explained the mining machinery recently put up in the laboratory of the Institute; after which the Society adjourned to witness its operation.

April 11. Mr. Langley exhibited and described a new fusible plug, and showed it in operation on a boiler.

Mr. J. A. Grosvenor explained a new injector, also exhibited it in operation.

Mr. Libby, of Medford, Mass., exhibited a model of a diagonal turbine water wheel of his invention.

April 25. Prof. Watson made a communication on Compound Marine Engines, illustrated by a model of the Engines of the Cunard Steamer "Hecla."

May 9. Mr. E. C. Merrill explained a process, invented by himself, of making artificial stone, illustrated by an extensive suite of specimens. His materials are oxide and chloride of zinc, and carbonate of baryta.

May 23. Mr. N. M. Lowe exhibited and explained a new instrument for recording by electricity the force and direction of the wind, devised by himself, with valuable suggestions from Mr. H. E. Cole.

Prof. Pickering then described the changes introduced in the department of Physics during the past year.

To show the practical nature of the work done this term by the students of the graduating class, a number of specimens of their handiwork were next described. They included a model

of a suspension bridge, having a span of about eight feet, a Howe truss, and a queen-post truss, and the flexure under different loads carefully measured by them. A new method of measuring the torsion or twisting of a beam under different loads was shown, using mirrors attached to each end, and placing opposite to them telescopes by which the reflection of a graduated scale was observed. A very slight motion of the beam and mirror moved the image of the scale several inches, so that extreme accuracy was thus attainable. The apparatus was also shown by which they had measured the coefficients of efflux or flow of water through apertures of various sizes, also the resistance or friction of water in pipes. These quantities form the basis of the science of hydraulics.

A chronograph for measuring very small intervals of time, as a hundredth or even thousandth of a second, was also shown. In this instrument, which was entirely the work of another student, Mr. Guild, the time is measured by the vibrations of a tuning fork drawing a line on smoked glass.

As work of quite a different kind, a collection of photographs were exhibited, taken by different students as a part of their regular studies, among them several views of objects seen under the microscope and greatly magnified. Although the platform and tables were covered with apparatus like the above, yet much remained that was not exhibited for want of room, showing that the amount of work done by the class was extremely large.

Among the advantages claimed for this kind of instruction the following may be mentioned: First, it cultivates the powers both of the mind and hand, and gives a thorough practical familiarity with methods of experimenting, commonly attained only by long and laborious trials on the part of the student after graduating, when called upon to perform these experiments in connection with his daily duties. Again, much of this work is of considerable scientific merit, and with proper means results might be obtained not only of great scientific value, but of

equal value to the mechanical arts, especially all matters relating to heat, steam and motors. The large amount of work is in a great measure due to the interest felt in the matter by the students themselves, who often come into the laboratory late in the afternoon, or during the dinner hour; and, since it becomes a pleasure, it is sure to be done well. Finally, many of the experiments once prepared by an older student can afterwards be used by the younger ones, and thus they are like so many assistants, improving the course for their successors at the same time that they are instructing themselves.

There have been elected during the year 13 members of the Society of Arts, of whom 12 have consummated their membership. One life member has joined during the year, Mr. Allen; no corresponding or honorary members have been elected.

Prof. Daniel Treadwell, the only Honorary Member, has died during the year; Mr. Jacob A. Allen, of Lynn, has also died, one of the victims of the Revere disaster. Deducting 2 who have died, 21 who have resigned, and 10 who have been dropped for non-payment of fees, there are now on the list 345 members, of whom 65 are life members, exempt from assessment.

About 280 students have attended the school of Industrial Science during the year. Of these, two are graduates pursuing an extended or post graduate course. In the first year were 91 students, in the 2d 39, in the 3d 33, in the 4th 17; and 90, not candidates for a degree, following various special or partial courses, principally chemistry, drawing, and architecture. Thirty-one professors and teachers are connected with the school, and the fees from the students have been about \$37,000.

The apparatus for instruction has been largely increased during the year. Full details on the various departments of the school have been presented by the professors in charge.

The Lowell courses this year have been given on the following subjects :

- A course of ten lectures on English Writers of the 18th and 19th Centuries, by Prof. Atkinson, on Wednesdays, at 7½ P. M. beginning November 15, 1871.
- A course of eighteen lectures on Progressive Development of Life in Geological Ages, by Prof. Kneeland, on Tuesdays and Fridays, at 7½ P. M., beginning November 14.
- A course of eighteen lessons in Elementary German, by Instructor Krauss, on Mondays and Thursdays, at 7½ P. M., beginning November 13.
- A course of eighteen lessons in Elementary French, by Instructor Levy, on Mondays and Thursdays, at 7½ P. M., beginning January 22, 1872.
- A course of twenty lectures in Elementary Chemistry, by Professors Richards and Nichols, on Tuesdays and Fridays, at 6½ P. M. beginning January 16.
- A course of twenty-four Laboratory Exercises in Chemical Manipulations, by Professors Richards and Nichols, on Wednesdays and Saturdays, at 2½ P. M., beginning February 3.
- A course of twenty-four Laboratory Exercises in Physics, by Prof. Pickering, on Wednesdays and Saturdays, at 2½ P. M., beginning February 3.

These courses were well attended, the greater number of persons availing themselves of the last two courses being engaged in teaching.

At a meeting of the Corporation, held June 13, the following votes were passed :—

Voted, That the Corporation will hereafter confer the degree of Bachelor of Science in the department of——, instead of graduate of the Massachusetts Institute of Technology, in the department of——, as heretofore.

Voted, To establish advanced courses of study and to confer the degree of Doctor of Science, subject to the following conditions :

1. *Advanced Students*. Bachelors of Science in any department of the Institute may enter upon these courses without examination ; but bachelors of arts, science, or philosophy, of any

other institution, must give satisfactory evidence, by examination or otherwise, that they are fully qualified to enter upon any proposed course of study.

Any person may enter upon an advanced course of study, and become a candidate for the degree of Doctor of Science, who, by examination, shall be found qualified to take the degree of Bachelor of Science in any department of the Institute.

2. *Advanced Courses.* The course of study which any student may wish to pursue must be presented in writing and approved by the Faculty. His proficiency in this course will be tested by frequent examinations. All departments will be open to him, but there will be no examination required in voluntary studies.

The methods of instruction, whether by lectures, or projects, or field or laboratory work, will be adapted to each particular case.

3. *Term of Residence.* The minimum term of residence will be two years, but the degree will not be given until the student shall have fully completed his chosen course.

Occasional short absences from the Institute, spent in professional work by the advice of the Faculty, will be counted as residence.

4. *Examinations.* Periodical examinations will be held to inform the student as to his progress; and the results of all such examinations, as well as of the semi-annual and degree examinations, will be taken into account in conferring the degree.

He must present at least one printed thesis upon some subject embraced in his course.

5. The fees will be \$150 a year, and the cost of materials consumed in laboratory work.

6. There are five advanced scholarships of \$150 each which will be awarded by the Corporation on recommendation of the Faculty. Applications must be made to Samuel Kneeland, the Secretary of the Institute, in writing, on before the first of October next.

SAMUEL KNEELAND, Secretary.

Massachusetts Institute of Technology.

REPORT OF THE DEPARTMENT OF GEOLOGY AND MINING ENGINEERING.

To the President of the Institute:—

The changes recently made in the department of Geology, Mining and Metallurgy, and the very considerable additions made to the means of instruction in these studies, more especially the establishment of a Mining and Metallurgical Laboratory, are sufficient reasons for calling the attention of the Corporation to the present condition of this department.

The regular course extends over four years, and the range of studies pursued is indicated by the following scheme of instruction.

FIRST AND SECOND YEARS.

Mathematics. Algebra. Solid Geometry. Mensuration. Plane Trigonometry and Spherical Trigonometry. Analytic Geometry. Elements of the Calculus.

Surveying. Field-work. Plotting Surveys. Computing Areas. Plans.

Physical and Industrial Geography.

Physics. Mechanics of solids, liquids and gases. Sound. Light. Heat. Magnetism. Electricity.

Chemistry. Qualitative Analysis. Chemistry, Organic and Inorganic.

French.

German.

English.

Descriptive Geometry.

Mechanical and Free-Hand Drawing.
Descriptive Astronomy.
Physiology and Hygiene.

THIRD YEAR.

Civil Engineering. Survey and Construction of Roads and Railways. Measurement of Earthwork and Masonry. Field Practice.
Mathematics. Differential and Integral Calculus. Analytic Mechanics.
Applied Mechanics. Stress. Stability. Strength and Stiffness.
Geology. General descriptive and theoretical Geology.
Zoology and Palæontology.
Mining. Ore-deposits. Prospecting. Boring. Sinking Shafts, etc. Methods of Mining.
Mineralogy. Descriptive and Determinative. Crystallography. Use of the Blowpipe.
Chemistry. Lectures and Laboratory Practice in Quantitative Analysis.
Assaying. Wet and dry ways.
Metallurgy. Metallurgical processes. Constructions and Implements.
Physics. Laboratory Practice.
English and Constitutional History.
French or Spanish.
German.
Drawing.

FOURTH YEAR.

Mining. Ventilation. Winding-machinery. Underground-transport. Pumps. Dressing and Concentration of ores. Practice in Mining Laboratory in Ore-dressing.
Economic Geology. Detailed description of American ore-deposits and mines.
Strength of Materials and Hydraulics.
Machinery and Motors. Hand-machinery. Water-wheels. Boilers. Steam-engines.
Chemistry. Lectures, and Laboratory Practice. Synthetic Experiments. Quantitative Analysis.
Geology. American Geology; Lithological, Stratigraphical, Palæontological.
Chemical Geology. Origin of rocks, vein-stones, ore-deposits, coal, petroleum, salt, etc.
Metallurgy.
Practical Lithology and Building materials.
Physics.

Drawing. Geological Maps and Sections. Plans of Mines. Mining Machinery and Implements.

English Literature.

Political Economy.

French or Italian.

German.

The four years' course is so arranged as to secure to the student a liberal mental development and general culture, as well as the more strictly technical education which is his chief object.

The studies of the first and second years are somewhat general in character, but are regarded as a necessary foundation for the more special studies of the two succeeding years.

The special professional studies peculiar to this department commence with the third year.

Instruction is given by lectures and recitations, and by practical exercises in the field, the laboratories and the drawing-rooms. In most of the subjects problems are given the students, to be worked out outside of the lecture-room. A high value is set upon the educational effect of these practical exercises.

The space devoted to laboratories, and the prominence given to laboratory work, in Physics, Chemistry, Assaying, Blowpipe-analysis, Metallurgy and Ore-dressing is a marked feature in the scheme of instruction of the Institute. It is believed that this school offers unusual facilities in this regard.

The Chemical Laboratories cover 4,000 square feet.

The Mining, Metallurgical, and Assay Laboratories cover 2,000 square feet.

The Blowpipe Laboratory covers 550 square feet.

The Physical Laboratories cover 3,500 square feet.

The Drawing Rooms cover 8,556 square feet.

A course of thirty lectures on Physical Geology and Geography is given to the students of the second year by Professor Niles.

The study of the surface of the earth, of its external fea-

tures, their origin and modifications, is essentially the subject of this course. A proper knowledge of the surface includes necessarily a corresponding acquaintance with the arrangement of rock-masses, in so far as they have determined the character of the surface-features, and especially the geological agencies which are constantly producing the changes of the surface.

The aim of the instruction, in the course of Prof. Niles is, therefore, to present clearly the most important relations between surface features and underlying geological formations, and to show the action of the great dynamical forces; or in other words to teach Physical Geography and Physical Geology in their natural relations.

The knowledge of these relations becomes of great practical value in determining the extent or even probable occurrence of certain ore-bearing rocks, and of coal-beds in certain districts, since, where the rocks are completely covered by soil, the topographical features may be the only guide in "prospecting."

EXERCISES, THIRD AND FOURTH YEARS.

Descriptive and Theoretical			
Geology	30 lectures	Prof. Hunt.	
American Geology	30 lectures	" "	
Practical Lithology and Building Stones	15 lectures	" "	
Chemical Geology	15 lectures	" "	
Mining	70 lectures	Prof. Rockwell.	
Economic Geology	20 lectures	" "	
Palæontology	50 lectures	Prof. Hyatt.	
Metallurgy	40 lectures	Prof. Ordway.	
Industrial Chemistry	40 lectures	" "	
Quantitative Analysis	40 lectures	Prof. Crafts.	
Chemical Laboratory Practice.	10 to 15 hours a week	" "	
Assaying, dry way	10 ex. (2½ hrs. each)	Prof. Richards.	
Blowpipe and Determinate Mineralogy	45. ex. (1 to 2 hrs. each)	" "	
Descriptive Mineralogy	15 lectures	" "	
Mining and Metallurgical Laboratory Practice	10 hours a week		
Physical Laboratory Practice	3 hours a week, 1 year	Prof. Pickering.	

Calculus	60 lessons	Pres. Runkle.
Mechanics	60 lessons	“ “
Civil Engineering	40 lessons	Prof. Henck.
Strength of Materials and Hy- draulics.	40 lessons	Prof. Watson.
Machinery and Motors	25 lessons	“ “
Natural History	25 lectures	Prof. Kneeland.
French	2 hours a week	
German	2 hours a week	
English	2 hours a week	
Drawing	3 to 6 hours a week	

GEOLOGY, LITHOLOGY, ETC.

The instruction in Geology and certain related subjects is given by Prof. Sterry Hunt, in four courses, delivered yearly to students of the 3d and 4th years.

I. *3d Year.* The *first* is a yearly course of thirty lectures on *Descriptive and Theoretical Geology*. This embraces the classification of the Sciences; Scope of Geological Studies; Nature of Rocks, or Lithology; Stratigraphy; Succession of Formations; Zoological History; Geological Dynamics; Chemical and Physical Forces; Aqueous and Igneous Agencies; Currents; Sedimentation; Elevation and Subsidence; Geographical Distribution of Formations; Nature and Origin of Mountains; Volcanic Action.

II. *4th Year.* The *second* is a yearly course of thirty lectures on *American Geology*, comprising Introduction; Geological History; Geology of North America, considered (1) Lithologically; (2) Stratigraphically; (3) Palæontologically; Comparative Geognosy.

III. The *third* is a yearly course of fifteen lectures on *Practical Lithology*, comprising the mineralogical composition of Rocks; Building-stones, their cohesion, porosity, etc.; Granites, Marbles, Limestones, Sandstones, Slates; Limes, Cements, and Mortars; Ornamental Stones and Gems.

IV. The *fourth* is a yearly course of fifteen lectures on *Chemical Geology*, or the Chemical History of the Globe; comprising the Origin of Rocks, both stratified and unstrati-

fied ; the History of Vein-stones and Ore-deposits ; the Formation of Coal and Petroleum ; the Chemistry of Salt-deposits and of Mineral Waters ; the Seat and Origin of Volcanic and Earthquake phenomena.

MINING AND ECONOMIC GEOLOGY.

The instruction in Mining and in Economic Geology is given by Prof. Rockwell, in two yearly courses, delivered to students of the 3d and 4th years.

I. The *first* is a yearly course of 70 lectures on *Mining*. The student is made acquainted with the general character of the various deposits of the useful minerals, and with the theory and practice of mining-operations, such as the methods of search or "prospecting," — boring for oil, coal or water,—the sinking of shafts, with the timbering, walling or tubing of the same, the driving of levels ; the different methods of working lodes, coal-beds, etc., the underground-transportation of the mineral, hoisting, pumping, ventilation and lighting, together with the machinery and other appliances connected with these and other operations ; in short, the great variety of operations comprised under the general term, Exploitation. Ore-dressing, or the mechanical separation of ores from their gangues, is discussed somewhat at length, and the machines described by means of which this concentration is most economically effected. The practical course of ore-dressing and smelting in the Mining and Metallurgical Laboratory, affords the student opportunities for acquiring a familiar knowledge of the treatment of ores, such as can be got, under ordinary circumstances, only at the best mines.

II. The *second* is a yearly course of twenty lectures on *Economic Geology*, mainly devoted to a detailed description of the coal and ore-deposits of North America, especially such as are most extensively worked.

The student who is a candidate for the degree of the Institute, is expected to spend a portion of his vacations in some one

of the principal mining-districts in the study of the local peculiarities of the ore-deposits, and the details of actual working, and to submit a full report upon the same, with drawings. Those who intend to become metallurgists, may take smelting-works instead. Through the kindness of several proprietors certain mines in different regions have been made accessible to students, for the purpose of systematic study.

METALLURGY AND INDUSTRIAL CHEMISTRY.

The instruction in Metallurgy and in Industrial Chemistry is given by Prof. Ordway, in two courses of two years each, delivered to students of the 3d and 4th years.

I. The *first* is a two years' course of forty lectures on *Metallurgy*. The subjects discussed are fuels, fluxes, slags, furnace construction, and the roasting, smelting and refining of the various metals.

II. The *second* is a two years' course of forty lectures on *Industrial Chemistry*. The manufacture of acids, alkalies, salts, pottery, glass and organic products, and the arts of dyeing and printing are the principal subjects treated of.

In connection with these lectures, excursions are made to Manufactories and Metallurgical Works, and practical exercises are given in the laboratories. The students are required to make drawings and designs of apparatus used or to be used in large operations.

MINING AND METALLURGICAL LABORATORY.

The purpose of this laboratory is to furnish the means of studying experimentally the various processes of ore-dressing and smelting. Ores of all kinds are here subjected to precisely the same treatment, and by the same machinery and other appliances that are in use at the best Mines and Metallurgical Works of this and other countries.

The laboratory has already in successful operation the most approved Ore-dressing and Mill-machinery for gold and silver ores now in use in California and Nevada; consisting of a *five-stamp-battery*, an *amalgamating-pan*, a *separator* and a *concentrator*, complete in every respect, and capable of treating half a ton of ore a day. These were obtained the past summer in San Francisco. There will be added during the present year an ore-crusher, a hydraulic jigger, a Rittinger shaking-table, and all other appliances necessary for the treatment of every kind of ore. The machinery is driven by a steam-engine of upwards of 15 horse-power.

For Metallurgical treatment the laboratory contains at present a reverberatory roasting-furnace, crucible and assay-furnaces, and a blacksmith's forge; and there are now being erected reverberatory and blast smelting-furnaces capable of working 400 pounds of ore per day, and a cupelling-furnace sufficient for working 50 pounds of lead at once. To these will be added retort and other smaller furnaces for various uses. All of these will be ready for use by October of the present year.

The experimental work of this laboratory is carried on by the students, under the immediate supervision of Prof. Richards. A sufficiently large quantity of ore is assigned to each student, who first samples it, and determines its character and value by analysis and assays, and makes such other preliminary examinations as serve to indicate in a general way the proper method of treatment. He then treats the given quantity, makes a careful examination of the products at each step of the process, ascertains the amount of power, water, chemicals, fuel and labor expended. In this way the same ore is subjected to several methods of treatment, and by a comparison of the results obtained, the student learns the relative effectiveness and economy of different methods, as applied to the same ore. It is believed that the experiments conducted in this way, and upon such a scale, will prove of direct practical value, not only to the student, but to the Mining interest at large, by showing how existing methods of treatment may be advantageously modified meet the requirements of new complex ores.

The Institute has now on hand about eleven tons of gold and silver ores, representing over seventy different mines in Colorado and Utah, which were collected by the Institute-party of professors and students during their recent trip to these territories. These ores will be worked, and reports of the results sent to those who so generously contributed them; and it is hoped that by such coöperation the laboratory will continue to receive the necessary amount and variety of ores.

The following experiments upon gold ores have been begun; but all the products have not yet been fully tested, on account of the approach of the annual examinations:—

1. The — Lode, Nevada City, Colorado, 324 lbs.
2. The — Lode, Nevada City, Colorado, 110 lbs.
3. The — Lode, Central City, Colorado, 255 lbs.
4. The — Lode, North Carolina, 103 lbs.
5. The — Lode, Central City, Colorado, 250 lbs.

PALÆONTOLOGY.

The instruction in Palæontology is given in a yearly course of 50 lectures by Prof. Hyatt, one-half of which are delivered to the 3d year and one-half to the 4th year students.

Palæontology, or the history of ancient animal life, and Stratigraphical Palæontology, or the study of the distinctive and characteristic fossils of the different formations, are taught as a necessary foundation for the further study of Geology. The aim of the course is to give the student a practical acquaintance with the structure of the characteristic families, and orders of living and extinct animals, and by a judicious selection of examples to familiarize him to some extent with the genera which characterize various formations.

The handling and the drawing of specimens by the students is an essential feature of the method of instruction. The lectures of the instructor are devoted largely to explanatory demonstrations of the specimens which the students are at the same time drawing. The success attending this mode of teaching palæontology has shown its value.

MINERALOGY AND BLOWPIPE PRACTICE.

The instruction in Mineralogy and the use of the Blowpipe is given by Prof. Richards, in two courses to students of the 3d year.

I. The first is a course of 45 exercises (of one to two hours each), in which the student is taught Determinative Mineralogy by the study of crystalline forms, and the physical properties of minerals. He is instructed in the use of the blowpipe for the qualitative determination of minerals, and in the quantitative assay of silver and copper ores.

II. The second is a course of fifteen lectures on Descriptive Mineralogy, accompanied by critical examinations, and the handling of specimens on the part of the student.

ASSAYING.

The instruction in assaying is given by Prof. Richards in a course of ten exercises (of two to three hours each), in which the student learns to perform the ordinary dry assays of gold, silver, lead and other ores. Instruction in wet assaying is given by Prof. Crafts.

CHEMICAL COURSE FOR MINING ENGINEERS.

The chemical instruction of the mining-students extends through the four years. The course in General Chemistry occupies the first year; and during this time the students work two hours each week in the chemical laboratory. Each student performs for himself a great variety of experiments designed to illustrate the properties of the various chemical elements and of their more important compounds: he also prepares a number of such simple and compound substances as are of use in the arts or serve to illustrate the laws of chemical change. The knowledge thus acquired by the practical work of the laboratory is

supplemented and enforced by lectures, recitations and frequent examinations.

During the second year, more particular attention is given to the theory of Chemistry, and to Qualitative Analysis. The latter branch of the subject is taught by laboratory-exercises, each student working four hours a week. As during the first year's course, these laboratory exercises are accompanied by recitations and examinations.

During the third year the mining-students take a systematic course of quantitative analyses, occupying six hours per week in the laboratory, and attend a weekly lecture, or exercise in which methods of analysis are discussed, and the results of investigations too recent to be found in text-books are presented to them. Mining-students may take in addition, as a voluntary exercise, a course of special analytical methods, reciting from German text-books.

In the fourth year the students are engaged in laboratory-work during the hours between 9 A.M. and 5 P.M., which are not devoted to recitations and problems in drawing, metallurgy, etc., which more nearly concern their professional studies. They all get about three hours daily for chemical work; and many are able to spend more time in the laboratory without neglect of their other studies. They accomplish a tolerably thorough analytical course, comprising the analyses of salts, the more common minerals, and particularly of ores and metallurgical products, and extending as far as the more difficult analyses, such as the determination of all the constituents of cast iron or steel; so that a student in his professional work as a mining-engineer may be independent of the assistance of a chemist, and competent to deal with all ordinary investigations.

Some students, who show a special aptitude for chemistry, are encouraged to take up special investigations connected with metallurgy; and all accomplish work which may be considered a sufficient preparation for their professional career.

PHYSICS.

The instruction in Physics, extending through the first three years of the course, is given by Prof. Pickering. During the first two years the whole subject is thoroughly discussed mathematically and experimentally in lectures illustrated from the extensive collection of physical apparatus of the Institute.

In the third year the students enter the Physical Laboratory, and learn to use the different instruments and to perform a variety of experiments. Special attention is paid to the testing of physical laws by comparing the observed and computed results.

The students further carry on systematic investigations of particular subjects, during the fourth year, and pursue such courses of experimentation as have a direct bearing on their professional studies.

COLLECTIONS.

The geological collection of the late Prof. Henry D. Rogers of the University of Glasgow, presented to the Institute by Mrs. Rogers, is made up chiefly of fossils and rock-specimens from American localities, and in certain branches is peculiarly valuable for instruction. The collection of ores and vein-stones is already large and varied, and is constantly receiving additions from the various mining regions.

A typical set of models of mining-machinery, chiefly from Freiberg, Saxony, is used in the course of instruction. They are designed mainly to illustrate the principles of the various processes of mining and ore-dressing, but combine also the latest improvements in machines. They show in detail the methods of working underground by underhand and overhand stoping, the timbering and walling of shafts and levels, the arrangements of pumps, man-engines, ladder-ways, hoisting-ways, the sinking of shafts, etc. The machines for ventilation as well as those for ore-dressing are working models. The latter illustrate all the stages of the concentration of ores.

The collections and library of the Boston Society of Natural History are, by an agreement between the Society and the Institute, freely open to the students. These collections rank among the first in the country for extent and value, and in many departments are unsurpassed; the library is rich in works on Geology and Natural Science and embraces the leading American and European journals and periodicals on those subjects.

The instruction in certain subjects is given by the Professors of the Institute in the lecture-room of the Natural History Society, whose building is upon the same square with the Institute of Technology.

The private collections of some of the professors, especially that of Prof. Hunt (which is very complete in lithology and mineralogy), are available for purposes of instruction.

The Boston Public Library. The professors and students of the Institute are also allowed the full use of this extensive and valuable library.

REPORT UPON THE INSTRUCTION IN QUANTITATIVE ANALYSIS IN 1871-1872.

The opening of a new laboratory room has increased by about three-fifths the space devoted to the work of the third and fourth years' classes in Quantitative Analysis, so that the desk-room is amply sufficient for the ordinary work of classes of the present size.

It has, however, been found impossible to secure the small rooms, which should adjoin the main working rooms, and which should contain the more delicate pieces of apparatus, such as the balances, microscopes, spectroscopes and apparatus for gas-analysis. In default of these, a glazed partition has been thrown across a part of one of the laboratories, and in this way, without sacrificing the light of a window, a small room has been provided for the balances and the chemical library, which answers its purpose very well; but unfortunately it is not far enough removed from the laboratory to secure the balances from danger of injury from acid fumes, which occasionally escape into the air of that room as the result of an accident. The weighing room is also too small for laboratories provided like ours with places for forty-six students. The cases in which operations with acids are carried on, are connected with flues having an excellent draught, and thanks to them it has been found possible, with careful manipulation on the part of the students, to keep the air of the laboratories as pure as it usually is in such rooms; but this task is rendered irksome by a deficiency in proper ventilating flues opening directly into the rooms,

and by the fact that the rooms, having a low ceiling, offer a restricted bulk of air to deal with. These are defects which cannot apparently be remedied in the existing building.

Several new appliances for facilitating the laboratory work have been introduced during the past year. These include, besides improved forms of apparatus, some of those labor-saving contrivances, which may find their place in a laboratory as well as in a work-shop. Under Professor Ordway's directions several wrought iron steam boxes, capable of resisting a great pressure, have been purchased and set up. They are connected with the boilers used for heating the building, and when the steam is passing through them they serve as iron tables, which can be maintained at a constant temperature, and on which solutions to be evaporated can be left without danger of being over-heated.

One of the most remarkable improvements in analytical chemistry has been the introduction by Professor Bunsen, of Heidelberg, of an ingenious mechanical attachment to the ordinary filters, allowing them to be connected with a very simple air pump, worked by water and greatly accelerating filtration. A few such pumps had already been constructed in the school, after the discovery by Professor Richards of some important improvements in their form. This year one has been set up at each desk in the new laboratory, while means are provided to the student for making for himself the apparatus attached to the filters. These appliances have proved so easy to manage, so inexpensive, and of such value in shortening the time required for analysis, and consequently allowing the student to take a more extended course, that it is proposed to provide each desk in the old laboratory with them next year.

A new method of making copper assays, which has lately been tested with great thoroughness in Germany, has been successfully tried in the laboratory, and even beginners have obtained very exact results with it. The process depends upon the use of a galvanic battery, and a number of these of Meidinger's pattern, which remains in constant action many weeks,

have been set up in different parts of the laboratories. It was deemed that such processes would be of little use to the student in his after career, unless he could easily procure the necessary apparatus, and it was therefore considered an essential part of his instruction to suggest to him by examples, ways of supplying his needs with the commonest materials.

The batteries in question were made in the laboratory from pieces of lead pipe and broken bottles, and the perishable part, which is the zinc element, was cut from the thick plates of zinc, which have been introduced of late years for sheathing vessels. With a few hints in such directions a student may often supply himself at a small cost with apparatus that is not attainable ready made in this country; and in this connection may be mentioned a new apparatus for weighing hygroscopic bodies, made entirely by the students, of which an account will shortly be published; also the preparation by some of the students of their own measuring tubes for gas analysis, which are graduated by means of Bunsen's simple instrument, and the graduations are afterwards etched upon the glass.

In the absence of a proper room for gas-analysis, through Professor Pickering's kindness, a portion of the physical laboratory has been set apart for this purpose, a sufficient quantity of mercury has been purchased and instruction in this important part of a chemical course will be given next year.

As important additions to the laboratory apparatus may be mentioned a Hofmann's combustion furnace, and a new balance by Becker. A spectroscope by Steinheil of Munich, a saccharometer by Soliel of Paris, with quartz compensating prisms, and a very large and delicate balance by Lingke of Freiberg, have been placed at the service of those students who require them for any special purpose.

The progress of the students in their analytical work has been satisfactory, and a considerable number of them have voluntarily spent more than their required time in the laboratory.

The students who take the course in Quantitative Analysis are of two classes, those who take it as a part of their course in Mining Engineering, and those who make it their principal study with the intention of becoming chemists. It was felt that the distinction between the studies required in each course was not sufficiently marked, and that the chemical students had time to take up more of the theory and practice of chemistry, than the pressure of the other studies of the mining students would allow them to attend to during the last term.

By way of experiment two new classes were established; one a voluntary class of the third year's students, reciting from a small German text book upon some special subjects in analytical chemistry; the other comprised all the chemical students of the fourth year's class, as well as two volunteers, who were graduates of the school. The subject was organic chemistry, and it was looked upon from two points of view. In the first place an endeavor was made by using very advanced text books, and by giving citations from the chemical journals of the most important of the discoveries, more recent than the text books, to show the student where to look for the complete description of the facts, which subsequent work might require him to study, and at the same time to impress upon his memory the more important points, presenting them in relief against the minor ones. In the second place considerable attention was paid to the somewhat intricate theories of organic chemistry, in the belief that it is the best ground upon which to encounter and master the theories of chemistry in general.

The choice of text books was left free and the larger number in the class selected Kekulé, a work in German, and the most complete yet published on the subject. It was with some apprehension that this formidable text-book in a foreign language was attacked, but the experience of the term seems to approve the choice.

The lessons covered about twelve hundred pages octavo and of course the whole text was not even read in preparation for a recitation, but it was not difficult to select the more important statements; familiarity was gained with the arrangement of the

best guide to a complete knowledge of the subject, and a favorable position attained for beginning its thorough study as a specialist when separated from the assistance of a teacher. Some stress may be laid upon the value of the acquirement of the technical words in German during a course of study of this kind.

It is very possible that the class of this year were unusually well fitted to take up this subject, several of them reading German with ease, and certainly it would be premature to found a decided opinion about the best course for the future upon so short an experience; it has been determined, however, to require next year, for the chemical students of the third year's class, an additional course in a special branch of analytical chemistry from a small German text book (no good English one on the subject is procurable), besides the regular course of lectures on analytical chemistry, which are taken by the chemical and mining students alike; and in the fourth year's course, the chemical students will have two recitations a week on organic chemistry, accompanied by lectures, and the choice of text-book will be left free. A written description has been given to the class of several text-books, and no advice as to a choice is given, even when asked. Success with one or the other depends so much upon the character of the person using the book, that it is thought desirable to leave the responsibility with each individual.

In conclusion, the fruits of the year's work which we can offer to the public, are two short investigations ready for publication, one made by a student of the graduating class who has shown an unusual aptitude for chemical work, another by one of the professors.

It is to be hoped that in the future a larger number of the students may be able to go over untrodden ground before finishing their course, and also that the laboratory may offer sufficient inducements to attract more experienced workers to make investigations there.

J. M. CRAFTS,

Professor of Analytical and Organic Chemistry.

June 3, 1872.

REPORT OF THE DEPARTMENT OF ARCHITECTURE.

President Runkle, Dear Sir:—

At the close of the fourth year in which this Department has been in active operation I beg to present the following account of its present condition, of what it has thus far accomplished, and of what had previously been done by way of preparation for this work.

This preparation had consisted chiefly in such examination as I had been able to give to foreign schools of architecture, with some personal consultation with architects both in this country and abroad, and in the collection of casts, photographs and drawings, and other materials, which the generosity of some friends of the school had given the means of purchasing. Some unusually favorable circumstances rendered these collections much more extensive and valuable than was reasonably to be expected, especially in respect to mediæval sculpture and carvings and architectural drawings. A large and almost unique collection of casts from Lincoln and Southwell fortunately fell into my hands, which, I was afterwards able to supplement by considerable additions from French Gothic work of the same period. At the moment of returning home I was also enabled, by the generosity of Mr. Ernst Benzoni, of London, formerly a resident of Boston, to purchase an unusually good collection of school drawings, made by students in architecture at the Ecole des Beaux Arts, in Paris, and at the French Academy in Rome.

These collections were largely augmented by the kindness of many gentlemen, mostly architects, who, both in England and on the Continent, evinced a lively interest in our undertaking, and contributed not only photographs of their works, but tracings and lithographic copies of working drawings, with specimens of specifications, estimates, bills of quantities and various forms of business papers. Our thanks are specially due to Mr. Waterhouse, Mr. Withers, Mr. Keeling, Mr. Norton, Mr. Nash, Mr. Rickman, Mr. Edis, and the late Mr. Papworth in London, and Mr. Bryce in Edinburgh, and to M. Viollet le Duc, M. Charles Garnier and M. Lesoufacher in Paris, for their generous contributions. M. César Daly also presented to the department his valuable work illustrating the domestic architecture of the Second Empire, and the French Minister of Public Instruction, M. Duruy, acting through our Minister, Gen. Dix, put at our disposition a number of illustrated works relating to the architectural history of France, among which were the magnificent monograph of the Cathedral of Chartres and the two volumes entitled the "Statistique Monumentale de Paris." The Secretary of the Institute of Scottish Architects in Edinburgh also gave us a nearly complete series of the publications of that Society, the Architectural Publication Society of London added their miscellaneous publications, and the Royal Institute of British Architects not only presented us with a complete set of their valuable Proceedings, but were good enough to put us upon their books, so that we have continued regularly to receive the papers they have published. Altogether, besides these books and papers, the collections comprised, at the moment of opening the school, about 2,000 photographs, 500 prints, 400 plaster casts, 200 crayon drawings, 40 water-colors, mostly of architectural subjects, and 30 manuscript architectural drawings, large and small, besides 100 sheets of working drawings, mostly tracings, and some specimens of tiles, pottery and stained glass.

These various objects were classified and arranged in the rooms of the Architectural Museum during the spring and summer of 1868, and wall-catalogues giving the names of a

chief part of the plaster casts were printed for the convenience of visitors, of whom several hundred visited the Museum during the next year. On the opening of the Department at the beginning of the school year in October, sixteen pupils presented themselves, four of whom were special students in architecture within the school, spending their whole time over their school-work. The others were students or draughtsmen in offices, coming to the school only to attend lectures.

During this year the lectures were mostly historical and critical, as a part of the Course of Design, the Course of Construction not being undertaken. A course of lectures upon Perspective, however, was given in the course of the winter, which was attended by the whole of the Third Year's class. The work of the year, after some preliminary exercises in the use of india-ink and color, consisted of a series of problems in design, of gradually increasing difficulty, originated and worked out by the students under my advice and supervision; such as, among others, a Balcony, a Bridge, a Triumphal Arch, a Swimming Bath, a Mausoleum, a Chapel, and some problems of ornament, such as a Honeysuckle frieze, a four-leaved Corinthian capital, etc., etc.

The second year, beginning in October, 1869, I was fortunate enough to secure the services, as my assistant, of Mr. Francis W. Chandler, now Assistant Supervising Architect of the Treasury Department at Washington. Mr. Chandler had formerly been a student and draughtsman in my office, and had then just returned from the completion of his studies in Paris. He continued in the school until the first of April, spending his whole time in the drawing-room, giving the class just at the moment each might need it the benefit of his advice and assistance. The marked improvement made by the class under this arrangement convinced me, of what indeed hardly to my mind needed this proof, that the only way to secure rapid progress in this work is to have personal instruction from a highly accomplished teacher constantly at hand to save the students from the loss of time and trouble, which, in the beginnings of so

difficult and complicated a study must otherwise be very great. During the last part of the year the class were strong enough to get along without more constant supervision than I could myself give them. I, however, engaged the services of Mr. Langerfeldt to give them lessons in water-color drawing, and of Mr. Virgil Williams, who for several months gave them lessons in crayon drawing several times a week.

During this year there were twenty-two students attached to the Department, of whom twelve were students in offices, and only attended lectures. The other ten spent their whole time at the school as special students in Architecture, many of them taking in addition to their professional work some of the mathematical or other studies open to them in the school.

My own work comprised, besides the instruction given to the class in Design, of the same general character as the year before, a course of lectures in Construction, in which the ordinary detail of office work was gone over in connection with the specifications and working drawings. The work of the class, in like manner, comprised, besides the series of problems in design, the working drawings of a small frame house, with details and specifications, according to designs of their own. The problems in design embraced, among other things, a Campanile, employing the Doric, Ionic and Corinthian orders; a Hospital and Alms House for 40 pensioners, with Chapel, Refectory, Hospital, etc., all with open roofs; a set of church furniture, font, pulpit, etc., etc.; a half-timbered house; a school and library building, with passage to a church beneath; a summer-house between two bridges; and a number of minor subjects. A considerable number of the drawings embraced in these series were drawn in perspective. Much of the work was in the Gothic style.

The Boston Society of Architects, "wishing to do its part in the work of architectural education," established this year two annual prizes, consisting of books, of the value of fifty dollars each, to be given to the students who should exhibit at the end of the year the best year's work. A committee consisting of Mr. Cabot, Mr. Cummings and Mr. Van Brunt, awarded the

prize for the best work in the class of Design to Joseph A. Pond, of Allston, and a committee consisting of Mr. Hartwell, Mr. Preston and Mr. Brigham awarded the prize for the best work in the class of Construction to William M. Woollett of Albany, N. Y.

The third year, from October, 1870, to June, 1871, the class numbered fourteen special students, many of whom were the same as the year before, with only two or three from the offices. Indeed, experience had shown that it was almost impossible for young men actively employed as draughtsmen to command time for any other stated avocation, by day. The attendance of this class of students had in the previous years been very irregular, ceasing almost altogether towards the end of the year.

The work resembled very closely that of the previous year, except that for accidental reasons, although the lectures in construction were carried on, the work done by the class under this head was but slight. The prize in construction was accordingly not awarded. That in design was given to Frank Spinning, of Dayton, Ohio. Mr. Langerfeldt and Mr. Williams continued their lessons in water-colors and crayon-drawing, and towards the end of the year the class had a course of a dozen lessons in modelling under the care of Mr. Alexander Johnston.

Mr. Chandler's engagements were such that, to my great regret and that of the class, he was obliged to relinquish part of his work at the school in January, and on the 1st of March gave it up altogether. It proved impracticable to supply his place either for the remainder of the year or for the year to come, very few young men in this country having the sort of training that fits them for school-work, and those few being in great demand for other work. In this case there seemed to be only one course left, and as soon as Paris was open to the mails I wrote to my correspondents both there and in London, begging them to employ their good offices to find among the young men about to leave the *École des Beaux Arts* some one competent and suitable for our vacant post. It was not until the month of December, however, that any definite result was

reached, and it was January before I had the pleasure of welcoming my new assistant, Mr. Eugene Létang, and the satisfaction of sharing with him a labor which I had borne almost without assistance since the preceding March.

This somewhat adventurous step, which from the circumstances of the case I was obliged to take almost upon my sole responsibility, has met with a success even greater than I had hoped. In professional attainments, I knew that of course a student of the *Première Classe*, a pupil of so eminent an architect and successful an instructor as Mr. Vaudremer, could not but be a thoroughly accomplished architect, and one thoroughly versed in the best methods of the best system of architectural discipline. Still, it is not without anxiety that one invites a foreigner to take part in our own undertakings, and in the present case there was cause to fear that the obstacle of language might prove an insuperable one. The event has proved, however, that these fears were unfounded. The awkwardnesses of the position have been met with tact and good sense, and as the young men have for the most part some knowledge of French, and are glad to practice what they know, what promised to be a source of embarrassment has been, in fact, a positive advantage. But of late English has again begun to prevail in the drawing-rooms.

The year's work has been of substantially the same character as before, except that during the last half of the year a considerable number of small problems, each occupying only a couple of days, or at most a week, have been introduced. The subjects of these have been, for instance, a Porch, a Carriage-Porch, a Portico in a Garden, a Peristyle, a Mantel-piece, etc., etc. The crayon or charcoal drawing has also, in Mr. Létang's hands, assumed a more prominent position, and the class have made good progress in it. I have also required the class every morning to bring in in their sketch books a pencil-sketch of some building, a plan, or an architectural detail, an exercise in every way salutary. A considerable part of the class have also done a fair amount of work in Descriptive Geometry, and in

shades, shadows and perspective, partly under my own instruction, and partly in connection with other departments of the school. The study of Detail Drawings has also been pursued with very satisfactory results, though to but a limited extent, in connection with lectures upon Carpentry and Joinery. It is impossible to go very thoroughly into these subjects without an entire interruption, for the time, of everything else. But in view of the fact that a chief part of the class were looking to spend a portion, at least, of their four months' vacation in architect's offices, it seemed best to do what could be done in preparation for that work.

The different topics embraced in the Lectures have been chosen so as to illustrate as far as possible the work the class might have in hand. These have been on Construction, on History and Criticism, on Shades, Shadows and Perspective, and the Perspective of Shadows, on the Composition of Mouldings, of Details and of masses; on the Orders, on the Topography of Rome, on the Tuileries and the Louvre, making about seventy lectures in all, delivered two or three times a week, and occupying an hour and a half or two hours each in the delivery. It has been necessary to give a good deal of information, *viva voce*, that might better have been obtained from text-books, if proper text-books were to be had. Indeed, a chief part of my own labor has consisted in collecting and putting into shape the common-places of architectural information, things which every architect knows, but which are not as yet accessible to students.

These various works occupied the first six months of the year, and sufficed for preliminary study. On the 1st of April a more important subject was taken in hand, which has occupied the rest of the year; the sketches and finished drawings for a Casino or Pleasure House, situated in a formal garden and surrounded with statues and fountains. This sort of subject, though remote from daily use and experience, is for that very reason best suited to this stage of advancement, as it necessitates the close study of the best masters, stimulates the fancy

and imagination, and does not involve the numberless considerations of practical detail, which it would not do to slight, and yet which the class are not yet prepared to entertain. A more practical problem would require for its solution a more extended experience than such a class can possibly have had. Work of this kind, on the other hand, while it taxes their powers to the utmost, both in the design and in the execution of the drawings, does not demand for its satisfactory performance any greater resources, either of knowledge or skill, than they have at command.

The result has amply justified this view, which is, indeed, supported by our own previous experience and by the practice of the best schools abroad. The progress of the class during these eight months, in the essentials of professional culture, has been very satisfactory. It is only by such incessant practice of original design, under proper guidance and criticism, that the creative and imaginative faculty can be exercised and developed. Moreover, it is through the varied manipulations which exercises of this sort exact, that artistic draughtsmanship is best acquired. Drawing thus becomes to the student not a mere mechanical exercise of hand and eye, but a means of expression, — a language by which to convey the architectural idea he has conceived in his mind.

The plans, sections and elevations which the class exhibit as the result of these two months' work are confidently presented in vindication of these views. They are in great part the work of students who had begun the study of architecture six months before. About half the class accomplished this work. The rest, who through absences or from other causes, were not strong enough to undertake it, have spent the time in exercises more suited to their condition.

Hitherto the classes in Architecture had consisted entirely of Special Students in this Department, most of whom had had no previous connection with the school. This year, however, two Regular Students presented themselves, young men, that is to say, who had been through the first two years' course, passing

all the required examinations, and who proposed to take, along with their architectural work, the further scientific studies requisite for a degree. This they have satisfactorily accomplished, and although they have not, of course, done as much Architectural work as the students who could give all their time to it, they have kept up with the class, and have constantly shown the value of the preliminary training the earlier years of the school had given.

The work of the Regular Course thus gone over, in connection with the Departments of Engineering, has comprised the elements of the Differential and Integral Calculus, and their application to Statics and Dynamics, illustrated by work in the Physical Laboratory, consisting of about a dozen practical problems in Friction, the Resolution of Forces, and the Deflection of Beams under various kinds of strain. These students have also done seventeen problems in Stereotomy, with the necessary drawings, and had instruction in Electricity and Magnetism, besides keeping up their exercises in French, German and English.

The Scientific studies of the Fourth Year will be less numerous, and will give Regular Students in this Department more time for their professional work. It will embrace a series of exercises in the Physical Laboratory, specially desired to illustrate architectural problems, and a course of lectures upon Building Materials, Mortars and Cements.

This development of our work promises to be a permanent one, several students of the present Second Year having signified their intention to become regular students in Architecture in the autumn.

The history of the last year was marked by an incident of special interest in the meeting in Boston of the Fifth Annual Convention of the American Institute of Architects, which, by invitation of the Institute of Technology, was held in the rooms of this Department. The opportunity of seeing so large a number of men, eminent in the profession, from different parts of the country, and of listening to their discussions, was keenly

enjoyed by the students. The Convention, in adjourning, besides making their acknowledgments for the courtesies extended to them, signified in strong terms their satisfaction and pleasure in observing the scheme of Architectural Education the Institute of Technology had set on foot.

The work of these four years, though in great part tentative and experimental, and full of the deficiencies that come from limited resources and limited experience, has not been without its good results, and has been highly encouraging for the future. At the present moment, it may be claimed that the Department has fairly established itself in the confidence of the profession and of the community, and it may count upon a constantly increasing support and more extended usefulness. It is as yet too early to say how many students will be in attendance another year; but there is no reason to look for any diminution of numbers. On the contrary, the number who have already entered their names, and the frequent applications for information from students and architects in different parts of the country, seem to justify the expectation of a considerable increase. There is no doubt that we are better able than ever before to meet the reasonable expectations of the profession, and to furnish the instruction and discipline, of every sort, that an architectural education implies.

In this respect the proposed establishment in the School, of Post-Graduate courses of study, will be of special advantage to this Department, enabling us at the same time to extend the range of our work and better to arrange and classify it. As the professional work in the other Departments of the School is accomplished during the Third and Fourth Years, we have hitherto, in order to conform to them, had to set down the architectural work also, under the form of a two years' course; but to give notice that hardly in any instance could two years suffice to complete it. The extension of the period of study for an indefinite term after the regular course is finished will relieve us from this embarrassment. It will now be possible by exacting a certain amount of vacation-work and somewhat

diminishing the work set down to be done in connection with the classes in Civil Engineering, to give the regular students of these two years a sufficient knowledge of the elements of Architecture not to discredit the school — not enough to make them architects, even in the sense in which their fellows become at once Chemists and Civil Engineers, — but enough for Bachelors of Science, enough to enable them to pursue their further studies, in offices and in this Department, to the best advantage. This undergraduate work will thus be complete in itself, including all that relates to the scientific basis of the profession, giving all that an architect needs to know of Mathematics, Chemistry, Physics, Geology and Engineering, with as much of Architectural Drawing and of Architectural Design as can reasonably be comprised within the regular curriculum of a school of science.

The Post-Graduate course will then take up such special scientific topics as may prove desirable, with something of Practice; but it will be chiefly occupied with advanced work of composition and design, in continuation of that begun in the Third and Fourth Years. This work is perhaps more germane to a school of Art than to a school of Science. But it is a work greatly in demand, and one which we may ourselves take in hand with great advantage to our own undergraduates, to more advanced students, wherever trained, and to the community.

By the study of Practice is meant a systematic discussion of professional and business matters, such as contracts, specifications and working drawings, and the relations of architects to their clients and to their workmen. These topics are obviously, in the main, better suited to advanced students than to beginners, and a class fitted to take it up can go over this ground to very great profit in a limited period of time.

But for the main work of the Post-Graduate course, the study of Architecture as a branch of the Fine Arts, no period of time can be fixed, and no special curriculum assigned. Architecture in this aspect is not an exact science, and the methods appropriate to a school of science are less pertinent to this part of the

work than those of a school of art. Still it may be possible, without attempting to set any limit of time, nor to fix upon any course of study as in itself sufficient, to prescribe certain tests of attainment, as is done at the Ecole des Beaux Arts, by which the further honors of the school shall be governed. Just what these honors shall be, and by what rules they shall be awarded may best be left for time and experience to determine.

Such a course of architectural study, beginning with the preparatory work of the Undergraduate course, and extending in the Post-Graduate course over an indefinite period, should be made available, not only for the regular and special students, but for draughtsmen working on half time, or by intermittent and temporary engagements, in the architects' offices of the city. The great advantage to the school of securing such a class of students is obvious, and they should be received on such terms and for such periods as may best suit their necessities. Their work would naturally exhibit a seriousness of purpose and a command of resources that could not fail to act as a powerful stimulus upon their juniors, and to affect in the most favorable manner the tone of the school and its whole standard of performance. It is in this way, moreover, that the Department can best profit by the advantages of its position, in being established in a community where the practice of architecture is so excellent in respect both of construction and of design, and where the character of the profession is so respectable in point both of ability and of attainments. A practical familiarity with the work of the profession, which no schooling of course can give, must needs be sought in a good office, while the best discipline of an office needs to be supplemented by an academic training. If, by coming to Boston young men can combine both opportunities, and thus, in time, earn enough to pay their expenses as they go along, without foregoing the work of personal culture, they will not be slow in any part of the country in finding it out. To young men already well advanced in their professional studies,

the advantages of such an opportunity will hardly need to be insisted upon.

And in no other way, it seems to me, can we meet the reasonable expectations of the friends of the school, answer the higher demands of the profession, and do justice to our own position and resources. Architects so much need draughtsmen and assistants of all sorts that our students are constantly drawn off into office-work before we have begun to show what we can do with them. But we are prepared to give a first-rate architectural education, and the profession and the community are eagerly demanding young men who have received it. By enabling practicing draughtsmen to attach themselves permanently to the school, working upon an advanced class of problems during such leisure as they can command, during a term of years, the Department may hope to meet this want, and to vindicate its claims to a place among the agencies of a superior culture.

As time goes on and our needs are defined by experience, the deficiencies of our equipment in respect both of books and of models, begin to be keenly felt. It is very desirable that some regular provision should be made for supplying from year to year what proves to be most needed. The constantly increasing collections of the Engineering Departments are indeed of great service to us, especially in respect of Descriptive Geometry and Stereotomy, and the Trustees of the Public Library, in opening it to our students, and in promptly buying such new books as may be asked for, have given us every advantage which we could obtain from a library of our own. The establishment of the Museum of Fine Arts, also in the immediate neighborhood of the Institute, will presently put at our command extensive collections of works of art of every kind. But besides these resources we need to have certain things close at hand, in daily service. Books for consultation and constant reference, freely accessible to the students, are our most present want, and the more manifest deficiencies of all our collections need to be made good, and recent productions added. The generosity of the friends and patrons of

the school is, however, constantly doing much to relieve these wants, and the collections have considerably increased since their formation by various voluntary contributions. The most conspicuous of these additions is the stained glass, which has been partly purchased, but is in chief part the gift of the makers. It is arranged in four movable screens, and comprises work by Messrs. Morris & Co., Lavers, Barraud and Westlake, Heaton, Butler and Bayne, Clayton and Bell, J. T. Lyon and G. E. Cook in London, Cottier in Glasgow, and Cook and Mac Donald in Boston, besides some fragments of mediæval windows. Messrs. Maw & Co., of Brosely, Salop, have sent us four large squares of their mosaic and encaustic tiles, suitably mounted for exhibition, besides numerous smaller specimens, to which have been added a considerable number of painted tiles, chiefly by the glass-stainers just mentioned. We have also received from Dr. Salvia a gift of a capital specimen of his revived manufacture of Venetian glass mosaic, for which and for many other benefactions we are indebted to the good offices of Mr. R. P. Spiers, of London, one of our constant friends. Among other additions to the collections may be mentioned a complete set of the photographs of the original designs for the Law Courts in London, and a cast of the head of Michael Angelo's David at Florence, presented by Mr. Edward Atkinson. Mr. C. F. Shimmin has given us an early set of Hancock's reduced restorations of the friezes from Phigaleia and from the Parthenon. Mr. Hatfield and Mr. Wight also, architects of New York, sent us, on returning from the Convention in November, valuable additions to our stock of working drawings and specifications. Besides occasional purchases, our stock of books has been increased by a set of fourteen volumes of the "Illustrated London News," presented by Mr. F. H. Jackson, and the first seventeen volumes of the "Builder," by Mr. J. C. Hoadley.

We have also received an interesting collection of drawings, illustrating the system of black-board instruction in use in the public schools of Belgium, presented to the Institute by the municipal authorities of the Commune of St. Josse-ten-Noode,

Brussels, through Mr. Hendrickx, the originator of the system. The Trustees of the Boston Athenæum have also deposited with us, on loan, a number of casts of architectural details and models of buildings; and the Trustee of the Lowell Institute has, in like manner, given us the use of a large collection of lecture diagrams, a valuable addition to our resources in this particular, which, though constantly growing, are as yet far behind our needs.

Among the most interesting objects upon our walls have been the works of the students themselves, which have been regularly hung in the Eastern or Green Room, under the French drawings, remaining there until displaced by their successors. Some of the best of them have been photographed before being returned to their authors, with a view of forming a porte-folio of students' works.

These various subjects have not only been of service to ourselves, but have been freely used in the cause of art education, wherever, in the present deficiency of such appliances, they have promised to be useful. Especially in the evening drawing classes, recently established in Boston and other towns, and which have to a considerable extent depended for teachers upon the students in this and other departments of the School, they have done excellent service.

The whole undertaking has proved more arduous than it seemed at first, and constantly grows more and more difficult as we enter upon its higher paths. But from the point we have now reached we see more clearly the dangers we have escaped as well as the difficulties of the road before us, and the degree of success which, in spite of all shortcomings, has attended the efforts already made, is the best possible encouragement for the future.

The best work, of course, that a school can do is to discover and develop first-rate talent and to turn it towards the work for which it is best fit, and it is the aim and ultimate hope of this Department to attract the attention of young men of superior capacity, so to arrange its methods of instruction

as to stimulate their best efforts, and thus constantly to recruit the ranks of the profession with highly gifted, as well as with well-trained workmen. It is as yet too soon to say what measure of success may be reached in this regard, but the rapidly extending knowledge of the elements of art among all classes may justify the expectation that whatever germs of artistic power may exist in the community will be brought to light, and this Department may hope to do its part in their training. There is already reason to believe that we are not behind other nations in the quality of our raw material. The quality of our products will depend on the perfection of our educational processes.

I am, very respectfully,

Your obedient servant,

WILLIAM R. WARE,

Professor of Architecture.

REPORT ON THE INSTRUCTION IN STEREOTOMY AND MECHANICAL ENGINEERING.

To the President of the Institute:—

The instruction in Stereotomy is given by lectures illustrated by diagrams and models, combined with practical exercises in drawing and modelling. It is furnished to the students in Engineering and Architecture, and comprehends the making of such plans, elevations, sections, patterns, and working drawings as are essential for the erection of structures in masonry, wood, and iron.

MASONRY AND STONE CUTTING.

The instruction in masonry and stone cutting includes the study of arches of various forms and positions, as cylindrical, conical, and warped arches; full centered, segmental, and elliptical arches; right, oblique, and rampant arches. The structures illustrating this part of the course have included portals, niches, corbels, groined, and cloistered arches, domes, stair-cases, and oblique bridges.

DESCRIPTIVE GEOMETRY.

Exercises in the more difficult parts of descriptive geometry have occasionally been introduced to facilitate and ensure the employment of exact methods.

MODELLING IN PLASTER OF PARIS.

Sets of modelling tools are provided and practical exercises in modelling have been given; these consisted in executing from rough pieces of plaster, models of portals, oblique, and rampant arches, with the aid of patterns and drawings previously prepared by the students themselves.

It may not be out of place to state, that although this kind of modelling is taught in the European schools of engineering, no attempt has hitherto been made to teach it in this country.

Moulding in plaster has been taught to a limited extent.

STRUCTURES IN WOOD AND IRON.

The instruction in carpentry includes framing, bay work, the construction of roofs, etc. Examples of Mansard roofs, of English roofs, showing the combination of iron with wood, ensuring strength and durability; and the most approved forms of iron roofs according to the system of Polonceau, have been given.

Problems in construction and design, accompanied with numerical data, have been given to exercise the ingenuity of the student, and put to a practical test his acquired knowledge and skill.

GRAPHICAL WORK.

Graphical exercises have been given to each student beginning with an exercise in descriptive geometry as follows:—

PROGRAMME OF THE FIRST PROJECT IN THE APPLICATION OF DESCRIPTIVE GEOMETRY TO THE ARTS.

Intersection of a Surface of Revolution by a Plane.

A torus, the radii of whose generating and directing circles are respectively r and R , and the distances of whose centre from the planes of projection a and b , is intersected by a plane. This plane has a declivity t ; its horizontal trace making an angle α with the ground line, is at a distance d from the axis of the torus. (a = distance above H.P. b = distance in front of V. P.)

The students will present,

1st. A drawing containing the two projections of the intersection of the plane with the torus, with one or more tangents to the limiting curve. The section should be colored according to the conventional tint.

2d. A drawing containing the curve and its tangents in their own plane.

3d. A memoir, explaining fully the principles and processes of the solution, the method in detail for tracing upon the solid in relief the curve of intersection, for cutting the solid, and for testing the accuracy of the section. [The pattern for verification should be constructed from the 2d drawing.] The students will use the following numerical data in alphabetical order.

R=	2.16	2.24	2.32	2.16	2.24	2.32	2.16	2.24	2.32	
r=	1.12	1.20	1.28	1.28	1.20	1.12	1.20	1.12	1.20	
α =	45°	46°	47°	48°	49°	45°	46°	47°	48°	
t=	0.5		a=	2.00		b=	4.00		d=	4.00

This exercise is varied by substituting for the plane or the torus, or both, developable, double curved, or warped surfaces.

Then follow the exercises in masonry and stone cutting executed by each student.

Each drawing contains the plan, elevation, profile, section, and development (if possible) of the arch, with the patterns of the joints.

These exercises are as follows: —

1. Right cylindrical arch.
2. " portal in a battering wall.
3. Full centered oblique portal.
4. " " portal in a round tower.
5. Spherical niche.
6. Solid corbel (known by the name of *Trompe*.)
7. Vaulted conical portal.
8. " portal (known as *Arrière voussure de Saint Antoine*.)
9. " portal (" " " " *de Marseille*.)
10. Groined arch.

11. Cloistered arch.
12. Dome.
13. Exercise to illustrate the properties of the warped surfaces.
14. Spiral staircase.
15. An original exercise with numerical data, illustrating the intersection of one arch with another of a different size.
16. Oblique bridge. Helicoidal System.
17. Rampant arch.

EXERCISES IN MODELLING.

The students this year have made three complete models :

1. A vaulted conical portal.
2. A rampant arch.
3. An oblique arch.

EXERCISES IN CARPENTRY.

1. Construction of a Mansard roof.
2. Construction of an English roof, illustrating the combination of wood with iron.
3. Bay work.
4. Construction of an iron roof according to the system of Polonceau.

[This last problem has not yet been completed.]

MECHANICAL ENGINEERING.—THIRD YEAR.— FIRST TERM.

The instruction in Mechanical Engineering commences with Cinematics, or the study of motions as exhibited in machines, and treats of the composition and resolution of such motions, and their graphical representation by means of curves, which serve to show the spaces, velocities, accelerations, and paths of the moving points or pieces. Applications of these principles

are at once made in the construction of cams and sliding pieces. Next, the properties of rolled curves, with the exact and expeditive methods for their delineation, are explained and applied in the construction of all kinds of gearing.

PRINCIPLES OF MECHANISM.

The principles of mechanism are next taught according to the system of Willis. The study begins with simple elementary combinations, and is extended so as to include the various contrivances for modifying the motion or the path of a moving piece, such as epicyclic trains, parallel motions, speed cones and pulleys, universal joints, link motions, etc., etc.

A recent examination paper is here introduced to illustrate the instruction, which varies from year to year as improvements suggest themselves.

SEMI-ANNUAL EXAMINATION. THIRD YEAR.

CINEMATICS.

1. *Helical motion.* Investigate the motion of a body rotating around a given axis, and moving at the same time parallel to this axis.

Example. A body makes 40 revolutions per minute, and has at the same time a velocity of translation $4\frac{1}{2}$ times its angular velocity. Determine the trajectory, as well as the direction and velocity of a point 6 ft. from the axis of rotation.

2. *Combined Parallel Rotations.* Let a plane passing through a fixed axis O, rotate about it with a given angular velocity a . Let C be a second axis in that plane, and parallel to the fixed axis O; and about the moving axis C, let a rigid body rotate with an angular velocity b relatively to the plane OC. Show how to find the position of the instantaneous axis and the resultant angular velocity.

3. *Curvature of the Epitrochoids.* Deduce the radii of curvature of the following curves employed in the construction of the teeth of wheels:

The Epicycloid, the Trochoid, the Cycloid, the Involute of the Circle, the Archimedian Spiral.

4. *Rotations about Intersecting Axes Combined.* Let OA be an axis assumed as fixed, and about it let a plane passing through OA

rotate with an angular velocity a . Let OC be a second axis in that plane and intersecting the first axis at O ; about the moving axis OC let a rigid body rotate with an angular velocity b . Show how to find the position of the instantaneous axis, the surface it describes, and the resultant angular velocity.

Bevel Wheels. Two axes intersecting at an angle of 80° are to be connected by a pair of bevel wheels: one axis is required to make three revolutions to one of the other. The largest radius of the pinion is 12 in.; this pinion is to have 44 cast iron teeth. The teeth of the wheel are to be of wood, and the width measured along the pitch surfaces is to be 5 in. The profiles of the teeth are to be involutes of the circle; and finally there must always be at least one pair of teeth on the first in contact with a pair on the second wheel. Show how to lay out the teeth.

5. *Combined Rotation about Axes not in the same Plane.* A rigid body rotates with an angular velocity p , around a given axis A in space; this axis revolves around a second given axis B , not in the same plane with the first, with an angular velocity q . Required the resultant angular velocity, the position of the instantaneous axis, and the surface it describes.

Skew bevel Gearing. It is required to connect two perpendicular axes not situated in the same plane by a pair of skew bevel wheels. The shortest distance between the axes is 12 in.; the least diameter of the pinion must be 24 in.; it must have 72 teeth 6 in. in width, measured along the pitch surface. The profiles of the teeth are to be formed by epicycloids and hypocycloids.

6. *Non Circular Wheels.* What are the geometrical conditions that must exist between a pair of rotating surfaces, in order that they may move in rolling contact round fixed axes?

Example. The equation of the base of a cylinder rotating around a fixed axis is $\log. r = A\theta + B$; what must be the equation of the base of a second cylinder rolling in contact with the first and rotating around a second fixed axis.

7. *Sliding of Teeth.* Given the arcs of approach and recess, to find the amount of sliding of one tooth over another.

8. *Sliding of Involute Teeth.* Find the amount of sliding of two involute teeth, supposing the tangent to the base circles to make an angle of $75\frac{1}{2}^\circ$ with the line of centres.

9. *Adendum of Involute Teeth.* Show how to find the adendum for involute teeth.

10. *Swash-Plate.* Find the equation expressing the motion transmitted by the swash-plate.

Show how to make a cam which will give the same motion.

11. *Cams.* Show how to construct a cam which shall give any assigned motion to a moving piece. Given $s = f(t)$.

Example. Make a cam which shall give exactly the motion of an eccentric.

MECHANISM.

12. *Wheels in Trains.* Suppose two axes are to be connected, whereof one revolves once in 24 hours, and the other in 362 days 5 hrs. 48 min. 48 sec., show how to arrange the train.

13. *Screw-Cutting Lathe.* What train should be used upon a screw-cutting lathe with a guide screw of $\frac{1}{2}$ an inch pitch, to cut a screw with $13\frac{1}{4}$ threads to the inch?

14. *Least number of Axes.* Given the value of a train, the least number of teeth allowed upon a pinion, and the greatest number allowed upon a wheel, to find the least number of axes.

Example. Required the least number of axes in a train of wheels which shall cause the last axis to revolve 180 times as fast as the first axis, allowing that none of the drivers contain more than 54 teeth, and none of the followers less than 9.

15. *Epicyclic Train.* Deduce the general formulæ for finding the value of epicyclic train.

Example. Ferguson's Paradox.

16. *Parallel Motion in Gorgon Engines.* Explain the theory and construction of the parallel motion used in a certain class of marine engines, known as Gorgon Engines.

The above instruction is completed in four months, and is followed by a course on the dynamics of machinery.

**DYNAMICS OF MACHINERY. — THIRD YEAR —
SECOND TERM.**

This comprehends the estimation and measurement of force and power; the application of the principles of virtual velocities to machines; the theory and use of the indicator and dynamometer; the estimation of the effects of centrifugal force; the determination of the safe speed of rotation for fly wheels, mill stones, polishing stones, etc.; the method of balancing locomotives to prevent dangerous oscillations when running at high speeds; the estimation of the effects of fluctuations of speed; the study of regulating apparatus, as fly-wheels, governors, cataracts, brakes, etc; the computation of the loss of power due to secondary resistances; resistance of friction; estimation of the loss of mechanical effect, occasioned by the friction of journals, pivots, teeth, screws, cords, belts, chains, etc.

To illustrate this last important subject, a powerful machine is taken and the loss of power on account of the friction of each piece is successively calculated, and the efficiency of the whole machine deduced.

GRAPHICAL WORK.

The instruction in making sketches and finished drawings of machinery from models, and from actual machines is continued during the third year, but in addition to this, numerical and graphical problems pertinent to the subjects of the lessons are given from time to time: such as the construction of cams, eccentrics, link and valve motions, and all kinds of gearing.

This is followed by exercises in drawing complete machines from given numerical data. For this purpose, liberal use is made of the collection of models belonging to this department.

At end of the year an examination over the whole course is held. The following is an examination paper:

ANNUAL EXAMINATION—THIRD YEAR.

MECHANISM.

1. *Epicyclic Trains.*

Deduce the general formulæ for finding the value of an epicyclic train.

Example.—Explain the *differential motion* of the bobbin and fly frame, in cotton spinning machinery, and calculate the velocity ratios of the bobbin and the flier corresponding to several different positions of the belt upon the speed cones.

2. *Watts' Parallel Motion.*

Explain the theory and construction of the parallel motion used in beam engines, or in side lever marine engines.

3. *Boring Machines.*

Explain the machinery used for boring steam cylinders.

Example.—Show how to arrange a train with the guide screw of $\frac{1}{4}$ an inch pitch, so that the cutter shall advance $\frac{1}{16}$ of an inch for every revolution of the boring bar.

4. *Speed Pulleys.*

Open Belt.—Find the length of an open belt upon a set of speed pulleys.

Example.—Let the diameters of two speed pulleys be 4, 6, 8, 10, 12 inches respectively and the distance between their centres 6 ft. Find the difference in length of belt required for the pulleys 12 and 4, and that required for the pulleys 8 and 8.

Crossed Belt.—Find the length of a crossed belt for the above system of pulleys and show that it will fit any pair of the speed pulleys with perfect exactness.

DYNAMICS OF MACHINERY.

5. *Friction of an Axle.*

Example.—A water wheel weighs 30,000 lbs., the radius of its circumference is 16 ft., and that of its gudgeon is 5 in.; how much force is required at the circumference of the wheel to overcome the friction, or to maintain it in uniform motion when running empty, and how great is the corresponding expenditure of mechanical effect when it makes 5 revolutions per minute? Co-efficient of friction 0.075.

6. *Friction of a Pivot.*

Find the moment of friction of a pivot.

1st. General case in which the equation of the longitudinal section is $y = f(x)$.

2d. Flat pivot.

Example.—A Turbine weighing 1800 lbs. makes 100 revolutions per minute and the diameter of the base of the pivot is 1 inch, how much mechanical effect is consumed in a second by the friction of this pivot? Co-efficient of friction = 0.10.

3d. Schiele's anti-friction pivot (Tractrix). Find the moment of friction.

7. *Effects of Centrifugal Force.*

Example.—The dimensions, density, and strength of a mill-stone are given; required the angular velocity and number of revolutions per minute, which will cause rupture in virtue of centrifugal force. Radius of the mill stone 2 ft.; radius of the eye 4 in. Modulus of rupture 720 lbs., specific gravity 2.5.

8. *Fluctuations of Speed.*

Determine the coefficient of fluctuation of speed in a machine.

Example.—The fly wheel of an engine of 35 horse power makes 20 revolutions per minute, its diameter is 20 ft., and its weight 20 tons. If the engine were employed to lift a tilt hammer weighing 4000 lbs., the centre of gravity of which is raised 3 ft., and if this were done merely by the work accumulated in the fly wheel what part of its angular velocity would it lose?

9. *Rankin's Isocronous Gravity-Governor.*

Find the relations between the dimensions, the revolving mass, the load and the speed.

10. *Efficiency of Teeth.*

Find the efficiency and counter-efficiency of a pair of spur and a pair of bevel wheels.

Example.—A force of 912 lbs. is applied to the circumference of a pair of spur wheels having 221 and 111 teeth respectively. The coefficient of friction is 0.10. What is the counter-efficiency and what force is transmitted to the second wheel?

FOURTH YEAR.—FIRST TERM.

The instruction comprehends:—

The examination of the materials used in Machinery, viz.: iron, steel, other metals and their alloys, wood, leather, hemp, etc.; their uses, defects, and the methods of preserving them from rust and decay; their moduli or coefficients of strength, elasticity and stiffness.

RESISTANCE OF MATERIALS.

This includes the estimation of the strength and stiffness of pieces exposed to tensile, shearing, bending, and twisting strains; factors of safety; calculation of the strongest forms of pieces; practical approximations to these; the effects of shocks and vibrations; the estimation of the strength of structures of stone, wood, and iron, as foundations, beams, columns, roofs, etc.; theory of continuous, and bowstring girders.

This portion of the course, which is thoroughly illustrated with practical examples, is followed by the students of Architecture, as well as those of Mining and Mechanical Engineering.

SEMI-ANNUAL EXAMINATION.—FOURTH YEAR.—COURSES I, III, IV.

1. *Extension.* Deduce the general formulæ for extension and compression, and solve the following problem:—

What must be the upper cross section of a wrought iron beam of the strongest form, 1000' in length, when, besides its own weight, it has to sustain a load of 75,000 lbs.?

What will be the elongation?

Modulus of Tenacity, $T = 10,000$ lbs. Modulus of Elasticity = 29,000,000 lbs. Weight of inch bar wrought iron per running foot = 3.34 lbs.

2. *Resilience.* Compute the work necessary to extend or compress a given beam or shaft.

Example. The pumping apparatus of a mine is connected with the engine by means of a series of wrought iron rods 200' long;

the section of each rod is $\frac{3}{4}$ of a square inch; the strain is estimated at 6 tons. How many units of work are expended at each stroke in the elongation of the bars? Modulus of Elasticity = 29,000,000 lbs.

3. *Flexure and cross breaking.* Investigate the case of a beam built in at one end, supported at the other, and uniformly loaded.

4. Apply the foregoing investigation to the theory of *continuous girders*, and solve the following problem :

A wooden beam 40' long, bearing a load of 500 lbs. per running foot, rests upon three equidistant supports, what must be the dimensions of the beam? Modulus of working load 1000 lbs.

5. *Compression.* If in the last example the centre support were a wooden post, what should be its diameter if the modulus of rupture be 6500 lbs., and a six-fold security allowed?

6. *Torsion.* Deduce the formulæ to determine the strength of shafts to resist torsion.

Example. The cast iron, upright axle of a turbine exerts at the circumference of a cog wheel, 30'' in diameter, keyed to this axle, a force of 2500 lbs. What diameter must be given to the shaft? Modulus of rupture 27,000 lbs., and a six-fold security to be allowed.

7. *Timbering in a mine.* At what distance from each other must the 10'' stretchers be laid to support a pile of refuse 60' high of an over hand stope, in a vein 4' thick, and dipping at 70°? The weight of a cubic foot of material to be supported is 65 lbs.; the coefficient of friction upon the supports is $\frac{1}{3}$.

8. *Calculations for the establishment of a bowstring girder.* A bowstring girder, consisting of two beams 12' long, 4'' high and 12'' wide, with diagonal braces and vertical struts, is supported at the extremities and loaded in the middle; the greatest opening between the beams is 10''.

What is the moment of flexure of the *upper beam* unloaded, caused by the middle strut?

What is the radius of curvature of its mean fibre, and the relative elongation of the extreme fibre?

What is the radius of curvature of the *mean fibre of the girder*, and its relative elongation?

What weight will the girder bear with safety? Modulus of strength = 12,000 lbs., and a three-fold security allowed.

Compute the increase in strength due to the struts and bracing.

The following additional questions were given to the class in Mechanical Engineering.

9. *Strength of an axle.* A round, wooden axle of a water wheel, 10' long, has to sustain the wheel together with its own weight, and a uniformly distributed load of 10,000 lbs. What diameter must the axle have? Modulus of strength 10,000 lbs., and a ten-fold security to be allowed.

10. *Limit of speed.* Given the radius and section of the rim of a fly wheel, it is required to find the number of revolutions per minute, which will cause rupture from the action of centrifugal force. How many revolutions per minute can it make with safety?

11. *Dimensions of fly wheels.* Given the energy stored in a fly wheel, the number of revolutions per minute and the weight of the rim, to find the mean radius and section of the rim.

12. *Strength of gear wheels.* Given the radius of the pitch circle of a gear wheel transmitting N horse power, and the number of revolutions per minute. Show how to calculate the pitch, number of teeth, their dimensions and those of the rim.

13. *Effect of fluctuations of speed.* The fly wheel in a rolling mill is connected with the rolls by a pair of spur wheels. At the instant at which the blooms pass under the rolls (according to the experiments of Morin), a fluctuation of speed occurs of one-thirtieth, which lasts about one-seventh of a second. Suppose the number of revolutions of the fly wheel to be 70 per minute; let the energy stored in its rim be estimated at 3,600,000 ft. lbs., what would be the pressure thus occasioned on the teeth of one of the spur wheels, having a radius of 3 ft. 8 in., and situated on the same shaft as the fly wheel?

FOURTH YEAR.—SECOND TERM.

CONSTRUCTION AND ESTABLISHMENT OF MACHINES.

This comprehends:—

The calculation of the strength, the requisite proportions and dimensions of the parts of machines, viz., those exposed to shearing stress, as rivets, pins, keys, wedges, gibs, cottars, bolts,

screws, etc.; those exposed to tensile strain, as cords, bands, rods, links, etc.; those exposed to shocks, and combined bending and twisting actions, as shafts, journals, cranks, rims, arms, teeth, etc.; the computation of the straining effects due to the power; allowance for the centrifugal tension of bolts, of wheels and pulleys; centrifugal whirling of shafts.

To illustrate this part of the course a powerful machine is selected, and the calculations made to determine the stress upon each piece, and the proper proportions and dimensions which should be given to it.

THE PRINCIPLES OF THE ACTION OF CUTTING TOOLS.

Description of shearing, paring and scraping tools; proper angles and speed for different kinds of work; estimation of the work done in dynamical units; combinations of cutting tools; advancing and transverse feed motions; machine tools—punches, lathes, drills; planing, slotting, shaping machines, etc.

ANNUAL EXAMINATION FOURTH YEAR.

CONSTRUCTION OF MACHINES.

1. *Straining effects of Reaction.*

Example.—A piston and its appendages weigh 300 lbs., the length of the crank is 15 in., the number of revolutions per minute is 60. Required the straining effect due to the accelerating force of the steam on the piston.

2. *Strength of Belts. Centrifugal Tension.*

Example.—Suppose a belt moving over a suitable pulley with a velocity of 600 ft. per minute, transmits a work of 5 horse power. Required the centrifugal tension, the tension due to the force transmitted, and the proper width of the strap.

3. *Strength of Axles.*

Example.—The crank at the end of a shaft receives and transmits a work of 50 horse power; this shaft rests upon two bearings 6 ft. apart, and carries one of a pair of spur wheels; this wheel situated at a distance of 5 ft. from the journal next the crank, weighs 3000 lbs., makes 35 revolutions per minute, and has a diameter of 14' 8". Find

the proper dimensions of the journal next the crank, taking into account; 1st, the force transmitted; 2d, the weight of the wheel; 3d, an approximate value for the weight of the axle; 4th, the reaction of the teeth of the wheel against its pinion. Show whether at this velocity the oil will be decomposed by overheating. Show also whether the pressure between the surfaces in contact is sufficient to expel the oil.

4. *Transverse Vibration of Pieces.*

Example.—1st. A pine rod 1 centimetre square, supported at two points 1 m. apart and loaded by a weight of 1.37 k. is deflected 0.032 m. What is its modulus of elasticity?

2d. The same rod was then loaded at the other end with a weight of 0.321 k. and put in vibration. The number of single vibrations in 30 seconds was 100. What was the modulus of elasticity?

ACTION OF CUTTING TOOLS.

5. Determine the pressures and the work performed by shearing and cutting tools.

Example.—What force does a punching machine exert in punching a hole through plate iron $\frac{1}{2}$ " thick, for a rivet $1\frac{1}{2}$ " in diameter? What amount of energy is expended? $f = 50,000$ lbs.

6. *Resistance and Work of Paring Tools.*

Compare the work of the machine with that of lifting the material pared off.

HYDRODYNAMICS.

7. *Impulse of Water on Vanes. Flat Vane.*

Example.—A stream of water whose cross section is 40 square inches, delivers 5 cu. ft. per second, and strikes normally against a flat vane, which moves away with a velocity of 12 ft. What is the impulse? The mechanical effect? What velocity must the vane have to produce the maximum effect? Required the mechanical effect, the pressure, and the efficiency due to this velocity.

HYDRAULIC MOTORS.

8. *Poncelet's Floats.*

Describe and give the theory of Poncelet's floats.

9. *Floating Mill Wheels.*

Find the mechanical effect of a wheel in an open current.

10. *Turbines.*

Give the theory of the turbine; compute the energy exerted by the water on the wheel, the energy expended, and the efficiency of the motor.

COURSE ON THE STEAM ENGINE AND OTHER PRIME MOTORS.

This course is given to all the students in Engineering, and comprehends the measurement of force and power; the theory and use of the indicator and dynamometer; the estimation of the resistance of friction in machines, and the principles of hydraulics pertaining to the construction of hydraulic machines and motors.

PRINCIPLES OF HYDRAULICS.

These comprise the measurement of water power; the computation of the discharge over weirs, through orifices and sluice gates; the estimation of the resistance in pipes due to friction, bends, mouth pieces, etc.; the calculation of the mechanical effect due to the impulse of water upon vanes of various forms, and moving in directions oblique to the jet; the computation of the speed of the vane to give the greatest efficiency; the best form of vane to receive a jet; the effect of friction during the impulse; the effect of centrifugal force.

HYDRAULIC MACHINES AND MOTORS.

The description of each hydraulic machine illustrated by models and diagrams; the theory of its action, and the calculation of its efficiency. These machines include the hydraulic press, single and double acting water pressure engines, water wheels, floating mill wheels, turbines, reaction wheels, etc.

PNEUMATIC MACHINES.

The description, theory, and the calculation of the efficiency of machines accumulating or using power by means of com-

pressed air; as the Chemnitz machine, the compressing pumps and engines employed in tunnelling Mt. Cenis, etc.

PROPERTIES OF STEAM AND GAS. — EFFECTS OF HEAT.

The results of Regnault's and Fairbairn's researches on the relations between the temperature, pressure, and specific volume of saturated steam; the results of Zeuner's researches on superheated steam; the computation of the loss of heat by radiation, according to the experiments of Peclet; the effect of jacketing; the computation of the heat thus economized per hour; the calorific power of different kinds of fuel; the total and available heat of combustion; the quantity of air required for combustion and dilution.

BOILERS, FURNACES AND FIRE GRATES.

The description and general arrangement of a furnace and boiler; the strength and construction of boilers; the total and effective heating surface; the water and steam room; the computation of the dimensions of a boiler to produce a certain quantity of steam per hour at a given pressure; the efficiency of a furnace; the efficiency of the heating surface; the requisite amount of grate surface.

STEAM AND GAS ENGINES.

The estimation of the work of the steam in an expansive steam engine: 1st, when the pressure is supposed to vary according to Mariotte's law; 2d, when the pressure is supposed to vary according to Laplace and Poisson's law; the efficiency of different kinds of engines; the estimation of the quantity of steam, feed water, and fuel, requisite to supply an engine running at a given speed with a given pressure of steam; the calculation of the effective work on the crank shaft; the theory of the slide valve, (Zeuner's graphical method); the expansion valve; the gas engines of Lenoir and Hugon; the recent improvements in this direction, with the binary steam and vapor engines.

This course has been illustrated throughout with numerical examples.

The following examination papers of last year are annexed :

MACHINERY AND MOTORS.—FIRST EXAMINATION FOURTH YEAR.

MEASUREMENT OF THE DYNAMIC EFFECT OF MACHINES.

1. *Dynamometer.* Explain the theory of Prony's friction dynamometer, and apply it in the solution of the following problem :

To determine the effect of a water wheel, a friction dynamometer was placed on the shaft when the water let on had been perfectly regulated for six revolutions per minute ; the weight in the scale pan, including the reduced weight of the instrument, was 530 lbs., the leverage of this weight was 10.5 ft. What was the horse power of the wheel ?

2. *Indicator.* Explain the theory of the indicator, and apply it in the solution of the following question :

A double acting expansive steam engine has two indicators, one at each end of the cylinder. The breadths of the diagrams given by each, measured on a scale representing pounds on the square inch, are as follows :

Top, 27, 83, 91, 91, 64, 57, 53, 42, 35, 22, 13 ; bottom, 36, 97, 96, 84, 64, 57, 46, 40, 32, 22, 12 ; the area of the piston is 345 square inches ; the length of stroke is 30 inches ; the number of revolutions per minute is $52\frac{1}{2}$; what is the indicated horse power of the engine ?

3. *Brake.* Explain the theory of the flexible brake, and apply it in the solution of the following question :

To let down a shaft a load of 1200 lbs. from a certain height, the rope to which this weight is attached is wrapped $1\frac{3}{4}$ times about a round, firmly clamped holder, and the other extremity is held by the hands ; with what force must this extremity be stretched that the load may slowly and uniformly descend ? Let the coefficient of friction, $f = 0.3$.

HYDRAULICS.

4. *Discharge through a rectangular orifice.* Example. If a rectangular orifice is 3' wide, $1\frac{1}{4}$ ' high, and the lower edge lies $2\frac{3}{4}$ ' below the surface of the water, what will be the discharge per second ?

5. *Friction of the water in pipes.* Example. What discharge will flow through a pipe 2' in diameter, under a head of 3' of water, when the coefficient of resistance, owing to the friction in the pipe, is 0.40.

ÆRO-DYNAMICS.

6. *Work of Expansion.* Compute the mechanical effect produced by the expansion of a given volume of air or steam.

Example 1. The inner diameter of the cylinder of a high pressure, double acting steam engine, without expansion, is 18", the number of revolutions per minute 24, the length of stroke 40". The steam gauge stands at 32.25 lbs. The barometer indicates the pressure of the atmosphere to be 14.1 lbs. What is the pressure on the piston, and what is the power of the engine?

Example 2. In the last example what would be the horse power of the same engine, working expansively, the steam being cut off at .4 of the stroke?

How much more steam would be used in the first case than in the second?

State the relative economy in using steam expansively.

7. *Compressing Engine.* Make a sketch of the compressing engine (*Compresseur à choc*) used at the Mt. Ceniz tunnel for supplying compressed air to the boring machines. Give the theory of this engine, and calculate its efficiency. Diameters of the tubes 0.62 metres; height of the column of air compressed at each stroke 4.05 metres; height of the fall, 26 metres; pressure of the atmosphere 10.330 metres; pressure in the manometer 7 atmospheres after each stroke.

8. *Compressing pump.* Make a sketch of the forcing pump (*Compresseur à pompe*) used for the same purpose. Give the theory of its working, and calculate its relative and absolute efficiency, supposing it to be driven by an overshot water wheel, using 60 cubic metres of water per minute, with a fall of 5.60 metres. Diameter of the pump 0.57 metres; length of stroke 1.20 metres; number of strokes per minute 16; manometric pressure 7 atmospheres. Assume the efficiency of the water wheel to be 75 per cent.

9. *Safety Valve.* Find the effective pressure necessary to open the safety valve and solve the following problem:

The statical movement of an unloaded safety valve is 10 inch lbs.; the sliding weight, 15 lbs., has a leverage of 10"; the arm of the valve measured from the valve to the fulcrum is 4"; the radius of the valve is 1.5"; what is the pressure per square inch on the valve?

HYDRAULIC MOTORS.

10. *Water Pressure Engine.* Calculate the principal parts of a single acting water-pressure engine used to drain a mine.

Given depth of the mine, $h = 230$ metres; quantity of water flowing in per minute, $q = 1.792$ cubic metres; source of power, a fall, $H = 60$ metres, giving a quantity, $Q = 20$ cubic metres per minute. Loss of head due to friction, bends, valves, etc., $k' = \frac{1}{3}$. Loss of water on account of the pierced valve, $k'' = \frac{3}{10}$. Assume the length of stroke, $Z = 2.3$ metres; the number of strokes, $n = 5\frac{1}{2}$ per minute, and limit the velocity of flow through the supply pipe to 2 metres per second. Calculate also the size of the supply pipe and the diameter of the forcing pump.

11. *Effect of Centrifugal Force.* Effect of the centrifugal force on an overshot water wheel.

Example. An overshot water wheel 32' in diameter makes 5 revolutions per minute, what angle does the surface of the water in the bucket at the extremity of a horizontal diameter make with a horizontal line?

12. *Poncelet's Water Wheel.* What should be the curve of the longitudinal section of the head race for Poncelet's water wheel?

SECOND EXAMINATION.

HEAT APPLIED TO AIR AND STEAM.

1. *Combination of the laws of Mariotte and Gay Lussac.*

Example.—If 800 cu. ft. of air at a temperature of 10° C., and at a pressure of 15 lbs., are brought by means of the blowing engine and warming apparatus of an iron furnace to a temperature of 200° C., and a pressure of 19 lbs., what volume will it assume?

2. *Specific Volume of Saturated Steam.*

Example.—What quantity of feed water does a boiler require to produce 500 cu. ft. of saturated steam at a pressure of 3 atmospheres?

3. *Specific Volume of Superheated Steam.*

In the last example let the steam be superheated to 150°C , and at the same pressure; what will be the amount of feed water then required?

4. *Peclet's Law of Cooling.*

Example.—A wrought iron boiler contains water at a temperature of 100°C , and has a surface of 15 square mtrs. exposed to the air at 20°C ; what hourly cooling takes place?

Effect of the Jacket. If the same boiler had a jacket of 25 square mtrs., what cooling would then take place?

CONSTRUCTION OF BOILERS.

5. *Boiler with Heaters.*

Example.—Determine the dimensions of a cylindrical boiler with hemispherical ends to supply 520 lbs. of steam per hour. Let the boiler be furnished with two heaters.

6. *Strength of Boilers.*

Example.—Find the proper thickness of plate iron for the foregoing boiler, on the supposition that the working pressure is to be 4 atmospheres.

THERMODYNAMICS.

7. Apply Poisson's law for the specific heat of gases to determine the work done by the expansion of a given quantity of air, gas or steam; and state what modification the formulæ would undergo for each of these fluids.

Example.—The inner diameter of a high pressure, double-acting, expansive steam engine is 18"; length of stroke is 40"; number of revolutions per min. 24; the steam gauge stands at 65 lbs; the steam is cut off at .4 of the stroke; what is the power of the engine, and how much steam is required per hour?

QUANTITY OF FUEL CONSUMED BY A STEAM ENGINE.

8. A low pressure, non-expansive steam engine has a cylinder 6' long, and $2\frac{1}{2}'$ in diameter; number of revolutions per minute 18; temperature of the steam 104°C ; temperature in the condenser 35°C ; efficiency of the engine, 0.60. What is the power exerted on the

crank? How much steam is used per hour? How much feed water at 30° C., will be required to supply the boiler? How many units of heat per second will be required to produce this steam? Let the efficiency of the furnace be 0.75, that of the heating surface be 0.60 and suppose 1 lb. of coal to contain 7500 units of heat. How much coal is consumed per hour? How much per horse power per hour?

9. *Expansion slide Valve.*

Example.—The radius of the eccentric is 1.57", the steam is to be cut off at $\frac{1}{4}$ of the stroke. Compute the breadth of the port in the expansion valve.

10. *Balancing Locomotives.*

Show how to compute the proper weights to balance the centrifugal force in a locomotive.

Example.—Show how to balance an inside cylinder engine of the following dimensions: Distance between the centres of the cylinders = 2' 6", distance between the wheels 4' 7". Weights of the moving parts; crank referred to the pin 93 lbs.; connecting rod 188 lbs.; piston and rod 174 lbs.; cross head 64 lbs. Distance of the centre of the counterpoises to be 3 times the length of the crank. Determine the weight and position of each counterpoise.

GRAPHICAL WORK: PROJECTS.

Projects for machines and motors are given when the students have been made acquainted with the doctrine of the strength of materials, so as to be able to find the dimensions of pieces to resist flexure, shearing, torsion, etc. They consist of original designs for machines, involving the determination of the strength, dimensions, and proper proportions of the several parts by calculation.

The programme of a project, given during the current year, is here inserted as an illustration of the kind of work accomplished.

PROJECT FOR A TRAVELLING CRANE TO BE USED IN THE CONSTRUCTION OF A STONE BRIDGE.

PART FIRST.

The load is to be moved along the bridge, across the bridge, and vertically.

For this purpose there should be established a line of railway, one rail being placed on each side of the service bridge; upon this track a car with four wheels is to run; the platform of this car should consist principally of two wrought iron hollow beams. Upon this car should be placed a second track, at right angles with the first and laid upon these beams. Upon this second track a second car should be placed carrying a crab engine furnished with a brake, a ratchet and detent.

The present project is divided into two parts. The first consists of a memoir and the sketches requisite for understanding the machine as a whole and in detail. In the memoir the arrangement of the parts should be clearly described, and the dimensions given to the principal pieces verified. Finally, the force necessary to produce each of these three motions is to be calculated considering the effect of friction. 35 lbs. should be the limit to the effort of a man turning a crank.

The traction of the car is two per cent. of the weight. The data are as follows:—

Maximum weight to be lifted	15,000 lbs.
Vertical distance “ “ “20 ft.
Width of the first track40 ft.

GRAPHICAL WORK: PART SECOND.

The students will make a general plan, an elevation, and a section; also, the details of the transmission of all the motions, the brake, the engaging and disengaging gear, and in fact every thing necessary for the complete comprehension and construction of the machine.

These drawings should be shaded in india ink, and the nature of the materials employed, should be shown by the conventional tints.

The following projects, requiring more or less original research have been done during the present year.

1. Project for an outward flow turbine to drive a cotton mill.
2. Project for a travelling crane to be employed in the construction of a stone bridge.
3. Report on the construction and efficiency of the compressing pumps used at the Mt. Ceniz tunnel, for supplying compressed air to the boring machines, accompanied with elaborate drawings.

4. The computation for the construction and establishment of a packing press capable of exerting a pressure of 80 tons.
5. Project for a water wheel according to the system of Poncelet; to be used for driving a flour mill.
6. Project for a rolling mill driven by a steam engine.
7. Project for a parallel flow turbine system according to the system of Jonval, to furnish the power sufficient for a machine shop.
8. Project for a gas engine according to the system proposed by Mr. Brayton.
9. Report on the construction and efficiency of the compressing engine used at the Mt. Cenis tunnel for supplying compressed air to the drills with drawings of the engine and its details.

These projects comprise:—

1. The plans, elevations and sections of the machines.
2. The working drawings of the details.
3. A memoir containing the description and theory of the machines; the estimation of the resistances; the calculation of the strength and proper proportions of the parts, and the reasons for the particular dispositions adopted.

EXCURSIONS.

In aid of the practical studies of the School, the students have made a number of excursions, for the inspection and study of machines. The most recent are as follows:

Feb. 17. To Brayton's Gas Motor:—

The principles, the mode of action, with the details of the construction were explained by diagrams, and illustrated by the practical working of the machine. The analogy between this motor and the common caloric engine was carefully explained, together with the devices employed for substituting for ordinary gas, the vapors of the volatile hydro carbons.

The differences between this engine and those explosive engines of Lenoir and Hugon were pointed out, together with the novel and ingenious application of the principle of Bourdon's gauge for automatically regulating the pressure.

Feb. 24. To the Boston Gas Works to examine the practical working of Hugon's Gas Engine.

The mechanism of the valves and the construction of the interior of the machine were shown by diagrams; the quantity of gas consumed was observed, and the cost of running estimated. The effect of the introduction of a jet of water into the cylinder was exhibited by curves showing the changes in the manometric pressure.

March 2. To Houghton's Automatic Steam Pump. The apparatus was shown by a beautiful glass working model. The analogy between this and Savery's steam engine was pointed out, together with the improvements introduced which rendered it safe and automatic.

March 14. To the Navy Yard in Charlestown, to see the powerful machinery employed in bending timber, the invention of Mr. Griffith, together with the travelling cranes, hydraulic presses, the Corliss steam engine, boilers, feed water heating apparatus, etc.

March 30. To the works of the Iron and Steel Company at Nashua, N. H. Here the students had an opportunity of seeing a Semen's gas furnace, the Martin process for making steel, Armstrong's hydraulic cranes and accumulators for handling the ladles and ingots, the process of forging and finishing steel, and the rolling of large steel tires, requiring the use of heavy steam and hydraulic machinery. They also visited the Nashua Cotton Mills, where they saw a Boyden turbine of enormous power; also the works of the Nashua Lock Company.

April 27. To the Atlantic Works, in East Boston, to observe the practical working of Mr. Ellis's Binary Vapor Engine for economizing the heat of exhaust steam by using it to vaporize sulphide of carbon. The ingenious air condenser was noticed, also the precautions to prevent the leakage of the volatile fluid. The analogy and the difference between Mr. Ellis's engine and that of M. DuTrembley was pointed out. Visits were made to the pattern shop, forge, and machine shop.

In concluding this portion of the report the Professor in charge desires to express his obligations to the Superintendent of the Boston, Lowell and Nashua Railway, and to the Super-

intendents of the various establishments visited, for courtesies extended.

ADDITIONAL MODELS.

The following additional models have been received during the past year:—

A beautiful model of a warped helicoid with its tangent hyperbolic paraboloid.

A set of models illustrating the principles of perspective.

A set of models of right and oblique bridges, with their approaches and other accessory works.

Model of a furnace and fire grate.

Model of a French boiler.

Model of an endless screw motion.

Model of a face wheel and lantern gearing.

A highly finished model of the compound engines of the screw steamship Hecla, of the Cunard Steamship Line, presented by David MacIver, Esq., of Liverpool, England.

The following models were omitted in the report for last year:—

A new form of coupling, presented by Mr. S. P. Ruggles.

A new form of pulley, presented by Mr. N. M. Lowe, and called by him a universal pulley.

A silent feed motion used in sewing machines, presented by Mr. Charles L. Spencer.

A model of the metallic packing of a steam piston, presented by Mr. Horace McMurtrie.

Models of the peculiar mechanism of stem-winding watches, presented by Mr. J. H. Gerry.

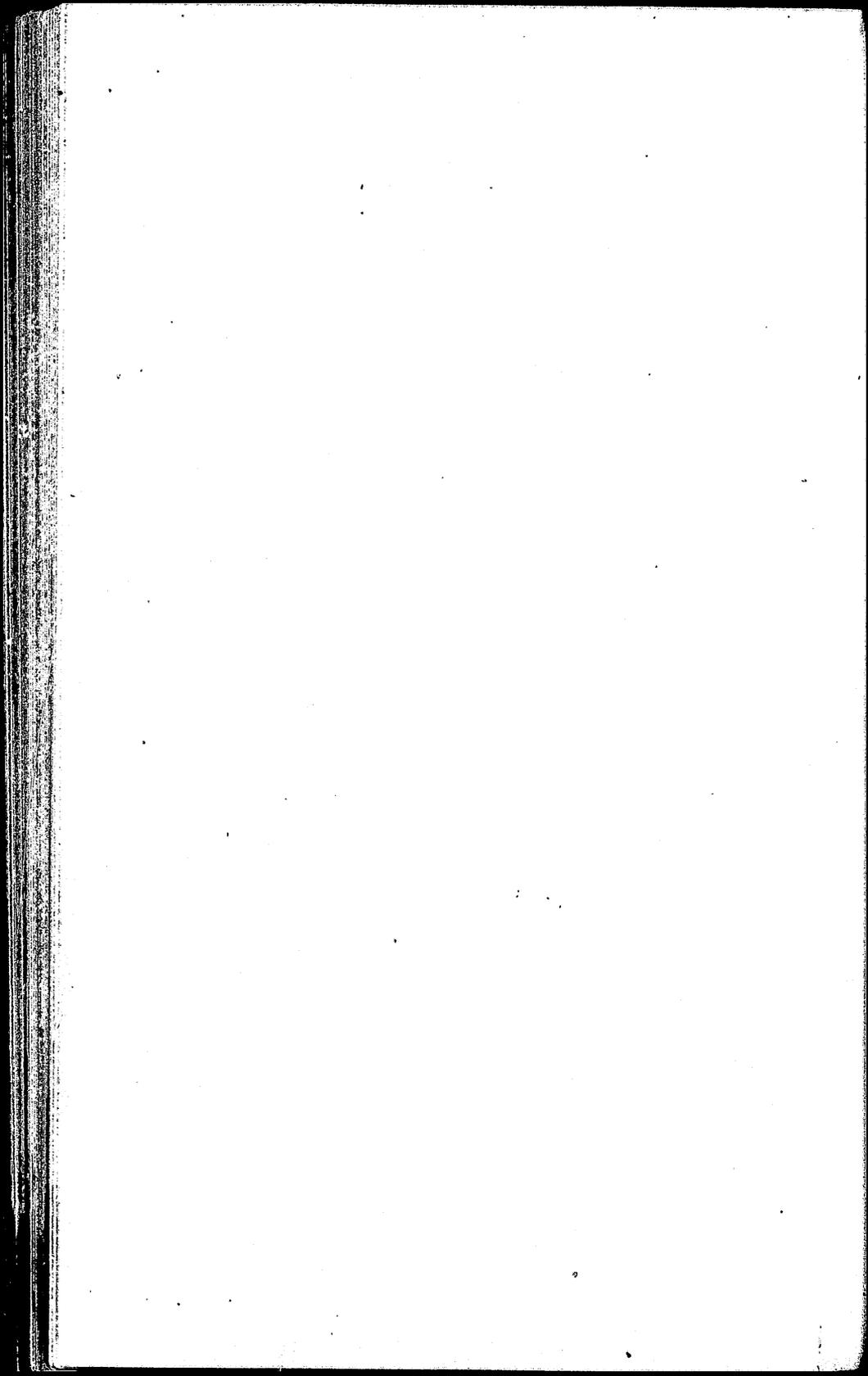
Models of eccentric gearing, presented by Mr. S. P. Ruggles.

In conclusion, attention is called to the three-fold use of the models; first, in the drawing rooms as objects from which sketches and finished drawings are made; second, in the lecture

rooms, to illustrate the principles of machinery, and to exhibit to the eye what would otherwise require long and tedious explanations; and third, in the practical exercises in construction and design, which would be difficult, if not impossible, without them.

All of which is respectfully submitted,

WM. WATSON,
Professor of Mechanical Engineering,
Mass. Institute of Technology.



REPORT ON THE INSTRUCTION IN THE DEPARTMENT OF ENGLISH.

President J. D. Runkle, Sir :—

I beg leave to present the following Report of my doings in the department of English and History during the past school year.

The question of the best method of adjusting my instruction to the real wants of the students of the Institute, has been from the outset a very perplexing one. The imperfect preparation for the scientific studies of the course which the students bring with them lays a heavy pressure upon them in that direction; and, on the other hand, the deficiencies of too many of them in English studies require an attention to rudimentary drill, especially in Composition, which should properly have been completed before admission. A gradual but steady rise in the standard of qualifications for admission to our school, to correspond with the improvements which are making in the English and Scientific instruction given in our High Schools, will eventually remedy much of this difficulty. I have to report that I have been successful in securing a regular attendance and an interested attention to my lectures. I have nothing but praise for the conduct of the students, and am confident that good results have been attained beyond what can be exhibited by a formal

examination. Students just emancipated from the restraints of school, and just passing from boyhood into young manhood are in a peculiarly receptive condition of mind in regard to the moral, political, social and æsthetic questions which form the real subjects of instruction in History and Literature. They are beginning to think for themselves, and are looking forward to a new future, where they will have to act for themselves. It is a period when judicious oral instruction can be made of more value than either before or afterwards. Lecturing therefore forms a very legitimate method of instruction, and, where the student's brain is constantly taxed by a very large amount of hard mathematical and scientific study, so that the mental discipline must under any circumstances come mainly from the scientific side, lecturing must continue to hold an important place in the literary and historical departments; and, it is very observable that the mental training obtained through the instrumentality of the severe discipline of the former class of studies perceptibly increases the intelligent interest of the students in the latter.

But lectures, to be of any value, must be supplemented by some literary as well as scientific work on the part of the students; and as it would be wholly impossible for one teacher to give elaborate and distinct courses of instruction in Rhetoric, Logic and Criticism, and also in political and literary History, my aim has been to comprise as many different elements as I could in one or two courses, and to connect with them as much practice in writing as time permitted. The students of the classes of the first and second years have taken brief notes of lectures, and written them out in manuscript books, which have been regularly examined by my assistant, and all elementary errors in spelling, punctuation and style corrected. Elementary deficiencies are very general. I have taken the ground that while the Institute of Technology does not offer itself as a teacher of writing, spelling, punctuation and the rudiments of the art of composition, it will give all the incidental help it can to its students for the making up of such deficiencies in their

school education, but should refuse to give a degree or diploma to any student who, by the end of the four years, has not acquired, directly or indirectly, a satisfactory proficiency in them.

I think that by devoting a larger share of time to drill in composition during the first year, that object can be satisfactorily attained. After the first year, I am anxious to carry out more fully the system of requiring a certain amount of prescribed collateral reading in connexion with the lectures on History and Literature, accompanied by oral or written analyses of the same, or even lectures to be given by the students themselves. In this way practice in composition may be clearly combined with the oral instruction, and the general interest will be increased through the students themselves taking a more active share in the work. But for the proper carrying out of such a plan, I greatly need better library accommodations, and a better supply of carefully selected books; not a miscellaneous collection on any and all topics, but exactly the books that contain the collateral reading I wish to require. I consider that one of the greatest services I can do my pupils is to teach them how to use books. Their knowledge of the contents of English Literature and of the character and relative value even of modern writers, as tested by examination, is surprisingly small.

My course of instruction for the past year has been as follows:—To the first year's class I have lectured once a week on the writers of the last century, devoting a good deal of time to elementary ideas on the study of Literature in general. Notes of these lessons have been written out by the class. The other weekly exercise has been devoted partly to Composition, partly to lessons on Language and General Grammar, with special reference to the history of the English language. A portion of this last instruction could be given hereafter to better advantage by the Professor of Modern Languages, in connexion with the instruction in German and French, if a professor should be appointed who has a competent knowledge of the science of Comparative Philology, leaving me more time for much-needed work in the details of practical composition.

With the second my lessons have been mainly confined to the history and literature of the Eighteenth century, with special reference to English History and the events of our Revolution. The class have taken notes. They have shown much interest, especially in the American portion of these lessons, and might have done a good deal of collateral reading without detriment to their severer studies, if books on American history had been immediately at hand in the reading-room.

To the third year's class I have given a detailed series of lessons on the U. S. Constitution, along with as much instruction on English constitutional history and the general principles of constitutional law as time and my own reading permitted. These have occupied one of the two weekly hours. The other has been devoted to the oral translation, with a running commentary, of Guizot's "Civilization en Europe," the students having the French text open before them. Their knowledge of French has been thereby somewhat improved, and it has been the best means I could devise of giving the class a general view of the outlines of modern history. These lessons can be made much more valuable by going more slowly over the book and requiring some collateral reading, and occasional oral or written translations from the students.

With the fourth year's class my attention has been mainly devoted to Political Economy and the Commercial and Economical aspects of History. Adopting the smallest and least controversial manual that I could find, I have made it the text for a series of readings and oral lessons, designed mainly to interest the class in the investigation of the various politico-economical subjects, which have so close a connexion with their professions and future occupations in life. No subjects belonging to the English department are more important, or have proved more interesting to the students than these; but in the more technical parts of Political Economy, the subjects of Currency, Banking, &c., I have to lament my own lack of practical knowledge; and I would respectfully suggest that a brief course of non-contro-

versial lectures on these topics, explanatory of the ordinary course of business, and given by a practical business man, would be very useful.

The only assistance of this kind which I have received this year has been a short, but excellent course of lectures, given to the classes of the third and fourth years together, by Hon. Emory Washburn, Bussey Professor of Law in the Harvard Law School, in which the students were much interested. I feel personally under great obligations to Ex-Gov. Washburn, for this assistance, given, at the cost to himself of a good deal of time and trouble; and thanks are due to him for the interest he has thus again practically shown in our institution.

In this connexion I will also mention our obligations to Hon. Charles Sumner for repeated gifts of valuable public documents.

As the result of the enlargement and reconstruction of the course on Science and Literature, I have had, during the second term a small extra class in English studies. From want of time, owing to the absence through illness of Prof. Howison, I have not been able to do anything very systematic with them. They adopted my proposal to study, as far as time allowed, in connexion with our two weekly meetings, the actual present condition, political, social and economical, of some of the leading nations of the world, as given in the most recent authorities; as E. G. Martin's Statesman's Year-Book, the writings and speeches of Grant Duff, the leading periodicals, &c. The experiment was sufficient to show how valuable and interesting such instruction might be made to young men who are looking forward to the active career of business men, manufacturers or merchants, and I trust that as our institution develops, more resources may be put at the command of the English department for perfecting it.

After this detail of my labours I hardly need say that they have been too varied and multifarious to allow of their being performed with proper thoroughness. I look forward with the greatest satisfaction to the prospect of sharing the work of this department with another teacher. With the aid of a Professor

of Modern Languages, if we shall be so fortunate as to obtain one, I shall hope to be able next year to confine myself to a narrower circle, and to be able to undertake with the students in Science and Literature more careful and detailed extra instruction in History and English Literature.

All which is respectfully submitted.

W. P. ATKINSON.

May 19, 1872.

REPORT OF THE DEPARTMENT OF PHYSICS.

To the President of the Institute :—

A somewhat detailed account of the course of instruction in the Physical Laboratory has been given in previous annual reports, and it remains substantially unchanged for students of the Third Year, except by the introduction of many additional experiments. The present Report will therefore be confined to a description of the extension recently made by introducing the study of Physics into the Fourth Year. In the earlier part of the laboratory course a full description is given of each experiment, and the apparatus necessary for performing it is put in perfect order, so that the student can at once proceed. This, however, is very different from cases arising in actual practice. The engineer or chemist who wishes to undertake any original investigations must generally devise his own apparatus, make it, or at least superintend its construction, perform the necessary experiments, and finally, if the results are of value, prepare a report of them for publication. The subject is presented to the students of the Fourth Year in precisely this form. A problem in practical physics is suggested to them which they are expected to work out experimentally, and report the results. As examples the following extracts from a portion of these reports are appended, retaining as far as possible the student's own words. The illustrations are necessarily omitted, also the curves exhibit-

ing the results, and in most cases the tables are very much abridged. The actual amount of work done is therefore much greater than would appear from the perusal of the following pages. As this course has been on trial only during the past four months, great improvements are to be expected when experience has shown the kinds of experiments that can be most profitably performed by the student, but we believe that enough has already been done to show that results may be obtained, which shall be of great use to the student as a method of training, and at the same time possess considerable scientific value.

MECHANICS OF SOLIDS.

A number of pine rods as nearly alike as possible were provided and used by the students as units with which to form a variety of trusses. The following will serve as an example :

Report upon Experiments on a Queen-Post Truss and its component parts, by Messrs. C. S. Ward and B. E. Brewster.

Several series of experiments were made upon a number of beams supported at both ends, distance between supports being 66". Weight applied in the centre, 6 lbs.

The deflection was measured by means of a millimetre scale pasted upon a strip of wood, and suspended in the middle of the beam. The beams used were 6' long, and $\frac{1}{2}$ " square.

(In the original report a table is here inserted, showing measurements of scale-readings before and after the weight was applied, the deflection and permanent set. Five beams were used, and the measures repeated after turning them over. Deflections in cm. were as follows:— 7.85, 7.95, 9.15, 9.50, 7.95, 8.05, 10.30, 10.65, 7.45, 7.80).

Average Deflection, 8.86 cm. Average permanent set, .5 cm.

Another beam, No. 6, was similarly tested on its 4 sides to compare the relative strength. Deflections, 7.80, 8.00, 7.90,

7.85. Beam No. 6 was loaded as before with a wt. of 6 lbs. and readings taken at intervals of $\frac{1}{2}$ minute until deflection became constant. Results 12.90, 12.95, 13.05, 13.10, 13.15, 13.15, 13.15. The first reading was at the end of one minute. Curve No. 2, represents this increase of deflection.

Beam No. 5 was used for determining the deflection under a varying weight. Deflections from 0 to 8 lbs., 5.00, 6.30, 7.55, 8.85, 10.15, 11.50, 12.75, 14.05, 15.75. By examination we see that the changes in deflection were very constant, with the exception of the last, and in accordance with the law that the deflection is proportional to the weight. Curve No. 3 shows this result. Next, experiments were made to get the form of the deflected beam. For this purpose a constant weight of 8 pounds was applied in the middle, and a series of readings with and without the load was made at points 3" apart. Length of beam as before, 66". Deflections, 9.9, 9.85, 9.60, 9.80, 8.30, 7.35, 6.30, 5.10, 4.00, 2.65, 1.15. The deflections are shown in Curve No. 4.

A weight of 6 lbs. was then applied to the beam at different points taken at intervals of 3" from 33" to 15", in order to determine the relative deflections, which were 12.75, 12.60, 12.30, 11.70, 10.80, 9.80, 8.70.

The breaking strength of the beams was then tested. Distance between knife-edges, 5', weight applied in the centre. The tension on the beam at the moment of rupture was noted by means of a spring balance; accuracy limited to $\frac{1}{4}$ of a pound. Breaking weight of beams Nos. 7 and 8, $17\frac{3}{4}$ and $18\frac{1}{2}$ lbs. respectively.

From beams similar to those already experimented upon, a queen-post truss was built of the dimensions shown in the figure. Length of truss, 60". Height, 10". Distance apart of queen-posts, 20". Distance apart of two trusses forming sides of bridge, 12". Beams bolted together with iron bolts $1\frac{1}{4}$ " long, $\frac{1}{4}$ " in diameter.

The combined trusses were first subjected to a load of 100 lbs. applied midway between the trusses, and distributed uniformly throughout the length. Readings were taken at 7 points of the roadway at distances from one end of 3, 10, 20, 30, 40, 50, 57 inches respectively, that is one three inches from each end, one ten inches from each end, one at bottom of each queen-post and one at centre. Deflections, .20, .50, .50, .60, .60, .35, .20. The deflection was greater at one end of the beam than at the other, because there was a split in it. Curve No. 6 represents the results.

A weight of 70 lbs. was then applied in the middle of the truss with the following results, the points being at same distances as before. Deflections, .18, .04, .41, .88, .53, .02, .18. Curve No. 7 was constructed from these data. By inspection of this curve it will be seen that the beam actually rose a little between the bottom of the queen-posts and the ends of the main beams, owing to the whole thrust acting in the centre.

Measurement of the strain on the queen-post. The post was removed and a spring-balance substituted in its stead, the distance being kept constant with each succeeding additional weight by means of a rod with adjustable nut. Applying at the centre eight 10 lb. weights in succession the observed strains were as follows: — 2, $5\frac{1}{2}$, 8, 10, 12, $14\frac{1}{4}$, $16\frac{1}{2}$, $17\frac{3}{4}$. In curve No. 8, horizontal distances represent weights, and vertical distances strains, on the post.

Strain on Struts. Found by replacing one of them by a spring balance in a similar manner to that described in the preceding experiment. With weights of 0, 10, 20 and 30 lbs., the strains were $4\frac{1}{2}$, $10\frac{3}{4}$, $16\frac{1}{2}$, and $22\frac{1}{2}$ lbs. respectively. Curve No. 9 was constructed in a similar manner to No. 8.

Similar experiments were made by Messrs. Dodge and Sparrow, preparatory to building a model of a Howe truss.

They first tried different methods of connecting two beams

end to end, and measured the force required to separate them. To test the method of computing the strains on any part of a truss, a beam was fastened at one end to an upright, the other end being held by an oblique tie-rod. The strain on each of these was measured as before by inserting a spring balance and compensating screw. The strain was thus measured for each pound weight added to the end, up to 15 pounds, and compared with the theoretical strain. The deviations due to friction, error in the balance, &c., were very small.

They then constructed a complete Howe truss of length 64", width 12", and height 8". The ties were made of brass rods, on which they cut screw threads and made nuts to fit them. The finished bridge was tested by applying a load at the centre, ten lbs. being added at a time, with results as follows: —

Load,	10	20	30	40	50	60	70	80	90	100.
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Flexure,	.50	.75	1.25	1.75	2.25	2.75	2.85	3.45	3.75	4.25.
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It will be seen that the deflection was only about one-sixth of an inch for a load of one hundred pounds.

Comparing this result with the flexure of a single beam, we see that the stiffness of the latter is only about one three-hundredth of that of the truss, and the student by placing his hand first on one and then on the other, has a far more convincing proof of the value of the truss system, than he could attain by any amount of mere theoretical study. A very complete model of a suspension bridge was made by Messrs. Stafford and Shepard, using common iron chain for suspension. Its span was 8', and deflection 8". The roadway was hung by 15 suspension-rods on each side, and the change in position of each was measured with the load applied at a single point, and also when uniformly distributed.

Measurement of the Angular Deflection of Beams fixed at one end.
By Mr. C. F. Allen.

The apparatus for this experiment when ready for use was as follows:— I. The beam itself, whose section was $\frac{1}{2}$ inch square, and length about 30 inches, carried a scale extending over 20 inches of its length. The beam was firmly clamped at one end between two other beams of sufficient stiffness to prevent any bending action from being transmitted beyond the outer point of support, and at its end a wire was fastened from which weights could be suspended. II. A mirror of plate glass mounted so that it could easily be attached to the beam at any point. III. A telescope with cross-hairs, mounted upon a wooden stand placed 60 inches from the mirror, and carrying a vertical scale; the zero point of the scale and the line of collimation or axis of the telescope being in the same horizontal plane with each other and with some point of the mirror. IV. Weights of $\frac{1}{2}$, 1, 2, 2, 4, lbs. respectively.

Principle:—When the beam was unloaded, the 0 of the scale was reflected upon the cross-hairs of the telescope; when a weight was attached, the beam was bent, the plane of the mirror was deflected through the same angle as that point of the beam to which it was attached, and the line of collimation of the telescope moved through double this angle; so that the deflection shown on the scale (in inches) divided by 60 gives the tangent of twice the angle of deflection of the beam; therefore the angle is easily determined by observing the deflection on the scale.

The experiment was divided into three parts;

1. The length of beam remaining constant with the mirror placed at the outer end of the beam, the weights were varied.
2. The length of beam and weight remaining constant, the position of the mirror was varied.
3. The weight being constant and the mirror placed at the outer end of the beam, the length of the latter was varied.

1. The length of the beam in this case was 20 inches and the weights $\frac{1}{2}$, 1, $1\frac{1}{2}$ lbs., etc., adding $\frac{1}{2}$ lb. each time up to $5\frac{1}{2}$ lbs.; a second series of observations was then obtained by removing $\frac{1}{2}$ lb. each time; this was repeated three times making in all a series of six observations, with the following results:

<i>Weights.</i>	<i>Mean Scale Deflection.</i>	<i>True Angles.</i>
.5	1.08	0° 31'
1	2.15	1° 02'
1.5	3.21	1° 32'
2	4.52	2° 09'
2.33	5.65	2° 41'
3	6.80	3° 14'
3.5	7.92	3° 46'
4	9.23	4° 22'
4.5	10.38	4° 54'
5	11.56	5° 27'
5.5	12.65	5° 57'

2. The length of beam in this case was as before, 20 inches, the weight 5 lbs., and the mirror was placed at the outer end. Moving the mirror successively through intervals of 2 inches, the scale was read each time when the beam was not weighted, and again when the weight was added, the difference being taken as the scale deflection.

The results are shown below:—

<i>Distances from Fixed End.</i>	<i>Scale Defl.</i>	<i>True Angles.</i>
20	11.41	5° 23'
18	11.30	5° 20'
16	11.10	5° 14'
14	10.62	5° 01'
12	9.89	4° 41'
10	8.98	4° 15'
8	7.93	3° 46'
6	6.71	3° 11'
4	5.14	2° 27'
2	3.49	1° 40'

3. The weight was 5 lbs., the mirror was placed at the outer end of the beam, and the length of beam was varied two inches at a time, with the following results : —

<i>Length of Beam.</i>	<i>Scale Defl.</i>	<i>True Angles.</i>
20	11.42	5° 28'
18	9.56	4° 32'
16	7.56	3° 35'
14	5.93	2° 49'
12	4.56	2° 10'
10	3.17	1° 31'
8	2.07	0° 59'
6	1.32	0° 38'
4	0.65	0° 19'
2	0.24	0° 57'

Accompanying this are sheets showing the curves according to Experiment and Theory for each of the above cases.

Apparatus for ruling lines with a Diamond. By Mr. C. F. Allen.

This consists merely of a beam, with a slot at one end to receive the handle of a common glazier's diamond, and revolving upon an axis at right angles to its length, this axis being supported at its ends on upright posts. The pressure under which the diamond marks is thus kept sensibly constant and may be regulated by weights hung on the beam. The line is ruled by drawing the glass under the diamond.

This apparatus gives excellent results, some lines being so fine as to be difficult of perception under the $\frac{1}{8}$ inch objective of a microscope.

HYDRAULICS.

Coefficients of Efflux. By Messrs. W. B. Dodge and W. E. Sparrow.

The object of this experiment was to find the coefficients of efflux for different orifices and under various heads.

In this case there were two vessels, one for the water to flow from, and the other for receiving it. Each one contained a hook gauge by which heights could be measured very accurately. The gauge consisted of a wire with a pointed hook at its lower end; the other end moving vertically over a scale graduated to inches and decimals of an inch.

We fill the vessel until the water is level with the lower edge of the orifice, and take a reading by means of the gauge. The water is then allowed to run into the vessel and reach such a height that it just begins to flow away by the waste pipe. From the reading taken at this point, subtract the former one together with the distance of the centre of gravity of the orifice from its lower edge, and we thus have the true head.

In order that we may know the amount of water that flows into the second vessel, it must be carefully calibrated. This was done by pouring in one tenth of a cubic foot of water, taking a reading, and so continuing until the vessel was full.

Having described the apparatus in a general way we now proceed to perform an experiment. We first insert an orifice, say a circular one. The water is allowed to flow through it running to waste through a large rubber hose till the supply of water is so regulated that the head becomes constant. Then determine its magnitude in the manner described above. At a given signal the hose is removed and the water allowed to flow into the second vessel; at the end of a given interval of time the rubber hose is replaced and the water again runs to waste. The difference between the readings of the gauge in the lower vessel before and after the experiment gives the amount of water that will flow through the orifice, with the given head, during the given interval of time.

For heads which are at least four times the height of the orifice, theory gives for the discharge, the area of the orifice multiplied by the velocity due to the height of the water above the centre of gravity of the orifice. By dividing the actual by the theoretical discharge we obtain the coefficient of efflux.

Different orifices were used under various heads, and the results are placed in tabular form below :—

Shape of Orifice.	Dimensions.	Area.	Head.	Time.	Discharge		Coefficient of Efflux.
					Actual	Theoretical	
Square.	.5" × .5"	.25"	14.51	2	.460	.724	.63
			14.64	2	.468	.768	.61
Rectangle.	height .25" depth 1.00"	.25"	14.62	2	.464	.767	.61
			10.10	2	.516	.638	.81
			10.10	2	.518	.638	.81
			10.12	2	.541	.638	.85
Rectangle.	height = 1.00" depth = .25"	.25"	12.64	1	.575	.713	.81
			12.78	2	.570	.717	.79
			12.64	1	.575	.713	.81
Triangle.	base .55" height .546"	.15"	14.85	3	.304	.465	.65
			14.97	3	.307	.466	.66
			14.83	4	.304	.464	.66
Circle.	diam. = .5"	.196"	14.53	2	.465	.613	.76*
			14.35	2	.382	.594	.65

The friction of water in pipes was also measured by several students, using a horizontal brass pipe to convey the water, with vertical glass tubes having scales attached to show the pressure at different points. This gave the friction under a velocity which was found by measuring the amount of water escaping per minute.

Buoyant effect of a column of heated air from a Bunsen burner.
By Mr. C. K. Wead.

A metal plate 283 mm. in diameter was placed over the flame and hung to one arm of a balance, and the force required to counterpoise it measured by double weighing. With no flame the force was 428.65 grs., with full flame 1 metre below, 431.2, at distance .8 m. 431.26, at .6 m. 431.

Using the formula for winds, (Silliman) velocity in miles per hour = $14.25 \sqrt{\text{pressure in lbs. per sq. ft.}}$

Hence velocity = 1.53 miles per hour = 2.24 ft. per second.

* Erroneous.

2d Experiment. A Casella's air meter was substituted for the plate.

Height above burner.	Full flame.		One half flame.	
	Mean Velocity.	Max. Velocity.	Mean Velocity.	Max. Velocity.
0.6	2.75	2.85	2.61	2.72
0.8	2.07	3.32	2.42	2.57
1.0	2.88	3.08	2.23	2.47
1.2	3.01	3.38	2.04	2.18
1.4	2.86	3.05	2.35	2.47
1.6	2.67	2.87	2.10	
1.8	2.48	2.85		
2.0	2.03	2.08		

The currents were easily diverted from a vertical direction, and so probably the maximum velocity is more correct than the mean.

OPTICS.

Law of Lenses. By Mr. C. K. Wead.

The focal length of the plano-convex lens A on the stand was found to be $23.93'' \pm .03$. In this experiment the formula $\frac{1}{F} = \frac{1}{f} + \frac{1}{f'}$ was used, and $f + f'$ taken equal to whole distance between conjugate foci, *i.e.*, no correction was made for thickness. The same lens was remeasured and focus computed allowing for thickness, that is, $f + f' + t =$ whole distance between conjugate foci; the formula used was

$$\frac{1}{F} = \frac{1}{f} + \frac{1}{f'} - \frac{t}{n} \left(\frac{r}{n-1} - \frac{1}{u} \right)^2$$

$t_A = .25''$, r_A (by spherometer) $= .12.64''$, $n = 1.53$. From this observation $F_A' = 23.62 \pm .02$ taking in all the terms.

$$F_A' = 23.56 \pm .03 \text{ omitting the third term.}$$

In this case it makes a difference of $.31''$ in the final result whether the focus of refracted rays is measured from the first or second surface of the lens, and if taken from the second surface the correction for thickness $= .06''$. Similar measurements were made on a second lens, and on the two combined and the results compared with theory.

The focus of a Tolles $\frac{1}{4}$ " objective, 2d quality, was measured by the method of Prof. Cross (Journ. Frank. Inst., June, 1870).

A spider line micrometer and $\frac{1}{1000}$ " stage, were used and both measured in turns of the same part of the screw of the dividing engine; there is therefore no absolute measure entering into the formula for focal length, except l the distance between object and image, which was taken with a steel mm. scale. The foci of the three lenses *A*, *B* and *C*, of the triplet, were measured singly and in combination with the following results:

<i>Lenses.</i>	<i>Focus.</i>	<i>l.</i>	<i>n.</i>
<i>A B C</i>	.2447	256	39.11
<i>A B C</i>	.2555	216	31.26(?)
<i>B C</i>	.4454	258	20.755
<i>A</i>	.3081	260	31.186
<i>B</i>	.5076	258.5	15.764
<i>C</i>	1.459	287	5.571

The relative distances of the lenses were then measured and gave for thickness of *A*, .066, of *B*, .101, of *C*, .124, space between *A* and *B* .090, between *B* and *C* .007; length of whole combination = .388. Computing focus of *BC*, we get .407 or .411, according as we do or do not consider the small uncertain distance between them. The formula is based on the supposition that the rays are parallel, which may account for the slight difference.

Photometric Experiments. By Mr. C. K. Wead.

The following observations were made with a photometer in which two images of a single flame are compared, thus eliminating all errors from the fluctuations of the light.

		Probable Error.	Absorbed.		Plates.	Probable Error.	Absorbed.		Plates.	Probable Error.	Absorbed.
1	} none		0.0	15	none	.6	—	28	none	.5	—
2				16	1	.4	15.7	29	1	.5	11.5
3					17	2	.6	24.8	30	2	1.0
4	A	.7	12.6	18	3	.9	35.5	31	3	.6	26.8
5	B	.6	12.3	19	4	.8	41.6	32	4	.6	36.2
6	C	.6	37.8	20	5	.7	48.0	33	5	.6	38.9
7	C'	.6	35.0	21	6	.3	52.8	34	6	.6	44.1
8	D	.8	37.3	22	7	.3	57.7	35	7	1.4	47.6
9	D'	.6	29.7	23	7'	.6	59.3	36	7'	.2	45.0
10	none	.8	—	24	3'	.2	32.5	37	4'	.5	31.4
11	A	.8	12.8	25	2'	.3	24.1	38	2'	.7	17.5
12	none	.6	—	26	1'	.3	14.9	39	1'	1.2	6.5
13	B	.6	7.8	27	none	.6	—	40	none	.7	—
14	E	.7	15.4								

Each of these observations is the mean of several. Nos. 1—14 were made with a candle, the others with a single-jet gas burner.

Plate A, double English; B, thick plate; C, single German ground, C', ground side to light, C', polished side to light; D, Berkshire ground, D', same with polished side to light; E, double German. The plates used in Experiments 15—27 were found not to be alike — some flint and others crown; they were mixed photographic glasses. The plates in Experiments 28—40 were thin unused photographic plates; No. 1 was always towards the light. Accented Nos. as (7', 1') denote a repetition of the experiment.

More light is transmitted by ground glass, if the polished side is towards the light, (6—9.) A wet cotton cloth transmits 18.7 of the light incident perpendicularly on it; when dry the amount transmitted was too small to be measured by this apparatus.

The following observations were then made with a common Bunsen photometer to determine the candle power of a 5 ft. Argand burner when consuming various quantities of gas.

<i>Consumption.</i>	<i>Observed C. P.</i>	<i>Corrected for candle.</i>	<i>Probable Error.</i>
5.974	24.03	25.00	.24
4.848	15.12	16.50	.13
4.818	15.20	16.09	.11
4.965	15.60	16.25	.12
3.828	12.86	10.45?	.12
2.568	3.46	3.29	.07
1.488	.222	.255	.005
.420			

The first column gives the consumption of gas; the second the observed ratio of the two lights, being the mean of from four to seven observations; the third the candle power corrected for amount of wax burnt, and the fourth the probable error. In the last case the light was too feeble to be measured, probably less than .001 of a candle power.

Experiments like the above by members of the 3rd Year's Class gave the following results.

<i>Messrs. Shailer & Harris.</i>			<i>Messrs. Blaisdell & Jewett.</i>		
<i>Consumption.</i>	<i>Observed C. P.</i>	<i>Corrected C. P.</i>	<i>Consumption.</i>	<i>Observed C. P.</i>	<i>Corrected C. P.</i>
6.12	18.35	19.27	6.45	19.7	21.67
4.92	18.9	19.37	5.98	17.5	18.37
3.60	11.56	12.14	5.22	15.7	15.31
2.28	2.91	3.28	5.38	17.2	15.90
1.52	.37	.35	4.84	12.4	13.02
1.44	.027	.029	4.35	14.1	11.47
.35	.00	.00	4.55	12.75	14.80
			4.09	12.79	12.79
			3.69	9.71	9.22
			3.37	7.34	7.71
			3.07	6.94	6.24
			2.96	3.84	4.03
			2.77	3.68	3.68
			2.46	2.17	2.28
			2.26	1.32	1.45
			2.04	.84	1.00

For the practical application of these observations, see papers by Profs. Silliman and Stimpson on Farmer's Law, in the *Amer. Journ. Sci.*, 1870.

To Find the Refractive Formula (that of Cauchy) for any Substance. By Mr. F. W. Very.

The substance must be in the form of a triangular prism which is obtained in the case of a liquid by pouring it into a glass vessel of this shape. In the case under consideration, the substance was a piece of very dense and highly refractive glass, made into a prism having an angle of about 60° .

The instrument used was an optical circle, carrying two telescopes, one stationary for the purpose of furnishing a parallel beam of light, the other moving around the axis of the graduated circle, and having two verniers by which the angle may be read. The prism being placed at the centre of the circle, the light is refracted and dispersed, and the spectrum is observed through the second telescope.

The operation is as follows. The refractive index of the prism is taken for several of the most prominent lines in the spectrum, whose wave-lengths are known. This is accomplished by measuring the angle of minimum deviation D for each line and the refracting angle A of the prism, when the index n may be calculated by the formula,

$$n = \frac{\sin \frac{A + D}{2}}{\sin \frac{A}{2}}$$

It is necessary to find the index for at least three lines, but to insure greater accuracy a number of others were taken. The results were compared by means of the graphical method, and a slight correction was made upon three measurements at some distance from each other in the series.

These three values of n were then substituted in the formula,

$$n = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4} + \text{etc.},$$

in which all the terms in the second member after the first three may be neglected. By elimination, the values of the con-

stants A , B and C for the substance under examination were found. In this case, they were as follows: $A = 1.683473$, $B = 96.30$, $C = 446.67$.

Having obtained the formula of the prism, it may be used to find the wave length of any line whose index of refraction has been measured.

To measure A , the refracting angle of the prism, this angle is placed facing the collimator so that the parallel rays coming from the latter shall be reflected from both faces of the prism as shown in the figure. The angle between the directions of the reflected rays $= 2A$ is measured. These measurements gave $A = 60^\circ 1' 7''$, $60^\circ 1' 0''$, $60^\circ 1' 41''$, or the mean $60^\circ 1' 20''$. The observing telescope was first focussed on an object about 80 ft. off, the focus of the collimator was then brought into agreement, and neither was changed during the measurement.

The prism being then placed in position and set at the minimum of deviation for each line in turn, the deviation was measured.

<i>Line.</i>	<i>Deviation.</i>	<i>n.</i>	$\lambda \times 10^7$	$\frac{1}{\lambda^2} \times 10^{-10}$
Na	58° 6' 45''	1.71499		
Li α	57° 13' 15''	1.70692		
B	57° 5' 37''	1.70576	6867	212.06
C	57° 21' 45''	1.70813	6562	232.24
a	57° 39' 0''	1.71081	6277	253.80
D	58° 6' 37''	1.71495	5892	288.05
E	59° 7' 52''	1.72404	5269	360.20
b	59° 17' 52''	1.72551	5183	372.25
F	60° 4' 7''	1.73226	4860	423.38
Ti	60° 38' 0''	1.73716	4665	459.52
Fe	61° 38' 0''	1.74573	4383	520.54
H	61° 49' 7''	1.74730	4340	530.91
Fe	61° 53' 22''	1.74790	4325	535.83
G	61° 56' 45''	1.74838	4307	539.08
	61° 59' 37''	1.74876	4300	540.83
Fe	62° 11' 37''	1.75011	4271	548.20
Cu	62° 20' 22''	1.75170	4226	559.94

Micro-photography. By Mr. C. S. Minot.

During the course of instruction in photography by Mr. Whipple, it occurred to me that some experiments in micro-photography would be interesting. I accordingly arranged an apparatus by which the tube and lenses of a microscope could be substituted for those of a photographic camera. A box was taken, the back was knocked out and a hole a little larger than the diameter of the tube of the microscope was bored in the front. This hole was lined with felt to make it light-tight. On the back was fitted a slide which carried the ground glass plate on which the image was focussed, and the plate-holder.

The first experiment was with an $1\frac{1}{2}$ inch objective of Smith and Beck, and a Tolles B eye-piece. The size of the image photographed was $2\frac{1}{4}$ inches. The exposure lasted 4 seconds, direct sunlight reflected from a plane mirror being used. See No. 1. Similarly a fly's tongue, No. 2, and a section of Echinus spine, mounted in balsam, No. 3, were photographed.

I next attempted to take *Arachnoidiscus Ehrenbergii* Bailey, using a Tolles 1st quality $\frac{1}{4}$ with a B eye-piece. After several failures, caused by the shaking of the table during the exposure of the plate, I was successful (see No. 4). The exposure was four minutes and forty seconds.

Other negatives were taken with a B eye-piece and various objectives (see Nos. 5, 6, and 7).

I made one trial with an extension camera in order to obtain greater enlargement. With this I took *Arachnoidiscus Ehrenbergii*, using no eye-piece. The focussing was not perfect, however, and at the intersections of the lines, a beaded appearance is quite sharp and distinct, and suggests a doubt as to the value of Dr. Pigott's views as to the structure of podura scales as seen by his so-called "wonderful" aplanatic searcher. This photograph is No. 8.

I had proposed to use monochromatic light but had no time. My intention was to use light passed through an ammoniacal

solution of cupric sulphate. The object in using blue light would be to avoid the difficulty of the objectives not being ground to the chemical focus.

The cost of the apparatus to take these photographs, when one is provided with a microscope and objective, and exclusive of what can easily be made, is only about \$10 for what is needed to take negatives, and \$5 or \$6 more for the printing.

Saccharimetry. By Mr. F. A. Emmerton.

The delicacy of the instrument to be used was first tested by adjusting the eye-piece, so that the sensitive violet tint was obtained, and then taking four successive readings, at the point when the color was the same in both sides, using water only in the tube.

These readings were as follows:

— .9 ; — .9 ; — 9 ; — 5 ;

thus showing that the instrument is quite sensitive.

The 0 point was evidently .9 of a division too far to the left, consequently it was adjusted, by use of the screw attached to one of the prisms, so that the point when the colors on each side of the field were the same, was always 0.

A sugar solution was prepared of presumably pure sugar so that it contained 16.471 grs. to the 100 c.c.

It was allowed to stand in the chemical laboratory five or six days before use, corked up in a flask. In that time it had changed by fermentation, as is shown by the following results :

99.1 ; 98.8 ; 98.9.—Average 98.9 per cent.

If the solution had not changed the readings should have been 100.

Another standard sugar solution was used immediately after preparation and gave the following results :

100.0 ; 100.1 ; 99.8 ; 100.1 ; 100.—Average 100.00 per cent., showing the sugar to be quite pure.

The long tube belonging to the instrument and intended to

be used for solutions after inversion ought to be one tenth longer than the short tube, in order to compensate for the 10 c.c. of HCl added to every 100.00 sugar solution in the inversion.

Consequently with a normal sugar solution it ought to give readings one tenth more than the short tube. It was tested with the pure normal sugar solution with this result:

110.9; 110.9; 110.6; 110.9; 110.9 per ct.—Average 110.88.

Showing the tube to be not exactly one tenth longer than the short one.

The same solution was tried three days after in the short tube with these results:

98.6; 98.4; 98.3; 98.3; 98.7—Average 98.46, showing how rapidly a sugar solution changes in strength even when corked up in cool weather.

In looking for statements about the relative rotating power of inverted and uninverted sugar solutions I found great discrepancy of statement, but concluded from a statement in Bolley that the amount of sugar which rotates to the right 100, rotates to the left at 35.7 at 15° C. I inverted the pure solution and got the following readings at 18° C.

—37.6; —37.3; —38.; —37.9; 37.2.—Average 37.6.

Subtracting .88 the error due to the length of the tube it gives 36.7 as the reading at 18° C. I could not find any tables giving the correction for temperature, but that correction whatever it is would bring the reading nearer still to 35.7.

A large number of electrical experiments were made by the class, including measurement of resistances, making coils, a Siemens' thermometer, magnetization by frictional electricity, and others, but they are omitted, believing that the above are sufficient to show the nature of the work done, both as regards quality and quantity.

All of which is respectfully submitted.

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