EXPERIMENTAL PHYSICS

A Laboratory Manual

BY

ALBERT EDWARD CASWELL, PH.D.
PROFESSOR OF PHYSICS,
UNIVERSITY OF OREGON

New York
THE MACMILLAN COMPANY
1928

All rights reserved

EXPERIMENTAL PHYSICS

THE MACMILLAN COMPANY
NEW YORK · BOSTON · CHICAGO · DALLAS
ATLANTA · SAN FRANCISCO

MACMILLAN & CO., LIMITED
LONDON · BOMBAY · CALCUTTA
MELBOURNE

THE MACMILLAN CO. OF CANADA, LTD.
TORONTO

PREFACE

Like most laboratory manuals of physics the present volume is the result of a process of evolution. It has evolved simultaneously with the author's text-book, *"An Outline of Physics,"* which it is intended to accompany. However, it may be used in any course in general physics. Very little in the way of special apparatus is called for. In most of the experiments standard pieces of apparatus found in practically all laboratories are used. The instructions for each experiment contain a brief outline of the underlying principle and a reference to the corresponding pages of the author's text. Under "Work to be Done" the student is given general instructions for the performance of the experiment, but the details are omitted, so that the student must think his way through the experimental processes.

The list of experiments and the organization of the material are such that a well-balanced laboratory course requiring either one or two three-hour laboratory periods throughout the year may easily be selected.

Many of the experiments are divided into parts arranged in order of increasing difficulty. The better students may be expected to complete the experiment in the allotted time, while the poorer ones will omit one or more parts on account of lack of time or ability. Laboratories operating on a two-hour period basis may use only the first part of an experiment, or may devote two periods to one experiment. A number of experiments, especially those introducing a new topic, contain preliminary exercises, which serve to arouse the student's interest and cause him to realize the significance of the experiment he is about to perform. These exercises may be omitted at the discretion of the instructor. Refinements of importance to those engaged in advanced work or research but which distract the beginner and often cause him to lose sight of fundamental principles are omitted.

General instructions dealing with laboratory apparatus and methods, computations, etc., are included, also logarithmic and trigonometric tables and a list of references to more extensive manuals.

A. E. CASWELL

EUGENE, ORE.
September, 1928

CONTENTS

此为试读，需要完整PDF请访问：www.ertongbook.com

APPENDIX

EXPERIMENTAL PHYSICS

GENERAL DIRECTIONS

Assignment of Laboratory Work. For convenience in administering the laboratory, especially where large numbers of students are involved, some system is usually adopted for assigning experiments. Whatever the system, the student should at the outset familiarize himself with it so that he may know something about the experiment he is to perform before entering the laboratory.

The method of making laboratory assignments followed with success by the author for a number of years is to assign each student a laboratory period, or periods, as the case may be, and also a group letter. A chart divided into rectangles is prepared with a vertical column of rectangles for each laboratory period and a horizontal row of rectangles for each laboratory group letter. Each student's name is written or printed in that rectangle belonging both to his laboratory period and his group letter. A second similar chart is prepared in which the vertical columns correspond to the weeks of the term, or semester, and the horizontal rows to the group letters, as before. The number of the experiment to be performed by any group during any week is written in that rectangle belonging both to the group and to the week. This second chart may be used year after year.

Objects of Laboratory Work. The student will bear in mind that the objects of laboratory work are two-fold, viz., (1) to acquire a first-hand acquaintance with physical facts and principles, and (2) to become trained in scientific methods and modes of thought.

Previous Preparation. Prior to the laboratory period the student should study carefully the instructions given in this manual concerning the experiment and the related lecture and text-book material. Outside reading on the experiment is also helpful. See the list of books given at the end of this volume.

He should also prepare an analysis of the experiment covering at least the following points:

(*a*) Definitions fundamental to an understanding of the experiment.

(*b*) Physical laws or principles either applied or tested in the experiment.
(*c*) Equations used in the numerical calculations. The meaning of the symbols used should be thoroughly understood.
(*d*) A brief description, illustrated by diagrams whenever conducive to clearness, and an outline of the experimental operations.

In the Laboratory. Upon entering the laboratory the student may find the table where he is to work indicated by the group letter (or whatever system is in vogue in the laboratory). Some of the apparatus may be found at the table, but any necessary apparatus which is not at the table may be obtained from the storeroom upon application to the storekeeper. This includes valuable pieces or those easily broken or lost.

Having obtained the apparatus to be used, the student should proceed with the experimental operations, observing the following recommendations:

(*a*) Be sure you understand the operation of the apparatus before beginning observations. If in doubt consult the instructor. Note the special instructions for the electrical experiments.
(*b*) Draw any diagrams which seem to be desirable.
(*c*) Note any numbers or distinguishing marks upon pieces of apparatus. You may need them sometime later.
(*d*) Whenever desirable (and this is usually the case) prepare with care a convenient table in which to record observed data and computed results. Before leaving the apparatus be sure that all necessary data have been recorded. Make your observations with the proper accuracy. See "Note on Significant Figures".
(*e*) Never sacrifice accuracy to speed.
(*f*) Handle all apparatus with care.
(*g*) If in doubt regarding the reliability of results obtained, consult the instructor.
(*h*) Directions and apparatus do not always correspond in all cases. Use your common sense.
(*i*) Do not remove apparatus from or to other tables. Do not take apparatus or books from the laboratory. Tables and laboratory should always present a neat and orderly appearance. Always leave apparatus in good condition. If you had to assemble it, take it down again before leaving

the table. Return borrowed apparatus to the storeroom after you are through using it. Watch the bulletin boards for special information concerning the laboratory work.

(*j*) Students are advised to keep their notes in a loose-leaf binder using paper $8\frac{1}{2}$ x 11 inches. Notes should be written clearly and legibly in ink. Use only one side of the paper. Numerical computations may be carried out on scratch paper, but data should always be recorded directly in the notes. Data should be tabulated whenever more than one measurement of a quantity is made.

(*k*) When two students work together both students should make at least one complete series of observations, but a student should record his partner's data, with suitable distinguishing marks, such as initials. In his report he may use both his own and his partner's data.

Reports. If possible, the report on an experiment should be handed in at the close of the laboratory period during which it is performed. In no case should it be handed in later than the next succeeding laboratory period. For the form of the notes see the preceding section.

The report on an experiment should contain:

(*a*) The student's name, partner's name (if any), number and title of the experiment, and date upon which it was performed.

(*b*) The data, diagrams, etc., mentioned in the preceding section.

(*c*) A sample calculation of the result, omitting details of the numerical work. All data should be used in the calculations, but the results alone should appear in the final report, preferably in a table of data.

(*d*) Discussion of probable sources of error and percentage of possible error in result, also the commonly accepted value of the quantity being determined, and the percentage difference between this value and the observed one.

(*e*) Graphs whenever called for in directions and also whenever likely to add to the value of the report.

(*f*) Conclusions drawn from the experiment.

(*g*) When the report is not completed within the laboratory period the student should file an approved data sheet with the instructor before leaving the laboratory.

Acceptance of Reports. No credit is allowed for an experiment until it has been "ACCEPTED." Within about a week of the time a report is handed in it will be returned to the student. If the work and report are found satisfactory, the report will be marked "ACCEPTED," and the student will be given credit for the experiment, the experiment being graded according to the character and amount of work done. If not marked "ACCEPTED," the corrections indicated should be made as soon as possible, and certainly within two weeks, and the report again handed in.

Remarks on the Use of Apparatus. Since the accuracy of an experimental result often depends upon one measurement more than upon any of the others, that one should be carried out with the highest degree of accuracy possible. This fact often determines the method employed in making a particular measurement. This matter is discussed very briefly in Experiment 6 on Thermal Expansion, and in the notes on the vernier and the micrometer. Serious errors may arise in the use of micrometers as well as other pieces of apparatus through neglect of precautions to avoid "lost motion." For example, in a worm gear, which is being used to move a microscope, if the screw has been turning in one direction and its motion is reversed, it may make a considerable fraction of a revolution before the article which it actuates will begin to move in the opposite direction. In all such cases the apparatus should always be set by a movement from one, and only one, direction.

Similarly, it is often desirable to measure the rotation of a mirror. In such a case a "telescope and scale" or a "lamp and scale" method is employed. Sometimes very short distances are measured in this way. The apparatus is then called an "optical lever." See Experiment 1A.

Apparatus should also be selected for its adaptability to the use to which it is to be put. For example, a small object weighing but a few grams or ounces should not be weighed on a trip scale that is accurate only to 0.1 gm. with light loads, and only to 0.5 gm. with heavy loads. It should be weighed upon an analytical balance, which may have an absolute accuracy between 0.01 gm. and 0.001 gm. On the other hand, analytical balances are not suitable for weighing objects beyond two hundred grams. The capacity of laboratory balances varies from a few hundred grams to about five kilograms. Corrections to the readings of an analytical balance may be made for the buoyant force of the air, but as a rule such corrections are not justified.

When to make corrections to the reading of an instrument, and when not to, is often a puzzling question for the amateur. When the percentage error introduced by using the uncorrected

此为试读，需要完整PDF请访问：www.ertongbook.com

readings instead of the corrected readings is less than the percentage error which is unavoidably present in the final result due to some other cause, there is no object in making the corrections. For example, in some experiments it is necessary to determine certain temperatures with the aid of a chemical thermometer, which may be read to 0.1° C., or possibly to 0.05° C. Another temperature to be found is that of boiling water, which depends upon the atmospheric pressure. With the aid of a vernier the height of the barometric column may be determined to within 0.1 mm. Corrections to this height may be made for altitude,

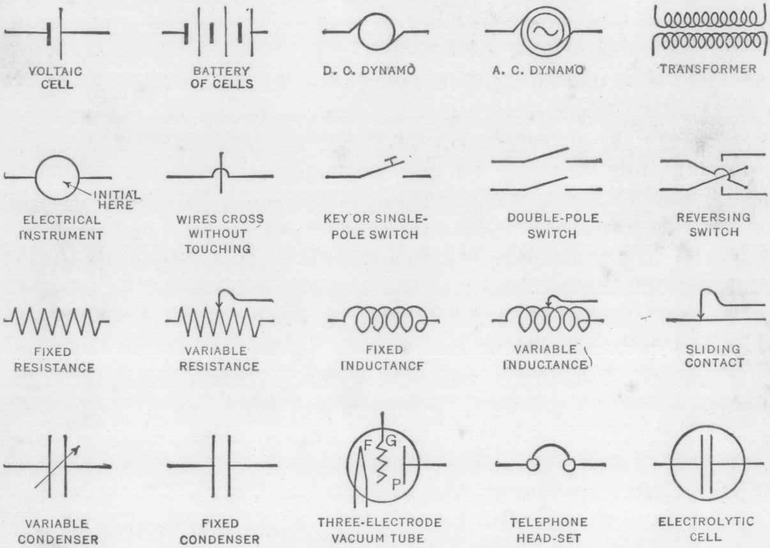

Fig. 1.—Conventional Electrical Symbols.

latitude and temperature. In general, these corrections are quite small. But it requires a difference in the barometric height of 1.35 mm. to make a difference of 0.05° C. in the boiling point. Hence, unless the corrections to the barometric height are approximately equal to, or greater than, 1.0 mm. they should be neglected. Obviously the converse is true, unless greater errors are inevitably present owing to other causes.

Special Instructions for Electrical Experiments. Always have a key or switch in series with all batteries or other sources of current, also with all electrical instruments, such as galvanometers ammeters, etc., unless a key is contained in the instrument.

Never close a circuit until certain that all instruments are properly connected. If you are using current from the lines installed in the laboratory, or have a standard cell in your circuit, ***get your set-up O. K.'d by an instructor before closing the switch.***

When first closing a switch always make a " tap contact," that is, close the circuit for as short a time as possible. While making the tap contact note the behavior of your instruments and other apparatus.

Remember that ***resistance boxes and galvanometers are not intended to carry large currents.*** Ammeters should always be protected by fuses of smaller capacity than the instrument. Voltmeters should never be connected in a circuit unless you are sure that the voltage is lower than the range of the instrument. In the case of double-range instruments, always connect to the higher range first.

Standard cells should never be used to supply current.

Failure to observe these instructions may result in damage to an instrument or other piece of apparatus. In such a case the student will be held strictly responsible.

In reports on electrical experiments the wiring diagrams should always be clearly shown unless the circuit is of the very simplest sort. Conventional symbols for various pieces of electrical apparatus should be used. A number of these are shown in Fig. 1.

1A. YOUNG'S MODULUS OF ELASTICITY BY STRETCHING

Read Caswell's *An Outline of Physics*, pp. 30–34.

The Principle of the Experiment. Whenever a wire is stretched by a force F, the elongation E produced is directly proportional to the stretching force (Hooke's law) and to the length L of the wire, but it is inversely proportional to the cross-sectional area A of the wire. It also depends upon the coefficient of elasticity of the material of the wire. This coefficient is commonly called Young's modulus of elasticity. The above facts are expressed by the relation $E = FL/YA$, where Y is Young's modulus. Hence,

$$Y = \frac{FL}{EA}. \tag{1}$$

If the wire is stretched by the weight of a mass of m grams, the stretching force in dynes is given by $F = mg$ ($g = 980.7$) and if d is the diameter of the wire, $A = \pi d^2/4$, whence

$$Y = \frac{4mgL}{\pi d^2 E}, \tag{2}$$

The wire to be tested is suspended from a steel chuck, which holds the upper end firmly, and near its lower end it passes through a small hole in a metal platform. A weight hanger is attached to a loop at the lower end of the wire. Weights are placed on the hanger to stretch the wire. It is best to load the hanger enough to completely straighten the wire before any measurements are made. Then add weights to produce the desired elongations. Moreover, these additional weights may cause the support that is holding the wire at its upper end to yield slightly and so vitiate the results. For this reason the weights to be added to the hanger should rest upon the support while the initial, or unstretched, length of the wire is being determined.

The elongation of the wire is such a small quantity that it must be measured with a high degree of precision in order to secure the percentage accuracy in this measurement that is easily obtained in the other measurements. To secure this accuracy, a device known as an optical lever is usually employed. This is a special case of the optical system known as "the telescope and scale."

A small plane mirror is mounted vertically on a horizontal platform which rests on three pointed legs. Two of these legs are directly beneath the mirror and the third is at a distance of a few centimeters behind it. The first-mentioned legs stand upon a rigid platform and the third rests upon a support which may move up or down. If it moves, the mirror is tilted forward or backward.

An observer looking through the telescope shown in Fig. 2, before the movement of the mirror, sees an image of the point A on the scale SS' attached to the telescope in coincidence with the cross-hairs of the telescope. When the third leg P attached to

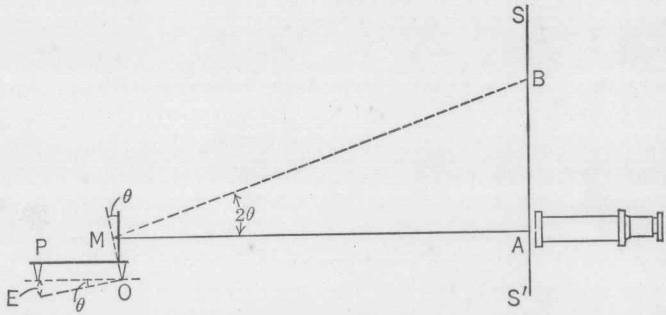

FIG. 2.—The Optical Lever.

the mirror M is depressed a distance E, causing the mirror support to rotate through an angle θ, the image of a different point B on the scale is observed to coincide with the cross-hairs in the telescope. The angle $AMB = 2\theta$. If the perpendicular distance from the line joining the points of the first two legs to the point of the third leg, i.e., PO, equals x, $E/x = \sin\theta$. But if the scale SS' is straight and perpendicular to the line MA, $AB/MA = \tan 2\theta$. If the angle θ is small, we have, as a close approximation,

$$2E/x = AB/MA, \qquad \text{or} \qquad E = \frac{x \cdot AB}{2 \cdot MA}. \tag{3}$$

Sometimes an incandescent lamp with a straight vertical filament is placed at A instead of the telescope, and a convex lens is placed between it and the mirror M, so that an image of the filament is formed on the scale SS'. If the scale is translucent the position of the image can readily be seen. The equation is the same as before.

In this experiment the third leg of the optical lever rests on a small collar attached to the lower end of the wire and a few millimeters above the point where it enters the hole in the metal platform. Usually this leg may be adjusted, or the position of the collar may be adjusted, or the position of the telescope and scale may be adjusted, so that the image of the point A may be seen in the telescope before the stretching weights are removed from the upper support and placed on the hanger.

The length of the wire stretched is the distance from the lower side of the upper chuck to the upper side of the collar supporting the third leg of the mirror mounting. The distance this collar is depressed by the weights is the elongation E, and this may be calculated from equation (3).

Work to be Done. A. Place the wire to be tested in the apparatus. A wire having a diameter between 0.05 cm. and 0.10 cm. is a convenient size. Make the necessary adjustments of the wire and weights so as to straighten the wire, and adjust the optical lever, as indicated in the preceding discussion. One meter is a convenient distance at which to place the scale SS' from the mirror M. Determine the diameter of the wire at a number of places with a micrometer caliper, and measure its length to the nearest millimeter. Record the scale reading of the telescope, and then place a 1 kg. weight on the hanger and record the new reading. To be sure that the wire has not slipped in the chuck, or that some other accident has not occurred, it is advisable to return to the initial load, by removing the 1 kg. weight, and to observe whether the telescope reading is the same as at first. If it is not the same, try to discover the cause of the discrepancy. After you have found it, repeat the observation. Calculate the elongation produced.

Repeat, using 2 kg., 3 kg., 4 kg., and so on, until you use all the weights available or else reach the elastic limit of the wire. Be sure to return to the initial or "no load" readings between successive loadings.

When the elastic limit has been reached, the elongation begins to increase more rapidly than before, and the wire does not return to its original length. From equation (2) calculate Y, using the means of your measurements of the diameter, and the sums of all your loads and elongations.

B. Repeat part A, using a wire of the same material and same length, but of a different diameter.

C. Repeat part A, using a wire of a different material.

D. Using rectangular cross-section paper, plot graphs for parts A, B, and C, using elongations as ordinates (i.e., plotted vertically) and the stretching forces in kilograms as abscissae (i.e., plotted horizontally). For each case draw the straight line which best represents your plotted points, disregarding any points whose positions may be due to excessive loading of the wire in question.

From the slopes of these lines determine the ratio of force to elongation (or vice versa) for each wire, and using these ratios recalculate the corresponding values of Y.

How do these results compare with the values obtained by using the sums of the forces and elongations? How do your results compare with those given in standard tables? Express differences in percentages of the standard values.

此为试读，需要完整PDF请访问：www.ertongbook.com