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MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

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PLAN

OF THE

PHYSICAL LABORATORY.

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1869.
It was a part of the original plan of the Institute of Technology to establish a Laboratory of Practical Physics for the purposes of instruction, and also of research; and it is the object of this supplement to give the outlines of the plan adopted. This laboratory will be ready for students at the beginning of the next session, Oct., 1869.

It is generally admitted at the present day that the true method of teaching Chemistry is by means of a laboratory in which each student performs the various experiments himself. In all the larger Scientific Schools in the country this method is adopted, notwithstanding the large attendant expense; and it is found that a student learns far more in this way, than he could by merely seeing the experiments performed by another. Moreover, when called upon to perform them, he is familiar with the apparatus, instead of having to accustom himself to its use. It is therefore somewhat remarkable that, while Physics is almost as much an experimental science as Chemistry, it is yet taught even in our best schools by text books or lectures, illustrated by such experiments as the teacher has the skill or inclination to give; nor is there a laboratory in the country in which instruction is given in physical research. As a consequence, even the simplest physical questions are left for
solution to professional physicists, or, more commonly, solved only by guesswork.

The difficulties in the way of establishing a physical laboratory are far greater than in the case of Chemistry. In the latter, with a few reagents and test tubes, a great variety of experiments may be performed, while in Physics a separate piece of apparatus is required for almost every one; and the expense is so large that duplication to a great extent is impossible. Furthermore, the various instruments differ so greatly that the student must be instructed in the use of each separately. For this very reason, however, a course of physical manipulation is especially valuable from an educational point of view, since the student who has pursued it properly would be familiar with so great a variety of instruments that he would acquire the use of a new one with comparative ease.

There are also difficulties from the great amount of time required for research, and the danger of injury to delicate instruments.

The following pages will show how these various difficulties are met.

The course adopted for regular students will first be described, and then the methods for original research.

Regular Course of Physical Manipulation.

To show what preparation the students have for entering the physical laboratory, the course in Physics will first be described. During the first two years all regular students attend a course of lectures on Physics, which is treated both experimentally and mathematically. In the second year they use Ganot's "Traité élémentaire de Physique," and are thus certain to acquire a sufficient knowledge of French to read it with tolerable ease. The same work is used in their French studies, the two departments thus aiding each other. To illustrate the lectures, a large number of photographs on glass of physical apparatus have been prepared, and are projected on
the screen by the magnesium lamp or by sunlight. They are
taken from the best engravings in works on Physics, and in
some cases, as in Regnault's Researches, from the illustrations
of the original mémoirs. The students also pursue a course of
chemical manipulation, by which they learn to use chemical
apparatus, and are therefore prepared to perform the more deli­
cate experiments of the corresponding course in Physics, which
extends through the third year. In addition, students wishing
to make this subject a specialty, are instructed in the methods
adopted in research, and in the verification of established laws
and determining physical constants. Such students, during their
fourth year, undertake original investigations, and assist in all
the more advanced physical work undertaken by the Institute.

As about twenty students at a time are to be accommodated,
tables for from twenty-five to thirty are prepared, so that a cer­
tain number may always be vacant. On each is placed the
apparatus for a certain experiment, and instead of giving a table
to each student, on which he does all his work, as in a chemical
laboratory, one table is devoted to each experiment, the student
changing his place after he has performed it. It is therefore
necessary to carry gas and water to only a part of the tables;
and, since most of the apparatus will not be moved until all the
students of the class have gone over these experiments, and
the tables are to be supplied with the apparatus for an addi­
tional series, there is much less danger of fracture.

As the rapidity with which the students work depends in
a great measure on their natural abilities, some will complete
their experiments much sooner than others; but as there are
more places than students, there need be no delay from this
cause. To avoid confusion, each table is numbered, and these
numbers, attached to a board, are hung up in the laboratory.
The name of each student is written on a card, and placed
under the number of the table he is using; and when he com­
pletes his experiment, he removes his card and places it under
the next unoccupied number. As almost every experiment
requires a somewhat detailed explanation, a complete description
is written out, and placed on the table devoted to it, so that each student can begin his work himself, and the instructor is enabled to have a general supervision of the progress of each experiment. Every student keeps a note-book, in which he records in full the results of his experiments, and these note-books are examined at intervals by the instructors.

To convey an idea of the kind of experiments to be performed, the following are given as examples.

**MEASURING AND WEIGHING.**

1. *Measurement of Lengths.* A new and simple form of measuring instrument is used, formed of a graduated steel rule and micrometer screw, by which distances are determined within less than a thousandth of an inch. By this the student measures the lengths of a number of steel bars and their diameters, also the thickness of some sheets of metal. He repeats the measurement with the gauges in common use, and compares them, using French and English measures, and reducing from one to the other.

   *Measurement of Radius of Spheres.* See No. 32.

2. *Measurement of Volumes.* Flasks are weighed when empty, and when full of mercury, and the volume is calculated.

3. *Graduation.* A glass tube is graduated to millimetres, and any variation in its diameter measured by the use of mercury. (See Bunsen's Gasometry.)

   *Weighing.* See No. 8.

**MECHANICS OF SOLIDS.**

4. *Centre of Gravity.* Found by suspending a piece of sheet metal at a number of points, also geometrically by dividing it into triangles, and the two results compared.


6. *Friction.* Verification of the laws of friction and measurement of the coefficient, both by using an inclined plane of varying angle, and by placing the body on a revolving cylinder and measuring the force required to keep it at rest.

MECHANICS OF LIQUIDS.

8. Specific Gravity. Measured by hydrostatic balance, for solids heavier and lighter than water, also for liquids.
9. Hydrometers. The specific gravity of the substances mentioned in No. 8 also determined by Nicholson's, Fahrenheit's and other hydrometers.
10. Gauge Flask. Determination of specific gravity a third time, by the gauge flask.
11. Efflux. Measurement of the flow of liquids through apertures of various sizes, using the hook gauge to measure the height of the liquid.

MECHANICS OF GASES.

12. Volume of Gases. A certain quantity of gas is collected over water, and the volume it would have at 0° and 760 mm. if dry, is computed. The experiment is repeated with hot water, and the results compared.

Barometer. See No. 22.

ACOUSTICS.


HEAT.

16. Thermometer. A thermometer tube is filled with mercury, and its zero and boiling point marked.
17. Weight Thermometer. A piece of glass tube is closed at one end and drawn out to a point at the other, it is weighed empty, and when filled with mercury at 0°, and at 100°. From this the expansion of mercury in glass is computed. Also applied to measure temperatures and the dilatation of solids.
18. Dilatation of Liquids. Measured by weight thermometer, also by bulb tube.
19. **Specific Heat.** Regnault's calorimeter applied to solids and liquids.

20. **Radiant Heat.** Experiments with thermo-pile, and measurement of diathermancy and reflecting power of glass.

21. **Latent Heat and change of Volume during Fusion.**

22. **Pressure of Vapor.** (See page 10.)

23. **Specific Gravity of Vapor.** Method of Gay-Lussac by volume of known weight.

24. **Specific Gravity of Vapor.** Method of Dumas and Regnault, by weighing known volume.

25. **Heat of Combustion.** Measurement of calorific power of various substances, and computation of the calorific intensity.

26. **Comparison of Fuel.** Berthier's method of determining relative amount of heat generated by different kinds of fuel, as wood, peat, etc.


**LIGHT.**

28. **Photometer.** Measurements of candle power, of gas, loss of light by glass, etc.

29. **Mirrors.** Measurement of foci of concave and convex mirrors.

30. **Index of Refraction.** Measured by Wollaston's method.

31. **Dispersion.** Measured for different liquids by hollow prism.

32. **Lenses.** Measurement of their foci, and radii of curvature (by spherometer), and computation of their index of refraction. Also testing the quality of the glass.

33. **Microscope.** Method of using, and measurement of its magnifying power in various ways.

34. **Camera Lucida.** Application to microscope, also goniometer and micrometers.

35. **Preparation of Microscopic Objects.**

36. **Telescope.** Method of using, replacing spider lines, measurement of magnifying power, and use of micrometer.


38. **Spectroscope (large physical).** Measurement of position of prominent lines, and intensity of light in different parts.
40. **Wave length.** Measurement by fine lines ruled on glass.
41. **Polariscope.** Measurement of optic axes of crystals, application to microscope.
42. **Saccharimeter.** Testing strength of solutions of sugar, rotary power of other liquids.

**Magnetism and Electricity.**

43. **Magnets.** Methods of making and testing their power.
44. **Distribution of Magnetism.** Coulomb's method.
45. **Torsion Electrometer.** Verification of Coulomb's laws.
46. **Proof Plane.** Distribution of electricity, and application to the Holtz machine.
47. **Galvanic Battery.** Amalgamation of plates, and method of using galvanic battery and induction coil.
48. **Power of Batteries.** Measurement of intensity and quantity of electricity generated by different galvanic and thermal batteries.
49. **Conduction.** Measurement of conductivity of metals and liquids by rheostat. Proof of Ohm's law.
50. **Telegraph.** Morse's alphabet. Students in different rooms required to send and read messages correctly.

In addition to the above course of experiments, each student in turn, at stated intervals, observes and records the reading of all the more common meteorological instruments, such as the various maximum, minimum, metallic, and other thermometers; aneroid and mercurial barometers; the amount of moisture of the air by the hair hygrometer, the wet and dry bulb, Daniell's and Regnault's, also by the Hygrodeik; the magnetic elements of declination, dip, and intensity; the anemometer, rain gauge, pyrheliometer, etc. Proper corrections where necessary are applied, and when two different instruments are used for measuring the same quantity, their results are compared.

The instructors and more advanced students meanwhile carry on original researches, and are assisted by those less advanced.
to initiate them into the methods adopted in delicate experiments.

To show more fully what is expected of each student, a more detailed description will now be given of one of the experiments of the above list, taking as an example number 22.

On the table devoted to this experiment is placed the following apparatus:

A glass barometer tube, three feet long, closed at one end, a beaker and bottle containing mercury, a small funnel, a thermometer, a bottle of ether, a small pipette, a stand by which the tube may be held vertically, and a cathetometer. The latter consists of a vertical steel rule a metre in length, graduated to millimetres, and a telescope with cross hairs at its focus, and a stand so that it can be raised or lowered, its axis remaining horizontal. The top of the table is hollowed out, so that if any mercury is spilt it will all run through a hole in the centre into a vessel placed to receive it.

The written directions for the student are as follows, only they are illustrated by sketches which explain the meaning more fully:

Fill the tube with mercury to within a few inches of the top by means of the funnel. (Sketch showing method of holding tube.) Close the open end with the finger and incline it, so that the bubble of air shall move slowly to the other end of the tube. Make it pass from end to end until all the small adhering air bubbles are removed. Then fill it full of mercury, and closing the end again with the finger, invert it, and immerse in the beaker, removing the finger under the surface of the mercury. The mercury in the tube will now fall to about thirty inches, leaving a vacuum at the top. To see if any air has entered, incline the tube and notice if the mercury rises to the top of the tube, and if when made to oscillate gently it strikes the top with a sharp click; if not, as is frequently the case, air has entered, and the experiment must be repeated.

Next, place the steel rule by the side of the barometer tube, and the telescope about six feet off. Raise the telescope until
its cross hair is just on a level with the top of the mercury, and read its position on the graduated rule. Then lower it until it coincides with the surface of the mercury in the beaker, and take a second reading. The difference is the height of the column of mercury. Compare this with the standard Kew barometer in the window. By means of the pipette (sketch showing method of using pipette) pass a few drops of ether into the tube. The mercury at once falls; measure its height as before, and the difference between the two columns gives the pressure due to the ether vapor.

**Apparatus.**

It is perhaps desirable to state how instruments of precision can be obtained of sufficient accuracy, and yet so cheap and strong as not to be liable to great loss by fracture. All measurements may be reduced to the determination of distances, volumes, weights, angles and duration of time. For distances the graduated steel rules of Brown and Sharp are used, great accuracy being attained when necessary by the use of micrometer screws. A cheap and efficient reading microscope or telescope suitable for many purposes, is formed by combining two common convex lenses with cross hairs at their common focus. Volumes are determined by filling with water or mercury, and weighing (see experiment 2). For weighing, a new form of Becker's balance is adopted, intended for pharmaceutical purposes. As accurately graduated circles are expensive, they are replaced whenever convenient by a mirror and scale as described on page 13. For measuring time various instruments are used, as Lissajous' comparateur, a metronome, a stop watch, or a modification of the electr-ochronograph.

A magnetic observatory will be established in the basement of the Institute, so that students may learn the most accurate methods of obtaining the three magnetic elements.

A class in photography will also be formed, and each student will learn to take a good negative on glass, and to print from it
paper positives. Thus, after all have seen the various operations performed by the instructor, they will be arranged in parties of five or six, who will work thus: The first prepares the plates, the second exposes them in the camera, the third develops and fixes them, the fourth prints the positives, and the fifth does the toning and fixing. If the sensitive paper is prepared in the building, a sixth will be required for this work. When each has learned to do his part properly they will change places, until each has done the whole work. When they are able to take good views in this way, they will try photographing some of their more elaborate drawings, and will thus be able to distribute copies of them. Photography is essential in many physical researches, and as all the apparatus will be in the building, it will often be useful for this purpose.

Original Researches.

As original researches will occupy a large part of the time of the more advanced students, it is perhaps well to state the methods by which they will be carried on. In the first place, they will be as far as possible quantitative rather than qualitative; that is, the establishment of laws numerically, or by measurement rather than the mere determination of facts, since such investigations do far more to supply the wants of modern physics, and cannot well be carried on outside of a laboratory. As much time is often lost in the attempt to eliminate small errors, while comparatively large ones are overlooked, great attention will be paid to the magnitude of errors of observation, and the accuracy attainable by various processes will be carefully studied. Students will also be required to compute the probable and also the greatest possible error in their results. From the great importance and convenience of the graphical method it will be largely adopted in giving the results of researches, and the curves obtained will be compared with those given by theory. An accurate record will be kept of all work done in the
laboratory and a copy will be preserved in the Institute. The more important conclusions arrived at, will be forwarded to the scientific journals for publication.

As a practical application, take the following example: To determine the effect of masses of iron, such as anchors, chains, cannon, or the plating, on a ship’s compass. A magnetic needle, to which is attached a mirror, is suspended by a filament of unspun silk. A telescope and graduated scale are placed opposite it, in such a position that on looking through the telescope the reflection of the scale is seen in the mirror, as in the common declination magnetometer. If now a piece of iron is brought near, the needle and mirror will turn, and a different part of the scale will be seen in the telescope; a very small motion of the magnet can thus be measured with great accuracy.

Since we can compute the effect of a large piece of iron at a distance, from that of a small piece near the needle, cannon balls weighing from one to twenty pounds will be used. Three effects are to be studied; those produced by changes in the direction, distance, or size of the iron. Thus to determine the effect of change of distance, the ball is first placed ten or twenty feet off, and the change in the needle noted as it is gradually brought nearer. Similar series of observations are made as the direction or size of the iron is altered. From the results, curves can be constructed in which horizontal distances correspond to the distance of the iron, and heights, to changes in direction of the needle. To measure the degree of accuracy attainable by this method, experiments will be made with the ball placed at the same distance N.E., N.W., S.E., and S.W., taking care that the angle with the magnetic meridian is in all four cases the same. These measurements, if repeated several times, should always give nearly the same results, except that sometimes the needle is turned by a certain angle to the East, and at others to the West. By taking the mean, and applying the method of least squares, the weight and probable error is calculated.
The results would then be compared with theory, or if necessary a theory proposed, and the differences between the observed and computed results compared with the probable error. Comparison could also be made with the experiments of Barlow and others. If such a research should be carried on well, it is believed that it would form a valuable addition to our knowledge of local attraction in vessels.

To determine the effect of permanent and induced magnetism of the vessel, similar experiments could be made with powerful bar-magnets.

**Special Students.**

The laboratory will also be open to persons not regular students, who wish to pursue a similar course, or to engage in original investigation.

To persons about to engage in any of the departments of applied physics, such as telegraphy, electroplating, photography, etc., an opportunity is offered to perfect themselves in the theory of the subject, in which way alone they can attain the greatest excellence in its practice.

Special attention will be paid to persons preparing themselves as instructors in physics. There is now no place in the country, so far as we know, where students are taught to perform the common lecture-room experiments. Teachers therefore have to learn from imperfect descriptions, or by trial, the use of apparatus, which is often defective or unsuitable. No one who has not tried it, can realize the amount of time and labor that must be expended on such work. As a consequence, many collections of apparatus are not used, or if used, rapidly deteriorate from improper treatment. Those intending to become teachers will, beside attending the lectures and the more elaborate and physical manipulations already described, receive especial instruction in the proper methods of performing the common lecture-room experiments, and the precautions to be taken to ensure success; they will also be required to repeat
these experiments themselves. They can see, or take part in
the preparations of the experiments for the regular lectures to
the students, of which six are now given every week. An im­
portant part of their course will be the designing of apparatus,
and obtaining estimates of its cost. It is expected that the
physical cabinet of the Institute will soon attain such a size as
to afford unequalled facilities in these respects.

Finally, the opportunity will be offered to men of science,
and others engaged in original investigation, to carry on their
researches at the Institute where they can have gas, water,
steam power and apparatus of all kinds, which could elsewhere
be obtained only at much greater expense. For this reason, al­
though almost any one may have a private chemical laboratory,
a laboratory of physics can be well carried on only by a large
institution.

Conclusion.

The advantages to be derived from this laboratory may be
summed up as follows: Students will secure a course of study
in Physics which will be much more practically useful than
they would otherwise obtain. It will, moreover, be rather of
the nature of a relaxation than a laborious and, to some, from
its mathematical nature, an irksome study. Preliminary trials
have shown that students undertake physical experiments
eagerly; and it is not unreasonable to suppose that the intro­
duction of laboratory work in this department will be attended
with as beneficial results as has been the case in Chemistry.

It is not, perhaps, too much to claim that such a la­
boratory will be of direct value to the cause of science. For
there are numerous questions which could easily be solved
by advanced students, which have never been undertaken
by professional physicists for want of time. For this rea­
son, and for want of proper apparatus, the number of persons
in this country engaged in quantitative physical research is
exceedingly small. In looking over any work on Physics,
almost every name is European. To show the practical
value of such researches, it is only necessary to state that the success of the Atlantic cables of 1865 and 1866, after the failure in 1857, was almost unquestionably due to the electrical experiments conducted by the committee of the British Association, in the meanwhile. All calculations on the theory of the steam engine are based on the elaborate physical researches of Regnault, and the practical value of these researches was felt to be so great that many thousand dollars were expended on them by the French Government.

The current expenses of this laboratory will not be large. A considerable outlay will be necessary in the beginning, for the purchase of apparatus, which once procured may be used for years without serious injury.

These remarks do not apply to experiments conducted on a large scale, as such are necessarily expensive. But these are the ones which will be of the greater pecuniary value, and will therefore be likely to be aided by those most directly benefitted by them.

Those interested in any department of this laboratory, and wishing further information, are requested to address the author.

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