A LABORATORY MANUAL OF PHYSICS

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PREFACE

This book has been written to satisfy the need for a suitable laboratory manual of general physics for use in the schools of Oklahoma. It contains the thirty-seven experiments which have been approved as a "minimum list" by the State Department of Education and which are outlined in the "Course of Study In Science." It also contains the ten additional experiments which are recommended for schools having the necessary apparatus. A few changes have been made in the apparatus and in the directions for performing the experiments, where the resulting advantages were too great to be disregarded.

This manual differs from similar books in several respects: (1) It provides a comprehensive course in elementary laboratory physics without requiring expensive apparatus. (2) Questions are used extensively and, instead of being grouped at the end of the experiment, are placed at the points in the experiment where they naturally arise. Each question should be answered by the student at the time that it is encountered in performing the experiment, so that the student will keep clearly in mind just what he is attempting to do and just how he should interpret his results. (3) Preceding the directions for each experiment is a brief introduction which provides an incentive for performing the experiment and also the fundamental facts which the student should have in order that he may realize the maximum benefit from it. (4) The manual contains a complete list of the apparatus needed for each experiment. Each list is designed to assist the instructor in preparing for the laboratory period in the minimum amount of time.

Special experiments requiring little or no additional apparatus have been introduced at various places throughout the book. These experiments should prove attractive to the student who has the ability and the desire to to do more work than is outlined by the minimum list. Because of their briefness, these special experiments offer opportunity for the development of originality and forethought in experimentation.

Many of the experiments have been divided into two or more parts in order that they may be adjusted to the length of the laboratory period and in order that each problem may be concrete and specific. Consequently in several of the experiments certain parts may be omitted if it is found desirable. Such omissions should depend upon the interest and training of the students and upon the limitations of apparatus.

It is suggested that each student be given the opportunity to perform several of the experiments alone. There is also considerable value in having several of the experiments performed by the class as a group, in which case the instructor or a student should manipulate the apparatus.

The appendix includes some material which would ordinarily be found in the body of the book. This arrangement facilitates ready reference to such topics as Graphs, Balances and Ammeters, and encourages the student to develop the habit of referring to sources of information other than those collected for the purpose at hand.

Elementary physics should be a fascinating subject for boys and girls and, while it is true that the subject will present difficulties even for the best students, there is no reason why a science which has contributed so abundantly to every phase of human progress should not be attractive. The authors have prepared this laboratory manual with the hope that it will assist the teacher in initiating his students into the wonderland of physical science and in arousing in them the desire to learn more about the "why" of things.

We take pleasure in thanking our colleagues Dr. William Schriever and Mr. Harvey C. Roys who read the manuscript and the proof, and we wish to express our appreciation to Mr. John Gilbert who exercised much patient care and skill in preparing the drawings. We are also indebted to the Welch Scientific Company and to the Central Scientific Company for a number of illustrations.

The authors will be glad to receive criticisms and suggestions from the teachers who use this manual.

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SPECIAL EXPERIMENTS

LABORATORY MANUAL OF PHYSICS

1. DENSITY OF SOLIDS BY WEIGHING AND MEASURING

Books on physics, engineering, and chemistry contain tables which give the densities of many substances, and these tables are often consulted by scientists, engineers and manufacturers. If an engineer knows the density of the wood and steel which he uses in building a bridge, he can calculate the mass of the structure with an accuracy sufficient for his needs.

The *density* of a substance is the mass of a unit volume. This is usually given in grams per cubic centimeter, although in applied sciences like agriculture and home economics, it is often more convenient to give the density of a substance in pounds per cubic foot, or in pounds per cubic inch.

1. If the mass of a block of wood is 280 g and its volume is 500 cm^3, what is the average density of the wood? Ans. 0.56 g/cm^3.
2. Why do we say "average density" in the case of wood, and simply "density" in the case of pure lead or iron?

To measure the density of a substance, we must find both the *mass* and the *volume* of a sample of the substance, and then divide the former by the latter. The mass can be measured on a beam or platform balance, but the way in which the volume is measured depends on the shape of the sample. In this experiment, we will deal only with samples which are in the form of rectangular blocks or spheres.

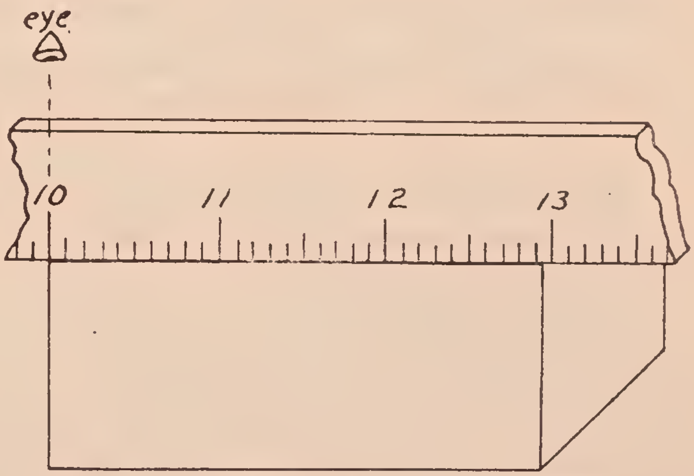

Fig. 1. Correct way to use a meter stick. Width of block is 2.94 cm.

Exp. 1, Part I. *Measure the densities of several kinds of wood or metal of which you have samples in the form of rectangular blocks.*

To find the *volume* of a rectangular block, we must first measure its length, width and thickness with a meter stick, and then compute the volume by means of the formula,

$$\text{Volume} = \text{length} \times \text{width} \times \text{thickness}.$$

Since there is no such thing as a perfectly rectangular block, it is necessary to measure the length, width and thickness at different points. We can then compute the *average* length, width and thickness, and from these determine the volume of the block.

First obtain the *average length* of the block. To do this, measure the four edges of the block which are parallel to its length, and then find the sum of these four measurements and divide this sum by four. Each measurement should be made to a hundredth of a centimeter and should be written down in centimeters and a decimal fraction thereof. Since a hundredth of a centimeter is one tenth of the *smallest division* on an ordinary meter stick, it will be necessary to estimate to tenths of the smallest division. The ability to estimate distances on a scale to tenths of the smallest division is very important in making measurements.

There will be less error in these measurements if the meter stick is placed on the block so that the scale divisions touch the wood, as in Fig. 1. The ends of the meter stick must not be used, unless these ends are tipped with metal. Why?

The *average width* and the *average thickness* of the block are obtained in the same way as the average length, in each case making four measurements.

Make a table for your data similar to the one at the end of this experiment, and record the result of each measurement just as soon as it is obtained. Compute the volume of the block and then proceed to measure its *mass* on a beam or platform balance. A description of various types of balances and directions for their use are given under *Balances* in the appendix.

EXP. 1, PART II. *Measure the density of steel, glass or some other substance of which you have a sample in the form of a sphere.*

To find the *volume* of a sphere, measure its diameter d and then compute its volume V, using the formula,

$$V = \tfrac{1}{6}\pi d^3 .$$

The diameter is best measured with a *micrometer caliper.* A description of the micrometer caliper and directions for its use are given under *Calipers* in the appendix.

First determine the *zero reading* of the micrometer caliper by the method explained in the appendix. This reading, if different from zero, must be added to, or subtracted from, all future readings made with the instrument. Then make, say, four measurements with the calipers of the diameter d of the sphere. Each measurement should be made to a thousandth of a centimeter and should be written down in centimeters and a decimal fraction thereof. A thousandth of a centimeter is the smallest reading which can be made on an ordinary micrometer caliper.

Record each measurement as soon as it is made in a table similar to the one at the end of this experiment. Never record data on scratch paper.

Obtain the *average diameter* of the sphere by finding the sum of the four measurements and dividing by four. Compute the volume of the sphere and then proceed to measure its *mass* on a beam or platform balance. A description of various types of balances and directions for their use are given under *Balances* in the appendix.

Note. If a micrometer caliper is not available, measure the diameter of the sphere with a meter stick. In this case it will be found best to use two identical spheres, placing them side by side between two blocks, as in Fig. 2. Measure the distance between the blocks at each end and at a level with the centers of the spheres. Then shift the blocks and repeat this procedure, obtaining four measurements in all.

Each measurement should be made to a hundredth of a centimeter and should be written down in centimeters and a decimal fraction thereof. Since a hundredth of a centimeter is one-tenth of the smallest division of an ordinary meter stick, it will be necessary to estimate to tenths of the smallest division.

There will be less error in these measurements if the meter stick is placed against the blocks so that the scale divisions touch the wood, Fig. 1. The ends of the meter stick must not be used, unless they are tipped with metal.

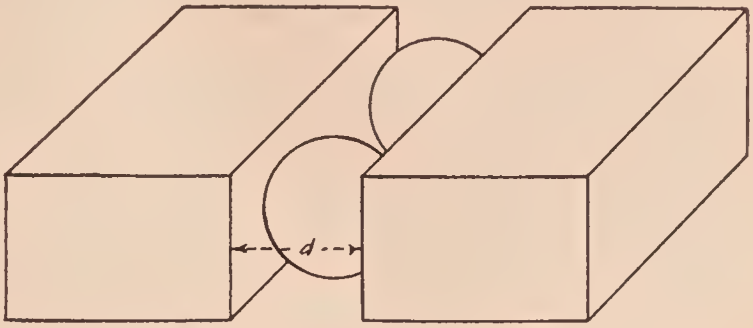

Fig. 2. Measurement of the diameter of a sphere with a meter stick.

Obtain the average diameter of one of the spheres by finding the sum of the four measurements and dividing by four. Compute the average volume of one sphere and then proceed to measure its mass on a beam or platform balance, directions for the use of which are given under Balances in the appendix.

Suggested form of record

PART I

Substance_______________________________________. Sample No.___________________.

Trial	Length in cm	Width in cm	Thickness in cm
1			
2			
3			
4			
Average			

SUMMARY OF RESULTS	
Substance and sample number	Density in g/cm³

Volume = (______________) × (______________) × (______________) = ___________cm^3.

Mass = ____________________ g.

Density = (________________) ÷ (________________) = _______________________ g/cm^3.

(Make a similar table for each block tested.)

PART II

Substance____. Sample No.____________________.

Diameter of spherical sample:

Trial 1 _________ cm; 2 _________ cm; trial 3 _________ cm; trial 4 _________ cm.

Average diameter______________________cm.

Volume of sample $= \dfrac{3.1416 \times (\_\_\_\_\_\_\_\_)^3}{6} =$ __________________cm^3.

Mass of the sample____________________g.

Density = (____________) ÷ (____________) = ______________________________g/cm^3.

SPECIAL EXPERIMENT. Find the density of a substance of which you have a sample in the form of a cylinder. Measure the dimensions of the cylinder with a *vernier caliper*, the directions for the use of which will be found under *Calipers* in the appendix.

Make three measurements of the length and three of the diameter of the cylinder, compute the average length l and the average diameter d, and then find the volume, using the formula,

$$V = \frac{\pi \times d^2 \times l}{4}.$$

Use a beam or platform balance to measure the mass of the cylinder and then calculate the density of the substance in the usual way.

2. ARCHIMEDES' PRINCIPLE AND THE DENSITY OF AN IRREGULAR SOLID

The density of coal, stone and similar substances is obtained by finding the mass and volume of a sample of the substance, and then dividing the mass by the volume.

It is difficult to obtain samples of such substances which are regular in shape and hence a meter stick or calipers cannot be used to find their volumes.

The volume of an irregular object can be found, however, by a method which is based on Archimedes' principle. The object is weighed in air and then in some liquid of known density, generally water, and its apparent loss of weight is noted. This "loss of weight" is, by Archimedes' principle, equal to the weight of the liquid displaced by the object. If the weight of the displaced liquid is divided by its density, the volume of displaced liquid is obtained; and this is also the volume of the object.

1. If a piece of granite weighs 180 g less in water than it does in air, what is the weight of the displaced water? Ans. 180 g.
2. In the above question, what is the volume of displaced water? Of the granite? (Density of water equals 1 g/cm^3.)
3. What is the density of this granite if its mass is 468 g?

EXP. 2, PART I. *Verify Archimedes' principle.*

Archimedes' principle can be verified by finding the loss of weight in water of some object of regular shape and comparing this with the weight of the water displaced by the object.

Make the initial adjustments of the beam balance[1] as directed under *Balances* in the appendix. Weigh in air an aluminum cylinder or other regular object of fairly large volume. Then suspend it in a vessel of water, Fig. 3, and again find its weight. Be sure that the vessel of water does not touch the pan supports, and that the object is completely immersed and free from air bubbles. Why?

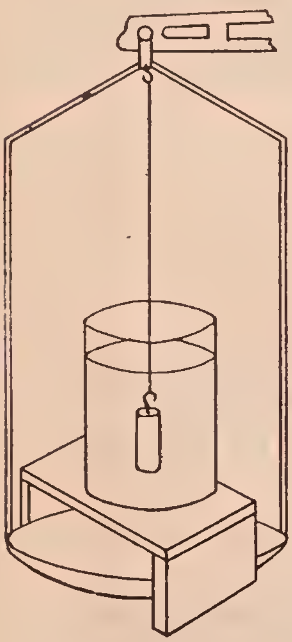

Fig. 3. Archimedes' principle.

The difference between the above weights is the loss of weight in water. It is this value which we wish to compare with the weight of the displaced water.

To find the weight of the displaced water[2], multiply

[1]A spring balance may be used, if necessary. Before making any weighings, hold the balance in a vertical position and note the reading of the balance with zero load. This reading, if different from zero, must be added or subtracted, as the case may be, from all future readings taken with the balance in question.

[2]An alternative method for measuring the weight of the displaced water is to fill an overflow can (or steam boiler) with water until it flows out the spout. Place an empty weighed beaker under the spout and carefully lower the object into the overflow can by means of a thread. When the last drop of liquid has overflowed, weigh the beaker and water and compute the weight of the water displaced by the object.

its volume by its density. The volume is the same as that of the immersed object, and since the latter is regular in shape, it can be found with calipers or a meter stick. If the object is rectangular or spherical in shape, get the volume by one of the methods given in Exp. 1. If it is a cylinder, make four measurements of its length and four of its diameter with a *vernier caliper*[1], and compute the average length l and the average diameter d;, then find the volume of the cylinder, using the formula,

$$V = \frac{\pi \times d^2 \times l}{4}.$$

If a vernier caliper is not available, measure the diameter with a meter stick, using a method similar to the one for measuring a sphere, given in Exp. 1, Part II.

4. Compare the loss of weight in water with the weight of the displaced water and state in your own words the principle thus verified.

5. Calculate the percent of difference between your values for the loss of weight and for the weight of displaced water, using the formula,

$$\text{Per cent of difference} = \frac{\text{difference between values}}{\text{either value}} \times 100.$$

EXP. 2, PART II. *Find the density of brass, coal, rock, or some other substance of irregular form.*

Weigh in air and then in water a sample of the substance whose density is to be found, Fig. 3. Observe the precautions given in Part I. Record your data in a table similar to the one given at the end of this experiment.

1. Show that the following formula is correct:

$$\text{Density} = \frac{\text{mass}}{\text{loss of weight in water}}.$$

2. The volume of an object immersed in water is numerically equal to the loss of weight. Why must we say "numerically"?

3. Why cannot the "loss of weight" method be used to find the density of rock salt?

4. What becomes of the "lost" weight, when an object is immersed in a fluid?

5. Given a balance, weights and a vessel graduated in cubic centimeters, how would you find the density of an irregular solid?

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[1]See Calipers in appendix.

Suggested form of record

PART I

Weight of object in air______________________g.

Weight of object in water______________________g.

Loss of weight in water______________________g.

Volume of immersed object (R ord data for volume as in Exp. 1):

Weight of displaced water = (______________) × 1 = ______________________g.

PART II

Substance______________________________________ Sample No.______________________

Weight in air______________________g.

Weight in water______________________g.

Loss of weight in water______________________g.

Volume of sample = vol. of water = $\dfrac{(\qquad\qquad\qquad)}{1}$ = ________________ cm^3.

Density = (________________) ÷ (________________) = ____________________g/cm^3.

3. DENSITY OF LIQUIDS AND OF SOLIDS LIGHTER THAN WATER

The density of a liquid like gasoline is one of the indications of its quality. Gasoline of high density should not be used in automobile engines and if used in an aeroplane engine, a serious accident may result. In some states filling stations are required to post the density or specific gravity of the gasoline which they have for sale. The *specific gravity* of a substance is the number of times that the substance is denser than water.

The special device used for measuring the density of a liquid is called a *hydrometer*. This important instrument is used commercially for testing milk, gasoline, oils and the liquid in automobile storage batteries. With a hydrometer it is easy to determine, for example, whether the milk which you buy is being "watered". The hydrometer makes use of the *displacement method* for measuring density, a method which is based on Archimedes' principle.

The displacement method is also used to measure the density of a solid lighter than water. Since such a solid will float in water, it is necessary to devise a means for keeping the solid under the surface while it is being tested

Exp. 3, Part I. *Make a constant-weight hydrometer and use it to measure the density of gasoline.*

Fig. 4. Constant-weight hydrometer.

Place the gasoline or other liquid to be tested in a deep vessel. Float a glass tube, about 50 cm × 2 cm, closed at one end, in the liquid and load this tube with shot until it sinks to within about 2 cm of the top, Fig. 4.

Place a rubber band or thread around the tube at the exact point where it meets the surface of the liquid. Remove the tube from the liquid, wipe it dry and measure the length immersed. Call this length l_x.

Now float the tube with its contents in a vessel of water, mark the point to which it sinks and again measure the length immersed. Call this length l_w.

Record your data in a table similar to the one at the end of this experiment. The room temperature should be read and included in the record because the density of a liquid varies considerably with temperature.

The density d_x of the liquid tested is l_w/l_x. The tube sank both in the water and in the liquid tested until it displaced its own weight. Hence the weight of water displaced equaled the weight of the unknown liquid displaced, and if the cross-sectional area of the tube is a,

$$l_x \times a \times d_x = l_w \times a \times 1,$$

$$\therefore\ d_x = \frac{l_w}{l_x}.$$

Compute d_x and check your result by testing the liquid with a commercial constant-weight hydrometer, if one is available.

1. Automobile gasoline should have a density of about 0.75 g/cm³ or less. Is the sample tested suitable for an automobile engine?
2. Why does the formula l_w/l_x give the density in grams per cubic centimeter?
3. How would you change this formula to get the density in pounds per cubic foot?
4. What is the specific gravity of the sample of gasoline tested?
5. Given a bottle weighing 30 g when empty and 80 g when filled with water, what would it weigh if filled with the gasoline which you tested?

EXP. 3, PART II. *Find the density of cherry or some other wood less dense than water, or of paraffin, wax or cork.*

The density of a substance can be computed if the *mass* and *volume* of a sample of the substance are known.

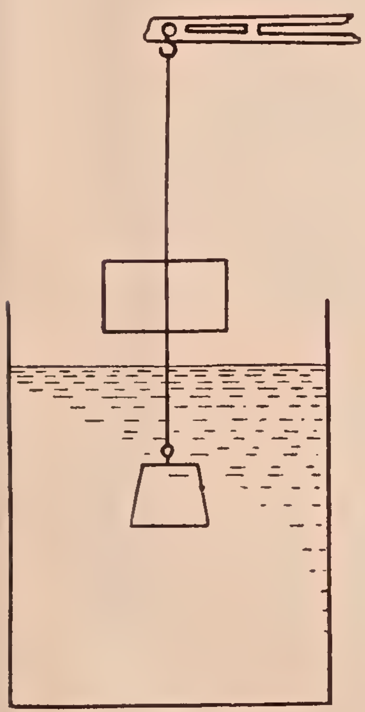

Fig. 5. Density of a solid lighter than water.

Obtain a sample of the substance to be tested and weigh it in air to get its mass. Next find the volume of the sample by observing its loss of weight when it is completely immersed in water. Since the sample is lighter than water, it will float unless weighted down by a sinker; hence, the following steps must be employed:

(a) Attach the sinker to the sample, hang both by a thread from the left arm of the beam balance, and weigh with the sinker alone immersed in a jar of water, Fig. 5. Be sure that the sinker hangs freely in the water and that the jar does not touch the pan supports.

(b) Next weigh when both sample and sinker are immersed in the water.

(c) The difference between these two weighings gives the weight of water displaced by the sample alone, and hence the volume of the sample in cubic centimeters. Why?

Since the mass and volume of the sample are now known, the density can be calculated by the usual formula. Record observed and computed data in a table similar to the one at the end of this experiment.

1. Why is the combined weight of the solid and sinker in water less than their combined weight when the sinker alone is immersed? Explain how this illustrates the principle of the life preserver.
2. What is the specific gravity of the substance tested? What is its density in pounds per cubic foot?

3. A block of wood weighs 92.4 g. The sinker alone weighs 204 g in water, while both sinker and block weigh 86.4 g in water. Find the density of the wood.

Suggested form of record

PART I

Density of____at___________________________°C.

Length immersed in liquid being tested, l_x____________________cm.

Length immersed in water, l_w____________________cm.

Density, d_x = (____________) ÷ (____________) = ____________________________g/cm³.

Value with commercial hydrometer = ___________________g/cm³.

PART II

Substance tested_____________________________________ .

Mass of sample________________________g.

Weight, sample in air and sinker in water__________________________g.

Weight, both sample and sinker in water__________________________g.

Weight of water displaced by sample alone________________________g.

Volume of sample____________________________cm³.

Density of___________________________________ = (____________) ÷ (____________) =

_______________________g/cm³.

SPECIAL EXPERIMENT. *Density of Milk.* Find the densities of samples of milk obtained from several dairies. If a lactometer is not available use an ordinary commercial hydrometer. "Unwatered" milk should test 1.027 to 1.033 g/cm³.

How would more water affect the density of milk? Would the density of milk change after it had stood half a day?

4. BOYLE'S LAW

When the pressure on air or any other gas is lowered, the gas expands. Thus at high altitudes, where the air pressure is low, the air is so "thin" that breathing is difficult, and automobile and aeroplane engines will not run properly unless an adjustment for the air is made on the carburetor.

The relation between the *pressure* and *volume* of a given mass of gas is described in a celebrated principle discovered in 1662 by Robert Boyle. Boyle used the apparatus shown in Fig. 6.

The short closed end of the tube contains a column of air *AB* which is separated from the outside air by the mercury in the bend of the tube. When the mercury stands at the same level in both tubes, the pressure on the inclosed column of air is evidently that due to the atmosphere alone, and it is found by reading the barometer.

If, however, the mercury level *C* in the open tube is *higher* than that in the closed tube, the column of inclosed air is under a pressure greater than that of the atmosphere. This pressure is given by the barometer reading *plus* the difference in levels *h* of the mercury. Thus the pressure on the inclosed air can be increased by pouring in more mercury. If the volume *AB* of the gas is measured for each new pressure, the relation between the pressure and volume of the gas can then be obtained.

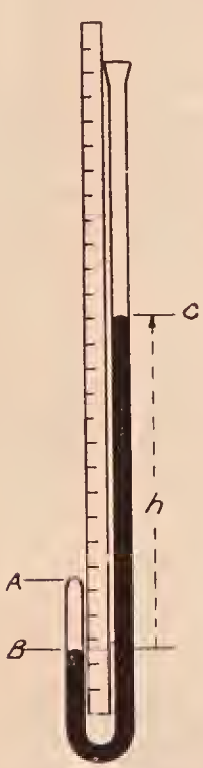

Fig. 6. Boyle's law apparatus.

There is one other factor besides pressure which changes the volume of a given mass of gas, and that is temperature. When the temperature increases, a gas expands. Hence, in studying the relation between pressure and volume alone, care must be taken to see that the gas is not heated or cooled.

EXP. 4. *Find how the volume of a given mass of gas changes with pressure, and thus test Boyle's law.*

Arrange the J-tube and meter stick as in Fig. 6, and carefully pour mercury into the tube until it stands a few centimeters higher in the open arm than in the closed arm. Tip the tube so as to allow air to escape from the closed arm until the mercury stands at about the same level in both arms.

The apparatus is now ready for the experiment. Record the temperature and also the reading of the barometer in centimeters and hundredths.

Read to tenths of the smallest scale division the heights of the upper end *A* of the air column and mercury surfaces *B* and *C*. The position of a mercury surface is read by placing the eye on a level with the mercury and reading the top of the surface. Avoid grasping the air column with the warm hands and do not take readings immediately after having changed its volume, as changes in volume temporarily heat or cool the gas.

Compute in centimeters the difference in mercury levels h, and add to this the barometer reading in centimeters. This gives the total pressure P on the gas.

Find the length of the air column AB. This length will be a measure of the volume V of the inclosed air, if we assume that the bore of the tube is constant.

Now pour in more mercury until the difference in level is increased, say, to 10 cm, and again find the pressure and resulting volume of the inclosed air. Continue this process until the air is compressed to about one-half its original volume.

Reread the barometer and thermometer at the end of the experiment. Record observed and computed data in a table similar to the one at the end of this experiment.

1. How do the values for $P \times V$ compare?
2. Did the temperature and atmospheric pressure vary any during the experiment?

If care has been taken to reduce the experimental error as much as possible, the product $P \times V$ will be found to be approximately *constant*. It is never quite constant, even when there is no error, but for small changes in pressure it way be considered constant. With the J-tube it is possible to get a series of values for $P \times V$ which do not vary by more than 2 or 3 percent.

3. You have found that, approximately, $P_1V_1 = P_2V_2 = P_3V_3 =$ etc. Show, then, that $\frac{P_1}{P_2} = \frac{V_2}{V_1}$.

4. Is the pressure directly or inversely proportional to the volume?

5. The equation $\frac{P_1}{P_2} = \frac{V_2}{V_1}$ is one way of stating Boyle's Law.

Express it in words.

6. Using the average of the series of values for $P \times V$ which you obtained, compute the relative volume, expressed in centimeters of length, of the air inclosed in your J-tube when the pressure is increased to 2.5 atmospheres (2.5×76 cm of mercury).

7. How would your values of $P \times V$ have been changed, (a) if a greater mass of inclosed gas had been used, (b) if the room had suddenly gotten warmer, (c) if the barometer had dropped during the experiment, unknown to you?

Suggested form of record.

Barometric pressure at beginning of experiment ________________ cm.

Barometric pressure at end of experiment ________________ cm.

Temperature at beginning of experiment ________________ °C.

Temperature at end of experiment ________________ °C.

Position of upper end of air column A ________________ cm.

Mercury surface B	Mercury surface C	Pressure h due to mercury, in cm	Total pressure P, in cm	Volume V of air AB	P X V

5. THE MOLECULAR STRUCTURE OF MATTER

It is now generally supposed that substances are made up of very minute particles called molecules. These molecules consist of one or more still smaller particles called atoms. Spaces exist between the molecules of a substance and this explains, for example, why a gas can be compressed into a small space and why two gases can be mixed together.

There is much evidence that these molecules are in rapid motion, though the manner in which they move differs for solids, liquids and gases. One evidence that the molecules of a gas are in rapid motion is the rapidity with which a gas will diffuse; the odor from cabbage being boiled in the kitchen soon penetrates to all parts of the house.

EXP. 5, PART I. *Show by an experiment that liquids are not continuous in structure, but are made up of discrete particles.*

Half fill the hydrometer tube of Exp. 3 with water. Incline the tube at an angle, to prevent mixing, and carefully add alcohol until the tube is filled.

Place the thumb *tightly* over the open end of the tube, slowly invert and note what happens. Continue this rotation of the tube until the liquids are thoroughly mixed, keeping the thumb over the open end.

1. Describe all that you observed.
2. Why was your thumb pressed into the tube?
3. Will a quart of sand and a quart of marbles measure two quarts when they are mixed together?
4. How does the experiment with alcohol and water illustrate the molecular constitution of liquids?

EXP. 5, PART II. *Show experimentally that gases diffuse rapidly.*

Procure two tumblers or beakers of about the same width. Wet the inside of one with a few drops of ammonia water and that of the second with a little hydrochloric acid. Place a cardboard or paper cover over each tumbler.

1. Describe the appearance of the gas in each tumbler.

Invert the second tumbler over the first, with the paper between them, placing them so that the edges will match. Remove the paper.

2. Describe what you see.

The two substances have united chemically to form a new substance, ammonium chloride, which is not colorless and therefore can be seen.

3. How does this experiment lend support to the view that the molecules passing off from the two evaporating liquids are moving rapidly in all directions?

6. PARALLEL FORCES AND THE PRINCIPLE OF MOMENTS

The ability of a force to *move* an object depends upon the magnitude of the force, and its ability to turn or *rotate* an object depends upon the distance of the force from the axis of rotation, as well as upon its magnitude.

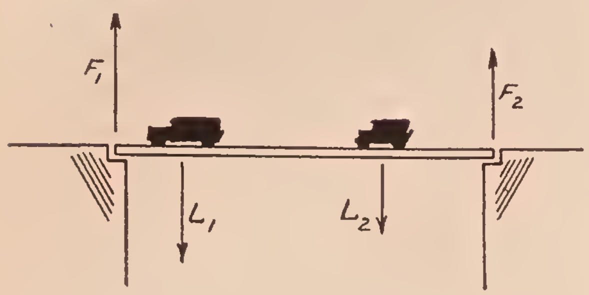

Fig. 7. Four parallel forces acting on a bridge.

The turning ability of a force is called its *moment*. The *moment* is the product of the force and its lever arm, the *lever arm* being the perpendicular distance from the axis to the line of action of the force.

Many cases arise in physics and engineering in which a body in equilibrium is being acted on by a number of forces, all of which are *parallel* to each other. This is true in the case of the bridge shown in Fig. 7.

Fig. 8 represents a laboratory model of this bridge. The two weights, L_1 and L_2, represent the loads on the bridge, and the spring balances the supports. The model is in equilibrium; it is prevented from moving and from rotating by the parallel forces acting on it. We wish to find how these parallel forces are related when the model is kept from moving, and how the moments of these forces are related in order to keep it from rotating.

In order to do this, we shall find by experiment how the sum of the upward *forces* due to the supports compares with the sum of the downward forces due to the loads. We shall also find how the sum of the *moments of force* tending to produce clockwise rotation compares with the sum of the moments tending to produce counterclockwise rotation.

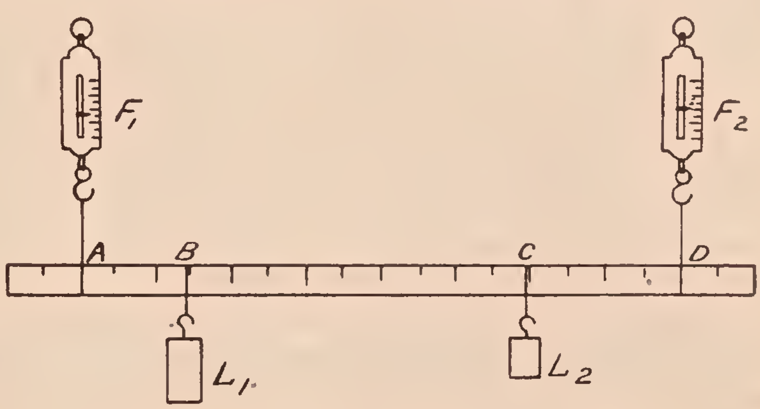

Fig. 8. Laboratory model of a bridge

When we have done this, we will know how parallel forces and their moments always are related in cases of equilibrium.

EXP. 6. *Set up a model bridge and find the two conditions which exist when it is in equilibrium under parallel forces.*

A. Forces. First we shall find how the sum of the forces in one direction compare with the sum of the forces in the opposite direction, when parallel forces are in equilibrium. Arrange the model as shown in Fig. 8. For good results the meter stick must be suspended in a horizontal position and the two supports, F_1 and F_2, must be accurately parallel. This latter condition can be obtained by hanging the spring balances from two nails or other supports which are exactly 80 cm. apart and fastening the hooks of the balances to the meter stick at the 10 cm and 90 cm marks. Why?

Record the initial balance readings. These readings are to be subtracted from later readings in order to eliminate the weight of the stick.

Hang the known loads L_1 and L_2, from the sliding loops at any two points such as B and C. Read each balance and from its reading subtract the initial reading. This gives the two upward forces F_1 and F_2.

Make two more sets of observations with the loads L_1 and L_2 hung at quite different places on the meter stick.

Compute in each case the sum of the upward forces, F_1 and F_2, and the sum of the downward forces, L_1 and L_2, and compare their values.

1. When your model bridge is in equilibrium, how does the sum of the forces acting in one direction compare with the sum of the forces acting in the opposite direction? Allow for possible experimental error, which should not exceed 2 per cent.

2. A 1500 lb. automobile is standing on a 60 ft. bridge which weighs 3 tons and which is supported at the ends. What is the *total* force which the supports must exert upward to prevent collapse? Do the results of your experiment show that this *total* upward force is dependent upon the position of the automobile on the bridge?

B. Moments. We will next find how the sum of the clockwise moments compares with the sum of the counter-clockwise moments when parallel forces are in equilibrium. If the support D were to break, your model bridge would rotate clockwise about A as an axis. We wish to find how the moments of the forces are related in order to prevent this rotation.

Hang the loads L_1 and L_2 at some convenient distance from the chosen axis, A, say 20 cm and 30 cm. Obtain the corrected reading F_2 of the balance at D and measure its lever arm, AD. Then compute the moment, $F_2 \times AD$, which tends to produce counter-clockwise rotation about A. Also compute the moments, $L_1 \times AB$, and $L_2 \times AC$, tending to produce clockwise motion about the same axis A.

Make two more sets of observations with the loads, L_1 and L_2, hung at other points, in each case computing the moments of the forces about the axis A.

In each case compare the sum of the moments tending to produce clockwise rotation with the moment tending to produce counter-clockwise rotation.

3. When your model bridge is in equilibrium, how does the sum of the moments of the forces tending to produce clockwise rotation about the point A compare with the sum of the moments of the forces tending to produce counter-clockwise rotation about the same point?

4. When A is regarded as the axis, what is the moment of F_1 about this point? Why, then, is this moment not included in either of the above sums of moments?

Since we arbitrarily chose A as the axis, we could just as well have chosen D, or, for that matter, any point on the meter stick.

5. What is the moment of F_2 about D as an axis. Of L_1 about B?

6. What is the advantage of selecting A, B, C or D as the axis, instead of some other point?

7. If, in Ques. 2, the automobile is standing 15 ft. from one end of the bridge, what is the force exerted by each support? (Regard the bridge as uniform, in which case its entire weight may be considered as concentrated at its middle point.)

Suggested form of record

A

Zero reading of balance at P ______________________g.

Zero reading of balance at S ______________________g.

Load L_1 ____________________g; load L_2 ____________________g.

Trial	F_1 in grams	F_2 in grams	$F_1 + F_2$ in grams	$L_1 + L_2$ in grams
1				
2				
3				

B

Lever arm of force F_2, AD ____________________cm.

	Trial 1	Trial 2	Trial 3
Force F_2 in grams			
Lever arm of L_1, AB, in cm.			
Lever arm of L_2, AC, in cm.			
Moment of L_1, $L_1 \times AB$			
Moment of L_2, $L_2 \times AC$			
Sum of clockwise moments			
Counter-clockwise moment, $F_2 \times AD$			

7. CONCURRENT FORCES

A child sitting in a hammock is held in equilibrium by three concurrent forces. Two of these forces are due to the tension in the hammock ropes and the third to the gravitational pull of the earth on the child.

Imagine the forces due to the two hammock ropes replaced by a single force producing the same result, that is, keeping the child from falling. This single imaginary force is called the *resultant* of the two forces due to ropes, and the two forces which it replaces are called *components*. The downward force due to the weight of the child is called the *equilibrant* of these components.

EXP. 7, PART I. *Find how the tensions change in two cords supporting a load when the angle between the cords is changed.*

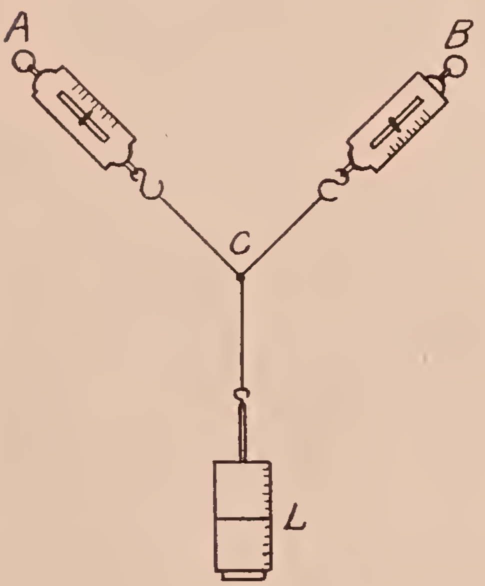

Fig. 9. Laboratory model of a hammock.

Tie the ends of the three cords together so that they will not slip. Each cord should be about 25 cm long. In the free end of each cord make a loop. Hang a load L of about 1.5 kg from the loop of one cord and slip each of the other loops over the hook of a spring balance. Suspend the two spring balances from the same level, Fig. 9, A and B being such a distance apart that the reading on each balance is approximately 1500 g. Record the reading of each balance.

Repeat with A and B about half as far apart, and again with A and B within a few centimeters of each other. Arrange data in some convenient tabular form.

1. How does the tension in the supports change as the angle between them is made smaller?

2. Why will a tightly stretched clothes line often break when clothes are hung on it?

3. Why are the forces in this experiment called *concurrent* forces?

4. We know from a previous experiment that when parallel forces are in equilibrium, the sum of the forces in one direction is equal to the sum of the forces in the opposite direction. From an inspection of your data, determine whether this is true when non-parallel forces are in equilibrium.

5. How would you arrange the two supporting cords A and B so that the sum of the forces exerted by them would exactly equal L?

6. An automobile is stuck in a mudhole. You have a 15 m cable attached to the car and 10 m in front of it is a stout post. Which

would you do, and why? (a) pull directly ahead on the cable, (b) tie the loose end of the cable to the post and pull sidewise on the cable, (c) run the cable around the post and pull on its free end?

EXP. 7, PART II. *Arrange an apparatus in which the concurrent forces are in equilibrium, and find how the resultant of two of these forces compares with their equilibrant.*

Use the apparatus of Part I, except that the weight L is replaced by a third spring balance, and the whole apparatus is placed in a horizontal plane, instead of a vertical plane.

Fasten the rings of the balances to table clamps placed along the edges of the table, Fig. 10, or, if a board with pegs is used, slip the rings of the balances over these pegs. Each balance should be stretched to about half its full range.

Place a blank sheet of notebook paper under the cords, with the center of the sheet near the point C, and fasten it down with thumb tacks or weights to keep it from slipping. In order to be sure that the balances are working freely, make a dot on the paper directly under C, then pull sideways on the cords to see if their intersection C returns to the same place. If it does not, raise the balances up slightly to do away with friction between them and the table.

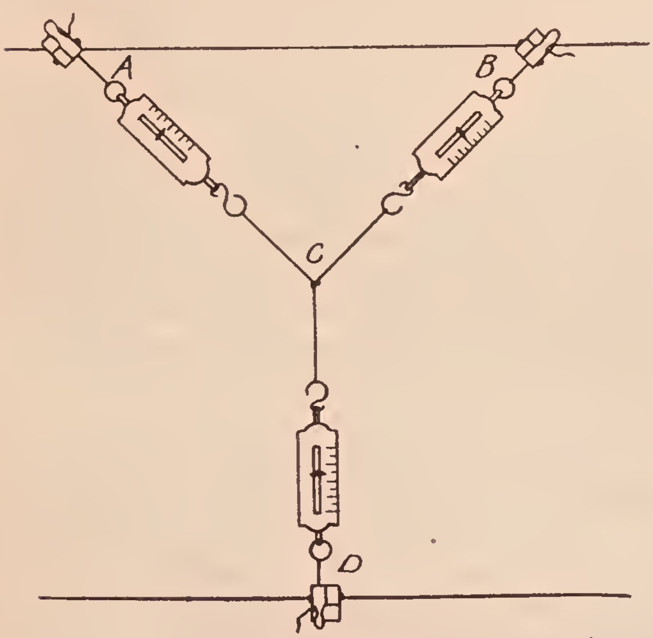

Fig. 10. Three concurrent forces in equilibrium.

Now place a wooden block on the paper so that its side just touches one of the cords but does not displace it. With a sharp-pointed pencil draw a line on the paper along the edge of the block and just under the string. Mark the directions of the other two cords in the same way.

Read each balance and record the tension in each cord at the end of the line which represents its direction.

Remove the paper and produce the lines until they meet. Select a convenient scale (say 1 cm to represent 150 or 200 g of tension) and measure off on each line from C the distance needed to represent the corresponding tension. Place at the end of each line an arrowhead to show the direction of the force.

Select any one of the three forces as *equilibrant* and lay off from C a dotted line representing a force *equal* and *opposite* to this equilibrant. Evidently this dotted line represents the single force which will just balance the equilibrant. Therefore it must represent the *resultant* of the two remaining forces.

With the two remaining force lines as sides, construct a parallelogram with ruler and compass (see any text-book on plane geometry). From C draw the diagonal of this parallelogram. Determine and record the magnitude of the force which this diagonal would represent. Compare it with the resultant as given by the dotted line.

1. How do the resultant and the diagonal of the parallelogram compare in direction and in magnitude? How, then, can you find the resultant of two concurrent forces?
2. When three concurrent forces are in equilibrium, how does the resultant of two of them compare in magnitude and direction with the third?
3. Make a diagram showing the forces acting on a person sitting in a hammock and draw the line representing the resultant of the supporting forces.
4. If the angle ACB were increased, how would this affect the length of the diagonal of the parallelogram having AC and BC as sides? Does this agree with the results of Part I?

SPECIAL EXPERIMENT. *Center of gravity.* This experiment will show that the weight of an object acts as if concentrated at the center of gravity.

A convenient "object" for use in this experiment is a meter stick loaded at one end with a strip of iron or lead. First locate the center of gravity of the loaded meter stick by balancing it on the edge of a triangular block of wood or by suspending it from a cord; balance is obtained by adjusting the position of this axis, or pivot, until the meter stick rests in a horizontal position.

Hang a 200 g weight from a point near the light end of the meter stick and adjust the position of the pivot until the meter stick again rests horizontally. Measure the distance D of the 200 g weight from the pivot and then calculate the moment, $200 \times D$, due to the 200 g weight.

Also measure the distance d of the center of gravity of the loaded meter stick from the pivot. Supposing that there is a force W acting downward at the center of gravity, the moment of this force will be $W \times d$.

Since the meter stick is in equilibrium, the clockwise and counterclockwise moments about the pivot are equal; that is, $200 \times D = W \times d$. Both D and d being known, the value of W can then be obtained.

A second trial should be made with the 200 g weight placed at some other point on the meter stick. Take the average of the values of W obtained from these two trials as the best value of W.

Remove the 200 g weight from the meter stick and weigh the loaded stick on the laboratory balance.

How does the gravitational force W acting downward on the object at its center of gravity compare with the weight of the object? Does the weight of an object act as if concentrated at the center of gravity?

8. THE SIMPLE PENDULUM

The chief use of the pendulum is to regulate motion in clocks. It is also used to measure the acceleration due to gravity g.

Since pendulums can be made long or short, heavy or light, and with a wide swing or a narrow swing, evidently it is important to know how these factors affect the rate at which the pendulum beats.

The *length* of a simple pendulum is the distance from the support to the center of gravity of the bob. When a pendulum swings from one end of its arc to the other, it is said to have undergone a *single vibration.* The time required for a single vibration is called the *period.* The extent of swing one side or the other from the central position of rest is called the *amplitude.*

EXP. 8, PART I. *Find how the amplitude, the mass of the bob and the length of a pendulum affect its period.*

A. Effect of amplitude. Attach a metal ball or bob to a thread and suspend it from a pendulum clamp or nail. Make the length l of this pendulum just 180 cm, the length being measured from the support to the center of the spherical bob.

Fasten a sheet of paper directly behind the bob so that a vertical line, which has been ruled on the paper, will indicate the position of the pendulum when it is at rest.

In measuring the period t of the pendulum, two students should work together, one acting as observer and the other as timekeeper. Start the pendulum swinging through a small amplitude of about 5 cm and wait until its motion becomes uniform. Then, as the bob passes its position of rest, begin to count aloud, *zero, one, two,* etc., every time the bob passes its position of rest. At the signal "zero" the timekeeper observes the time on the second hand of a watch, estimating the time to a fifth of a second. This will be made easier if the second hand of the watch is observed through a magnifying glass.

When the bob passes its position of rest on the fiftieth count, again take the time.

Keeping the length and amplitude the same, make a second determination of the time required for fifty vibrations. This second determination should agree with the first to within about one second. Take the average of the above two determinations and divide it by 50 to get the time of one swing, that is, the period t.

Without changing the length of the pendulum, increase its amplitude a few centimeters and again determine the period. Make two trials as before.

Finally, determine the period when the amplitude is very large, say 1 meter.

1. Does a small change in amplitude affect the period?
2. Does a large change in amplitude affect the period?

3. Explain why a clock runs too slow when it is first wound up.

B. Effect of mass of bob. Suspend a second pendulum of exactly the same length as the first, but made with a bob of different mass. The length of this pendulum should be measured, as always, from the center of the bob to the support. Set the two pendulums swinging together through a small amplitude and observe whether one pendulum gains on the other.

4. What conclusion do you draw as to the effect of the mass of the bob on the period?

C. Effect of length. Shorten the pendulum having a metal bob until it is 45 cm long, which is just one fourth of its original length. Swing this pendulum through a small arc and determine its period in the usual way.

Finally, determine the period when the length of this pendulum is one ninth of the original length, or 20 cm.

Compare the periods of the 45 cm and 20 cm pendulums with the period which the 180 cm pendulum had when its amplitude was small.

5. When the pendulum is made one fourth as long, does the period become one fourth as much or one half as much?
6. How does the period change when the length is decreased to one ninth of the original length?
7. Use your data to show that the periods of pendulums are directly proportional to the square roots of their lengths.
8. What would have been the period of your pendulum if you had made it one sixteenth as long?
9. Would you shorten or lengthen the pendulum of a clock which gains 3 minutes a day?

EXP. 8, PART II. *Use a simple pendulum to find g for your locality.*

The period t of a pendulum is given by the formula,

$$t = \pi \sqrt{\frac{l}{g}},$$

in which l is the length of the pendulum and g the acceleration due to gravity. If both members of this equation are squared, we obtain

$$t^2 = \pi^2 \times \frac{l}{g} \quad \textit{where } \pi^2 = 9.87.$$

Hence, if the length l and the accompanying period t of a simple pendulum are measured at a certain locality, the value of g at that place can be computed by means of the above equation.

To find g for your locality, use a pendulum with a metal bob and of length about 180 cm. Swing it through a small amplitude. Measure its length l and period t by the method given in *A* above, making numerous trials.

Compute the average length and period and then find g, using the above formula. If l is measured in centimeters and t in seconds, g will be obtained in centimeters per second per second.

1. How would the period of your pendulum change if you took it to the top of a mountain?
2. How long would a simple pendulum need to be to beat seconds at your locality?
3. What information does the formula for the simple pendulum give you with regard to, (a) the effect of the mass of the bob on the period, (b) the effect of the length of the pendulum on the period?

Suggested form of record

PART I

A. Effect of amplitude:
Length of pendulum, 180 cm.

Amplitude in cm	Time for 50 vibrations, in sec.			Period t in sec.
	Trial 1	Trial 2	Average	

B. Effect of mass of bob:

C. Effect of length:

Length l in cm	Time for 50 vibrations, in sec.			Period t in sec.	$\sqrt{t}$
	Trial 1	Trial 2	Average		
180					
45					
20					

PART II

Length of pendulum, l........................cm.

Time for 50 vibrations: trial 1....................sec., trial 2....................sec.,
trial 3....................sec., trial 4....................sec.

Average time for 50 vibrations........................sec.

Period, t....................sec.

Value of $g = \dfrac{9.87 \times (\qquad)}{(\qquad)^2} =$ .... cm per sec. per sec.

9. UNIFORMLY ACCELERATED MOTION

If a body is being acted on by a single constant force, its velocity will increase or decrease at a uniform rate, and it is said to have a *uniformly accelerated motion.* A stone falling in a vacuum is an example. A very dense object falling in air has approximately uniform acceleration, since the resistance of the air is such a small part of the total force acting on the object that this resistance can be neglected.

Objects fall so quickly through space that it is difficult to study their motion. Thus Galileo was led to use a long inclined plane, down which a ball will roll more slowly than it would fall vertically. During the War, the motion of aerial bombs dropped from aeroplanes was studied by attaching lights to the bombs and photographing their paths at night.

If an object has a uniform acceleration a, the distance s traversed by the body in a time t is given by the formula,

$$S = \frac{1}{2} at^2.$$

This formula can be used to measure the height of a tower or the length of a steep incline.

EXP. 9, PART I. *Study the motion of an object sliding down an inclined plane and verify the formula* $S = \frac{1}{2} at^2$.

Stretch tightly a strong smooth cord from an upper story of a building to the ground. A weighted glass awning ring or steel ring is to be allowed to slide down this cord, and the slope of the cord is to be such that it takes at least 4 seconds for the ring to slide the whole length of the cord. Attach a 2.5 cm drilled iron ball or other small weight to the ring.

Let the ring start sliding from the top and observe the time of fall t with a stop watch. Make several observations and compute the average time. If the total length of the string is S,

$$S = \frac{1}{2} at^2,$$

where t is the time of fall, which has just been found, and a is the acceleration, which is as yet unknown.

To find a, measure off a distance S' along the lower accessible part of the string and repeatedly find the time t' required for the ring to slide through this distance. The distance S' should be as long as possible, so as to reduce the error in measuring t'. The acceleration a can then be computed by means of the formula,

$$S' = \frac{1}{2} at'^2.$$

Since both a and t are now known, the length S of the string can be computed.

The result should be checked by unfastening the cord and measuring its length.

1. How would the results be affected if the incline were made steeper? Less steep?

2. Show from the formula for S that the distance passed through in the first second of fall is equal to one half the acceleration.

EXP. 9, PART II. *Find the height of a water tower, a building or a cliff by dropping a stone from its top and measuring the time of fall.*

Measure with a stop watch the time required for a stone to fall from the building or other high point. Make several trials and compute the average time t.

The acceleration in this case is g, which may be taken as 980 cm per sec. per sec. The height S is given by the formula,

$$S = \tfrac{1}{2}\, gt^2.$$

If possible, check your result by measuring with a meter stick the length of a weighted cord which will just reach to the ground.

1. An observer on a high tower measures the time elapsing between releasing a stone and hearing it hit the ground. Is this the time of fall?
2. A piece of cork and a stone of the same weight are dropped together from the same height. Will they hit the ground at the same time? Explain.
3. What is the result if two balls of the same size, one of cork and the other of lead, are dropped together from the same height?

Suggested form of record

PART I

Time t to fall whole length of incline:

Trial 1 _______________sec., trial 2________________sec., trial 3________________sec.

Average time, t______________________sec.

Known length of cord, S'____________________cm.

Time t' to fall known distance S':

Trial 1________________sec., trial 2________________sec., trial 3________________sec.

Average time, t'____________________sec.

Acceleration, $a = 2S'/t'^2 =$ ____________________cm per sec. per sec.

Length of string, $S = \frac{1}{2}\, at^2 =$ _____________________cm. or _________________________m.

PART II

(Devise your own form of record.)

10. BLOCKS AND TACKLE

Systems of pulleys are used to hoist and lower pianos, safes and other heavy objects. The single fixed pulley is often used in raising light loads such as awnings and windows. Painters use the arrangement of pulleys shown in Fig. 11c to raise and lower their scaffolds.

Work is not saved by using blocks and tackle. In fact, it requires an expenditure of more work to hoist an object with pulleys than it does to lift it without them.

The *efficiency* of a machine, such as the pulley, is given by the formula,

$$\text{Efficiency} = \frac{\text{useful work accomplished}}{\text{total work expended}} = \frac{W \times s'}{F \times s},$$

where W is the useful load, s' the vertical distance is moves, F the force required to lift the load, and s the distance this force moves.

In actual practice this efficiency will always be less than 100 per cent because of the presence of friction. Moreover, in pulley systems, the mov-

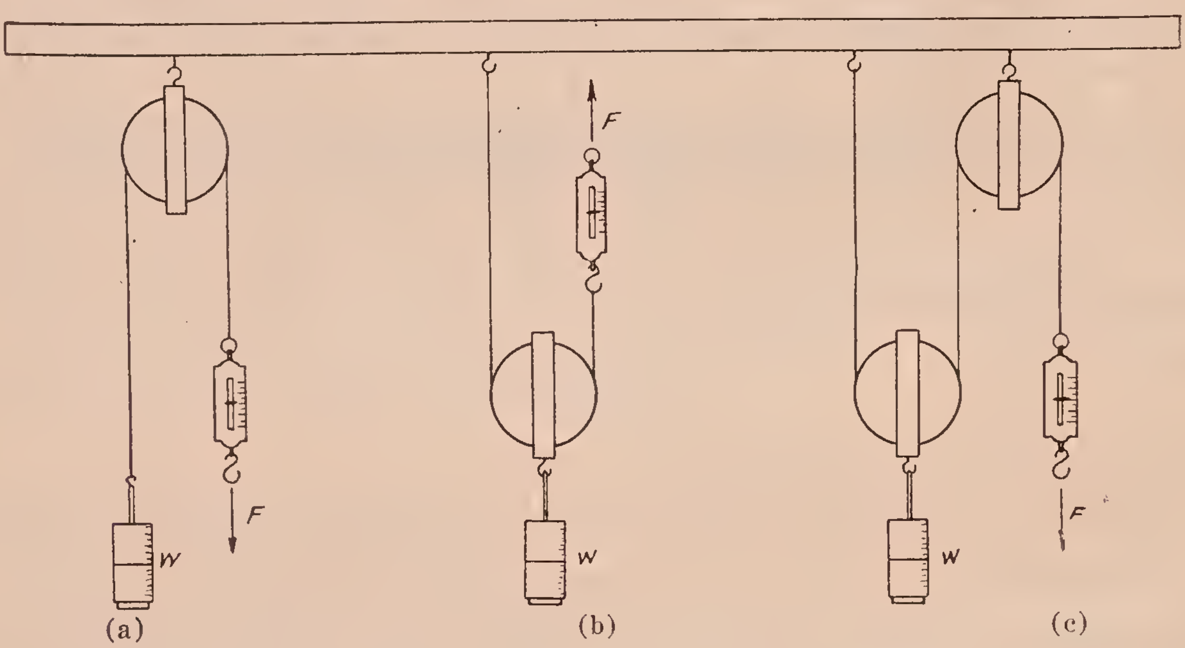

Fig. 11. (a) Single fixed pulley, (b) single movable pulley, (c) one fixed and one movable pulley.

able pulleys have to be lifted along with the useful load, and this requires an expenditure of work which does not result in useful work being accomplished. If there were no friction and the movable pulleys had no weight, the useful work accomplished would be equal to the work expended.

Exp. 10, Part I. *Find the efficiencies of several different kinds of pulley systems.*

A. Single fixed pulley. Arrange the apparatus as in Fig. 11a, the load being about 1 kg.

Lift the load W by pulling slowly and uniformly down on the hook of the balance, taking its reading as you do so. The force F is the reading of the balance plus the weight of the balance. Why?

Measure the distance s which F must be moved down in order to raise W a certain distance s', say 10 cm.

Tabulate data and calculate in gram-centimeters the work expended $F \times s$, and the useful work accomplished $W \times s'$, and find the efficiency.

1. Which is the greater, the expended work or the accomplished work, and why?

2. How do F and W compare? Why, then, is a fixed pulley ever used?

3. Why was it necessary to have the balance moving with a uniform speed?

B. Single movable pulley. Arrange the apparatus as in Fig. 11b, and follow the same procedure as in Part IA. In this case, however, do not add the weight of the balance to the balance reading to get F. Why not?

Notice also that while the total load lifted includes the movable pulley, yet the weight of this pulley is not included in W, since in efficiency tests you are interested in the *useful* work accomplished, and not the total work.

4. How does the efficiency of the single movable pulley compare with that of the single fixed pulley? Explain, bearing in mind that there is no increase in friction.

5. How do F and W compare? Why, then, is the movable pulley a useful machine?

6. The quotient W/F is called the *practical mechanical advantage*. What information does it give you?

C. One fixed and one movable pulley. Arrange the apparatus as in Fig. 11c. In this case the *useful load W* is again the weight hangar and weights only, while the force F is the weight of the balance plus its reading, as in Part IA. Follow the same procedure as in Part IA.

7. How do F and W compare in this case?

8. How does the practical mechanical advantage W/F of this device compare with that of the single fixed pulley?

9. In what way is it a more useful device than the single fixed pulley? Than the single movable pulley?

10. Why does the efficiency differ from that of the single fixed pulley? From that of the single movable pulley?

11. Show from your data that work is not saved by using a block and tackle.

EXP. 10, PART II. *Test the principle of work.*

We will use a single movable pulley, Fig. 11b, to test the principle of work.

Since the principle of work has to do with perfect machines, it will be necessary to eliminate the effects of friction. To do this, lift the load W by pulling uniformly and slowly up on the ring of the balance, taking the reading as you do so. Next lower W in a similar way, again taking the reading. The average of these two readings gives what the force F would be if there were no friction.

Measure the distance s which F must be moved upward in order to raise W a certain distance s', say 10 cm.

Weigh the pulley and add this weight to that of the hanger and weights to get the total load W.

Calculate in gram-centimeters the work expended and the work accomplished.

1. When there is no friction, how does the work expended compare with the work accomplished?
2. Give the algebraic statement of the principle of work as proved by your data.
3. Give two reasons why the quantity $W \times s'$ which you measured above is not the *useful* work accomplished?
4. When friction has been eliminated, W/F is called the *theoretical mechanical advantage.* What is its value for the single movable pulley?
5. Using the principle of work, show that the theoretical mechanical advantage is also s/s'.
6. Diagram a system of pulleys having a theoretical mechanical advantage of 5. How could this system be changed to give a mechanical advantage of 1/5?

Suggested form of record

PART I

Weight of balance____________________g.

Case	F	W	s	s'	$F \times s$	$W \times s'$	Efficiency Ws'/Fs
A							
B							
C							

PART II

F (up)________________g; F (down)________________g. Average F________________g.

Weight of pulley________________________g. Total load, W________________________g.

Work expended = (_______________) × (_______________) = _________________g-cm.

Work accomplished = (______________) × (______________) = _________________g-cm.

11. FRICTION

If there were no friction, an engine would not need to exert any pull to keep a train running at a uniform speed on a straight level track. On the other hand, the engine could not start and stop the train if friction were not present.

Without friction, nails would not hold, the fibers of a rope would not hold together, and walking and many other forms of motion would be impossible. In most machinery, however, it is important to reduce the friction as much as possible. This is done by using lubricants, by choosing suitable contact surfaces and by substituting rolling contacts for sliding ones.

Friction is a force which acts in a direction opposite to that in which a body is moving. Common forms are *sliding, starting, rolling and fluid* friction.

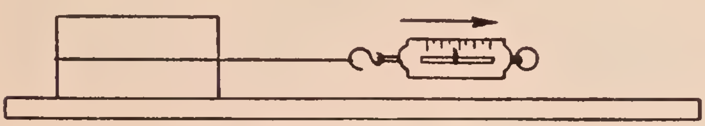

Fig. 12. Sliding friction.

If a block of wood is pulled at a uniform speed along a level board by means of a spring balance held horizontally, Fig. 12, the amount of sliding friction between the block and board is given by the balance reading. The *coefficient of sliding friction* for these two surfaces can then be obtained by dividing the sliding friction by the force pressing the block against the board; this latter is the weight of the block and it should be expressed in the same units as the friction.

$$\text{Coefficient of friction} = \frac{\text{load}}{\text{friction}}.$$

The *amount* of friction depends upon the kinds of surfaces in contact and upon other factors, as will be seen in the following experiments.

Exp. 11, Part I. *Find how sliding friction depends upon the load and upon the area of the surfaces in contact, and also how it compares with starting and rolling friction.*

A. *Effect of load.* Tie a string around a chalk box in such a way that it does not touch the bottom of the box and weigh the box by means of a spring balance.

Lay a board on the table, smoothest side up, and place the box on this board with a 500 g weight in it. Attach the hook of the spring balance[1] to the string, hold the balance horizontally, and use it to drag the box slowly but at a uniform speed over the board, Fig. 12.

If the box is kept moving at a uniform speed, the reading of the balance is the sliding friction between the box and board. This reading is subject to a correction because the balance is being used in a horizontal position, instead of in the vertical position for which it was made. See Balances in the appendix.

[1]In place of the spring balance, one may use a weight hanger and weights, fastened to the box by a cord hung over a pulley. Add weights to the hanger until the box will move uniformly along the board when started with a slight push.

It will probably be found easier to read the balance if the board is drawn under the box, instead of dragging the box over the board. Since the friction will vary a little at different places on the board, several trials should be made and the average taken.

Tabulate results and calculate the *coefficient of sliding friction* to two decimal places. Remember that the *load* is the weight of the box and its contents, expressed in the same units of force as the friction.

Repeat with the load increased by, say, 300, 500 and then 1000 g.

1. Does the sliding friction increase with the load?
2. Within experimental error, does the *coefficient of sliding friction* for these two surfaces vary with the load?
3. What, then, is the exact relation between sliding friction and load?

B. Effect of change in area. Turn the box so that the smoothest small end rests on the board, place a 1000 g weight in it, and find the average value of the sliding friction. Compare this value with that obtained with the same load, but with the box resting on its larger base.

4. How does the friction depend upon the area of the surfaces in contact?

C. Starting friction. Place about 1000 g in the box and read the balance just before the box starts to slide and also while it is moving uniformly.

5. Is starting friction greater than sliding friction? Explain.

D. Rolling friction. Without attempting to make careful measurements, compare the sliding friction for a certain load with the friction for the same load when two round pencils are placed under the box so as to act as rollers.

6. Describe and explain what you observed.
7. What pull would an engine have to exert to haul a train weighing 900 tons at a uniform speed on a level track, if the coefficient of rolling friction of the train is 0.009?

EXP. 11, PART II. *Find the coefficients of sliding friction for various surfaces.*

Place a sheet of tin or other material on the board or table and, using the method for measuring friction given in Part IA, find the sliding friction for a load of about 1000 g. Make several trials, compute the average value of the friction, and then of the *coefficient of sliding friction* for the two substances.

Repeat with a sheet of paper, brass, etc., on the board, or with paper on both the box and the board.

1. How would changing the load affect your results? Changing the area of contact by turning the box on end?
2. Explain why polishing a surface reduces friction.
3. If the coefficient of sliding friction of wood on ice is 0.06, how

heavy a timber can be pushed over ice by a horizontal force of of 45 lbs.?

4. If the friction and load in a certain case were measured in pounds of force instead of in grams of force, would the coefficient of friction be different? Explain.

Suggested form of record

Part I: A

Weight of box____________________g.

Initial reading of balance, horizontal____________________g.

Total load in grams	Balance reading in grams				Friction in grams	Coefficient of sliding friction
	1	2	3	Average		

Part I: B, C, and D

(Devise your own form of record.)

Part II

Total load____________________g.

Initial reading of balance, horizontal____________________g.

Nature of surfaces	Balance reading in grams				Friction in grams	Coefficient of sliding friction
	1	2	3	Average		

12. TESTING A THERMOMETER

Thermometers are among the most commonly used scientific instruments. Most people have at least one in the house and one outside. Everyone wants to know how cold it is in the winter and how hot it is in the summer. If you will go into the local store which sells thermometers you will find that those placed together in the show case do not indicate the same temperature. The variation may be only one or two degrees or it may be as much as ten degrees. Even laboratory thermometers may be in error several tenths of a degree, and, if used for accurate measurements, they must be tested. Fortunately there are two temperatures at which it is possible to make tests with simple apparatus.

EXP. 12. *Test a Centigrade theremometer.*

A. To test the zero point. Fill a tumbler with cracked ice or snow. Insert the thermometer until the zero point is just visible. Watch the mercury thread and, after it has come to rest, read the thermometer. Record this reading and then determine the amount by which the thermometer reads too high or too low. Enter this *correction* in your note book, remembering that if the reading is below 0°C., the correction will be positive, and if it is above 0°C., the correction will be negative.

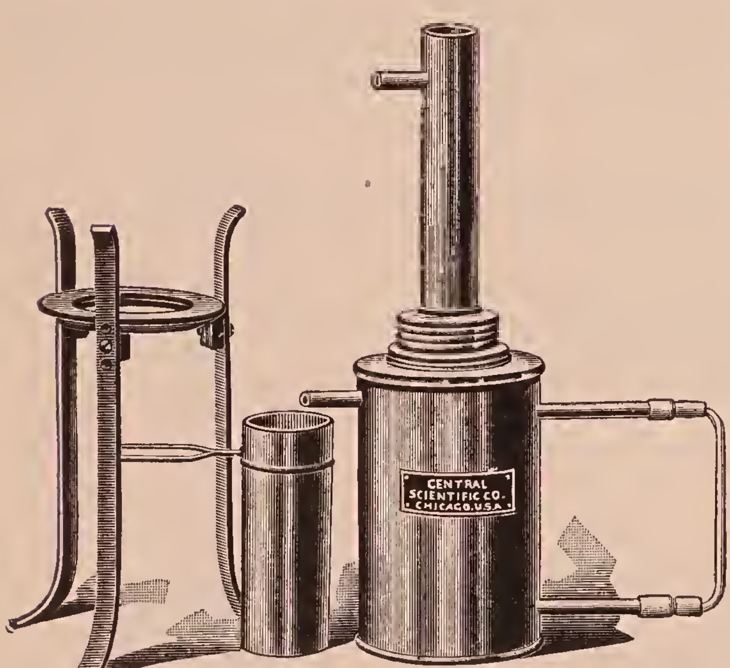

Fig. 13. Steam generator.

1. Where should you have your eye when reading a thermometer?
2. What is meant by the statement that the zero point of a thermometer has a correction of 1.2°C.?

B. To test the thermometer at the boiling point. Fill the boiler about half full of water and light the burner. While the water is heating, place the thermometer in the extension tube with the 100 degree mark a few millimeters above the supporting cork. When the water boils, watch for the appearance of the mercury, and, after it has ceased to rise, take and record the reading. Also read the barometer.

The amount by which the boiling point varies with barometric pressure[1] has been accurately determined and found to be 0.037°C. for each millimeter change in the barometer. The temperature of steam is 100°C. when the barometric pressure is 760 mm. From this data calculate the true temperature of the steam in your boiler.

[1]For an experiment on the effect of pressure on boiling point, see Exp. Add. 4.

In order to determine the effect of exposing the stem of the thermometer to the air, pull the thermometer out of the extension tube until only the bulb remains in the steam and note the change in the reading. Tabulate all data neatly.

3. Why must the thermometer not touch the water in the boiler?
4. Why must the boiler leak steam freely?
5. Considering the way in which you use a candy thermometer, would you test its boiling point with the stem completely immersed in the steam?

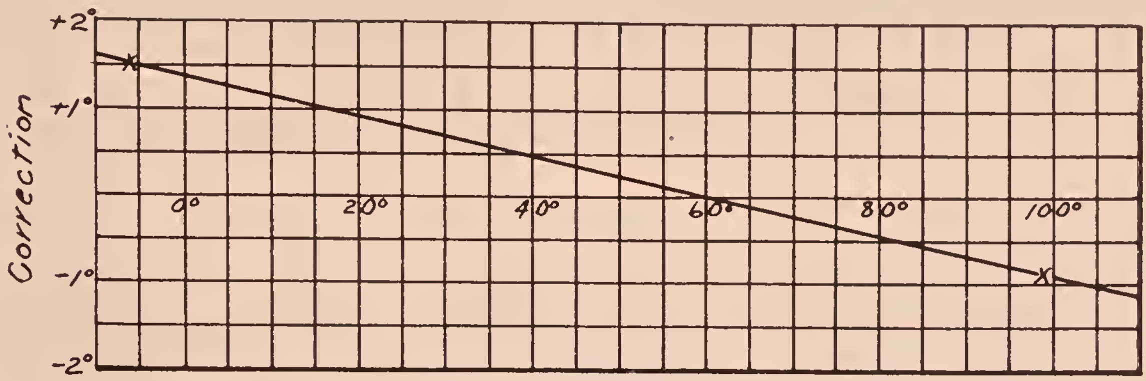

Fig. 14. Correction curve for Centigrade thermometer made from the following data: Reading of thermometer in ice, —1.45°C.; therefore, correction for a reading of —1.45° is +1.45°C. Reading of thermometer in steam, 100°C. the true temperature of the steam being 99.1°C; therefore, correction for a reading of 100.1°C is —0.9°C.

C. To make a correction curve for the thermometer. A knowledge of the errors of the thermometer at the *fixed points* is of little use unless a correction curve is drawn which will show the true temperatures for all readings of the thermometer. If we assume that the bore of the tube is uniform the correction curve will be a straight line.

Make a correction curve for your thermometer similar to the one shown in Fig. 14. See *Graphs* in the appendix.

6. At what temperature is your thermometer correct or most nearly correct?

Suggested form of record

Reading of barometer..............................mm.

Reading of thermometer in ice..............................°C.

Correction for a reading of..............................°C, is..............................°C.

Calculated temperature of steam..............................°C.

Reading of thermometer in steam..............................°C.

Correction for a reading of..............................°C. is..............................°C.

Reading of thermometer with stem exposed..............................°C.

Difference in reading due to exposed stem..............................°C.

13. DEW POINT AND RELATIVE HUMIDITY

The degree of dampness, or humidity, of the atmosphere is of great importance not only to the health of individuals but also to many manufacturing enterprises of which cotton spinning is one example. Whether or not the atmosphere is to be regarded as humid or dry depends not so much upon the actual mass of water vapor present as it does upon the relative humidity. *Relative humidity* is defined as the *ratio* of the mass of water vapor actually present in the atmosphere to the mass of vapor which would be present if the atmosphere were saturated.

The *dew point* is the temperature to which the atmosphere must be cooled in order to produce saturation. It is intimately related to relative humidity, for the lower the humidity the cooler will the atmosphere have to be before the dew point is reached. If either the relative humidity or the dew point is known, the other may be obtained easily by the use of tables which give the pressure of saturated vapor at various temperatures.

Exp. 13, Part I. *Determine the dew point and relative humidity of the air in the laboratory.*

A. Experimental determination of the dew point. Observe the temperature of the room. Then choose a brightly polished calorimeter cup and place in it two or three centimeters of cold water and a thermometer. Add ice, a little at a time, and stir thoroughly (a pencil may be used). Watch the surface of the calorimeter closely, continue adding ice (and a little salt if *necessary*) until a film of moisture appears on the outside of the calorimeter near the bottom, and immediately read the thermometer. Next add water gradually and take a reading just as the moisture disappears from the surface of the calorimeter. Now that you have learned how to find the dew point, proceed to determine it with greater accuracy, making three trials, and taking the average of the six readings as the best value of the dew point. Arrange the data neatly in tabular form.

1. Why must one be careful not to breathe on the calorimeter?
2. Under what conditions is one likely to need to add a little salt?

B. Calculation of relative humidity from the dew point. When the dew point and the temperature of the atmosphere are known it is an easy matter to find the relative humidity, using the *Vapor Pressure* table under *Humidity* in the appendix. First look in the table opposite the temperature of the room, say 22°C.; you find that the pressure of saturated vapor is 19.6 mm. of mercury. Then look opposite the dew point temperature, say 11°C., and you find the corresponding pressure to be 9.8 mm. Since the actual amount of moisture in the atmosphere is proportional to the vapor pressure, the relative humidity is given by the formula,

$$\text{Relative humidity} = \frac{\text{actual pressure}}{\text{possible pressure}}$$

and in the case which we have considered the relative humidity will be 9.8/19.6 or 50 per cent.

You will note that there is a third column in the vapor pressure table which gives the mass of saturated water vapor per cubic meter, at various temperatures. These masses are, of course, proportional to the vapor pressures, and the ratio of the mass per cubic meter *present*, to the mass which *would be present* were the atmosphere saturated, is the relative humidity.

3. Show that the relative humidity is the same whether computed from a pressure table or from a table giving the weight of water vapor per cubic meter.

4. Considering that the relative humidity should be from 50 to 60 per cent, do you find the humidity of your school room satisfactory? If not, how can the condition be remedied?

EXP. 13, PART II. *Determine the relative humidity of the atmosphere, using a wet and dry bulb thermometer.*[1]

Read and record the temperature of the atmosphere in the room. Then wrap the bulb of the thermometer with a bit of cotton gauze or cheesecloth, to form a wick extending one or two inches below the bulb. Suspend the thermometer with the end of the wick in a tumbler of water at room temperature. Fan the thermometer vigorously. When the mercury reaches the lowest point, read and record the temperature. The dryer the atmosphere the more rapid is the evaporation and the lower the reading of the thermometer. The relation is not a simple one and tables have been prepared to give the relative humidity when the dry and wet-bulb readings are known.

A table giving *Relative Humidity from wet and dry-bulb thermometer readings* will be found under *Humidity* in the appendix.

1. Is the humidity in your home sufficiently high? What are you or your parents going to do about it?

2. Give a brief statement of a few reasons why humidity is of considerable importance.

Suggested form of record

Temperature of room--------------------°C.

Temperature at which dew forms: (1)--------°C., (2)--------°C., (3)--------°C.

Temperature at which dew disappears: (1)--------°C., (2)--------°C., (3)--------°C.

Dew point-----------------------°C.

Pressure of saturated vapor at dew point-------------------mm.

Pressure of saturated vapor at temperature of room-------------------mm.

Relative humidity $= \dfrac{\text{actual pressure}}{\text{possible pressure}} =$ --------------- = ---------------per cent.

[1]This is an excellent experiment for the student to perform at home, as the humidity of the house is such an important factor in the health of a family. A household thermometer can be used but a laboratory thermometer is more convenient. The table in the appendix is for Centigrade readings and, if a Fahrenheit thermometer is used, either convert to Centigrade or use a Fahrenheit table.

14. COEFFICIENT OF LINEAR EXPANSION

Many useful appliances such as thermometers, thermostats, etc., depend upon the fact that substances expand with increase of temperature. On the other hand, this property of expansion may be a disadvantage, as is shown by the fact that expansion joints must be placed in railroad tracks, steam lines, bridges, etc. Different substances expand different amounts and in many cases account must be taken of this fact. For example, the wires leading the current through the glass of an electric light bulb were for a long time made of the expensive metal platinum because no other metal or alloy could be found with the same expansion as glass. It was only after years of scientific research that a substitute was devised.

A large amount of information about the expansion of various substances is published in handbooks, but it is often necessary in industrial and other scientific laboratories to test the expansion of samples of materials. In the present experiment we learn one method of making this important measurement.

In order to have a standard of comparison it is necessary to express expansions in terms of a given length of material and a given change of temperature. The *coefficient of linear expansion* of a substance is the amount of expansion which a unit length of the material experiences when heated through one degree. This is equal to the ratio of the increase of length, per degree rise in temperature, to the total length.

In order to determine this coefficient it is necessary to heat a given length l of the substance through a known change in temperature $t_2 - t_1$, and measure the increase in length i. Then,

$$\text{Coefficient of linear expansion} = \frac{\text{increase in length per degree}}{\text{total length}}$$

$$= \frac{i}{(t_2 - t_1)\ l}.$$

EXP. 14. *Measure the linear expansion of brass.*

Arrange the apparatus as indicated in Fig. 15, handling the tube as little as possible so that its temperature t_1 will be that of the room. The

Fig. 15. Coefficient of linear expansion.

temperature of the steam t_2 may be calculated (see Exp. 12) or measured by a thermometer inserted in the end of the tube.

The increase of length i is so small that a multiplying device, consisting of the roller and pointer, must be used. Care should be taken not to move or jar the apparatus after the steam is applied.

When all is ready read the position p_1 of the end of the pointer, reading to 0.1 mm. Then light the burner and wait until steam issues freely from the tube. When the reading of the pointer becomes constant, observe its position p_2. The length of the tube l from the shoulder to the roller should then be measured, and also the diameter of the roller. As this is small, a micrometer caliper should be used and read to .001 cm. All measurements of length should be expressed in the same units, preferably centimeters.

The increase of length i of the tube is determined from the diameter of the roller d, the length of the pointer r and the distance $p_2 - p_1$ through which the end of the pointer moves on the mirror scale. As the tube moves the distance i, Fig. 16, the roller is tipped through the same angles as the pointer. By similar triangles,

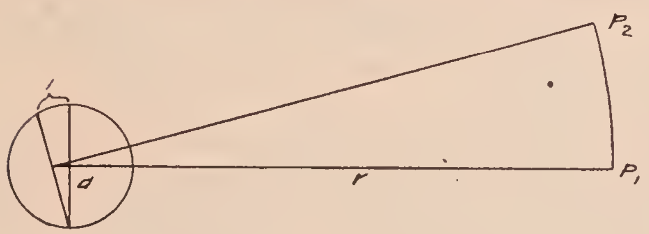

Fig. 16

$$\frac{i}{d} = \frac{p_2 - p_1}{r},$$

and

$$i = \frac{(p_2 - p_1)\,d}{r}.$$

1. Why is it necessary to read the diameter of the roller to .001 cm and the length of the tube to only 1 mm?
2. What would be the difference in the value of the coefficient of expansion if a Fahrenheit thermometer were used and the coefficient were expressed in terms of a Fahrenheit degree?
3. What would be the difference in the value of the coefficient if English units of length had been used instead of the metric units?

Suggested form of record

OBSERVED DATA

Length of tube, l ____________________ cm.

Initial temperature, t_1 ______________ °C.

Final temperature, t_2 _______________ °C.

First scale reading, p_1 ______________ cm.

Second scale reading, p_2 _____________ cm.

Diameter of roller, d ________________ cm.

Length of pointer, r ________________ cm.

CALCULATED DATA

Change of temperature,

$t_2 - t_1 =$ ________________ °C

Increase in length,

$i = \frac{(p_2 - p_1)d}{r} =$ ________________ cm.

Coefficient of expansion of brass,

$k = \frac{i}{(t_2 - t_1)l} =$ ________________

Accepted value of k ________________

Per cent of difference ________________

15. SPECIFIC HEAT

The specific heat of a substance is a measure of its ability to store heat. The high specific heat of water makes it an ideal substance for "hot water bottles." The fact that water is a liquid and that it changes to steam at high temperatures unfits it for use in fireless cookers but a solid substance such as soapstone, which has a comparatively high specific heat, is well adapted to this purpose. Substances vary greatly in specific heat, as will be found in this experiment.

This experiment depends upon the principle that a hot body immersed in a cup of water will give up its heat to the water and the cup, and that the heat lost by the hot body will exactly equal the heat gained by the water and cup. This is true only if no heat is lost and one of the greatest difficulties in heat experiments is to prevent heat from escaping from the inner cup of the calorimeter or entering it from the outside. Since air is a poor conductor of heat, the calorimeter which you are using is made in two parts with a layer of air between them.

Fig. 17. Calorimeter.

In order to allow for the heat absorbed or given up by the inner cup, it is necessary to know its mass and specific heat. Calorimeter cups are usually made of brass, specific heat 0.1, or of aluminum, specific heat 0.2.

Since the specific heat of a substance is the amount of heat required to raise the temperature of one gram of the substance 1°C., the heat taken in or given out by a sample of the substance is equal to the mass of the sample times the change in temperature times the specific heat of the substance of which the sample is composed. We may write,

Heat lost by substance = heat gained by water + heat gained by calorimeter,

or

$$M_s(t_s - t_{mix})\ S = M_w(t_{mix} - t_w)1 + M_c\ (t_{mix} - t_w)\ S_c,$$

in which M_s is the mass of the sample, t_s the temperature of the sample when hot, t_{mix} the temperature of the mixture, S the unknown specific heat of the substance, M_w the mass of the water, t_w the initial temperature of the water, M_c the mass of the calorimeter, and S_c the specific heat of the calorimeter.

No experiment illustrates, better than this, the necessity of laying out a plan for one's experimental work and of exercising skill in the manipulations. Remember that you will not always have the directions of a text-book and, that you should try to develop in yourself the ability to outline the procedure. For example, the weight of water may be determined easily and accurately if the calorimeter is weighed first without water and then with the water in it, the difference in the two weights being the weight of the water alone. This is much better than to measure or weigh the water in some other vessel as, in either case, some water will be left behind. A precaution which must be taken is to have neither too much nor too little water. If you have too much, the temperature increase will be small. Another precaution against error is to make the initial temperature of the water about as many degrees below room temperature as you believe the mixture will be above room temperature.

1. How does it happen that special precautions must be taken to prevent loss of heat?

2. Explain in your own words the reason why it is desirable, in calorimeter measurements, to start with the calorimeter as much below room temperature as you expect it to be above room temperature at the end of the experiment.

EXP. 15. *Measure and compare the specific heats of several substances.*

Substances such as lead, aluminum, copper, glass, and steel are to be tested, each group of students working with from one to three substances. The following instructions are written for lead in the form of shot. First start the boiler so that the water may be heating; then weigh out enough shot to fill the dipper nearly to the top. Carefully push a thermometer into the shot and put the dipper in the boiler.

While the shot is heating, weigh the inner calorimeter cup, put in it the proper amount of water (the less the better if enough to cover the shot), and then weigh the calorimeter and contents. If ice or snow is available, add it to the water until its temperature is reduced to about 10°C. below room temperature.

When the boiler has been generating steam for several minutes observe the temperature of the shot t_s, and of the water in the calorimeter t_w. *Quickly* pour the shot into the calorimeter. Stir the mixture and read its temperature with a thermometer, recording the maximum reading t_{mix}. Arrange the data in neat tabular form and repeat the experiment for as many substances as you have time.

If other students are working with other substances, record along with your results the names of the other students, the substances tested, and the value of S obtained by them. This gives you a small specific heat table determined in your laboratory, which may be compared with tables in the books.

3. Why is greater accuracy secured by using a small amount of water in the calorimeter cup?

4. Why is it more necessary to stir glass beads than it is to stir copper pellets when they are being heated? Why is it more essential to have glass in pellet form than copper or aluminum?

Suggested form of record

Substance	Mass of Substance M_s	Mass of calorimeter M_c	Mass of calorimeter and water	Mass of water M_w	Temp. of subst. t_s	Temp. of water t_w	Temp. of mixture t_{mix}	Specific heat of subst. S	Value of S from table

SPECIAL EXPERIMENT. *The household thermometer.* This experiment is for a student who wishes to test one of the thermometers used at home. Determine the freezing point as in Exp. 12, A. Then place the household thermometer and the laboratory thermometer, which you have already tested, in a beaker, or deep vessel, filled with a mixture of ice and water. Heat the water gradually and, after each increase of temperature of about ten degrees on the household thermometer, take readings of both instruments. During the time that each reading is being taken, the flame should be turned down or removed and the water thoroughly stirred, so that both thermometers may be at the same temperature and not changing in temperature too rapidly.

Determine the correction for each reading of the household thermometer, plot this data on graph paper and construct a correction curve by connecting adjacent points with straight lines. Why is it important that both thermometers be immersed in the water as high as the mercury column?

SPECIAL EXPERIMENT. *The vacuum bottle.* Place in a vacuum or Thermos bottle, a known weight of ice-cold water, take its temperature, allow the bottle to stand closed for a known period of time, say 10 hours, and again take the temperature of the water. Calculate the number of calories of heat which enter the bottle per hour.

Repeat the experiment with a known weight of hot water and calculate the number of calories of heat lost by the bottle per hour.

Does your vacuum bottle keep water cool better than it keeps it warm? Explain.

Describe the shape and the nature and appearance of the materials of which the vacuum bottle is made. Make a diagram showing its construction.

16. THE MECHANICAL EQUIVALENT OF HEAT

The measurement of the mechanical equivalent of heat is of interest for reasons quite different from those which lead us to test thermometers or to determine the specific heat of a substance. In an industrial laboratory one might be called upon at any time to test a thermometer or to measure specific heat, but never to measure the mechanical equivalent of heat. This experiment interests us because it enables us to repeat, in a crude way, one of the important experiments in the history of physics, for not only did it open the way for a better understanding of heat phenomena, but it also lead to the great principle of the conservation of energy.

In this experiment, you will have an opportunity to show that mechanical energy changes into heat energy and you will be able to compare your numerical result with the value which has been obtained by the most accurate methods.

When a body is raised to a certain distance, a definite amount of work is done against gravity and the body gains potential energy. If the body falls back through this same distance, the potential energy changes to kinetic energy. When the body is stopped there is no more motion and no kinetic energy; the energy reappears in the form of heat. In order to find the mechanical equivalent of heat, or the number of calories produced by one gram-meter of mechanical work, it is necessary to measure the mechanical energy which disappears and the heat energy which is produced. The energy of a falling body is equal to its mass $\times$ the height of fall, while the heat produced, if it can be confined to the body, is equal to the mass of the body $\times$ its specific heat $\times$ the increase in temperature.

1. Does the stirring of ice cream in the freezing process heat the cream? If so, why is a stirrer used?

EXP. 16. *Determine the mechanical equivalent of heat.*

In this experiment lead shot are caused to fall from one end of a long cardboard tube to the other. In falling once through the length of the

Fig. 18. Simple apparatus for determining the mechanical equivalent of heat.

tube the shot will generate but little heat. If it falls a number of times, the increase of temperature will be appreciable. The tube should be grasped in both hands with the hands far enough away from the ends so that the heat from the hands will not pass to the shot. Great care must be taken to see that the shot falls the length of the tube, no more, no less. Practice handling the tube before using the shot.

Weigh out about 2 kg of lead shot, measure its temperature t_1, and pour it in the tube. Insert the cork; plug the hole in the cork with a pencil, or a piece of wood, and tie the cork securely, so that it cannot possibly come out. Reverse the tube 80 to 100 times, keeping accurate count; the last time have the cork at the bottom.

Rest the end of the tube near the edge of the table, inclined sufficiently so that the shot will not run out when the plug is withdrawn. Take out the plug and insert the thermometer. Tip the tube up so that the shot forms a compact mass around the bulb of the thermometer and observe its maximum reading t_2. Next reverse the tube, remove the thermometer and cork, and measure the distance h from the shot to the point formerly occupied by the end of the cork. This distance is the average distance through which the shot fell at each reversal.

The mechanical equivalent of heat may be expressed in different kinds of units. In this experiment we will calculate the number of gram-meters of mechanical energy which must pass over into heat energy in order to produce one calory. The number of calories of heat produced is the mass of the lead M $\times$ the specific heat of lead, 0.03. $\times$ the change in temperature, $t_2 - t_1$. The work done, expressed in gram-meters, is equal to the mass of the shot (grams) $\times$ the height of fall (meters) $\times$ the number of reversals (N). Then, since the mass cancels out, the mechanical equivalent of heat J is given by

$$J = \frac{N \times L}{(t_2 - t_1)\ .03}.$$

2. If the accepted value for the mechanical equivalent of heat is 427 gram-meters per calory, how high must a waterfall be for the water to become 1°C. warmer at the bottom than at the top?
3. If you were to repeat this experiment how would you change the instruments or procedure in order to get better results?
4. Explain the reasons why a worker in an industrial laboratory would never be called upon to measure the mechanical equivalent of heat.

Suggested form of record

Mass of shot, approximate________________g.

Initial temperature, t_1 ________________°C.

Final temperature, t_2________________°C.

Number of reversals, N________________

Height of fall, L________________m.

Mechanical equivalent of heat________________gram-meters/calory.

Accepted value ________________gram-meters/calory.

Per cent of error________________

17. CHANGE OF STATE

A curious and interesting condition can be brought about if a liquid is kept very quiet while being cooled, for under these circumstances the liquid will cool below the freezing point. This phenomenon is called *undercooling*. The moment that the liquid begins to solidify, the temperature rises to the freezing point and remains there until all the liquid is solidified. After solidification is complete the solid gradually cools off and its temperature goes down. Acetamide, sodium thiosulfate (hypo), water, and many other substances exhibit the phenomenon of under cooling.

EXP. 17. *Obtain the cooling curve for acetamide.*

Support a test tube half filled with crystals of acetamide in a beaker of water on a ring stand, Fig. 19. When the acetamide is melted insert the thermometer, making sure that the acetamide does not obscure the 50 degree mark. Cut off the heat when the temperature reaches 90°C. and remove the beaker. The tube must now be allowed to cool and must not be disturbed in the slightest.

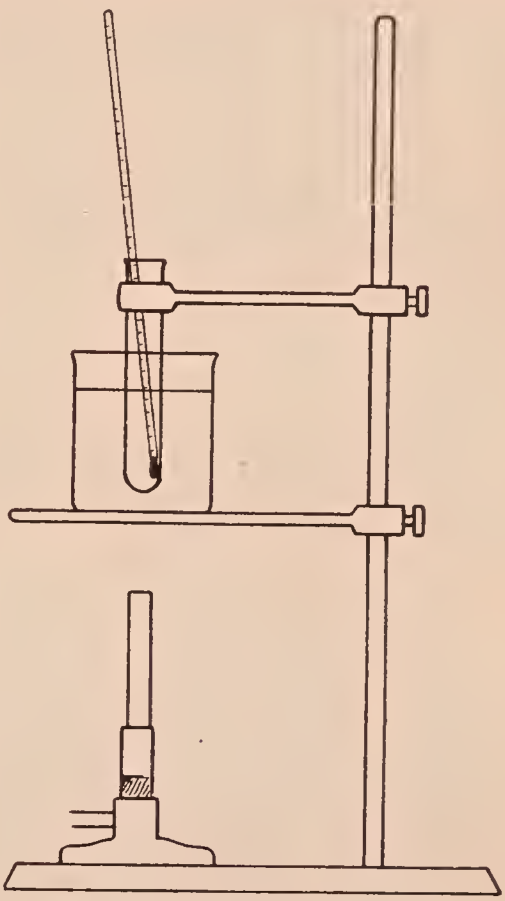

Fig. 19.

Begin immediately to observe temperatures each half minute and keep a careful record. Indicate the time at which solidification begins and continue to make readings at half-minute intervals until solidification is complete, then at minute intervals until a temperature of about 50° is reached.

Record the data neatly in two columns, the first column showing the times (to the half minute) as indicated by the watch, and the second column the corresponding temperature.

Plot a curve[1], similar to Fig. 20, which will show the characteristic cooling curve for acetamide.

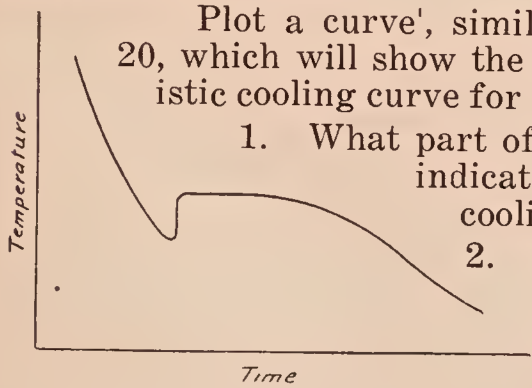

Fig. 20. Typical cooling curve.

1. What part of the curve indicates undercooling?
2. How do you account for the horizontal part of the curve?
3. What is the freezing point of acetamide?
4. Where did the heat come from when the acetamide "heated up"?

[1]See Graphs in the appendix.

18. HEAT OF FUSION OF ICE

The *heat of fusion* of a substance is the number of calories of heat required to melt one gram of the substance. The determination of the heat of fusion of ice has, of course, been done very accurately. Nevertheless, it is an interesting experiment to perform and it furnishes a test of one's skill as an experimenter, for, even with crude apparatus, a careful person can secure a result differing from the accepted value only by two or three per cent.

This experiment is closely related to Exp. 17 and, if you have not performed that experiment, you should read the introduction to it. In Exp. 17 we studied the temperature changes which occurred when acetamide changed to a solid while in the present experiment we will measure the heat taken up by ice when it melts. Why is this the same as the heat given up by water in freezing?

The heat of fusion of ice is measured by placing a piece of *dry* ice in some water contained in a calorimeter cup. The water and calorimeter cup furnish heat to the ice, causing it to melt.

Heat lost by calorimeter and water = heat gained by ice.

Notice that two things happen to the ice, each of which requires heat. First, the ice melts and then the resulting water is heated from 0° C. to the final temperature of the mixture, t_{mix}. The equation may be written as follows:

$$M_w (t_1 - t_{mix}) + M_c (t_1 - t_{mix}) S_c = M_i \times L + M_i (t_{mix} - 0° C.)$$

in which L is the heat of fusion of ice and the other symbols are self-explanatory.

Errors will be reduced if the initial temperature t_1 of the water is as much above room temperature as the final temperature of the mixture t_{mix} is below. Why?

EXP. 18. *Measure the heat of fusion of ice.*

In making the weighings in this experiment great care should be taken. First obtain the mass of the inner calorimeter cup M_c and then fill it two-thirds full of water which has been heated to about 25° C. above room temperature. Then weigh the calorimeter cup and water accurately, M_{c+w}. Place the inner cup in the outer calorimeter cup; stir and observe the temperature of the water, which should now be about 10° or 15° C. above the temperature of the room. In the meantime another student should have prepared a piece of ice about the size of a hen's egg. As the temperature of the water is being observed, this piece of ice should be *dried* carefully and thoroughly with a piece of paper towel or other absorbent material and slipped immediately into the calorimeter cup without splashing. Stir gently and observe the minimum temperature, t_{mix}, just as the last ice melts. If this temperature is not about as many degrees below room temperature as the water was above, repeat the experiment, making such changes in quantities or temperatures as may be necessary. Remember, other things being equal, that the larger the piece of ice the more accurate the result. Why?

Remove the thermometer, taking care that no water is lost, and make a final weighing of the calorimeter cup and contents, M_{c+w+i}.

1. What is the temperature of the ice just as you slip it into the water?
2. What is the temperature of water dripping from melting ice?
3. Explain why it is far more necessary to get the mass of the ice accurately than the mass of the water or calorimeter. Explain how you obtained the mass of the ice?
4. Heat is required to change ice at 0°C. into water at 0°C; what becomes of this heat?

Suggested form of record.

Weight of calorimeter, water, and ice, M_{c+w+i} -- g.

Weight of calorimeter and water, M_{c+w} -- g.

Weight of calorimeter, M_c -- g.

Weight of ice, $M_{c+w+i} - M_{c+w}$ -- g.

Weight of water, $M_{c+w} - M_c$ -- g.

Temperature of water, t_1 -- g.

Temperature of mixture, t_{mix} -- g.

SPECIAL EXPERIMENT. *Absorbing and radiating surfaces.* Secure two bright tin cans of the same size and blacken one of them with lamp-black and shellac or by holding it in a smoky flame. Fit each of the cans with a one-hole stopper containing a thermometer. Fill both cans with cold water of the same temperature, close them tightly with the stoppers, and suspend them by cords in the sunlight. Read and record the thermometers at known intervals of time for a period of one hour. Which kind of surface do you find to be the better *absorber* of radiant energy?

To find which surface *radiates* energy more rapidly, fill the cans with hot water of the same temperature, hang them in a cool place and make temperature observations at known intervals of time for a period of one hour.

Why are the walls of thermos bottles silvered? What kind of paint would you choose for a refrigerator?

19. SPEED OF SOUND

The speed of sound in air can be measured by noting the time between the flash and the report of a gun fired at a known distance away. It can also be found by striking a hammer against a board at a known distance from the flat wall of a large building, and finding the time that elapses between striking the board and hearing the echo. In this case, twice the distance to the wall, divided by the time, gives the speed of sound.

Both of these methods give only approximate results, although they serve as excellent illustrations of the speed of sound. They involve not only errors of observation, but errors due to changes in the magnitude and direction of the wind and to local differences in temperature.

Sound consists of waves in an elastic substance. It will not pass through a vacuum, as the presence of an elastic substance is essential. The more elastic a substance is, the faster does sound travel through it. Thus it travels at a high speed in steel but at a very low speed in rubber.

The less dense a particular substance becomes, the faster does sound travel through it. The speed of sound in air increases with a rise in temperature, chiefly because heat causes air to expand, and thus decreases its density.

EXP. 19, PART I. *Measure the speed of sound in air.*

Two groups of observers station themselves 500 m or more apart and with an unobstructed view between them. The distance between the two stations is measured with a long cord or rod of known length. The temperature of the air is also read and recorded.

A member of the group at one station gives a prearranged warning signal and then fires a blank cartridge. At the other station an observer measures the time between the flash of the pistol and its sound. This procedure is repeated four or five times.

In order to eliminate effects due to the wind, the procedures at the two stations are interchanged, so that the direction of the sound is reversed. Repeated trials are again made.

The average of all these measurements is taken as the time it takes sound to travel the measured distance. The speed of sound in air at the observed temperature can then be calculated and this should be recorded in meters per second.

The speed of sound in air at 0° C. should also be calculated. Remember that the speed increases about 0.6 meters per second for a rise in temperature of 1° C.

Arrange your observed and computed results in tabular form.

1. Why not make allowance for the time required for the flash of the pistol to reach the observer?
2. Explain why interchanging the procedure at the two stations tends to eliminate the effects of the wind.

3. If a cannon is fired at 5:15 p. m. on a calm day, at what time will the report be heard at a point 30 km away, the temperature of the air being 22° C.?

EXP. 19, PART II. *Compare roughly the speeds of sound in air and in steel.*

The experiment is performed on a straight stretch of railroad track. One member of the class goes some distance down the track and strikes the rail with a hammer or a piece of iron while the remainder listen with their ears placed close to the rail.

1. Explain what you observed.
2. If a sound were heard through a steel rail in 0.1 sec., and then through the air 1.3 sec. later, and the temperature was 20° C., what was the speed of sound in the rail?

SPECIAL EXPERIMENT. *Interference of sound waves.* Sound a tuning fork of frequency 256, or thereabouts, and hold it close to the ear. Turn the fork slowly about its stem as an axis until you find positions of the fork where the sound is loudest and positions where it is faintest.

In what positions relative to your ear are the prongs when the sound is faintest? If you have difficulty in making the observations necessary to answer this question, hold the vibrating fork near the mouth of a resonance tube (Fig. 21), adjust the length of the tube until resonance is obtained (see Exp. 20), and then rotate the fork about its stem as an axis until you find the positions of the prong for which the sound becomes faintest.

The two prongs of a tuning fork vibrate with the same frequency, but in opposite directions. When you hold a vibrating fork near the ear, with the two prongs in the straight line joining the fork and the ear, the prong closest to you moves toward you (producing a *condensation* on the side nearer to you) ; at the same time the prong farthest from you moves away from you (producing a *rarefaction* on the side nearer to you). The condensation and rarefaction do not reach your ear at exactly the same time. If you now rotate the fork slightly, the farther prong is brought nearer to your ear, while the nearer prong is moved farther away. By properly adjusting the distances of the prongs from the ear, the condensation from the one prong and the rarefaction from the other will reach your ear at the same time and, *interference* will result; the two sounds will add to produce silence.

To test this explanation, find a position for the vibrating fork where the sound is silent, or nearly so, and then completely cover one of the prongs, without touching it, with a small paper tube. Do you again hear the sound? Explain.

20. WAVE LENGTH OF THE NOTE OF A TUNING FORK

If a vibrating tuning fork is held over the mouth of a pipe closed at the other end with a movable piston, Fig. 21, a very marked reinforcement of the sound will occur when the air column is made about one-fourth as long as the wave length produced by the fork. If the length of the air column is then increased by a distance which is just one-half of the wave length of the fork, maximum reenforcement will again occur. Hence, if s_1 denotes the shortest length of air column for maximum reenforcement, and s_2 the next length, the wave length l of the work is given by the relation,

$$l = 2\ (s_2 - s_1).$$

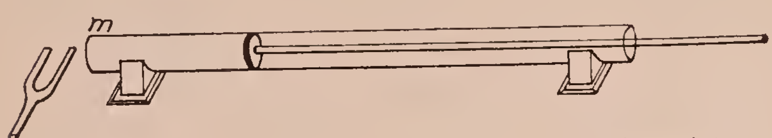

Fig. 21. Horizontal resonance tube with sliding piston.

A second way of finding the wave length l of the fork is by means of the formula,

$$l = \frac{v}{n},$$

where v is the speed of sound in air at the given temperature and n is the number of vibrations per second made by the fork.

Exp. 20. *Find the length of the sound wave emitted by a vibrating tuning fork.*

Set the tuning fork into vibration by striking it once on a flat cork. Quickly hold it in front of the mouth m of the tube, with one of the prongs next to the opening, Fig. 21 or Fig 22. At the same time pull the piston slowly away from this end until a position is found at which the sound is loudest. Mark the position of the front of the piston with a rubber band and then try the effect of moving the piston back and forth past this point until the best place is located. When found, measure the distance from the mouth m to the rubber band, calling this distance s_1. Now repeat the whole procedure and take the average as the correct length s_1 of the air column for the maximum reenforcement.

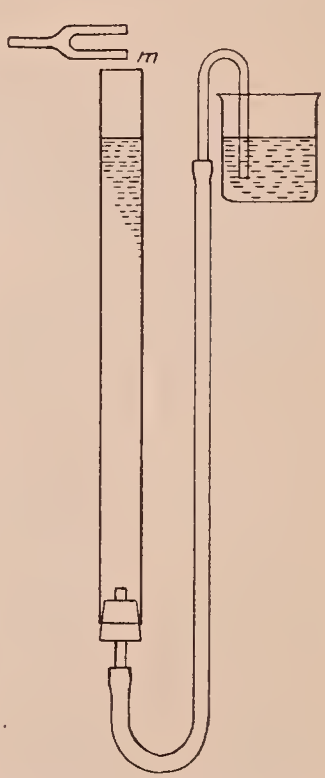

Fig. 22. Vertical form of resonance tube. The length is adjusted by raising and lowering the water.

Find a second length of air column giving maximum reenforcement. This column will be about three times as long as the first one. As before obtain the correct length by making several trials and computing the average length s_2.

The length of the waves set up by the fork can now be calculated by the formula, $l = 2\ (s_2 - s_1)$.

Hold a thermometer in the tube and find the temperature of the air. Also read the vibration number n marked on the fork. Then calculate the wave length l by means of the formula $l = v/n$ and compare this value with that obtained with the resonance tube. The speed of sound in air may be taken at 332 m per sec. at 0°C., with an increase of 0.6 m for each degree rise of temperature.

The experiment should be repeated with a tuning fork of another frequency.

1. How could a resonance tube be used to find the vibration rate of a tuning fork?
2. What effect has a drop in temperature on the pitch of an organ pipe?

Suggested form of record

Frequency of fork, n____________________.

Temperature of air____________________°C.

Length of air column for first resonance, s_1:

Trial 1.____________cm; trial 2.____________cm; Average______________________cm.

Length of air column for second resonance, s_2:

Trial 1.____________cm; trial 2.____________cm; Average______________________cm.

Wave length, $l = 2(s_2 - s_1) =$ ____________________cm.

Wave length, $l = v/n$__________________cm.

(Make a similar table for each additional fork tested.)

SPECIAL EXPERIMENT. *Another method for calculating wave length.* The shortest length of air column for maximum reenforcement s_1 is approximately one-fourth wave length. It is not exactly one-fourth wave length because the mouth m of the tube acts as if it extended farther out than it actually does. It has been found that if about four-tenths of the internal diameter d of the tube is added to the length of the air column s_1, the resulting length, $s_1 + 0.4\ d$, will be almost exactly one-fourth wave length.

Measure the internal diameter d of the tube and the shortest air column for maximum resonance s_1 with a certain tuning fork, if this has not already been done. Using these data, compute the wave length l of the fork and compare this value with those obtained in Exp. 20 with the same fork. Which is the better method of measuring the wave length, and why?

21. MAGNETIC FIELDS

The region about a magnet in which its effect can be detected is called the *magnetic field* of the magnet. If a magnetic pole is placed in such a field it will be acted upon by a force. The direction and magnitude of this force will not be the same in all parts of the field.

A small compass placed in a magnetic field points in the direction of the magnetic field. If the compass is placed near the N-pole of a magnet and then moved a short distance at a time, in the direction its north pole points, it will be found that it travels along a line which finally ends at the S-pole of the magnet. Such a line is called a *magnetic line of force.* These lines of force show the direction in which the magnetic force would act at the various points in the field, if magnetic poles were placed at these points. By the *direction* of a line of force is meant the direction in which the N-pole, or north-seeking end, of a compass needle points when placed on the line.

If several magnets are placed in the same region, the magnetic field at any point will be the resultant of the fields at that point due to the several magnets. This explains why a very small compass must be used in tracing lines of force in a field; a large compass needle would be strong enough to produce noticeable changes in the field in which it was placed. In performing the following experiment, it must be remembered that the earth is a magnet and that it is likely to produce slight changes in the fields of the magnets being investigated.

EXP. 21. *Make charts of several different types of magnetic fields.*

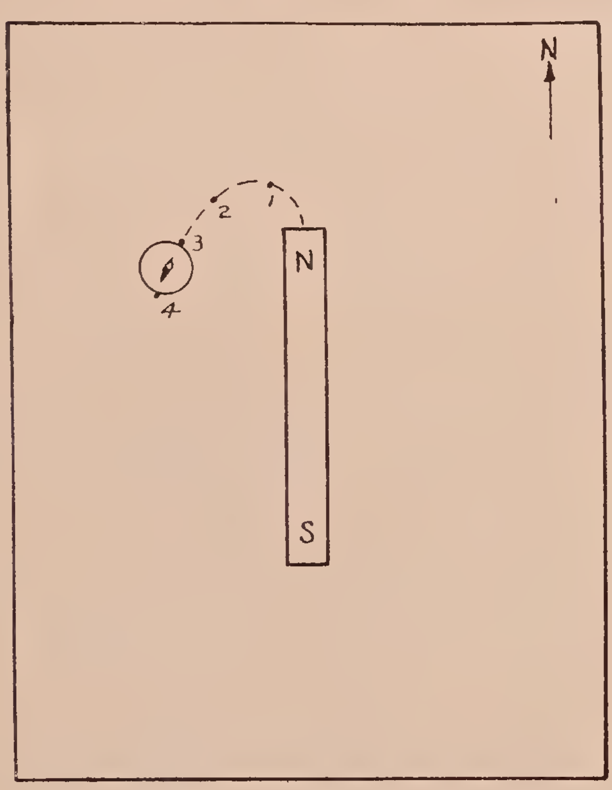

Fig. 23. Charting a magnetic field.

A. *The field about a single bar magnet.* Place a sheet of paper on a smooth table. With the help of a compass, turn the paper so that its longer edges are parallel to the compass needle. In doing this, be sure to have all magnets and magnetic materials several meters distant from the compass. The paper must not be moved from this position during the experiment.

Lay a bar magnet on the paper as in Fig. 23, trace with a pencil the outline of the magnet and mark on the drawing the positions of its N-pole and S-pole.

Near, say, the N-pole of the magnet make a dot (1), which is to serve as a starting point. Place the small tracing compass on the paper so that the south end of the needle is right above this dot, and then make a second dot (2) at the other end of the needle. Now move the compass until its south end is at (2) and make a third dot (3) at its north end. Continue this series of dots until you reach either the edge of the paper or the S-pole of the bar magnet. Draw a smooth curve through this series of dots and indicate by arrowheads the direction of this line of force which you have drawn.

Beginning at other points near the same pole of the bar magnet, trace several more magnetic lines of force on each side of the magnet. Then, starting from the S-pole of the bar magnet, trace additional lines from that end. Enough lines should be drawn, and their starting points should be so chosen, that the nature of the whole field about the magnet can be seen from the drawing.

B. *Combinations of magnets.* (a) Place a fresh sheet of paper on the table and with the aid of a compass, arrange it as in A, above. Place on the paper two bar magnets in line with each other and with their unlike poles about 15 cm. apart, Fig. 24a. Using the method given in A, above, trace with the small compass at least six magnetic lines of force leaving each of the adjacent like poles.

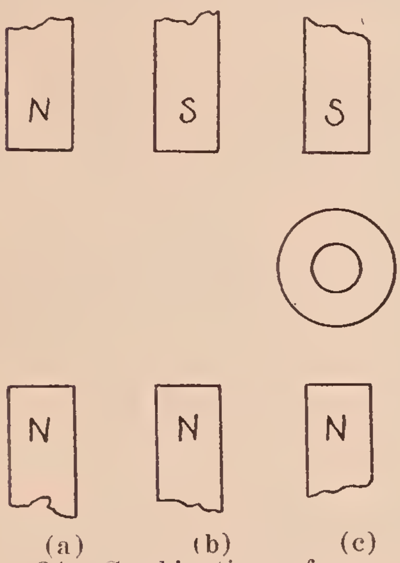

Fig. 24. Combinations of magnets.

(b) Make another chart but with unlike poles facing each other as in Fig. 24 b.

(c) Place a piece of unmagnetized soft iron, such as an iron washer, between the unlike poles, Fig. 24c, and make a chart of this field as before. Be sure to have some of the lines pass through the iron.

1. What is the form of the field between two like poles? Between two unlike poles?
2. Did any of the lines cross each other?
3. Can you find on your charts any effects due to the earth's magnetic field?
4. What is the result when a piece of soft iron is placed in a magnetic field?
5. Did you find that the poles of the bar magnet were located exactly at the ends?

22. THE NATURE OF MAGNETISM

If a piece of unmagnetized iron is held near either end of a compass needle, the needle is attracted by the iron. A substance which attracts *both* ends of a magnet is a *magnetic substance*, but it is not a *magnetized substance.* When two substances, both of which are magnetized, are brought near each other, the like poles repel and the unlike poles attract each other.

According to the *theory of molecular magnets,* magnetic substances are made up of molecules, each in themselves tiny magnets. When a magnetic substance is magnetized, the small molecular magnets point in the same direction. When the magnetic substance is not a magnet, the small molecular magnets point in different directions.

EXP. 22, PART I. *By testing a number of common substances, determine which of them are magnetic and also which of them act as magnetic screens.*

A. *Magnetic substances.* Hold a bar magnet close to small bits of various substances, such as glass, paper, sand, wood, iron, zinc, lead, nickel, tin and common "tin." Common tin is sheet iron covered with tin.

Also find out whether red hot iron is a magnetic substance. To do this, suspend a short piece of iron, or of steel watchspring, on a copper wire and hold it in a Bunsen flame until all of the iron is red hot. Then bring the bar magnet close to the iron.

Classify as *magnetic substances* those which are attracted by the bar magnet, and as *nonmagnetic substances* those which seem not to be attracted.

B. *Magnetic screens.* Place a small quantity of iron filings or iron tacks on a sheet of cardboard. Hold one pole of the bar magnet against the under side of the cardboard and move it back and forth beneath the bits of iron. Notice whether there is any evidence of magnetic action through the cardboard.

Now place the iron filings or tacks on a piece of sheet iron or common "tin" and make the same test. Repeat, using sheets of glass, copper, lead, brass, thin wood, etc.

Classify the substances which you tested according as they do or do not act as a *magnetic screen* to cut off magnetic action.

1. How do your lists of magnetic and non-magnetic substances compare with your lists of substances which do and do not act as magnetic screens.
2. Does air act as a magnetic screen?
3. What effects do the brass case and the glass of a compass have on the reading of the needle?

4. In what kind of case would you inclose a watch to protect the mainspring and balance wheel from becoming magnetized?
5. Will a magnet attract a tin can? Explain.

EXP. 22, PART II. *Make a permanent magnet and use it to study the theory of molecular magnets.*

(a) Hold one end of an unmagnetized piece of watchspring or hardened steel knitting needle close to a compass and show that it attracts both ends of the compass needle.

1. What two facts does this show with regard to the substance which you have thus tested?

(b) Magnetize the watchspring or knitting needle by stroking it from end to end, always in the same direction, with the N-pole of a bar magnet. Bring the magnet which you have thus made close to the compass and determine which end of it is the N-pole. Mark this end with a bit of thread.

2. What kind of pole do you find at the end of the needle which last leaves the magnet?

See if you can reverse the poles of your magnet by stroking it in the opposite direction with the N-pole of the bar magnet.

(c) Be sure that you know which end of your magnet is the N-pole. Then break it into several pieces, being careful to keep the pieces in their original order. Test the polarity of each piece with the compass and mark the N-poles.

3. Does each piece have one pole or two poles?
4. Show by means of a diagram the locations of the poles on the broken pieces when they are arranged in their original order, but slightly separated?
5. What evidence do you find here for the theory of molecular magnets?

(d) Suspend one of the short pieces of the broken magnet by means of a copper wire and hold it in a Bunsen flame until it is red hot. Allow it to cool somewhat and test it with the compass.

6. Is it still magnetized after heating? Is it it still a magnetic substance?
7. In view of the fact that the velocity of the molecules in the iron increases with an increase in temperature, how does this result lend support to the theory of molecular magnets?
8. Can you explain by means of this theory why red hot iron is not a magnetic substance?

23. STATIC ELECTRICITY

Electrostatic effects were known for hundreds of years before "current electricity" was studied. With the use of high voltages for the transmission of electrical energy and the development of radio, static effects, or the effects of *charges* as distinguished from *currents,* are of increasing importance.

An excess of *electrons,* such as is produced on sealing wax or ebonite when rubbed with flannel, is called a *negative charge.* A deficiency of *electrons,* such as is produced on a glass rod when rubbed with silk, is called a *positive charge.*

EXP. 23, PART I. *Make and use a pith-ball electroscope.*

From a convenient support hang by silk threads two pith balls or bits of cork. Charge an ebonite rod by rubbing it with flannel and bring it near the pith balls. Note that they are attracted to the rod. Manipulate the rod so that it comes in contact with various parts of the pith balls. In a short time the pith balls will be repelled and will repel each other. Bring the hand near the pith balls. Rub the glass rod with silk and observe the action of the balls under various conditions. Vary the experiment in a number of ways (including dampening the pith balls), observing the *conditions* you impose and the *results* you secure.

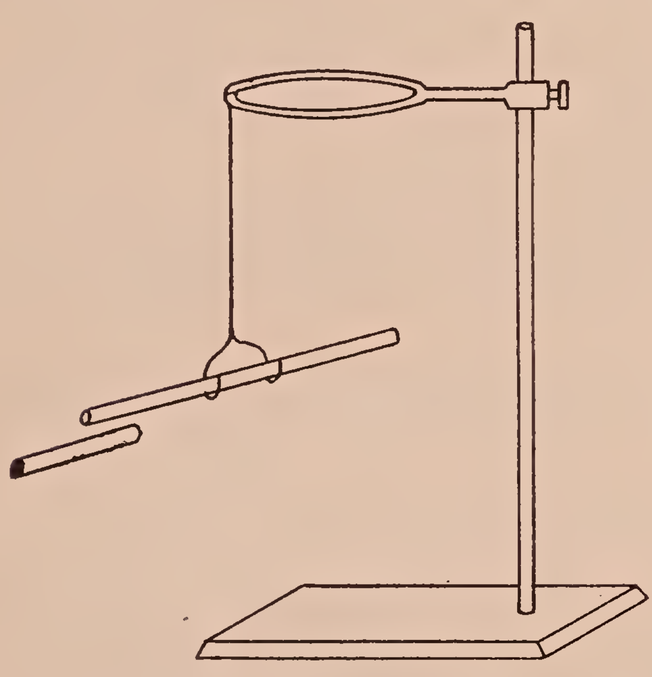

Fig. 25. Attraction and repulsion of electric charges.

1. Why were both balls first attracted and then repelled?

2. If at any time you had two unlike charges, describe the conditions and results and explain them.

3. If at any time you had two like charges, describe the conditions and results and explain them.

EXP. 23, PART II. *Verify the laws of attraction and repulsion.*

Suspend in a stirrup, hung on a silk thread, an ebonite rod which has been charged by rubbing it with flannel, Fig. 25. Bring near it a glass rod which has been rubbed with silk. Observe the effect on the ebonite rod.

Charge another ebonite rod, or a stick of sealing wax, by rubbing it with flannel, hold it near the suspended rod and observe the effect.

1. What confirmation have you of the law that like charges repel? That unlike charges attract?

EXP. 23, PART III. *Charge a leaf electroscope.*

A. *To charge an electroscope by contact.* If a charged body like a rod of ebonite is brought directly in contact with the knob of the electroscope, Fig. 26, there is great danger that leaves will be torn from the support. Consequently an instrument called a *proof plane* is used to transfer small charges from the electrified body to the electroscope. A proof plane may be made easily by sticking a cent on the end of a glass rod with sealing wax. Touch the proof plane to the charged rod and then to the electroscope. Repeat until the leaves diverge about 45 degrees. The charge on the electroscope will have the same sign as the charge on the rod; hence, if a glass rod is used, the sign of the charge will be positive.

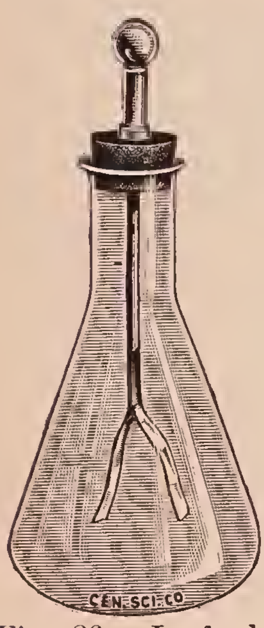

Fig. 26. Leaf electroscope.

Bring the charged glass rod near the electroscope. What do the leaves do? Explain.

Bring a charged ebonite rod slowly toward the electroscope. Watch the leaves carefully. What do they do first? What next?

B. *To charge an electroscope by induction.* Bring an ebonite rod toward the electroscope until the leaves diverge about 45 degrees. Keeping the rod in this position, touch the knob of the electroscope with the hand for an instant. Then remove the rod. What do you observe? Is the electroscope charged positively or negatively?

1. On what principle does the leaf electroscope work?
2. Why is it important to look for the *first* motion of the leaves when determining the sign of an unknown charge?
3. When an electroscope is charged by induction is its charge like the original charge or opposite in sign?

EXP. 23, PART IV. *Charge two metal balls by induction.*

Suspend two metal balls on silk threads. If you are skillful you can hold the threads in the hand. Bring a heavily charged ebonite rod close to them, in a line with their centers, and while the rod is in this position separate the balls. Now bring each ball in turn near the electroscope and determine its charge. Then touch the two balls together and again hold them near the electroscope.

1. When two parts of an insulated body are charged by induction, which part is charged like the original charge? Explain why this should be the case.
2. How does this experiment answer the question as to whether any electricity is *produced* when a body is charged by induction?

24. THE VOLTAIC CELL

Although the modern development in electricity is largely due to the use of electrical generators run by steam or water power, there are actually more *voltaic cells* used to-day than ever before. Nearly every automobile carries a battery of three cells. Every flash light has from one to three cells. Cells are also used extensively in operating telephones, radio sets, door bells, and signalling devices.

EXP. 24, PART I. *Set up a single cell and study its action.*

A. *Chemical action.* Fill the cup, Fig. 27, with dilute sulfuric acid (one part of acid to twenty parts of water), insert a zinc element and observe whether any bubbles of gas are formed. Repeat with a copper element.

Clamp both elements in place, put them in the solution and observe the bubbles. Join the binding posts with a piece of copper wire and note what happens at the elements.

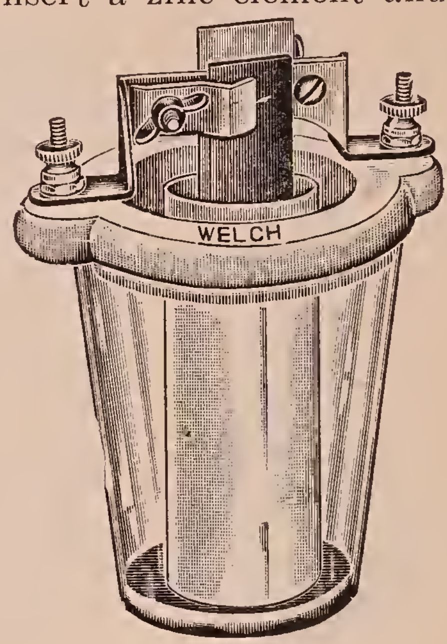

Fig. 27. Daniel cell.

1. Describe the action of the acid upon the elements under each of the four conditions mentioned above.

B. *Amalgamation.* Repeat the above experiment, using an amalgamated zinc element. Zinc may be amalgamated by dipping it in sulfuric acid and then rubbing a little mercury over its surface.

2. (a) Are bubbles of gas formed when amalgamated zinc is placed is placed in dilute sulfuric acid? (b) How does this result differ from that obtained with unamalgamated zinc? (c) What is local action?

C. *Production of current.* (a) Connect pieces of copper wire to each binding post of the cell and touch each of these wires in turn to the tongue. Also hold both wires to the tongue at the same time.

3. What is the effect of an electric current on the tongue?

4. The current flows from the copper to the zinc through the tongue. Can you tell, by the tongue, the direction in which a current flows?

(b) Place a galvanoscope[1] so that the turns of wire are parallel to the compass needle and connect the cell to the single-turn coil. Place the

[1]See Galvanoscope in the appendix.

needle under this turn, and observe the effect. If the effect is not large, use more turns. Reverse the connections and note the effect. The magnetic effects of a current will be studied in Exp. 25; in the meantime we shall use the galvanoscope as a means of roughly determining the strength of currents.

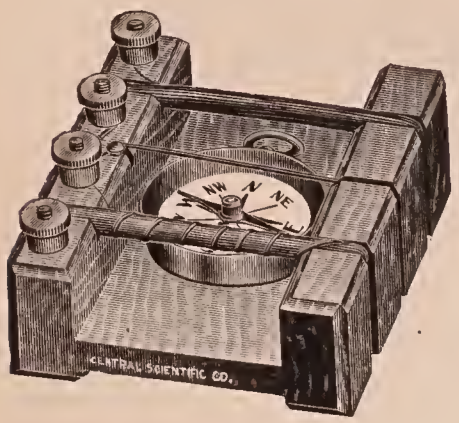
Fig. 28. Galvanoscope.

D. *Polarization.* Connect the cell to the largest number of turns of the galvanoscope and insert sufficient No. 36 German-silver wire to bring the deflection down to less than 45 degrees.[1] Remove the elements; dry the zinc and heat the copper in a Bunsen flame in order to free it from hydrogen gas.

Replace the elements and observe the deflection of the galvanoscope needle as soon as it comes to rest. Observe the needle and also the action at the plates. After a minute or two, short circuit the cell, i. e. touch both binding posts with a short piece of copper wire. Observe what happens in the cell, especially at the surface of the copper plate. While the cell is short circuited, the galvanoscope will show no readings. Remove the short circuit and note the reading of the needle.

5. Describe the nature and effects of polarization as you have observed them.

EXP. 24, PART II. *Set up a Daniel cell and study its action.*

(a) Pour a part of the acid into the porous cup and place the cup in the tumbler. The acid should be at about the same height in each. Insert the plates in the clamps, with the zinc plate in the porous cup. Take observations similar to those of Part I, D.

1. What effect does the porous cup have on polarization?

(b) Remove the elements and porous cup from the tumbler and replace the acid in the tumbler with copper sulfate solution. Replace the elements, the zinc in the acid and the copper in the copper sulfate. You now have a *Daniel cell.* Make observations similar to those under (a), above.

2. Does the copper sulfate of a Daniel cell prevent polarization?

3. Explain why no bubbles form on the copper element when it is surrounded by copper sulfate.

[1]If you do not have enough resistance wire to reduce the deflection sufficiently, move the compass along the frame away from the coil. The experiment will be more successful, however, if resistance wire is used.

25. MAGNETIC EFFECTS OF AN ELECTRIC CURRENT

It was only a little over a hundred years ago that Oersted, a Danish physicist, made the important discovery that an electric current has a magnetic field. This was the beginning of the science of electromagnetism. The apparatus with which Oersted experimented consisted of a voltaic cell, some wire, and a magnetic needle, much like those which we will use in this experiment.

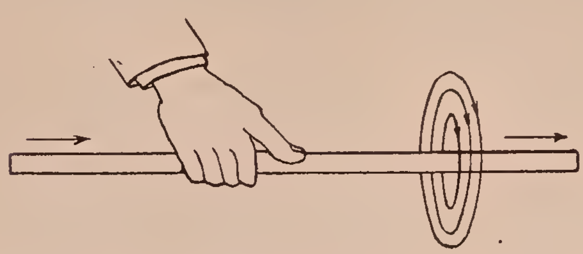

Fig. 29. The right hand rule for the direction of the field surrounding a wire carrying current.

The observations which are taken in this experiment should in each case agree with the predictions from the *right hand rule*. This rule states that if you grasp a wire in the right hand with the thumb in the direction of the current, the fingers represent the direction of the circular magnetic field which surrounds the wire, Fig. 29.

Exp. 25. *Study the magnetic effects of an electric current.*

A. *Magnetic effects of a single conductor.* Connect a cell through a reversing switch to a long loop (2 or 3 meters) of copper wire, Fig. 30. By using the same length of copper wire throughout the experiment, the resistance of the circuit is kept constant, and the current remains at nearly the same value. If an open circuit (polarizing) cell, such as a dry cell, is used, it is a good plan to close the switch only when the observations are being taken. Why?

(a) Place the wire across the top of the compass parallel to the needle, with the current flowing from South to North. Close the switch and observe the direction and amount of the deflection. Reverse the current and note the deflection.

1. Show that these results could have been predicted from the right hand rule.

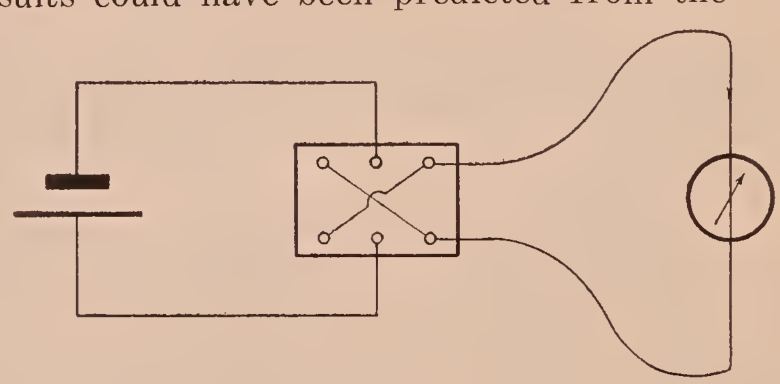

Fig. 30. Magnetic effect of a current.

(b) Place the compass near the North edge of the table and hold the wire in a vertical position close to the N-pole of the needle, with the current going *down*. Using the right hand rule, predict what will happen. Close the switch and see if you were right. Reverse the current and note the effect.

(c) Place the wire under the compass with the current flowing from North to South. Observe the deflection. Reverse the current and again observe the deflection.

2. Show that these results agree with the right hand rule.

B. *Magnetic effect of a single loop of wire carrying a current.*

3. Consider the results of the above experiments and decide how the needle will be affected by a current which passes around the needle in one complete loop, across the top from South to North, down on the North side, back across the bottom and up on the South side.

(a) After answering the above question try it and see if your answer is correct.

(b) Turn the loop of wire so that it is at right angles to the needle and note the effect. Reverse the current and observe. Try other positions for the loop.

4. In what position, relative to a needle, should a loop be placed to exert the maximum *moment* (twist) upon the needle?

(c) Fold the loop back on itself so that the two parts are side by side. Place the loop in various positions with respect to the needle and observe the effect.

5. How do you account for the effects observed in (c)?

C. *To find the direction of an electric current.* Have someone connect two wires to the cell and cover the cell with a piece of cloth. Determine which way the current flows from the cell, (a) by touching the tongue (see EXP. 24), (b) by using the compass and applying the right hand rule. After reaching your conclusions remove the cloth and see if you were right.

1. Explain briefly how to determine the direction of an electric current if the source of the current is inaccessible.

Suggested form of record

Position of wire	Direction of current	Direction and amount of deflection
Above needle	S to N	
	N to S	
In front of N end of needle	Down	
	Up	
Under needle	N to S	
	S to N	
Loop parallel to needle	S to N on top	
	N to S on top	
Loop at right angles to needle	E to W on top	
	W to E on top	

26. MAGNETIC PROPERTIES OF COILS

If you have not as yet performed Exp. 25, you should read the introduction to that experiment. In it you were given the right hand rule for finding the direction of the magnetic field surrounding a linear conductor. There is a similar rule for the field of a coil carrying a current. If you grasp the coil in the right hand, Fig. 31, with the fingers pointing in the direction of the current, the thumb points in the direction of the north pole of the coil. It is quite unnecessary for you to tax your memory in regard to these two rules beyond remembering that you *grasp* with your *right* hand and that the *thumb* and *fingers* represent the directions of either field or current, as the one or the other fits the case.

EXP. 26, PART I. *Make an electromagnet and study its magnetic field.*

A. *The magnetic field of a helix.* Make a helix by wrapping a long piece of copper wire around a soft iron rod. Remove the rod and connect the wire to the cell through a reversing switch. Trace the current, apply the right hand rule, and make up your mind which end of the helix will act as an N-pole. Hold a compass near this end of the helix and see if you were right. Try the other end. Reverse the current and observe the effect.

Fig. 31. The right hand rule for a coil.

1. What is the direction of the field inside a helix carrying a current?

B. *A study of the electromagnet.* (a) Insert the iron rod in the helix or wind a new coil on the rod. Connect the coil to the cell through a reversing switch. Turn on the current, trace its direction, and by making use of the right hand rule, decide which end of the helix is the N-pole. Test your conclusion with the aid of the compass.

Compare the strengths of the fields of the helix with and without the iron core.

2. Show that the right hand rule enables one to tell which pole of an electromagnet is the N-pole?

3. What is the effect on the strength of the field, or introducing an iron core into a coil carrying a current?

(b) Wind about twice as many turns of wire on the iron core and note whether the strength of the poles is increased.

4. If you wind a coil on a rod from one end to the other and then back again (like thread on a spool) is the magnetic effect reduced by the second layer? Explain fully.

5. What is the function of the iron core in an electromagnet?

(c) See how many tacks the electromagnetic will pick up. Remove the core and try the helix alone. Next wind the horseshoe-shaped core with about thirty turns of wire. Test its polarity and strength. Add a great many more turns and test the result.

6. What can you say in regard to the relative lifting forces of bar and horseshoe magnets?

EXP. 26, PART II. *Set up and study a d'Arsonval galvanometer.*

In the galvanoscope we have an example of a stationary coil and a movable magnet. D'Arsonval designed an excellent galvanometer in which he used a powerful fixed magnet and a light movable coil. Nearly all high grade direct current voltmeters are of the "moving coil" or d'Arsonval type.

Set up the d'Arsonval galvanometer, Fig. 32, level it, and connect a short piece of copper wire across its terminals to act as a shunt. Then connect the galvanometer with the source of current through a reversing switch. If possible trace the wires from the cell through the galvanometer coil and decide which end of the coil will be the N-pole, which end will be the S-pole, and also which way the coil will turn when the switch is closed? Are you right?

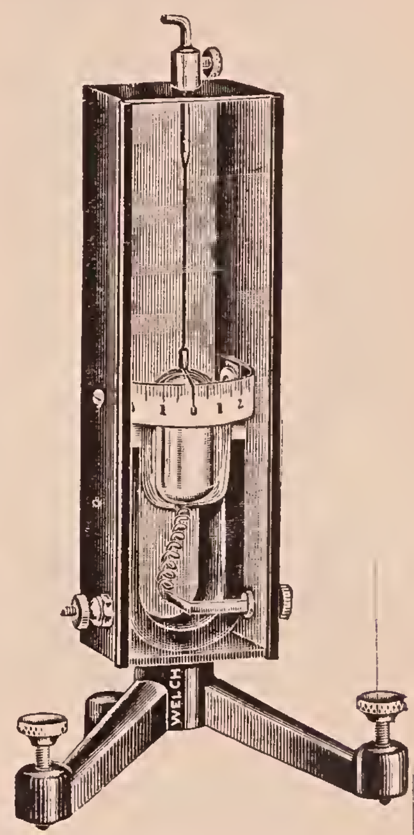

Fig. 32. D'Arsonval galvanometer.

Learn how to adjust the zero point of the galvanometer.

7. (a) How do you adjust a d'Arsonval galvanometer so that the pointer reads zero on the scale, before the current is turned on?

(b) How do you adjust a *galvanoscope* so that it will read zero at the start?

8. Why is the pointer of a d'Arsonval galvanometer attached to the moving coil in such a way that the coil must be parallel to the lines joining the poles of the magnet when the pointer reads zero?

9. Why may a d'Arsonal galvanometer be set up in any position relative to the earth's magnetic field, while a galvanoscope must be placed with the coils parallel to the earth's field?

10. Which is more sensitive to current, the galvanometer or the galvanoscope which you have used?

11. Explain the advantages which would be gained by (a) a stronger magnet, (b) a larger number of turns on the coil?

27. THE ELECTRIC BELL

Exp. 27. *Study the operation of an electric bell and the arrangement of bell circuits.*

A. *Construction and operation of an electric bell.* Connect an electric bell with a cell, through a switch or push button. Trace the current from the positive terminal of the cell through the bell and decide on the polarity of the poles of the electromagnet. Test the polarity with a compass. In your note book make a drawing of the bell and connections. Indicate the direction of the current and the polarity of the magnets.

1. (a) Are the two poles of opposite polarity? (b) Are the two coils wound in the same direction? (c) How can both answers be correct?

2. What is the purpose of the small spring on the armature?

3. Explain what makes the hammer move toward the bell and what makes it move away from the bell.

Find a way to connect the bell so as to make it a *single stroke* bell.

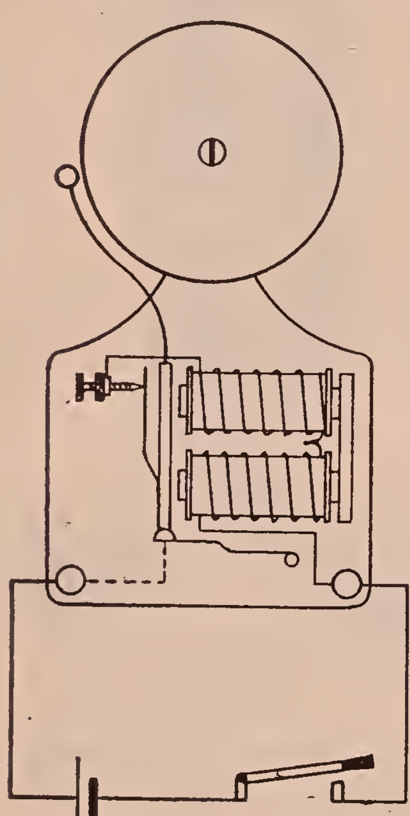

Fig. 33. Electric bell.

B. *Repair of an electric bell or bell circuit.* The instructor should disable the bell or circuit and require the student to find and repair the trouble, so that he may be able to make similar repairs at home.

C. *Electric bell circuits.* (a) *Two bells from one push button.* Make a drawing of the wiring necessary when one push button is used to operate two electric bells. Two cells are to be used.

(b) *House circuit for two push buttons.* Two bells, one on the first floor and one on the third floor, are to be operated by the front door push button, and two buzzers placed beside the bells are to be operated by the push button at the kitchen door. The entire circuit is to be operated by two cells placed in the basement. Make a drawing of the connections. Four groups of students should agree on a plan for the wiring and by combining their equipment try it out.

28. ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE OF CELLS

Two conductors immersed in a liquid which acts on one of them more than the other constitute an *electrolytic cell*. The *electromotive force,* or electrical pressure exerted by the cell, depends on the material of which the two conductors are made and on the nature of the liquid, or electrolyte, as it is called.

In this experiment a number of different cells will be assembled and their electromotive forces compared.

EXP. 28, PART I. *Study the factors upon which the electromotive force of a cell depends.*

A. *Cells having the same electrolyte but different plates.* Set up a simple cell, using zinc and copper plates and dilute (1 to 20) sulfuric acid as the electrolyte. Connect the cell to the galvanoscope[1], using the largest number of turns. Insert sufficient No. 36 German silver wire to make the deflection less than 45 degrees. The galvanoscope[1] serves as a crude voltmeter. Record the reading of the galvanoscope and note which way the needle deflects and to which terminal the copper is connected. Copper is *positive* with respect to zinc and later on when you use other metals the plate connected to this same terminal is positive with respect to the other plate if the needle deflects the same way; if it deflects the opposite way the plate is negative.

Replace the copper plate with plates of aluminum, lead, carbon and any other materials available and record the deflections of the needle. Note also which metal is positive with respect to the other.

Next replace the zinc plate with a lead plate and try it in combination with all the other plates, taking observations as before. Arrange the data neatly as indicated in the table at the end of this experiment.

1. Which pair of substances gives the greatest electromotive force when immersed in sulfuric acid?
2. Arrange the substances in a series so that each substance is + with respect to those following it and — with respect to those preceding it.

B. *Cells having the same plates but different electrolytes.*

Set up a simple cell with zinc and copper plates and first use as an electrolyte dilute sulfuric acid. Follow the directions for the use of the galvanoscope given in Part I and measure the electromotive force. Replace the sulfuric acid, first with dilute nitric acid, and then with dilute hydrochloric acid, copper sulfate, and water, in turn. Measure the electromotive force of each cell. The plates should be thoroughly washed before using them with each new electrolyte.

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[1]A low range voltmeter should be used if one is available. A voltmeter is connected directly to the cell. See Voltmeter and Galvanoscope in the appendix.

3. Which electrolyte gives the greatest electromotive force with zinc and copper plates?

EXP. 28, PART II. *Study the effect of internal resistance on current.*

The electromotive force of a cell depends only upon the material of the plates and the electrolyte[1]. It is in no way affected by the size of the plates and the distance between them. The size of the plates and distance between them is, nevertheless, of the greatest importance in the construction of cells as we shall see in this experiment.

Set up a simple cell (zinc-copper, sulfuric acid) and connect it to the largest number of turns of a galvanoscope, using a sufficiently long piece of German silver wire in the circuit to bring the deflection down to about 40 degrees[2]. Wait until polarization is complete and observe the deflection. Then carefully and slowly raise the elements until they are clear of the solution and observe the deflection as you do so. Remember that, by Ohm's law, the current in a circuit is equal to the electromotive force in the circuit divided by the *total* resistance and that the electromotive force is required to drive the current not only through whatever is connected to the cell but also through the cell itself.

1. Why does raising the elements in the solution increase the internal resistance of the cell?
2. Does the reduction of the current mean that the electromotive force is reduced? If not, what does it signify?

Replace the plates and place them just as near together as possible without touching. Read the deflection of the galvanoscope after it becomes constant. Then separate the plates as far as possible and again note the deflection.

3. What effect does increased distance between plates have on the internal resistance of the cell?
4. If you wish to construct a cell and get from it a very large current what would you attempt to do in respect to (a) size of plates, (b) distance between plates?
5. Automobile storage batteries are made so that they will deliver a very large current. Examine such a battery. (a) Why are there so many plates? (b) Why are they so close together? (c) What then can you say about the internal resistance of such a storage battery?

EXP. 28, PART III. *Study the effect of series and of parallel connection of cells.*

A. *Series connection.* Connect two cells in series, i. e. with the positive terminal of one connected to the negative terminal of the other.

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[1]Polarization affects the electromotive force of a cell because it changes the material of the plate, substituting a surface of hydrogen for the copper.

[2]The smaller the deflections of the needle of the galvanoscope the more nearly are they proportional to the current. If a voltmeter is used, its readings are proportional to the current.

Connect the free terminals to a voltmeter and read the combined voltage of the cells in series. Also read the voltage of each cell separately.

If a voltmeter is not available a galvanoscope may be used. If enough resistance can be placed in series so that the deflection is less than 25 degrees the deflections will be almost proportional to the voltage.

1. What is the effect on the total voltage when cells are connected in series?

B. *Parallel connection.* Repeat the experiment with the cells in parallel.

2. What is the effect on the voltage when cells are connected in parallel?

Suggested form of record.

PART I

A. Cells having same electrolyte but different plates:

Pair of plates	Electromotive force	Pair of plates	Electromotive force
Zinc — copper +		Lead-- aluminum--	
Zinc-- aluminum--		Lead--- carbon---	
Zinc---- carbon---		Lead--- copper---	
Zinc----- lead-----			

B. Cells having the same plates but different electrolytes:

Electrolyte	Plates		Electromotive force
Sulfuric acid	Zinc (—)	copper (+)	
Nitric acid	(----)	(----)	
Hydrochloric acid	(----)	(----)	
Copper sulfate	(----)	(----)	
Water	(----)	(----)	

PART III

Voltage of first cell------------------------ Voltages of cells in series ----------------
Voltage of second cell---------------------- Voltages of cells in parallel -------------

29. ELECTROLYSIS AND ELECTROPLATING

When a small amount of sulfuric acid (H_2SO_4) is placed in water, the molecules, of their own accord, break up into hydrogen ions and sulfate ions. Each hydrogen (H^+) ion is an atom of hydrogen with a single positive charge and each sulfate ion (SO_4) consists of one sulfur atom and four oxygen atoms with a double negative charge. If there is an electric field in the solution, such as is produced when two plates, connected to a battery, are placed in the solution, the H^+ ions are attracted toward the negatively charged plate and the SO_4 ions are attracted toward the positively charged plate.

When the hydrogen ions reach the — plate they acquire electrons from the plate and become uncharged hydrogen gas which rises to the surface.

When the SO_4 ions reach the + plate they give up their electrons and at the same time unite with hydrogen from the water. Since water is composed of hydrogen and oxygen, oxygen is freed and it rises to the surface as bubbles.

It will be noted that no sulfuric acid is used up in this process but that the water is decomposed into its two constituents, hydrogen and oxygen. This process is known as *electrolysis* and it is used commercially to produce large quantities of hydrogen and oxygen.

An enormous electro-chemical industry has been built upon the industrial applications of the principles of electrolysis. Electroplating of copper, nickel, silver, etc. is one of the best known applications but electrolysis is also used in the smelting of ores and the refining of metals like copper. The discovery of an electrolytic method of extracting aluminum from its ores was the necessary factor in the development of the aluminum industry, for it brought the price of aluminum to the point where the metal could compete in the industrial market.

EXP. 29, PART I. *Decompose water by electrolysis.*

Wrap the bare ends of two lengths of copper wire around two nails. Connect the wires to a source of electric current and insert the nails in a tumbler filled with dilute sulfuric acid (1 to 20). Observe the bubbles of gas which appear.

1. (a) Is the nail from which bubbles come more freely, connected to the + or — terminal of the battery? (b) Is this gas hydrogen or oxygen?
2. Is gas given off at the other nail? If so, what gas?
3. Give a brief explanation of the reason why the hydrogen and oxygen appear at the respective nails.

EXP. 29, PART II. *Electroplate a coin with copper.*

Scrub a nickel (coin) with soap and water and rinse it thoroughly. Attach it to a copper wire with a paper clip or some other simple device. Attach another copper wire to a carbon plate or rod and place the coin and carbon in a tumbler of copper sulfate solution prepared with distilled water or rain water. Connect the wires to two or more dry cells in series, the nickel to the — terminal. Observe what goes on at the nickel electrode and at the carbon electrode. If gas is not formed on the surface of the carbon rod, bring it very close to the nickel. Let the current pass for five minutes while you answer the following questions:

4. (a) Into what parts do the molecules of copper sulfate ($CuSO_4$) divide when in solution? (b) What charge does each part carry?

5. To which electrode do the Cu ions travel, the + or — ? What becomes of them when they reach this electrode? Is gas given off?

6. To which electrode do the SO_4 ions travel? What happens when they reach this electrode? Is gas given off?

Replace the carbon with a strip of copper.

7. Is any gas given off at the surface of the copper?

8. When the SO_4 ions reach the copper plate what happens that could not happen in the case of carbon?

9. Is the copper plate being used up?

Take out the nickel, examine it thoroughly and replace it in the solution. Reverse the current and let it pass for a little longer time than it did before. Remove the nickel and examine it.

10. What has become of the copper which was on the nickel?

11. If two copper plates are placed in a solution of copper sulfate and current is passed through the solution for many hours, what will happen to the plates? To the solution?

30. ELECTRIC CURRENTS BY ELECTROMAGNETIC INDUCTION

In 1831 Faraday discovered that electrical currents can be produced by the relative motion of magnets and coils. His experiments showed the way by which mechanical energy could be used to produce electric currents and thus furnish a cheap source of electrical energy. Practically all the modern applications of electricity are directly or indirectly dependent upon the experiments of Faraday. These experiments may be repeated with simple apparatus and you can verify for yourself the principles of electromagnetic induction.

EXP. 30. *Generate electric currents by electromagnetic induction.*

A. *To generate currents by the use of a coil and magnet.* The currents will be produced by the relative motion of a coil[1] and magnet. As the currents will not be very large a galvanometer should be used, if one is available, but a galvanoscope may be used if necessary.

Connect the two terminals of the galvanometer with a piece of wire to act as a shunt. Call the right hand terminal of the instrument the positive terminal and connect it to the positive terminal of a cell. Complete the circuit and note the direction of the deflection. You are now able to tell the direction of any current sent through the galvanometer..

Remove the shunt, which is used merely to protect the galvanometer from excessive current, and connect the 60-turn coil to the galvanometer with a sufficient length of wire so that it can be moved about.

(a) Pass the coil quickly over the N-pole of the bar magnet and note the direction and amount of the deflection. Remove the coil and note the deflection.

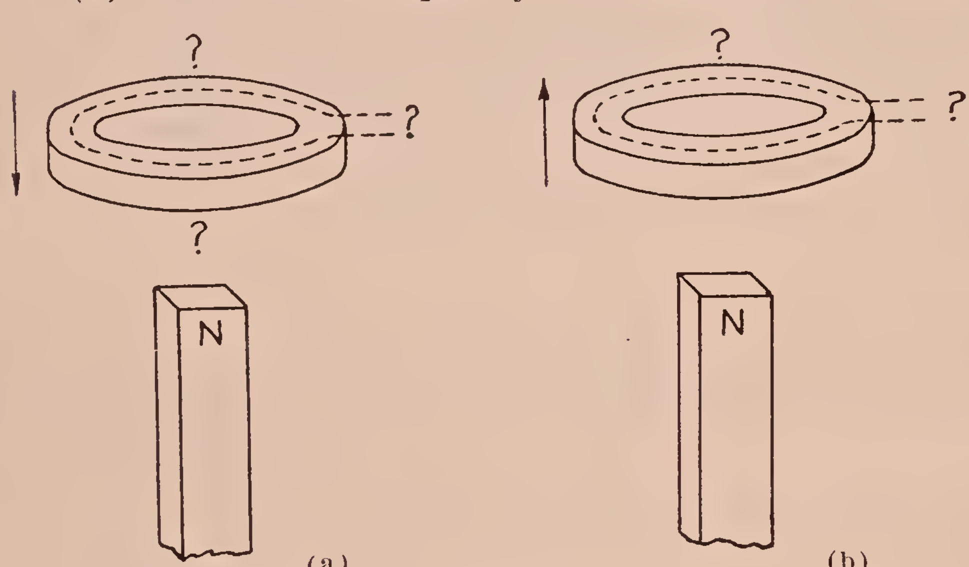

Fig. 34. Producing currents by electromagnetic induction.

1. Complete the drawing of Fig. 34a by showing the direction of the current in the coil and the polarity (N or S) of the un-

[1]Coils of your own construction are very satisfactory. They may be made of No. 18 bell wire or No. 24 double cotton covered wire. It is a good plan to wind one coil with twice as many turns as the other. The number of turns necessary will depend upon the sensitivity of the galvanometer or galvanoscope and the strength of the magnets. Coils of 30 and 60 turns will serve for a galvanometer but it may be necessary to use 100 and 200 turns, or even more with a galvanoscope. They may be wound around the fingers, leaving a center hole about two inches in diameter, and bound in several places with tape or cord. The instructions are written on the assumption that you have coils of 30 and 60 turns and a galvanometer. If a galvanoscope is used, the connecting wires must be long enough so that the magnets will not affect the needle directly.

der side and upper side of the coil.

2. How can you tell from the diagram whether it is necessary to *do work* to produce current by induction?

3. Complete the drawing of Fig. 34b.

4. Is the motion of a coil with respect to a magnet opposed or assisted by the magnetic effects of the induced currents?

(b) Reverse the magnet and repeat the experiment.

5. Make diagrams similar to Fig. 34.

6. Explain how the law of conservation of energy could be used to predict the direction of the induced current.

(c) Use a coil of half the number of turns and note the effect on the deflection.

7. How does the strength of the induced current change when a coil of fewer turns is used?

B. *To produce currents by the use of two coils.* (a) Connect the larger coil to the galvanometer and the smaller coil to a dry cell through a reversing switch. Close the switch and place the second coil on top of the first in one quick motion. Observe the effect on the galvanometer.

8. How do the directions of the currents in the two coils compare? How do the polarities of the faces of the coils in contact compare?

(b) Quickly remove the second coil from on top of the first and observe the effect.

9. How do the directions of the currents in the two coils compare in this case? How do the polarities of the two faces of the coils which are next to each other now compare?

(c) Open the switch and place the coils in contact. Without moving the coils, make and break the circuit by means of the switch and note the effect. Quickly reverse the current and note the effect.

10. Explain the results obtained when the current is made and broken and reversed.

(d) Insert a soft iron core through both coils and repeat the procedure used in (c).

11. Account for the effect of the iron core on the strength of the current.

12. Make as simple a statement as possible, covering all the cases which you have examined, regarding the way in which electric currents are induced.

31. MOTORS AND GENERATORS

Motors and generators are used so universally that everyone has some idea of the extent to which modern life depends on them. The fundamental principles upon which motors and generators operate are those which were discovered a hundred years ago by Faraday and Henry, and which have been studied in Exp. 30. Electric *generators* and *motors* consist essentially of two parts, one of these parts being the *field magnet* and the other the *armature.*

In the machine which you will study, the field magnets are stationary and the armature rotates. Like many other electrical machines, it may be used as either a motor or generator. When the armature is turned by mechanical means, this machine acts as a generator and produces electrical current. When, on the other hand, an electric current is furnished to the armature, the armature will rotate and produce mechanical energy.

In some electrical machines the field magnets consist of permanent magnets, as in the generator of a Ford automobile. All large generators, however, make use of electromagnets.

Exp. 31, Part I. *Study the direct-current motor.*

A. *A motor with a field produced by permanent magnets.* Assemble the motor with the permanent magnets, Fig. 36, and connect the armature to a dry cell through a reversing switch. Close the switch and adjust the brushes until the motor runs its best. Open the switch and throughout the experiment keep it open, except when you are taking observations.

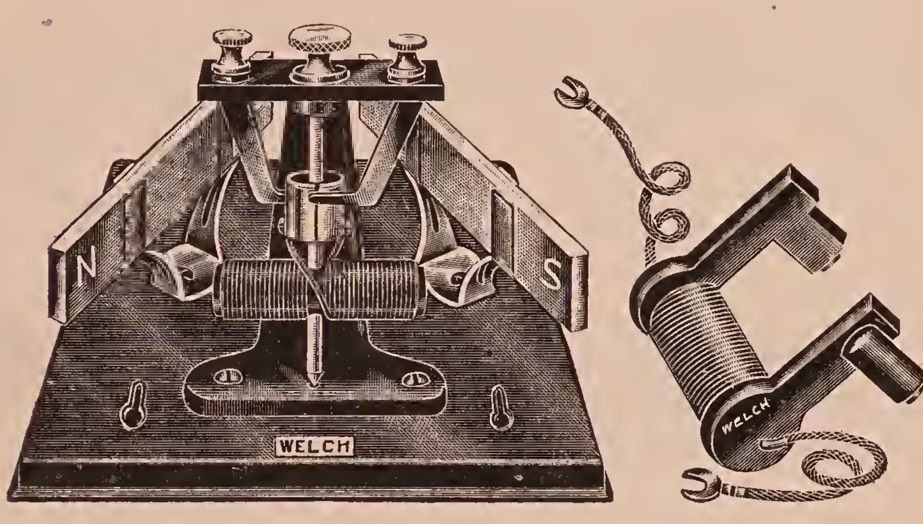

Fig. 35. Small motor and generator.

1. What is the purpose of the commutator?

2. What should be the position of the poles of the armature at the moment when the current in the armature reverses?

3. Explain, using simple diagrams, why the armature turns.

Make tests which will enable you to answer the following questions:

4. What is the effect of reversing the connections in a permanent magnet motor?

5. How is the speed of the motor influenced if the field is weakened by swinging the magnets away from the armature?

6. What is the result when resistance is inserted in the armature circuit?

B. *A motor with a field produced by an electromagnet.* Remove the magnets and connect the electromagnet in *series*, as indicated in Fig. 36, so that the current will pass through both the armature and field *one after the other.* Perform such experiments as will enable you to answer the following questions:

7. When the current furnished a series motor is reversed, what is the effect on the direction of rotation?

8. Describe two ways in which the direction of rotation of a series motor may be reversed.

Rewire the apparatus as a shunt motor, as indicated in Fig. 36, so that the current will *divide* between the armature and field. Answer the following questions:

9. When the current furnished a shunt motor is reversed, what is the effect?

10. How is the direction of rotation of a shunt motor reversed?

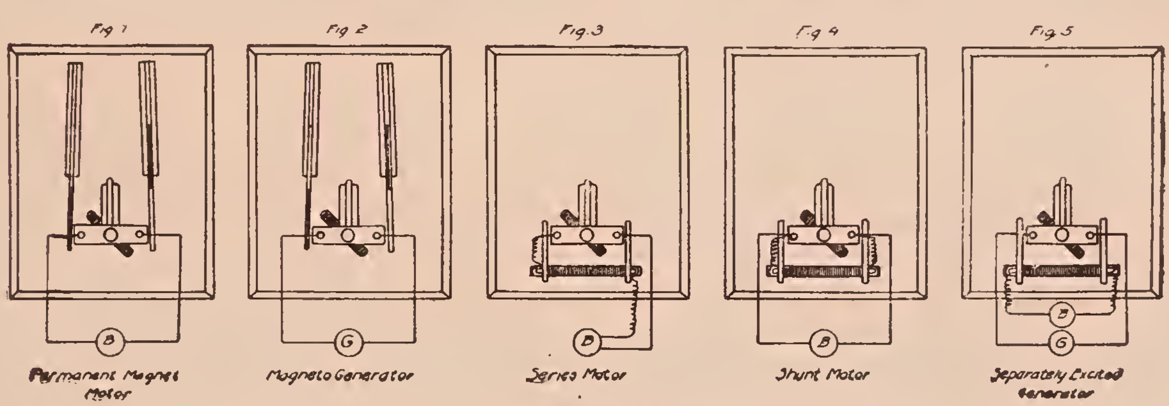

Fig. 36. Various forms of motors and generators.

EXP. 31, PART II. *Study the direct-current generator.*

A. *The magneto.* A magneto is an electrical generator in which the field is produced by permanent magnets. Many automobiles use magnetos for ignition. They are used extensively in simple telephone instruments.

Set up a magneto, Fig. 36, using the permanent magnets for the field. Connect the armature directly to a sensitive galvanometer or galvanoscope. Spin the armature with the fingers or with a thread wound around the armature shaft.

1. (a) How do you know that the armature becomes a magnet? (b) As a pole of the armature approaches a pole of the field does it have the same or opposite polarity? Give a complete explanation.

2. (a) Does this magneto deliver a direct or alternating current? (b) Is the current in the armature itself alternating or direct? (c) What change could be made in this generator so that it would deliver alternating current?

B. *Generator with an electromagnet for the field.* This is the usual type of generator and it is exactly the same in principle as the magneto, the only difference being that the field is created by an electromagnet instead of permanent magnets.

Connect the field coil to a dry cell through a reversing switch and be sure to have the switch open when you are not taking observations. Spin the armature as before and answer the following questions:

3. (a) What seems to be the advantage of using an electromagnet for a field? (b) Are large generators made with permanent magnets or field coils?

4. What effect does reversing the direction of rotation have on the direction of the current? Explain.

SPECIAL EXPERIMENT. *To test a lead storage cell.* The liquid in a lead storage cell consists of sulfuric acid dissolved in pure water. When a cell is being used, or is allowed to stand for a long time, part of the acid leaves the water and attaches itself chemically to the cell plates. This causes the liquid gradually to become less dense during "discharge." When the cell is being recharged, the opposite process takes place. Thus the density of the liquid indicates the degree of charge.

If acid is added to a cell by anyone except an experienced battery man, the density test will have no meaning; a cell may read 1.3 under these conditions and still be discharged. Distilled water must be added to a cell frequently, but a density test should never be made immediately afterwards.

To test a cell, remove the vent plug and draw enough of the liquid into a syringe hydrometer to cause the float to rise. Hold the tube in a vertical position so that the hydrometer floats freely and read the density on the scale at the surface of the liquid. Return the liquid to the same cell from which it was taken and replace the vent plug. A Willard storage cell at 80° F. will read 1.28-1.30 when fully charged, about 1.22 when half discharged and 1.15 or less when discharged. Use the following formula to find what the density of your cell would be at 80° F.: Density at 80° F. = 5/2 (Room temp. in °F. — 80°) + reading at room temp. What is the degree of charge in the cell tested?

Repeat the test with the other cells of the battery.

32. REFLECTION FROM A PLANE MIRROR

When light strikes an ordinary plane mirror, part of it is reflected from the front surface of the mirror and part of it, passing through the glass, is reflected from the back surface. If, however, the back of the mirror is painted black, reflection will occur only at the front surface; this will also be true if the mirror is made of a piece of polished metal.

A ray of light falling on a surface is called the *incident ray*, and the part of it which is reflected, the *reflected ray*. The angle between an incident ray and the normal to the mirror is called the *angle of incidence*, while the angle between the reflected ray and the normal is called the *angle of reflection*. According to the laws of reflection, these two angles lie in the same plane and they are always equal.

When an object is placed in front of a mirror, rays of light pass from it to all points on the mirror. The reflected ray from any one of these points can be located by sighting along a ruler at this point and at the *image* of the object in the mirror. As long as the object is not moved, the image will not move, no matter from what angle it is viewed.

EXP. 32, PART I. *Find by experiment the relation between the angle of incidence and the angle of reflection.*

Draw across the middle of a sheet of notebook paper a straight line *MM'*. Erect a perpendicular *OP* to this line near its middle point, Fig. 37. This perpendicular can be drawn with the aid of a protractor, or it can be constructed with dividers, using the method given in plane geometry.

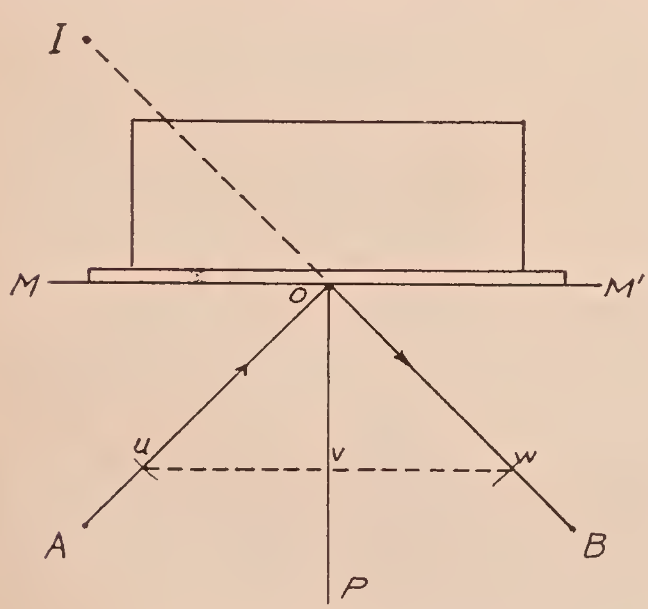

Fig. 37. Reflection in a plane mirror.

Obtain a plane mirror which is blackened on one side and attach it to a small block of wood by means of rubber bands.

Stick a pin vertically at the point *O*. Then place the mirror and block on the paper, so that the front edge of the mirror is exactly on the line *MM'*, the pin being against the glass. Place a second pin at a point *A* 10 or 12 cm in front of the mirror. Both pins should be as nearly vertical as possible.

The line *AO* marks the direction of a certain ray of light passing from the pin *A* to the mirror. This ray is being reflected at *O* by the mirror in a certain fixed direction. To find this direction place your eye on a level with the paper and in line with *O* and the *image I* of the pin *A*, and place a pin *B* somewhere in this line of sight.

Remove the mirror and pins, draw the lines *AO* and *BO*, and indicate the directions which the light traveled along these lines by arrowheads.

1. Which is the angle of incidence, *AOP* or *BOP?* Which is the angle of reflection?

Measure the two angles with a protractor or else by drawing an arc with *O* as center, which cuts the paths of the incident and reflected rays at *u* and *w*, and measuring the lines *uv* and *wv*, Fig. 37.

Repeat the experiment with the pin *A* in some other position.

Label all parts of your drawings and include on them the observed data.

2. How does the angle of incidence compare with the angle of reflection in each of the above cases?
3. Explain why a blackened mirror was used.

EXP. 32, PART II. *Find by experiment the location and nature of an image formed by a plane mirror.*

On a fresh sheet of paper, draw a line *MM′* across the middle and place the front edge of the blackened mirror on this line as in Part I. Stick a pin *A* 10 or 12 cm in front of the mirror, Fig. 38.

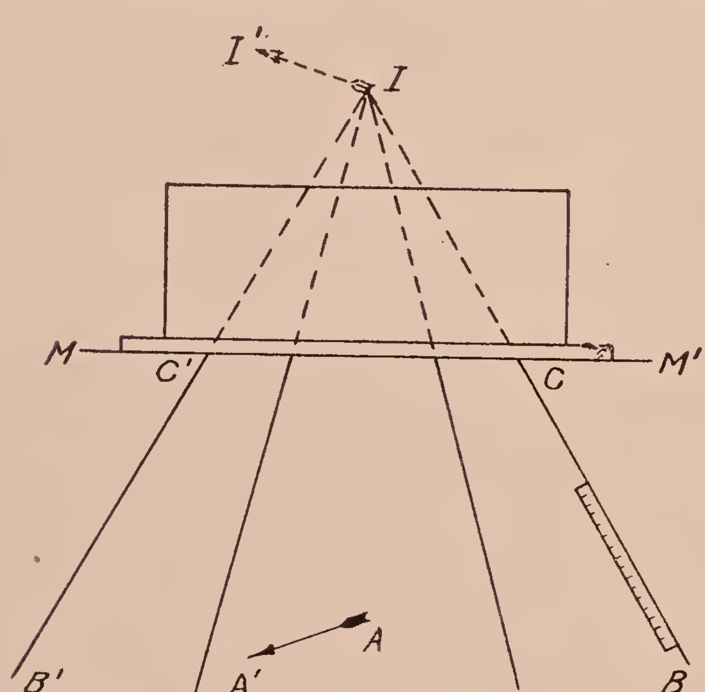

Fig. 38. Locating an image in a plane mirror.

To locate the image of this pin, lay a ruler on the paper in some position such as *BC*, so that it points directly toward the image *I* in the mirror. Sight along the edge of the ruler until *I* appears to be exactly in line with it and then draw along this edge the line *BC*.

Place the ruler in a new position, such as *B′C′*, so that it again points toward the image *I*, and draw the line *B′C′*.

In the same way draw at least two more lines which point directly toward the image. Then remove the mirror and extend these lines until they meet. Their point of intersection is the location of the image *I*.

In the same way, locate the image *I′* of a pin placed at *A′*, the head of the arrow *AA′*, Fig. 38. Draw the image *II′* of the arrow.

1. How does the distance of the image from the mirror compare with the distance of the object from the mirror?

2. How large is the angle between the mirror line MM' and the line AI? Between MM' and $A'I'$?

3. How does the length of the image of the arrow compare with the length of the arrow?

4. Draw a mirror line on a sheet of paper and in front of it draw a triangle. Without using a mirror, construct accurately the position which the image of this triangle would have in a plane mirror placed on the mirror line. How do the image and object compare with regard to shape, size and position?

5. Why is the image of a tree in a pond inverted?

6. Why do printers often use a plane mirror to read the type which they have set?

SPECIAL EXPERIMENT. *Concave mirrors.* (a) Measure the focal length f of a concave spherical mirror by supporting the mirror in the sunlight by means of a clamp and obtaining the image of the sun upon a narrow strip of cardboard held in front of the mirror. The *focal length* f of the mirror is the distance from the center of the mirror to the point where the spot of light is smallest and brightest. Why?

If the sun is not shining, throw the image of a distant building on the thin strip of cardboard. The distance of this image from the mirror will be very nearly the focal length. Why?

(b) Place in a darkened room a small electric lamp or a candle flame at a distance D_o, about three times the focal length from the mirror. Find the position of the image of this source of light by letting it fall on the thin strip of cardboard. Measure the distance of the object from the center of the mirror D_o and the distance of the image D_i. Compute the focal length f of the mirror from the formula $\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$.

How does this value of the focal length compare with that obtained by using the sun or a distant building as the object?

33. REFRACTION OF LIGHT BY A PRISM

When a ray of light passes in a slanting direction from air to glass, or the reverse, it is bent at the surface separating the two substances. This bending, which is called *refraction,* is a result of the change in the velocity of light which takes place when it enters or leaves the glass.

It is because of refraction that objects viewed through a prism appear to have changed their position; the light rays are bent in passing through the prism and an observer sees the object in the direction of the rays which finally enter the eye.

The *index of refraction* of a substance is the *ratio* of the speed of light in air to its speed in the substance. This ratio can be found for many substances with the use of very simple apparatus.

Exp. 33, Part I. *Trace the path of a ray of light through a triangular prism.*

Lay a triangular glass prism in the middle of a sheet of paper, and carefully trace its outline with a sharp pencil, Fig. 39. Stick two pins in the paper at A and B, placing them several centimeters apart and in such a position that the line AB makes an angle of about 45 degrees with the side of the prism.

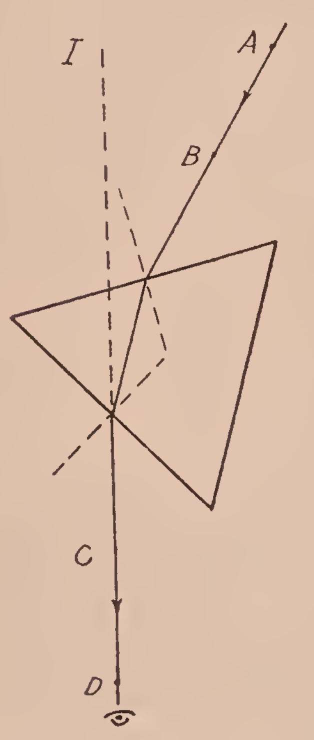

Fig. 39. Path of a ray of light through a prism.

Place the eye on a level with the table and sight through the other face of the prism at these pins. Stick two pins C and D in such a position that the four pins seem to be in the same straight line.

Remove the prism and pins. Draw the lines AB and CD, which represent the paths of the incident and emerging rays, respectively. Also draw the line representing the path of the ray through the glass and indicate the direction of the light along $ABCD$ by arrowheads.

Using dotted lines, make the following constructions on your diagram: (1) the normal (perpendicular) to the side of the prism at the point where the incident ray strikes the glass; (2) the normal to the other side at the point where the ray emerges from the glass; (3) the path the incident ray would have taken if the prism were not there.

Label all parts of the diagram, including the angles of incidence and refraction at the two faces of the prism.

1. How is a ray of light bent with regard to the normal when it enters an optically denser substance? When it emerges into a less dense substance?

2. Why did all the pins appear to be in the same straight line *DCI*, Fig. 39?

3. Is a ray passing through a triangular prism refracted toward the thicker or the thinner part?

EXP. 33, PART II. *Determine the index of refraction of the glass in your prism.*

With a sharp pencil, make a dot *A* on a sheet of paper. Place a triangular glass prism on the paper with one edge accurately at *A*, Fig. 40. Hold the prism firmly against the paper and carefully trace its outline.

Lay a ruler upon the paper at *BC* and, with one eye closed, sight along the edge of the ruler at the upright edge *A* of the prism as seen in the glass. The ruler should be placed so as to make a large angle with the perpendicular. With a sharp pencil, draw a fine line *BC* along the edge of the ruler to mark the line of sight.

Now place the ruler in a new position *B′C′*, again sight along the ruler at the same edge *A* of the prism and draw a second line *B′C′*.

Remove the prism and extend the lines *BC* and *B′C′* until they meet at some point *I*. The point *I* is the position of the *image* of the edge *A*.

It is shown in textbooks of physics that the *index of refraction* of the glass can be found by dividing *BA* by *BI*, Fig. 40. Make careful measurements of these distances, estimating to 0.01 cm, and calculate the index of refraction of the glass.

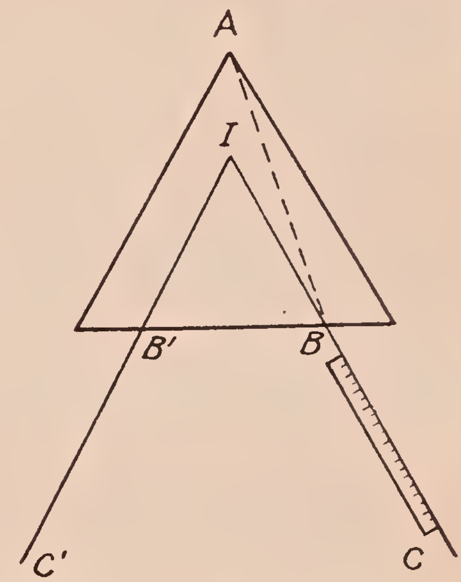

Fig. 40. A way of measuring the index of refraction of glass.

Repeat the experiment and compute the per cent of difference between the two values obtained. If this exceeds 3 per cent, more trials certainly should be made. Take the average of your values as the index of refraction of the glass.

1. What is the velocity of light in the kind of glass contained in your prism?

2. Explain how the above method could be used for finding the index of refraction of water.

3. State in your own words why the above method enabled you to obtain the index of refraction of the glass. Consult a textbook if necessary.

34. THE RUMFORD PHOTOMETER

The candle power of a source of light is measured by comparing it with a *standard candle* or with some other light of known candle power. This comparison is usually made by placing the two lights near a screen and adjusting their distances until each light produces on the screen the same brightness as does the other. The candle power of the light being tested can then be computed, using the principle that *the candle powers of the two sources af light are directly proportional to the squares of their distances from the screen.*

If the two lights which are being compared differ much in color, it will be found difficult to compare the brightness effects on the screen and to determine just when the effects due to the two lights are equal. For this reason it is best to compare lights of the same type. If, for example, an incandescent lamp is being tested, it can be compared with a similar incandescent lamp which has been standardized, say, by the Bureau of Standards.

A *standard candle* gives 1 c. p. and an ordinary paraffin candle about 1.25 c. p. A 16 c. p. incandescent lamp gives approximately sixteen times as much light as a standard candle. (See table at end of Exp. Add. 8).

The apparatus used in measuring candle power is called a *photometer* (*photos* = light). There are many different forms of this instrument, but one of the simplest to construct is the *Rumford shadow photometer.* It serves to explain the principle of the more accurate and elaborate instruments and it has the advantage that it does not have to be operated in a light-tight box or in a totally darkened room.

Exp. 34. *Construct a Rumford photometer and use it to test the relation between the candle powers of two lights and their distances from the photometer screen.*

(a) In a partially darkened room set up a vertical screen *AB* consisting of a sheet of unglazed white paper and a few centimeters in front of it place an upright rod *R,* Fig. 41. Stand a single candle *L* about 15 cm from the screen and observe the nature of the shadow cast on the screen by the rod *R.*

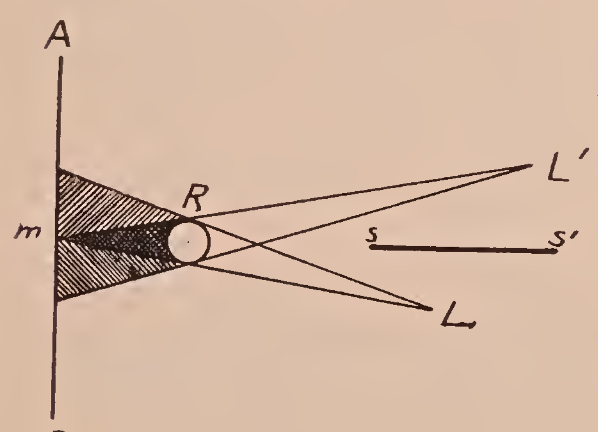

Fig. 41. The Rumford photometer.

Place a similar candle at *L′*, in such a position that another shadow is cast on the screen by *R.* It is a good plan to separate the two sources of light by means of a dividing screen *ss′*. The two shadows should be made nearly to touch each other without

[1]For a similar experiment with the Bunsen photometer, see Exp. Add. 10.

overlapping. Note that the candle L illuminates the shadow cast by the other candle L' and that L' illuminates the shadow cast by L.

If necessary, trim the candle wicks to make them burn equally and then move the candle at L' back and forth until the two shadows are equally bright. Measure and record the distance from each candle to the shadow which it illuminates, not the one which it makes. If the shadows are close together, these distances will be mL and mL'.

(b) Place two candles at L', one directly behind the other and as close together as possible. Make sure that all the candles are burning properly and then move the two candles at L' back and forth until the shadows are again equally bright. Again measure the distances of L and L' from m.

(c) Repeat with three, and finally four candles placed at L'.

(d) For each of the above four cases, compute the ratio of the candle powers of the two sources L and L' and also the ratio of the *squares* of their respective distances from m.

1. State in your own words and also in symbols the principle revealed by a comparison of these ratios.
2. Why should the distance be measured in each case to the nearer of the two shadows?
3. If a light is moved three times as far away from an object, how much brighter must the light be made to illuminate the object to the same degree as before?
4. Explain how your photometer can be used to measure the candle power of an incandescent lamp.

Suggested form of record

Distance of L from nearer shadow, mL..............cm.
Number of candles at L, 1.

Candles at L'	Distance of L' from nearer shadow, mL'	$\frac{\text{C. P. at } L}{\text{C. P. at } L'}$	$\frac{(\text{Distance } mL)^2}{(\text{Distance } mL')^2}$
1			
2			
3			
4			

35. CONVERGING LENSES

A lens that is thicker at the middle than at the edges tends to *converge* the rays of light passing through it, while the opposite is true if the lens is thinner at the middle. Examples of *converging lenses* are burning glasses, reading glasses and camera lenses.

When *parallel* rays of light pass through a converging lens, they are refracted to a point called the *principal focus.* Rays from the far distant sun and even from objects a few hundred meters away are so nearly parallel that they converge to points very close to the principal focus.

The *focal length* of a lens is the distance from the center of the lens to the principal focus. Its value depends upon the index of refraction of the lens material and upon the shape of the lens. The thicker a lens, in proportion to its diameter, the shorter is the focal length.

The images formed by lenses and mirrors are of two kinds, *real* and *virtual.* An image is *real* when the rays which produce it actually pass through the image, making it possible to cast the image on a screen. An image is *virtual* when the rays which produce it only appear to pass through the image; a virtual image cannot be cast on a screen, but must be observed by the eye. A converging lens produces either real or virtual images while a *diverging lens* produces only virtual images.

The position of an image, and the matter of whether the image will be real or virtual, erect or diminished and enlarged or reduced, depend upon both the distance of the object from the lens and the focal length.

Exp. 35, Part I. *Measure the focal length of a converging lens.*

(a) Set up a reading glass in the sunlight, with the lens turned directly toward the sun. Place a white screen back of the lens and adjust its distance until the image of the sun on the screen is as nearly as possible a point. Measure the distance from the center of the lens to the image. Make two more trials and take the average as the focal length f of the lens.

If the day is cloudy, obtain the focal length by pointing the lens through an open window so as to obtain on the screen a sharp image of a house, a brick wall or some other well-lighted object, a hundred or more meters distant.

1. Why is the distance from the image of the sun to the lens the focal length?

(b) Measure the distance from the center of the lens to the screen when a sharp image is obtained of an object about 25 meters away.

2. How does the value obtained in (b) compare with the focal length?
3. Explain why it is not necessary to focus a small box camera.

Exp. 35, Part II. *Study the images formed by a converging lens.*

Arrange the apparatus as in Fig. 42, using the same lens as in Part

I. The *object* is the screened opening at O, the lamp behind this opening serving merely to increase illumination.

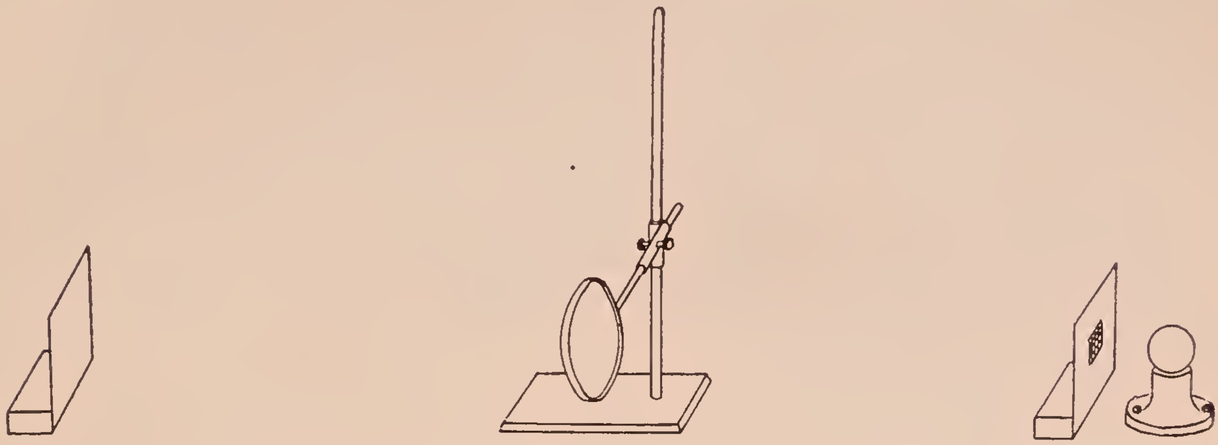

Fig. 42. Method of studying the images formed by a converging lens.

Case 1. Place the lens so that its distance from the object O is more than $2f$. If, for example, f was found in Part I to be 17.2 cm, place the lens more than 2×17.2 cm from the object.

Now move the screen I back and forth until the image formed upon it is as sharp as it is possible to get it. Then measure the distance D_o from the center of the lens to the object O, and the distance D_i from the center of the lens to the image I.

Also measure the width L_i of the image and the width L_o of the object.

Record your observations in a table similar to the one given at the end of this experiment. Under "Remarks," state whether the image is (a) magnified or reduced, (b) real or virtual, and (c) erect or inverted. To find whether the image is erect or inverted, hold a pencil near one corner of the object and observe its position on the image.

Calculate $\frac{1}{D_o} + \frac{1}{D_i}$, $\frac{D_i}{D_o}$ and $\frac{L_i}{L_o}$, expressing all fractions decimally.

Cases 2 *and* 3. Place the lens in the positions given in the first column of the table and, for each position, repeat the above procedure.

Case 4. With $D_o = f$, find whether it is possible to cast a distinct image on the screen.

Case 5. With $D_o < f$, try to find a position for the screen such that a sharp image will be formed. If unsuccessful, look through the lens toward the object and describe what you see.

1. How does the position and nature of the image change as an object is brought nearer to a convex lens?

2. How do the values for $\frac{1}{D_o} + \frac{1}{D_i}$ compare with the value for $\frac{1}{f}$ obtained in Part I? State the formula thus verified.
3. What information does the ratio L_i/L_o give you?
4. How does D_i/D_o compare in each case with L_i/L_o? What, then, is the relation between the relative sizes of image and object and their relative distances from the lens?
5. When you read fine print with a reading glass, do you make use of a real image or of a virtual image?

Suggested form of record

PART I

Lens No.____________________.

(a) Focal length f:

Trial 1________________cm; trial 2________________cm; trial 3________________cm;

Average____________________cm.

(b) Approximate distance of object________m; distance from lens to image________cm.

PART II

No. of lens____________________.

Focal length, f____________________cm (From Part I); $1/f$______________________cm.

Width of object, L_o____________________cm.

Position of object relative to lens	D_o cm	D_i cm	$\frac{1}{D_o} + \frac{1}{D_i}$	L_i cm	$\frac{D_i}{D_o}$	$\frac{L_i}{L_o}$	Remarks
More than 2 f							
Exactly 2 f							
Between 2 f and 1 f							
Exactly 1 f		Observations:					
Less than 1 f		Observations:					

36. THE MAGNIFYING POWER OF A SIMPLE MICROSCOPE

The naked eye sees an object most distinctly when it is about 25 cm away. If the object is viewed through a microscope, this distance becomes much shorter.

The *simple microscope* consists of a single converging lens of short focal length f. If the eye is held close to such a lens, and an object is placed slightly nearer to the lens than its focal length, one sees a virtual, erect and magnified image.

Linen testers, reading glasses and pocket magnifiers are simple microscopes. The linen tester consists of a single convex lens and a metal screen containing a square hole, both mounted on a frame in such a way that the hole is slightly nearer the lens than its principal focus.

EXP. 36. *Measure the magnifying power of a simple microscope.*

Place a meter stick on the table and support the lens just 25 cm above the scale, Fig. 43.

Close one eye and with the other eye look down through the lens at the virtual *image* of the square hole. Notice that the image is erect and enlarged. The distance D_i from this image to the lens is 25 cm, this being the distance of most distinct vision for the normal eye.

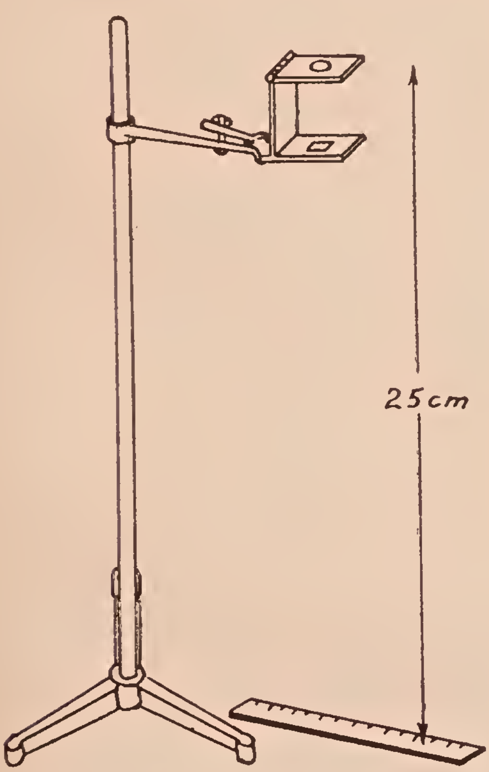

Fig. 43. Method of measuring the magnifying power of a simple microscope.

To measure the *width* L_i of the image, place the right eye as close as possible to the lens. Look through the lens with the right eye and at the same time look directly at the meter stick with the left eye. Count the number of millimeters which the image of the hole as seen through the lens by the right eye seems to cover on the meter stick as seen by the unaided left eye. The number of millimeters counted is the *width* L_i of the image.

Compute the *magnifying power* of the lens by dividing the width L_i of the image by the width L_o of the object. The width of the object is found by measuring in millimeters the actual width of the square hole.

Again compute the magnifying power of the lens, this time by dividing the image distance D_i by the object distance D_o. The object distance D_o is found by measuring carefully the distance from the square hole to the middle of the lens.

1. By actual trial, find how far from your eyes you must hold a

printed page in order to see it most distinctly. How does this distance compare with the 25 cm taken as the standard?

2. Show that the magnifying power of a simple microscope is approximately 25/f.

3. When an object is held very close to the naked eye, is the image in the eye behind or in front of the retina?

Suggested form of record

Lens No.------------------.

Width of image, L_i--------------------mm ; width of object, L_o--------------------mm.

Magnifying power, $L_i \div L_o$ = ----------------------diameters.

Image distance, D_i------25----cm ; object distance, D_o--------------------cm.

Magnifying power, $D_i \div D_o$ = --------------------diameters.

SPECIAL EXPERIMENT. *The compound microscope.* The compound microscope in its simplest form is a telescope used for examining objects near at hand.

To make a model compound microscope, use the arrangement shown in Fig. 44, and follow the directions given in Exp. 37 A, with the exception that the object is to be a candle flame or other illuminated object placed near enough to the objective lens to cast an *enlarged* image on the screen S.

Measure the distance D_o from the object to the objective, and the distance D_i from the image at S to the objective; then compute the magnifying power of the objective alone by means of the relation D_i/D_o. Also compute the magnifying power of the eyepiece, which is $25/f$. The magnifying power of your compound microscope will then be the product of the magnifying powers of the objective and eyepiece.

37. THE ASTRONOMICAL TELESCOPE

The astronomical telescope, in its simplest form, consists of a large lens of considerable focal length, called the *objective lens,* and a smaller lens of shorter focal length, called the *eyepiece.*

The objective lens forms a real, inverted, and diminished image of a distant object. This image is viewed through the eyepiece, which merely acts as a magnifying glass or simple microscope. The final image seen through the eyepiece is virtual and inverted.

When this telescope is used for astronomical purposes, the inverted image causes no inconvenience. If this telescope is to be used to view objects on the earth, the image is turned right side up by placing lenses or prisms between the objective and eyepiece.

EXP. 37. *Construct an astronomical telescope and measure its magnifying power.*

A. *To make a telescope.* Arrange the apparatus as shown in Fig. 44, with the objective lens facing an open window. Use a reading glass for the *objective lens* and a linen tester or other short-focus lens for the *eyepiece.*

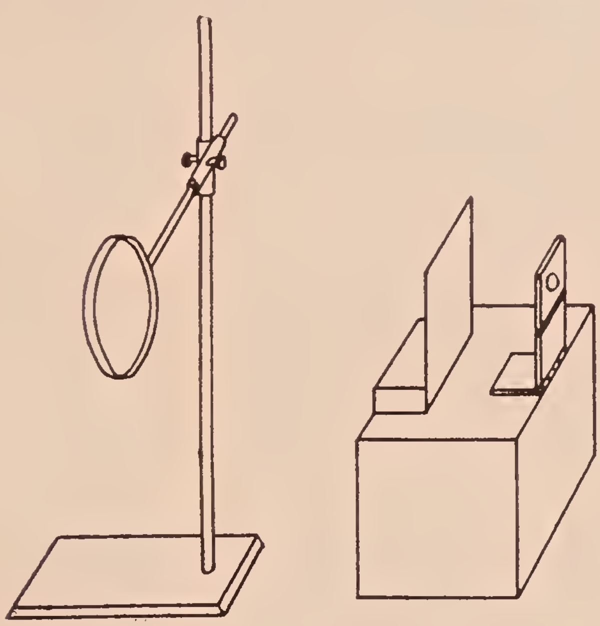

Fig. 44. Model of an astronomical telescope.

Place the eyepiece near the edge of the block, and with the eye held close to the eyepiece lens, adjust the white screen S until you can see the magnified image of its surface distinctly.

Now move the block supporting the eyepiece and screen until a sharp image of a distant object is cast on the front of the screen by the objective lens.

Remove the screen and readjust the eyepiece, if necessary, so that when you look through the eyepiece you can see clearly the inverted image of the distant object. You are now using the eyepiece as a simple microscope to view the real image which exists at S.

Measure the distance between the two lenses and compare this distance with the sum of the focal lengths of the lenses. The focal length F of the objective, and the focal length f of the eyepiece, can be found, as in previous experiments, by casting on a screen the image of the sun or of another distant object.

1. Explain why this simple relation exists between $F + f$ and the distance between the lenses.
2. How would these quantities compare if the telescope were focused on an object only a few meters away?
3. What defects did you observe in the image formed by your telescope?

B. Magnifying power. Draw on the blackboard two heavy horizontal lines, about 15 cm apart, and view them through the telescope from the other side of the room. Adjust the position of the eyepiece until you obtain a distinct image of the lines.

Now look through the eyepiece with one eye and at the same time look at the blackboard directly with the other eye. Direct another student where to draw two horizontal lines on the blackboard which seem to have the same positions as do the images of the lines seen through the telescope.

Find the magnifying power of your telescope by dividing the distance L_i between the two image lines by the distance L_o between the two object lines. Repeat the experiment several times and take the average as the best value of the magnifying power.

Again compute the magnifying power, this time by dividing the focal length F of the objective by the focal length f of the eyepiece.

Suggested form of record

Objective lens: lens No.______________________; focal length, F______________________cm.

Eyepiece lens: lens No.__________________________; focal length, f______________________cm.

Distance between lenses______________________cm.

F + f = ____________________cm.

Magnification

Trial	Image width in cm L_i	Object width in cm L_o	Magnification in diameters $L_i \div L_o$

Observed magnification L_i/L_o, average value____________________diameters.

Magnification, by formula F/f, ____________________diameters.

ADD. 1. PRESSURE IN A LIQUID

If a pencil is plunged endwise into water and then released, it springs back into the air. If a strong steel buoy is accidently sunk to the bottom of the sea by having too heavy a weight attached to it, it is often found that, when recovered, it has been crushed out of shape, as though made of paper. It is evident that water must exert pressure on any immersed surface, and that at considerable depths, the pressure must be very great.

We must distinguish between the terms *pressure* and *force* as these terms are used in physics. *Pressure* is force per unit area. It is measured in grams of force per square centimeter, or in pounds of force per square inch.

1. Suppose that six 1 cm cubes of iron are placed on the table, one above the other in a vertical column. Find the pressure on the table in grams per square centimeter, and also the force in grams. Density of iron is 7.4 g/cm^3.

2. What would be the pressure and also the force on the table if two such columns of iron cubes were placed side by side?

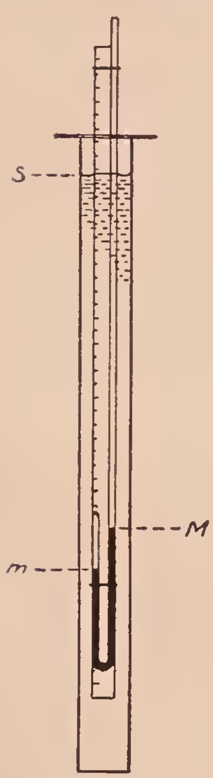

Fig. 45. This mercury manometer is being used to measure the pressure at m in the liquid.

The *open-tube manometer,* containing mercury, is well adapted for the investigation of the pressure in a liquid. This instrument is fully described under *Manometers* in the appendix. It is lowered into the liquid until the short arm is in the region of the liquid to be investigated, the end of the long arm being left exposed to the air. The difference in the mercury levels in the manometer, measured in centimeters, is the pressure in the liquid in centimeters of mercury, at the point where the liquid touches the mercury in the short arm.

EXP. ADD. 1. *Measure the pressure at various depths in water and then in gasoline, and find how the pressure varies with depth and with the density of the liquid.*

A. *To measure the pressure in a liquid with a manometer.* Place the water, gasoline or other liquid whose pressure is to be investigated in a deep vessel. Fasten an open-arm manometer tube to a meter stick by means of rubber bands, and add mercury to the tube until it stands to a height of about 12 cm in either arm. Lower the manometer and attached scale vertically into the liquid in the deep vessel, immersing it as far as possible without submerging the top of the meter stick or the top of the long arm of the manometer. Suspend the manometer in this position by means of a pencil laid across the top of the vessel and fastened to the meter stick with a rubber band, Fig. 45.

Observe and record the reading on the meter stick at the surface S of the liquid. If this liquid is water or gasoline the surface S will be curved upward where it touches the meter stick and sides of the vessel, Fig. 46. The lowest point in this curved surface is to be regarded as its true position.

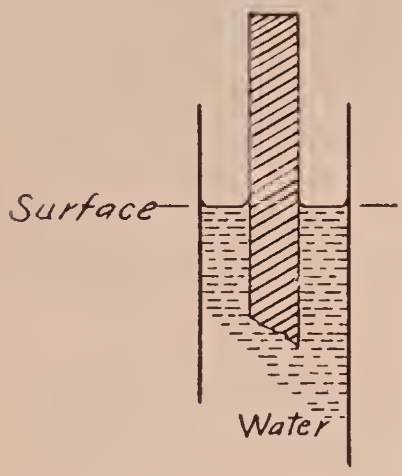

Fig. 46. Concave surfaces are read at the bottom.

Also read to tenths of a millimeter the positions of the mercury at M and m, being sure to keep your eye on a level with the mercury and reading the *top* of the surface (Fig. 59, appendix).

Note that $S—m$ is the distance h below the surface at which the pressure test is being made, while $M—m$ is the height of the mercury column supported by the pressure of the liquid. Hence $M—m$ is the pressure p, in centimeters of mercury, at a depth h in the liquid. Compute the pressure p and depth h.

Raise the manometer about 15 cm, make the necessary readings and compute the new pressure and depth. Continue in this way until the liquid has been explored to within about 15 cm of the surface.

Repeat the experiment, using another liquid such as gasoline.

B. *Effect of depth and density of liquid on pressure.* In the case of both the water and gasoline, compute the quantity depth/pressure, or h/p, for each depth h.

3. Making allowance for experimental error, how do the quotients h_1/p_1, h_2/p_2, h_3/p_3, etc. for water compare with each other? How do they compare with each other in the case of gasoline?

4. If, in a given liquid, the depth h is doubled, how will the pressure p change? What if h is tripled?

When a change in one quantity is accompanied by a change in some other quantity, the one quantity is said to *vary* with the other. When two quantities change in such a way that their ratio, or quotient, is a constant, one of these quantities is said to vary *directly* as the other.

5. Is the pressure in a liquid directly or inversely proportional to the depth?

To plot the pressure-depth curve, follow the general directions given under *Graphs* in the appendix. Make the lower left-hand corner of the squared paper the origin, plotting depths h along the X-axis and pressures p along the Y-axis. After you have plotted the points for water, you will find that a *straight* line can be drawn from the origin so that about half the points will be close to one side of the line and the other close to the other side.

6. Use your data to plot a curve showing the relation between the pressure in water and its depth.

7. How do we know that this line will pass through the origin? Why will it never pass exactly through all of the points when these points represent experimental data?

8. How are two quantities related if the curve drawn to show how one varies with the other turns out to be a straight line?

9. On the same sheet of paper, and using the same scale as for water, plot the curve for gasoline.

10. Read from your curves the pressure of water and of gasoline at a depth of 38 cm. Compare the pressures in the two liquids at various other depths. Which has the greater pressure at a given depth, the denser or the lighter liquid?

11. Which of the two curves has the steeper slope and why? Would the curve for mercury be steeper or less steep than that for water? Explain.

12. In answering Question 1, what assumption did you make with regard to the effect of pressure on the density of iron? Is this true for a liquid? For a gas?

Suggested form of record

Pressure beneath the free surface of______________________________

Surface reading S	Position of mercury in short arm m	Position of mercury in long arm M	Depth h in liquid in cm S-m	Pressure p in cm of mercury M-m	$\frac{h}{p}$

(Make a similar table for the second liquid.)

ADD. 2. LUNG-PRESSURE; PRESSURE IN THE CITY GAS MAINS

Lung pressure and gas pressure are measured with a *pressure gage.* This instrument is also used to find the steam pressure in factory, locomotive and heating boilers, and in the pressure cookers used in high altitudes by housewives. The barometer is one kind of pressure gage, it being used to measure atmospheric pressure and to forecast the weather.

A familiar type of gage is the one used to find the air pressure in an automobile tire. The life of a tire is prolonged by keeping it under the proper pressure. This pressure depends upon the size and kind of tire.

In the above cases, pressures greater than atmospheric pressure are considered. Pressures *less* than that of the air can also be measured with certain gages. Such pressures are often made use of, as in pumps and vacuum sweepers.

Accurate measurements of fluid pressure can be made with a form of gage known as the *manometer.* For measuring gas pressure and lung-pressure, the *open-tube manometer* is often used. Its form and operation are fully described in the appendix.

1. Does the open-tube manometer measure the excess of pressure above that of the atmosphere, called the *gage pressure,* or does it measure the total, or *absolute,* pressure?
2. If the opening of a gas cock has a cross-sectional area of 0.6 cm^2 and the gas pressure is 24 g/cm^2, what would be the force in grams exerted by the gas on your finger if you held it against the opening?
3. A man blowing steadily into an open-tube mercury manometer produces a difference in levels h of 9.82 cm. What is his effective lung pressure in grams per cm^2? Density of mercury is 13.6 g/cm^3.

EXP. ADD. 2, PART I. *Measure your lung-pressure and also the reduction in pressure which you can produce by the mouth.*

(a) Fill an open-tube manometer half full of mercury and support it in a vertical position with a meter stick between the two arms.

Attach an 8 cm glass tube, rounded on the ends in a Bunsen flame, to the short arm of the manometer by means of a piece of rubber tubing. If several students use this mouthpiece, sterilize it each time in boiling water.

Blow steadily into the tube for two or three seconds. A quick hard blow into the mouthpiece will not give you a true measure of your lung-pressure. Why?

While blowing, pinch the rubber tube and read to tenths of a millimeter the positions M and m of the two mercury surfaces. (See Fig. 59 in the appendix.) Place your eye on a level with the mercury and read the top of the mercury surface.

Tabulate data and compute the average value, in centimeters of mercury, of the pressure above that of the atmosphere which you can produce by blowing.

Reduce this value to grams per square centimeter.

4. If you had used water in the manometer, instead of mercury, what would the difference in water levels have been?

5. Would more or less accuracy have resulted from using a longer manometer containing water? Explain.

6. Compute the average lung pressure of the class and find what per cent your lung-pressure is of the class average.

7. The mercury barometer is a form of manometer. Examine the one in the laboratory and explain how it measures atmospheric pressure. If necessary, refer to a textbook.

(b) The same manometer can be used to measure the *reduction* in pressure which you can produce with the mouth. It may be necessary to remove some of the mercury, as great care should be taken not to get any of it into the mouth. Apply the mouth to the tube and draw the air out as completely as possible. Then follow the same procedure as in the case of measuring pressure due to blowing. Record data and find the average value of the reduction in pressure in centimeters of mercury. Reduce this value to grams per square centimeter.

EXP. ADD. 2, PART II. *Measure the pressure in the city gas mains.*

The pressure in the gas mains must be greater than that of the atmosphere or the gas will not flow out. If the gas pressure is too low, a gas stove often will not operate satisfactorily.

(a) Fill an open-tube manometer a little more than half full of water and support it in a vertical position with a meter stick between the two arms. (See Fig. 59 in the appendix.)

Attach the short arm of the manometer to the gas outlet by means of rubber tubing and turn on the gas slowly. Read to tenths of a millimeter the positions of the two water surfaces, placing your eye on a level with the water and reading the bottom of the water surface (see Fig. 46). From these two readings compute the difference in water levels.

Turn off the gas and repeat this operation several times. This is especially necessary if there is much fluctuation in pressure.

Tabulate data and compute the average value of the gage gas pressure in centimeters of water and also in grams per square centimeter.

4. What would the difference in the levels have been if you had used mercury in the manometer instead of water?

5. Would more or less accuracy have resulted from using mercury? Gasoline? Explain.

6. Compute the *absolute* or total pressure of the gas in grams per square centimeter by adding the gage pressure to the atmospheric pressure. To do this, read the barometer in centimeters of mer-

cury to the same degree of accuracy that you read the manometer (to tenths of a millimeter); reduce this reading to grams per square centimeter by multiplying by the density of mercury, and add this to the gage pressure expressed in the same units.

(b) A second very simple apparatus for measuring gas pressure consists of a piece of straight glass tubing about 30 cm long which is attached to the gas supply with rubber tubing. Lower the end of the glass tube into a deep vessel of water and turn on the gas.

7. Compare the value of the pressure obtained with this apparatus with that obtained with the manometer. Explain why the gas pressure can be obtained by this method.

8. Does this apparatus measure the gage pressure or the absolute pressure? Explain.

SPECIAL EXPERIMENT. *How to make a barometer.* Use a heavy glass tube with one end sealed, about 80 cm long and with about a 4 mm bore. Cleanse the bore of the tube with sulfuric ether, allowing the ether to evaporate. To fill the tube, stand it in a dish at an angle of forty-five degrees and drop clean mercury into it with a medicine dropper. Remove all air bubbles by means of a long straight wire on the end of which are tied securely some small bits of thread.

With the tube filled to the brim, place the finger over the open end, invert the tube, and place the end of the tube below the surface of mercury contained in a wide-mouth bottle or shallow dish. Remove the finger under mercury without allowing any air to enter the tube.

Support the tube in a vertical position, with the open end resting lightly on the dish or on a small piece of wire screen, which will allow free passage of the mercury. Place a meter stick beside the tube so that the zero mark is just level with the mercury in the dish. To find the atmospheric pressure in centimeters of mercury, measure the height of the mercury column, reading to the *top* of the convex surface in the tube. Why the top?

If possible compare your barometer with a standard mercury barometer; if there is any differenec in the readings, learn how to correct the error.

If desired, fasten the barometer tube with wires to a vertical board at the lower end of which is a shelf large enough to hold the bottle or dish of mercury. The meter stick must be placed on the board in such a manner that the scale can be moved up or down. Why is this necessary?

Will changes in the temperature affect the reading of a barometer? Why is it essential that the barometer scale be accurately vertical? Why must the zero mark of the scale always be level with the mercury surface in the dish before a reading is taken? How is this adjustment of the scale made on a standard mercury barometer?

ADD. 3. THE INCLINED PLANE

If a cake of ice is too heavy for the iceman to lift, he can get it into the wagon by sliding it up a plank or *inclined plane*. Work is not saved, however, by using the inclined plane, for it requires more work to slide the ice up the incline than to lift it into the wagon.

The inclined plane can be studied by constructing a small model like Fig. 47. The total work *expended* in moving the small car from the bottom to the top of the incline is $F \times l$, that is, the product of the force F parallel to the plane and the distance l through which the car moves in the direction of this force.

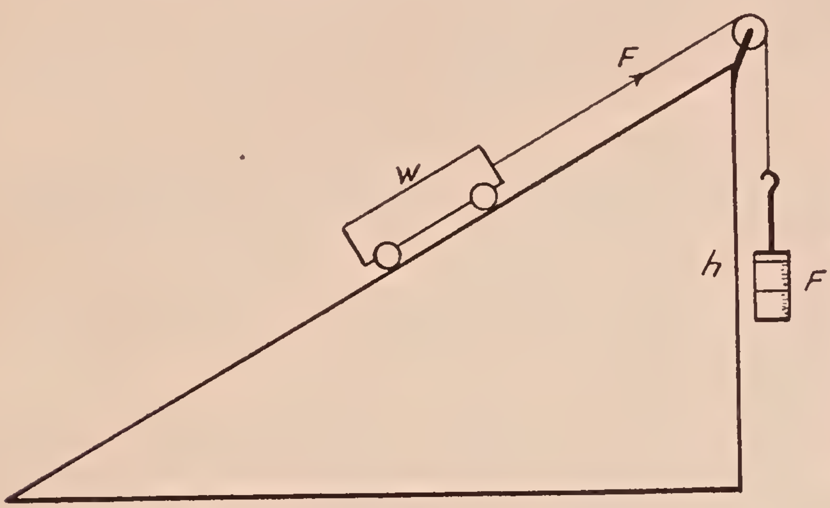

Fig. 47. Model of an inclined plane.

The useful work *accomplished* is $W \times h$, the product of the load or weight of car W and the vertical distance h. This *accomplished* work is the work which would be done if the car were lifted to a height h against the force of gravity W without the use of a machine like the inclined plane.

If the distances l and h are measured in centimeters and the forces F and W in grams, the products $F \times l$ and $W \times h$ will each be in gram-centimeters of work.

The efficiency of a machine is given by the formula,

$$\text{Efficiency} = \frac{\text{useful work accomplished}}{\text{total work expended}} = \frac{W \times h}{F \times l}.$$

In actual practice this efficiency will always be less than 100 percent because of friction. If there were no friction, the useful work accomplished with the inclined plane would be equal to the work expended on it.

EXP. ADD. 3. PART I. *Construct an inclined plane and find its efficiency.*

Arrange an apparatus similar to that of Fig. 47, with the board making an angle of about 30 degrees with the table.

Add weights to the weight hanger until the car moves steadily and slowly up the plane. If suitable small weights are not available it may be necessary to place some shot or other material in the car to get a final adjustment.

Measure h and l. Find the load W by weighing the car and its contents. Tabulate your values for W, F, l and h and from this data calculate in gram-centimeters the work which would be *expended* and also the work which would be *accomplished* in pulling the car from the bottom to the top of the plane, and then calculate the efficiency.

Repeat the experiment with the plane at a larger angle with the table.

1. Which is the greater, the expended work or the accomplished work, and why?
2. Why was it necessary to have the car moving uniformly on the plane?
3. Compare F and W and draw conclusions as to why an inclined plane is a useful machine.
4. Does making the slope steeper increase or decrease the efficiency? Why? What is the disadvantage of making the slope steeper?

EXP. ADD. 3. PART II. *Test the principle of work by comparing the work expended and accomplished on the inclined plane when the effects of friction are made negligible.*

Arrange the apparatus as in Fig. 47, with the board at an angle of about 45 degrees with the table.

Place enough weights on the weight hanger to exactly balance the weight of the car. Friction cannot be avoided but if the weights on the hanger are such that on giving a slight push to the car it moves with equal readiness down the plane and up the plane, these weights plus the hanger will then be the force F which would support the car W on the plane if there were no friction.

If suitable small weights are not available, some shot or other material can be added to the car to obtain an exact balance: The load W will then be the weight of the car and its contents.

Read and record W, F. l and h and from these data calculate in gram-centimeters the work which would be expended and also the work which would be accomplished in pulling the car from the bottom to the top of the plane if there were no friction.

1. How does work expended compare with work accomplished when there is no friction? What is the efficiency in this case?
2. The quotient W/F is called the theoretical mechanical advantage. Find its value for the inclined plane which you constructed and state what information it gives you.
3. Explain why the effects of friction were largely eliminated by the method which you used.
4. Neglecting friction, if an inclined plane is 5 feet high, how long must it be to enable a car weighing 2 tons to be pushed up its length by a force of 200 lbs?

ADD. 4. EFFECT OF PRESSURE ON THE BOILING POINT

The boiling point of water is 100°C only when the pressure of the air or vapor above the water is exactly 760 mm of mercury. If the pressure is less, the boiling point is reduced and account must be taken of this fact, as we found in Exp. 12. On the other hand, if the pressure is higher the boiling point is raised, this being the principle upon which *pressure cookers* operate.

Although the amount of change of the boiling point with pressure has been determined many times, it is an interesting experiment to perform. It gives one an opportunity to compare the results of his own work with those secured by skilled scientists using the best of equipment.

EXP. ADD. 4. *Measure the effect of pressure on the boiling point of water.*

Set up the steam generator as shown in Fig. 48, with the open-tube manometer filled with mercury to a height of about 8 cm. The pressure is to be controlled by the pinchcock and measured by the manometer.[1]

The pressure is increased by closing the pinchcock and thus preventing the steam from escaping freely. The *increase* in pressure is measured in millimeters of mercury by taking the difference in the mercury levels in the manometer arms.

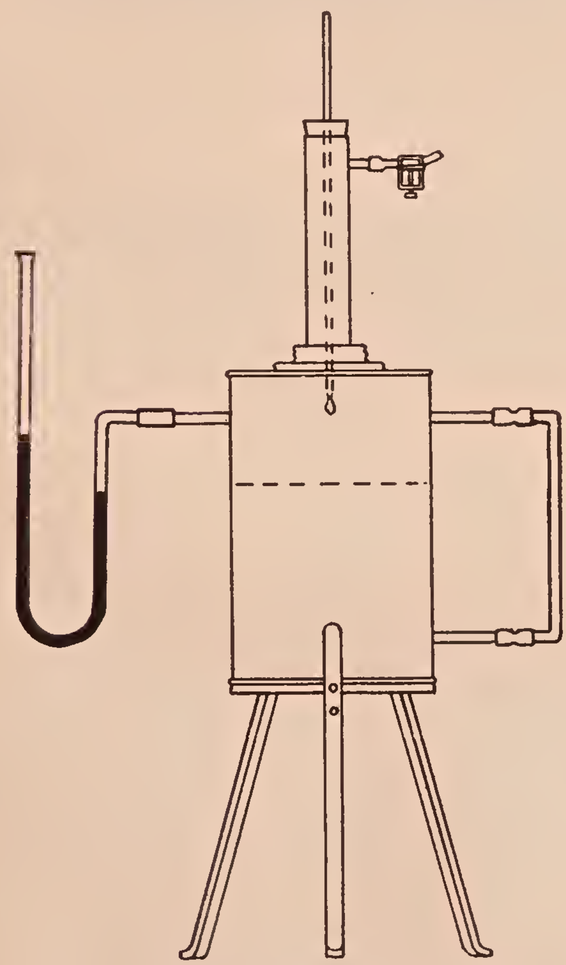

Fig. 48. Effect of pressure on the boiling point.

(a) First read the thermometer carefully when the pinchcock is wide open. The pressure in the boiler will then be that of the atmosphere and the mercury will be at the same level in both arms of the manometer.

(b) Now partly close the pinchcock until the manometer shows a difference in level of 40 to 50 mm. As soon as the readings of the thermometer and manometer become steady, observe and record these readings.

(c) Close the pinchcock still farther, until the difference in the mercury levels is about 20 mm greater than before, and repeat the observations.

(d) Repeat again, once or twice, finishing with a difference in level of about 100 mm.

In each of the above cases, calculate the change produced in the boiling point by a change of 1 mm in the

[1]See Manometer in the appendix.

pressure. Take the average of these calculations as the best value for the change in boiling point per mm change in pressure.

1. From your data calculate the change of pressure needed to change the boiling point by 1°C.
2. If the pressure in a pressure cooker is allowed to increase to twice that of the atmosphere, what is the temperature of the water in the cooker? Of the steam?
3. Explain why the boiling point is influenced by pressure.

Suggested form of record

Temperature of boiling point in °C.					
Total increase in temperature of boiling point, in °C.					
Manometer pressure in mm of mercury					
Change in boiling point per mm change in pressure.					

Average change in boiling point per mm change in pressure______________________°C.

Accepted value_________________________.

Per cent of difference____________________.

SPECIAL EXPERIMENT. *Measuring altitude with an aneroid barometer.* (a) Measure the vertical distance from the basement to the highest accessible point on a building by reading the aneroid barometer at both points. Place the barometer face up on the floor and tap the frame gently to assist the mechanism in overcoming the friction of the bearings. A change in reading of 1 mm means a difference in elevation of approximately 10.5 meters, providing that the temperatures of the two points are the same.

(b) How much does the elevation of your locality above sea level affect the atmospheric pressure? To answer this question, find the elevation of your locality from a map, or other source, and compute the local correction of a barometer. The pressure at sea level is to be taken as 760 mm of mercury.

ADD. 5. THE LAWS OF VIBRATING STRINGS

EXP. ADD. 5. *Find how the vibration rates of wires are affected by length and tension.*

A. *Effect of length.* (a) Stretch a fine steel wire on the sonometer, Fig. 49. Place the movable bridge under the wire at a point about two-thirds of the distance from its fixed end and tune the wire until it emits a sound of the same pitch as that given by the lowest tuning fork.

To accomplish this, pluck the wire in the middle with the finger and adjust the tension by means of the weights or set screws until the two tones are almost in unison. Then complete the tuning by adjusting the position of the bridge. When the two tones are almost, but not quite, in unison, you will be able to hear *beats*, which become less and less frequent as the two tones approach the same pitch. When the tones have the same pitch, the beats will cease.

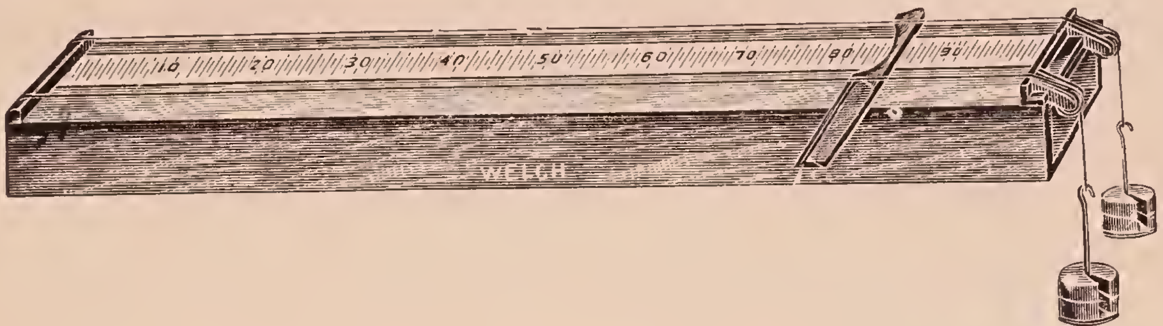

Fig. 49. One form of sonometer.

Measure the length of the wire. Then displace the bridge and, without changing the tension on the wire, repeat the tuning. Again measure the length of the wire and compute the per cent of difference between this measurement and the first one by means of the formula,

$$\text{Per cent of difference} = \frac{\text{difference between the two lengths}}{\text{either length}} \times 100.$$

If this difference exceeds about 0.5%, make additional trials, since so large an error indicates careless adjustments, changes in the tension of the wire or an incorrect determination of the length. Record your data in a table similar to the one at the end of this experiment.

(b) Without changing the tension on the wire, adjust its length by means of the movable bridge until it sounds exactly in unison with a second tuning fork of higher pitch than the first. Make several trials as before and record your results in the table. Repeat the tuning with such other forks as are available.

1. How do the measured lengths of the wire compare with their vibration numbers? State the relationship between the rate of vibration of a string and its length when the tension is kept constant.

2. Examine the strings on a piano and determine whether long or short strings are used for the high notes.

3. How much does the pitch of a wire change when its length is doubled? To test your conclusion, set the whole sonometer wire into vibration by plucking it near one end, and then touch the wire exactly at its midpoint with your finger.

B. *Effect of tension.* Stretch two fine steel wires of the same diameter on the sonometer. Place the same tension on both wires, using enough tension so that the wires produce a low but distinct tone when set into vibration.

(a) Without changing the tension on the wires, make one of them just half as long as the other by placing a bridge under its midpoint. Call the rate of vibration of the long wire n_1 and its tension T_1.

4. What is the rate of vibration of the short wire, as compared with that of the long wire? How do their pitches compare?

Without making any further changes in the lengths of the wires, adjust the tension on the long wire until it emits a sound of exactly the same pitch as that given by the short wire. The vibration rate n_2 of the long wire is now $2n_1$. Read and record the new tension on the long wire, calling it T_2.

5. How does the ratio $\frac{T_1}{T_2}$ compare with the ratio $\frac{n_1}{n_2}$? How does $\frac{\sqrt{T_1}}{\sqrt{T_2}}$ compare with $\frac{n_1}{n_2}$?

6. In order to double the vibration rate of a wire, how many times must the tension be multiplied?

(b) Repeat the experiment with the bridge placed under the short wire so that it is only two thirds the length of the long wire, both wires being under the same initial tension T_1. Again increase the tension on the long wire until both wires emit the same tone. Call this final tension T_2.

7. How much was the vibration rate of the long wire changed when its tension was increased from T_1 to T_2?

8. How do $\frac{n_1}{n_2}$ and $\frac{T_1}{T_2}$ compare this time? How do $\frac{n_1}{n_2}$ and $\frac{\sqrt{T_1}}{\sqrt{T_2}}$ compare?

9. How many times must we multiply the tension on a wire in order to triple its vibration rate?

Suggested form of record

A. Effect of Length

Length of wire in cm				Rate of vibration
Trial 1	Trial 2	Per cent of difference	Average length	

B. Effect of Tension

$\frac{n_1}{n_2}$	T_1 grams	T_2 grams	$\frac{T_1}{T_2}$	$\frac{\sqrt{T_1}}{\sqrt{T_2}}$

ADD. 6. LAWS OF RESISTANCE USING AMMETER AND VOLTMETER

There are a number of methods for measuring the resistance of a conductor. The ammeter and voltmeter method is one of the simplest and most convenient. It is based on Ohm's law, which may be written

$$\text{Resistance (ohms)} = \frac{\text{potential difference (volts)}}{\text{current (amperes)}}$$

It can be seen from the above law that the resistance of a given part of a circuit can be found if both the potential drop or voltage over this particular part of the circuit and the current in the circuit are measured.

EXP. ADD. 6. *Measure the resistance of several wires alone and when connected in series and parallel.*

A. *Measurement of resistance using an ammeter and voltmeter.* Connect the apparatus as indicated in Fig. 50, using one cell.[1]

Measure the current in each wire and the potential drop over the wire. Calculate the resistance of each.

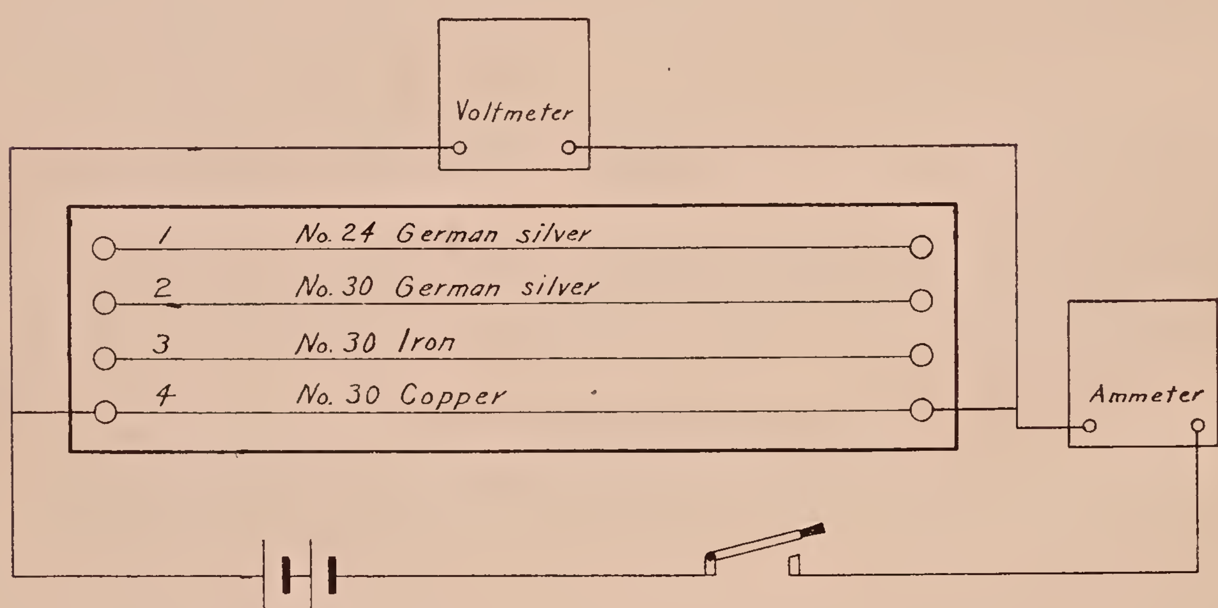

Fig. 50. Measuring the resistance of a wire with an ammeter and voltmeter.

In order to find out whether the current has any effect on resistance, add another cell and repeat the observations and calculations.

Measure the diameters of the wires with a micrometer caliper and also ascertain the material of which the wires are made.

1. Compare the resistance of two equal lengths of wire, of the

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[1]See Ammeters and Voltmeters in the appendix.

same material but of different sizes, and see if your results show that resistance varies inversely with the square of the diameter.

2. Compare the resistances of equal lengths of wire, of the same diameter but of different materials, and give your conclusions regarding the importance of the material of which an electrical conductor is made.

3. (a) What effect does the current in a conductor have upon its resistance? (b) How does the voltage drop over a conductor vary with the current?

B. *Resistance of conductors in series.* Connect two of the wires in series so that the current passes through one after the other and also through the ammeter. Connect the voltmeter to read the potential difference over both wires. Calculate the resistance from the ammeter and voltmeter readings and check the result against the sum of the resistances of the separate wires as found in *A*.

Connect three of the wires in series and measure the total resistance. Compare with the sum of the resistances of the separate wires as found in Part I.

4. Give the general law for calculating the total resistance of a number of resistances in series and show that it is confirmed by your experiments.

5. (a) Which is the same in all parts of a series circuit, voltage or current? (b) What can be said about the possible positions of an ammeter in a series circuit?

C. *Resistance of conductors in parallel.* Connect two of the wires in parallel. When the resistance of wires in parallel is to be measured, the ammeter must be placed so as to read the total current through the wires. Connect the voltmeter so that it will read the potential drop in the wires. Record current and voltage and compute the resistance of this parallel circuit. Using the values of resistance of the separate wires found in A, above, calculate the resistance of this parallel circuit and compare your answer with the value obtained experimentally.

6. Give the law for calculating the resistance of two branches in parallel and show that it is confirmed by your results.

Connect three or four wires in parallel and measure their combined resistance.

7. Give the general law for calculating the resistance of any number of branches in parallel and show that it is confirmed.

8. Adding resistance in parallel has what effect on the total resistance? On total current?

9. Adding resistance in series has what effect on the total resistance? On the current?

Suggested form of record

A

Wire No.	Diameter and material of wire	Potential drop or voltage V	Current I	Calculated resistance R
	Using one cell			
1				
2				
3				
4				
5				
6				
	Using two cells			
1				
2				
3				
4				
5				
6				

B

Resistance of two wires in series:

Voltage drop over wires No.____________and No.____________in series, ____________volts.

Resistance of wires No.___________and No.___________ in series, (V/I)___________ohms.

Calculated resistance, using resistance from *A* ____________________ohms.

Resistance of three wires in series:

Voltage drop over wires No.________, No.________ and No.________, in series________volts.

Current_______________________amperes.

Resistance of wires No. _______________, No. _______________ and No.______________

in series, (V/I) ___________________ ohms.

Calculated resistance, using resistances from A ___________________ ohms.

C

(Devise your own form of record.)

ADD. 7. THE WHEATSTONE BRIDGE[1]

Charles Wheatstone in 1843 invented an instrument called the Wheatstone bridge which has a wide application in electrical measurements. Wheatstone bridges are made in several different forms but all depend upon the principle illustrated by the simple diagram of Fig. 51.

Four resistances X, R, a and b are connected as indicated in the diagram. When the key k is closed, the current divides at C and one part, i_1, flows through X and R to D and the other part, i_2, flows through a and b to D. One end of the galvanometer G is connected permanently to E while the other end is connected to some point F, so chosen that no current flows through the galvanometer.

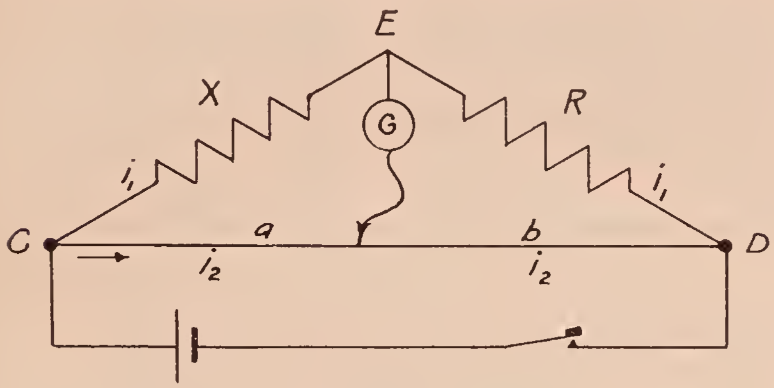

Fig. 51. Diagram of a Wheatstone bridge.

In the form of Wheatstone bridge which we will use in this experiment, called the *slide wire bridge*, the resistances a and b are parts of a long straight wire of uniform cross-section. This wire is stretched between the points C and D, the point F being found by sliding the movable contact back and forth along this wire, until a point is found on the wire for which the galvanometer shows no deflection.

When the point F has thus been located, the bridge is said to be *balanced* and E and F are at the same potential. Why? This means that the potential drop over the resistance X, which by Ohm's law is equal to $i_1 \times X$, is exactly the same as the potential drop over the resistance a, which is equal to $i_2 \times a$.

As $\quad i_1 \times X = i_2 \times a,$

similarly $\quad i_1 \times R = i_2 \times b.$

Dividing the first equation by the second,

$$\frac{X}{R} = \frac{a}{b}$$

In the slide wire form of bridge, the resistances a and b are parts of the same uniform wire; consequently, these resistances are proportional to the lengths of wire CF and FD and the above equation becomes

$$\frac{\text{Unknown resistance}}{\text{Known resistance}} = \frac{\text{length of wire adjacent to unknown resistance}}{\text{length of wire adjacent to known resistance}}$$

[1]This experiment is substantially the same as Exp. Add. 6, except for the method of measuring resistance.

EXP. ADD. 7. *Measure the resistance of several wires alone and when connected in series and parallel.*

A. *Measurement of resistance with a Wheatstone bridge.* Arrange and connect the apparatus[1] as indicated in Fig. 52, and measure the resistance of a number of wires.

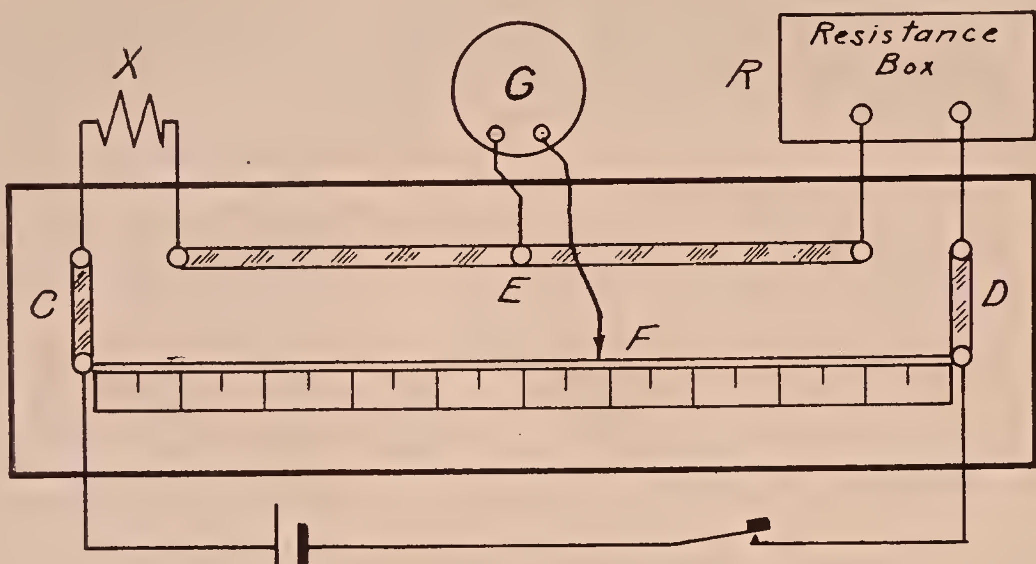

Fig. 52. Slide-wire Wheatstone bridge.

Connect the unknown resistances at X, using connecting wires of as low a resistance as possible. If the resistance of the connecting wires is appreciable in comparison with that of X, it is a good plan to short circuit the connecting wires and measure their resistance. This may be subtracted from the values of X found by experiment, giving the true resistance of X.

In order to balance the bridge, guess at the value of the unknown resistance and adjust the resistance box to this amount. If you have guessed correctly, the bridge will balance with the point F at about the middle of the wire. Make contact at the middle and note the *direction* of the deflection of the galvanometer. A very brief contact is usually sufficient. Try making contact at various points on the wire until you obtain a deflection in the *other direction.* Then find the point for which there is no deflection. The accuracy of the result is greatest when the point F is not too close to the ends. By changing the value of the known resistance in the box it is possible to bring the point F nearer the middle of the wire.

[1]It is an easy matter to construct a serviceable slide wire bridge. Mount two binding posts a meter apart on a long board and stretch between them a meter length of No. 36 German Silver wire. (Any length will serve but a meter length is convenient). The heavy strips of metals shown in Fig. 52 are not necessary. Their purpose is to make it possible to use short connecting wires to the resistances X and R. If as short lengths as possible of No. 18 copper wire, or larger, are used the arrangement shown in Fig. 51 will be perfectly satisfactory.

1. If the balance point F is in the exact middle of the bridge wire, what is the relation between the unknown resistance X and known resistance R?

2. If the balance point F is found to be close to the end of the wire connected to the resistance box R, which is the smaller resistance, X or R?

3. If the balance point F is found to be very close to the end of the wire connected to the resistance box R, should one increase or decrease the resistance in R, so as to make F come nearer the middle of the wire?

B. *Resistance of conductors in series.* Connect in series two of the resistance wires used in Part I and place them at X. Measure their resistance in series and check the result against the sum of the resistances of the separate wires as found in Part I.

Connect three or four of the wires in series and measure their total resistance. Compare your result with the sum of the resistances of the separate wires, as found in Part I.

4. Give the general law for calculating the total resistance of a number of conductors connected in series and show that it is confirmed by your experiments.

C. *Resistances of conductors in parallel.* Connect two of the wires used in Part I in parallel and measure their combined resistance.

5. Give the law for calculating the resistance of two conductors connected in parallel and show that it is confirmed by your results.

6. Explain why the combined resistance of conductors in parallel should be less than the resistance of either conductor alone.

Connect three or four wires in parallel and measure their combined resistance.

7. Give the general law for calculating the resistance of conductors in parallel and show that it is confirmed by your results.

8. Adding resistance in parallel has what effect on the total resistance?

9. Adding resistance in series has what effect on the total resistance?

Suggested form of record

A

Wire No.	Size and kind of wire	Distance adjacent to X $C\,F$	Distance adjacent to R $F\,D$	Known resistance in ohms R	Unknown resistance in ohms X
1					
2					
3					
4					
5					
6					

B

Measured resistance of wires No.__________and No.__________, in series__________ohms.

Calculated resistance of wires in series, using values from A____________________ohms.

Measured resistance of wires No.____________, No. ____________, No. ____________ and No.____________ in series ____________ohms.

Calculated resistance of wires in series, using values from A ____________________ ohms.

C

Measured resistance of wires No. _______________, and No. _______________, in parallel_________________ohms.

Calculated resistance of wires in parallel, using values from A___________________ohms.

Measured resistance of wires No.____________, No.____________, No.____________ and No.____________, in parallel____________ohms.

Calculated resistance of wires in parallel, using values from A___________________ohms.

ADD. 8. EFFICIENCY OF INCANDESCENT LAMPS

When Edison invented the incandescent lamp with the carbon filament he made possible the lighting of houses with electricity. Since then great progress has been made in increasing the efficiency of incandescent lamps. Two of the most important steps have been the use of filaments made of tungsten, which has a very high melting point and can be operated at a much higher temperature than carbon, and the use of gas-filled bulbs. The gas in a gas-filled bulb exerts a pressure on the filament and thus keeps it from evaporating so quickly. The filament can then be operated at a higher temperature than is possible in a vacuum lamp. In this experiment the old fashioned carbon lamp, operating at a temperature of about 1850° C. and giving a yellowish light, will be compared with modern tungsten lamps, operating at temperatures of about 2300° C. and giving a much whiter light.

In order to measure the *power* required to operate a given lamp, it is necessary to know the current passing through the lamp and the potential drop.

Power in watts = potential drop in volts $\times$ current in amperes.

In order to compute the total amount of electrical *energy* used in a lamp it is necessary to consider the time during which the power has been used. The unit of electrical energy usually employed is the kilowatt-hour.

$$\text{Energy in kilowatt-hours} = \frac{\text{power in watts} \times \text{time in hours}}{1000}$$

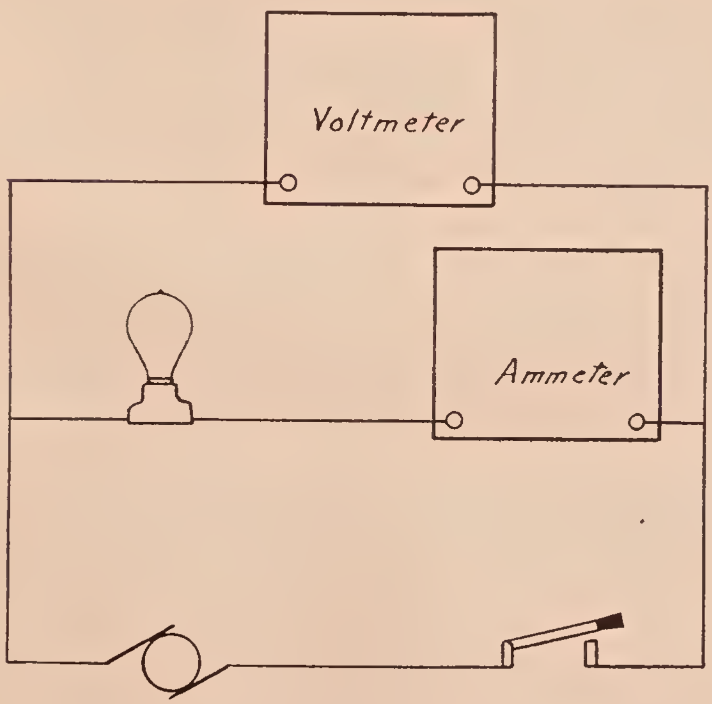

Fig. 53. Ammeter-voltmeter method of measuring resistance and power.

Cost of operation per hour = kilowatts $\times$ cost per kilo-watt-hour.

When the efficiency of an incandescent lamp is measured in candle power per watt, the efficiency is given by the relation,

$$\text{Efficiency} = \frac{\text{candle power}}{\text{power in watts}}$$

The approximate candle powers of several types of lamps are given in the table at the end of this experiment.

EXP. ADD. 8. *Measure the power necessary to operate various types of electric lamps.*

Connect the apparatus as indicated in Fig. 53, with the ammeter measuring the current through the lamp and the voltmeter the potential difference, or voltage, applied to the lamp[1].

Measure the current and voltage for each lamp and calculate the power in watts. Record the observed data in the table at the end of the experiment and compute the data for the other columns.

It is not expected that you will be able to test all the lamps listed. Some of the questions involve lamps which you will probably not test. In such cases use the information printed in the data table at the end of the experiment and make whatever computations are necessary to answer the questions.

1. Compare the power required by a 32 c.p. carbon lamp and a 40-watt vacuum tungsten lamp. Compare their candle powers. How much more efficient is the tungsten lamp than the carbon lamp?
2. How many times more efficient is a 100-watt gas-filled tungsten lamp than a 25-watt vacuum tungsten lamp?

Gas-filled lamps are not made in the smaller sizes since they are then not as efficient as vacuum lamps. This is because of the large amount of heat lost through convection and conduction when the bulbs are small. The heat losses become relatively less and less as the size increases, a 1000-watt gas-filled lamp being twice as efficient as a 40-watt vacuum tungsten lamp.

3. How many times more efficient is a 200-watt gas-filled lamp than a 100-watt gas-filled lamp? Than a 25-watt vacuum lamp?
4. How much more light is given by a 200-watt gas-filled tungsten lamp than is given by five 40-watt vacuum lamps?
5. Which is better for lighting a living room, one 200-watt gas-filled lamp in a properly designed fixture or six 40-watt lamps on a chandelier? Explain.
6. Can you give a good reason why some dentists prefer to use carbon lamps, rather than tungsten lamps, to illuminate the mouth of a patient?
7. What is the resistance of a 25-watt tungsten lamp? Of a 40-watt tungsten lamp? Of a 16 c.p. carbon lamp? Of a 32 c.p. carbon lamp?
8. Write down the simplest formula which can be used to compute the resistance of a lamp, if its voltage and wattage are known.

[1]See **Ammeters** in the appendix.

Suggested form of record

Description of lamp	P. D. in volts	Current in amperes	Power in watts	Rated watts	Rated candle power	Efficiency in c. p. per watt[1]	Cost per hour
16 c. p. carbon					16		
32 c. p. carbon					32		
25-watt tungsten					18		
40-watt tungsten					32		
60-watt tungsten					50		
75-watt gas-filled tungsten					72		
100-watt gas-filled tungsten					103		
200-watt gas-filled tungsten					240		

[1]The candle power listed is based on the operation of the lamp at **rated watts** and consequently, in computing the efficiency, the rated watts rather than the observed watts should be used.

SPECIAL EXPERIMENT. *School electric lighting system.* Examine the main wires, the switch-box, the fuses and the branch wires. Trace and make a diagram of the circuit from the point where it enters the building to the branch wires.

Read the meter. Turn on more lights in the building and observe the effect on the meter.

What is the purpose of the main switch? Why are the main fuses placed between the meter and the point where the circuit enters the building?

What is the advantage of having a separate set of fuses for each branch circuit? Describe the type of fuse used. What is its ampere carrying capacity?

Examine one of the branch circuits to see if it is overloaded. To do this, add up the number of amperes taken by all the lamps and appliances on the circuit. If this sum exceeds the rating stamped on the fuse, the fuse will blow. The number of amperes used by lamps operating at from 105 to 120 volts may be taken as follows: 25 watt, 0.13; 50 watt, 0.43; 75 watt, 0.65; 100 watt, 0.87. The current used by electrical appliances can generally be learned by examining the name plate on the device.

If convenient, place a low capacity fuse in one of the branch circuits and try the effect of overloading the circuit.

ADD. 9. ELECTRICITY IN THE HOME

In this experiment we will study the power used by heating devices and motors and will determine the efficiency of some form of heating device.

When electrical energy is transformed into heat, every watt-hour of electrical energy produces exactly 864 calories of heat. The question of whether this heat is available for the purpose for which you wish to use it is a matter which depends upon the efficiency of the device. For example, a great deal of the heat from an electric toaster is wasted in the room. On the other hand an electric heater, made to heat a room, is 100 per cent efficient, for all the heat remains in the room. An immersion coil for heating water is nearly 100 per cent efficient, for the heating element is almost completely surrounded by the water.

The *practical efficiency* of a heating device is the fraction of heat produced which is available for the intended purpose.

$$\text{Practical efficiency} = \frac{\text{useful heat produced}}{\text{total heat produced}}.$$

It is not always an easy matter to determine the practical efficiency, due to the fact that it is often difficult to measure the *useful heat* produced. Fortunately the *total heat* produced is easily determined, not by direct measurements of the heat, but from a knowledge of the fact that

$$\begin{aligned}\text{Heat in calories} &= \text{volts} \times \text{amperes} \times \text{time (seconds)} \times 0.24,\\ &= \text{watts} \times \text{seconds} \times 0.24,\\ &= \text{watt-hours} \times 864.\end{aligned}$$

EXP. ADD. 9, PART I. *Measure the power required by various household appliances.*

Connect each of the applicances, in turn, as indicated in Fig. 53. Place the ammeter so that it reads the current which passes through the device being tested and connect the voltmeter *outside* the ammeter.[1]

Read amperes and volts and record the data in a table similar to that at the end of this experiment. Compute the power in watts and the cost per hour, using the local rate.

1. Compare the power consumed by the various applicances. Which are more expensive to operate, household electric motors or household electric heating appliances?
2. How does the power required to operate a flatiron compare with that needed to light the living room in your house?
3. How does the power required to operate an electric fan compare with that used by a 25-watt lamp? With that used by an electric iron?

[1] See Ammeters in the appendix.

EXP. ADD. 9, PART II. *Determine the practical efficiency of some form of water heater.*

This experiment may be performed with a dish of water placed on a hot plate, or with water contained in the dish of a small electric stove or chafing dish. At least one group of students should test an immersion coil, if one can be secured.

Connect the apparatus in such a way that the current is measured by the ammeter and the potential drop by the voltmeter. Weigh or measure an amount of water suitable to the container and measure its temperature t_1. Place the water on the hot plate and turn on the current on an even minute, nothing the time T_1 on a watch. Stir the water gently from time to time and, when its temperature is about 90°C., turn off the current on an even minute and note the time T_2. Stir the water and observe its temperature t_2.

Compute the watt-hours of energy consumed and the number of calories of heat actually delivered to the water. Then compute the practical efficiency of the applicance, including the dish, in calories per watt-hour. Also compute the efficiency in per cent of the maximum possible efficiency, which is 864 calories per watt-hour.

1. Explain fully why an immersion heater is a more efficient appliance for heating water than is a hot plate or chafing dish.
2. Why does a flatiron require a relatively large amount of heat?
3. Discuss the effect of the dishes used with an electric stove upon its efficiency, considering among other factors, (a) shape, (b) material, (c) size.

Suggested form of record

PART I. POWER REQUIRED BY APPLIANCES

Description of appliance	Current in amperes	P. D. in volts	Power in watts	Rated watts	Cost per hour

PART II. EFFICIENCY OF APPLIANCES

	Appliance No. 1	Appliance No. 2	Appliance No. 3
Description of appliance			
Current in amperes, I			
Potential difference in volts, V			
Power in watts, VI			
Time of closing switch, T_1			
Time of opening switch, T_2			
Total time in hours, T			
Energy in watt-hours, VIT			
Cost of operating, per hour			
Mass of water in grams, m			
Initial temperature, t_1, in °C.			
Final temperature, t_2, in °C.			
Increase of temp. of water in °C., $t_2 - t_1$.			
Heat delivered, in calories, $m \times (t_2 - t_1) \times 1$.			
Efficiency in calories per watt-hour, $\frac{m(t_2 - t_1)}{VIT}$			
Efficiency in percent of ideal or maximum possible efficiency.			

ADD. 10. THE BUNSEN PHOTOMETER.

Before attempting to work with the photometer, the student should read the introduction to Exp. 34.

The *Bunsen photometer* is sometimes called the *grease spot* photometer, because it consists of a screen having in the middle of it a spot which is greased to make it partly transparent. If both sides of the screen are equally illuminated, this spot tends to disappear.

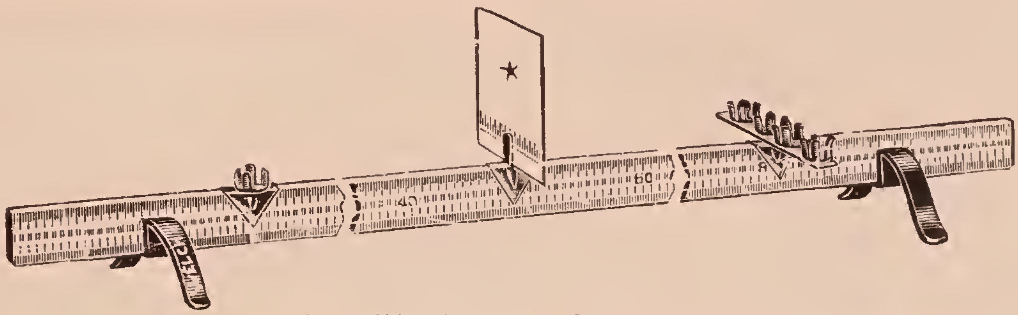

Fig. 54. Bunsen photometer.

When the candle power of a source of light is measured with this photometer, use is made of the principle that the candle powers of two sources of light which produce equal brightness on the photometer screen are directly proportional to the square of the distances of the sources from the screen. It is this principle which we will test in this experiment.

Exp. Add. 10. *Construct a Bunsen photometer and use it to test the relation between the candle powers of two lights and their distances from the photometer screen.*

In a darkened room, set up a Bunsen photometer[1] similar to the one shown in Fig. 54.

Place a single candle on each side of the screen. If necessary, trim the wicks to make them burn equally, and then move the screen back and forth on the meter stick until the grease spot either disappears or else appears as nearly as possible the same on both sides. Measure and record the distance of each candle from the spot on the screen.

Now place two candles on one side of the screen, leaving the single candle on the other side. Make sure that all three candles are burning properly and again adjust the position of the screen until the spot again disappears or has the same appearance on both sides.

Repeat with three, and finally four candles on one side, and a single candle on the other side.

For each of the above four cases, compute the ratio of the candle powers of the two sources and also the ratio of the squares of their respective distances from the screen.

[1]To make a Bunsen screen, put a drop of melted paraffin in the middle of a piece of unglazed white paper and heat it until the spot is about a centimenter in diameter and transparent. In an 8 cm piece of heavy card board, cut a 4 cm hole and paste the paper over the hole with the grease spot in the middle.

1. State in your own words and also in symbols the principle revealed by a comparison of these ratios.

2. Why does the spot tend to disappear when both sides are equally illuminated?

3. If a light is moved four times as far away from an object, how much brighter must the light be made to illuminate the object to the same degree as before?

4. Explain how your photometer can be used to measure the candle power of an incandescent lamp.

Suggested form of record

Number of candles, left source	Distance of left source from screen L	Number of candles, right source	Distance of right source from screen R	$\frac{\text{C.P., left source}}{\text{C.P., rt. source}}$	$\frac{L^2}{R^2}$

SPECIAL EXPERIMENT. Use a Rumford or Bunsen photometer to measure the candle power of an incandescent lamp, a gas burner or other source of light, following the directions given in Exp. 34 and Exp. Add. 10.

If an incandescent lamp is tested, first measure its candle power when it is in a vertical position, with the light from the side of the bulb falling on the screen; then when it is in a horizontal position, with the end of the bulb pointing toward the screen; and finally, when a shade is placed behind it. In each case make several trials and compute the average candle power. Compare the results for the several cases.

APPENDIX

AMMETERS. An ammeter is an instrument used to measure the current in an electrical circuit.

In a *series* circuit an ammeter may be placed at any point, since the current is the same in all parts of such a circuit. In the case of a *parallel* circuit, the ammeter may be placed in one of the branches to measure the current in the branch, or it may be placed in the main circuit to measure the total current.

Ammeters are made with a very low electrical resistance; in most cases the effect of their resistance may be neglected. Since an ammeter has such a low resistance, it is easily "burned out" and it must not be connected to a source of current unless sufficient outside resistance has been placed in series with it. If a circuit contains an ammeter, it is good practice to close the switch for only an instant at first, in order to see whether or not the current is too large to be read by the instrument.

Measurement of small currents with A. C. ammeters. You will find that the scales of alternating current ammeters are not uniform and that small currents cannot be read on them with accuracy. To secure a higher degree of accuracy in reading small currents on an A. C. ammeter, use the following method: Connect in the circuit some electrical resistance, such as an incandescent lamp, which will give a readable deflection of the ammeter; read and record this deflection. Then connect the device in which you are interested in *parallel* with the first resistance, so that its current is added to that of the latter; again read the ammeter. The *difference* between these two readings is the required current.

BALANCES. *Beam balances and platform balances* are instruments used to compare *masses*.

Before using the beam or platform balance, always make the following initial adjustments: (1) Observe whether the balance swings freely; (2) If the base is provided with leveling screws, adjust these until the base is horizontal; (3) Slide the weight on the graduated beam until it is in the zero position; (4) Adjust the beam until it will balance evenly when the pans are dry and clean.

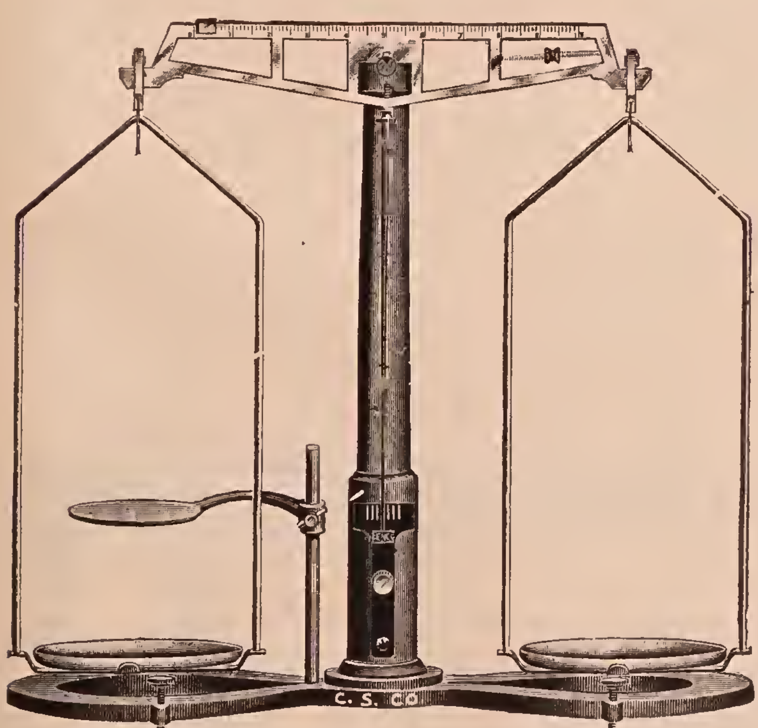

Fig. 55. Beam balance.

To measure the mass of an object, place the object on the left pan of the balance and counterbalance with weights placed in the right pan. Try out the larger weights first. Determine the largest single weight and then add smaller weights to the pan in succession. When the object has been balanced to within 10 grams of its mass make the final adjustment by sliding the weight, attached to the graduated beam, to the right. Do not wait for the oscillations of the balance to cease entirely; if the pointer moves through approximately equal small distances on both sides of the zero-point on the pointer scale, the weighing is sufficiently exact.

The mass of an object weighed in the above manner is the sum of the weights on the pan *plus* the reading of the left edge of the weight on the graduated beam, since each *small* division on the graduated beam represents one-tenth of a gram. The mass should be recorded in grams and a decimal fraction thereof.

Return weights to their proper place as soon as you have finished weighing. Leave the pans dry and clean.

Spring balances. A spring balance is a device used primarily for the measurement of force. The scale of a spring balance is so made that, when the balance is hung in a vertical position, it will give correctly the weight of an object hung from its hook or the amount of any other force acting vertically downward on the hook. If, however, a spring balance is poorly constructed or has been misused, it may not give a correct reading even when held in the vertical position for which it was made. Consequently, it is important always to test a balance before using it. Such a test is made by hanging the balance in a vertical position, with the hook hanging free and without a load on it. Under these conditions the pointer should read zero. If the reading is different from zero, the difference, called the "zero reading," should be read and recorded. A "zero reading" which is *less* than zero must be *added* to all future readings taken with the particular balance in question; if, on the other hand, the "zero reading" is greater than zero, the correction must be *subtracted* from future readings.

In measuring a force, it is often necessary to hold a spring balance horizontally, at an angle with the horizontal, or even in an inverted position. In any of these cases the hook and bar of the balance are not exerting their entire weight against the spring. In fact, when the balance is held horizontally, the spring of the balance is not supporting the weight of the hook and bar at all, while in the case of the inverted balance, the hook and bar are actually *compressing* the spring. It will be found, for example, that a 2000 g spring balance held in a horizontal position will read about 25 g less than the true reading, this being due to the fact that the hook and bar of such a balance weigh about 25 g.

Thus it can be seen that a "zero reading" should always be taken for the particular position in which a spring balance is to be used and that this reading must be added or subtracted, as the case may be, from all subsequent readings taken with the balance in this particular position.

Another way of finding the correction to be applied in the two cases where the balance is used in a horizontal or in an inverted vertical position is to hang from the balance a second balance like it, the latter one being hung in an inverted position. The correction for a horizontal position of the balance is then half the difference of the two balance readings, while the correction for an inverted position is the entire difference between the two readings.

CALIPERS. *Micrometer Caliper.* The fixed scale of a micrometer caliper is graduated in Millimeters and the movable scale is so graduated that the barrel moves through one hundredth of a millimeter when turned through one division. When the edge of the movable barrel stands exactly on a millimeter line of the fixed scale, the zero mark on the barrel coinciding with the line, the opening between the jaws is a whole number of millimeters. For example, the reading on the instrument shown in Fig. 56 is exactly 6 mm. It will be noted that in this case the zero mark on the movable scale falls exactly on the line running lengthwise on the fixed scale.

One complete turn of the barrel moves it through one-half millimeter (50/100 mm). Hence, if the edge of the barrel is *less* than half-way between two marks on the fixed scale, the opening between the jaws is a whole number of millimeters *plus* the number of hundredths of millimeters read on the movable scale. If the edge of the barrel is more than half-way between two marks on the fixed scale, a fact easily determined by the eye, the opening between the jaws is a whole number of millimeters *plus* 0.50 mm *plus* the number of hundredths of millimeters read on the movable scale.

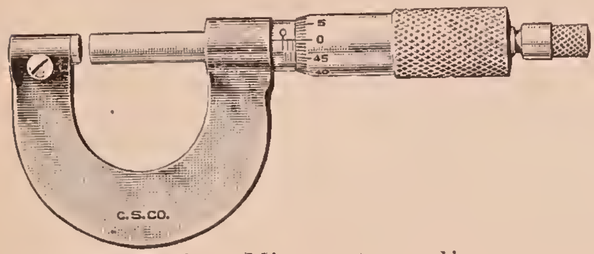

Fig. 56. Micrometer caliper.

In using a micrometer caliper it is first necessary to obtain the *zero reading*. Carefully close the jaws by turning the milled head on the extreme right, Fig. 56. If the instrument is provided with a ratchet stop, a clicking sound will be heard when the jaws make contact. If there is no ratchet head, hold the milled head lightly so that it will slip between the fingers when the jaws make contact. When the jaws are closed the zero mark of the movable scale should fall exactly on the line running lengthwise on the fixed scale and the edge of the movable barrel should rest exactly on the zero mark of the fixed scale. If this is not the case, determine the number of hundredths of a millimeter which this reading differs from zero; this correction must be added or subtracted, as the case may be, from subsequent readings made with the instrument.

To measure the thickness of an object, open the caliper jaws wide, insert the object between the jaws and again turn up the milled head until the jaws make contact with the object. Read the whole number of millimeters and half millimeters on the fixed scale and add the number of hundredths of a millimeter read on the movable scale. Finally, apply to this reading the zero correction.

Vernier caliper. The vernier caliper is equipped with a vernier scale. The *vernier* is a device for measuring the fractional parts of a scale division, thus making it unnecessary to estimate parts of a scale division, as has to be done in reading a meter stick.

The vernier caliper shown in Fig. 57 can be read to 0.01 cm or 1/128 in. It is equipped with two sets of jaws. The lower set of jaws is used for making outside measurements, such as the diameter of a sphere or of a rod. The upper set of jaws is for making inside measurements, such as the inside diameter of a piece of pipe.

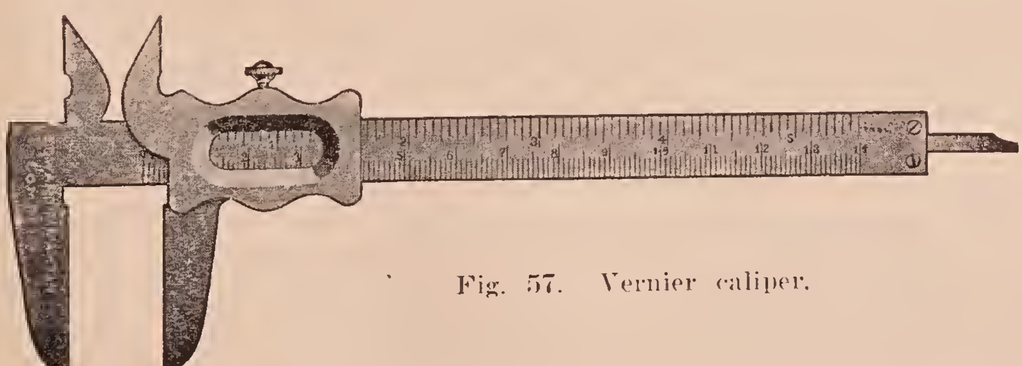
Fig. 57. Vernier caliper.

The narrow rod on the extreme right of the instrument, Fig. 57, is a depth gauge. A vernier caliper has two scales, a *fixed* scale and a movable *vernier* scale. The fixed scale is usually graduated on the upper edge in inches and sixteenths of an inch, and on the lower edge in centimeters and millimeters.

To use a vernier caliper, place the object to be measured between the jaws and press the jaws firmly against it. Observe the left-hand division on the fixed scale which is nearest to the zero mark on the sliding scale. (In Fig 58 this is 3.1 cm). Then observe the mark on the sliding scale which lies in the same straight line as some mark on the fixed scale (In Fig. 58 this happens to be the fourth line). This division on the sliding scale which thus coincides with a division on the fixed scale gives the fractional parts of the smallest scale division, or the hundredths of a centimeter, which must be added to the reading on the fixed scale. (Thus the complete reading on the scale shown in Fig. 58 is 3.14 cm).

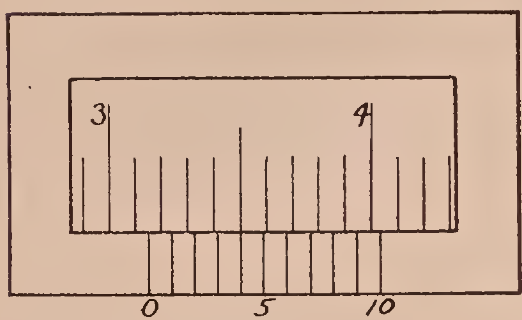

Fig. 58. Verner scale; reading is 3.14 cm.

DENSITIES. The densities of the following substances are given in grams per cubic centimeter:

Alcohol	0.81
Aluminum	2.70
Brass	8.4-8.7
Carbon bisulfid, at 22° C	1.26
Coal, anthracite	1.4-1.8
Coal, bituminous	1.2-1.5
Copper	8.93
Gasoline	0.74-0.76
Glass, crown	2.5
Glass, flint	2.9-4.5
Glycerin, at 20° C.	1.26
Gold, 18 carat	14.9
Gold, pure	19.3
Granite	2.6-2.8
Hydrochloric acid	1.27
Ice	0.92
Iron	7.1-7.8
Kerosene	0.78-0.80
Lead	11.3
Marble	2.6-2.8
Mercury, 0° C.	13.595
Mercury, 20° C.	13.546
Milk	1.028-1.035
Nickel	8.9
Platinum	21.4
Silver	10.5
Tin	7.3
Water:	
Sea, at 15° C	1.025
Pure, at 4° C	1.000
Pure, at 100° C	0.958
Woods:	
Cedar	0.5-0.6
Cherry	0.7-0.9
Chestnut	0.5-0.6
Ebony	1.1-1.3
Mahogany	0.6-0.9
Oak	0.6-0.9
Pine	0.4-0.7
Zinc	7.1

EQUIVALENTS.

1 cm = 0.394 in.	1 in. = 2.54 cm.
1 m = 39.37 in.	1 ft. = 30.5 cm.
1 km = 0.621 mi.	1 mi. = 1.61 km.
1 kg = 2.20 lb.	1 oz. = 28.4 g.
1 l = 1.06 qt.	1 lb. = 454 g.

GALVANOSCOPES. A galvanoscope, as is clearly shown in Fig. 28, consists of a coil or coils of wire which encircle a magnetic needle. When in use, the frame must be placed in such a position that the plane of the coil of wire is parallel to the needle, and the compass case should be turned until the needle reads zero. In order to keep the instrument in position it is a good plan to clamp the galvanoscope frame to the table, or to weight it down with books, blocks, or other non-magnetic material.

Galvanoscope frames usually have several coils with different numbers of turns. The more times the current passes around the needle the greater will be the deflection. For this reason the coil with the largest number of turns is used when the currents are weak.

No matter how strong the current may be, the needle will never deflect more than 90 degrees from zero. From this fact one can see that the deflections of the needle are not proportional to the current. In the case of small deflections, however, say less than 25 or 30 degrees, the deflections are nearly proportional to the current. It is partly for this reason that the student is urged, in many of the experiments, to introduce enough resistance in the circuit to bring all the deflections within this range.

GRAPHS. The *graphical* method is a very important way of making clear the relation between the quantities involved in an experiment and it should be used wherever possible. If the student is not acquainted with the graphical method, he should consult a text-book on algebra.

In many experiments the variable quantities involved are only two in number and, when a change in one of these quantities is accompanied by a change in the other, the one quantity is said to *vary* with the other. The way in which this variation occurs often can be learned from the plotted curve, or *graph*.

In plotting and readng curves, the following facts will prove useful:

(1) The *origin* O, which is the intersection of the horizontal X-axis and the vertical Y-axis, is generally placed in the lower left-hand corner of the page of cross-section paper (see Exp. 17, Fig. 20). In some cases, however, it is necessary to place the origin off the page and, in other cases, as in Exp. 12, Fig. 14, near the center of the page.

(2) In plotting curves it is not necessary that the same numerical value be assigned to a scale division on the horizontal and vertical axes. It is usual to choose values for the scale divisions so that the curve will just about fill the page. The scales chosen should be clearly indicated on the paper.

(3) A curve drawn through a series of plotted points should be a *smooth* curve. This curve should be drawn in such a manner that it passes as close as possible to the plotted points, leaving about half the points on either side of the line; this is the graphical way of averaging. It is not possible to draw a smooth curve through all the points, when these points represent the results of an experiment; this is due to the fact that the results obtained by repeating the same measurement differ slightly from one another, owing to unavoidable errors in making the readings and to imperfections in the instruments. One of the great advantages of the graphical method is that a serious error in experimentation is at once made evident by the fact that the point so obtained does not lie near the smooth curve which can be drawn close to the remaining points.

(4) When two quantities vary in such a way that their *ratio*, or quotient, is a *constant*, one of these quantities is said to vary *directly* as the other; any graph representing a *direct variation* must be a straight line and must pass through the origin. When, on the other hand, two quantities vary in such a way that their *product* is a *constant*, one of these quantities is said to vary *inversely* as the other; a curve repre-

senting an *inverse variation* will always be of a type known as a *hyperbola*. Besides direct and inverse variations there are other ways in which two quantities may vary, and for each kind of variation there is a typical kind of curve.

HUMIDITY

(a) Vapor Pressure and Mass of Water Vapor in Saturated Air

Temperature in ° C	Pressure in mm of mercury	Mass in grams per cubic meter	Temperature in ° C	Pressure in mm of mercury	Mass in grams per cubic meter
—10	2.2	2.2	14	11.9	12.1
— 8	2.5	2.6	16	13.5	13.6
— 6	2.9	3.0	18	15.3	15.4
— 4	3.4	3.5	20	17.4	17.3
— 2	3.9	4.1	22	19.6	19.4
0	4.6	4.8	24	22.2	21.8
2	5.3	5.6	26	25.0	24.4
4	6.1	6.4	28	28.1	27.2
6	7.0	7.3	30	31.5	30.4
8	8.0	8.3	32	35.3	33.8
10	9.1	9.4	34	39.5	37.6
12	10.4	10.7	36	44.2	41.7

(b) Relative Humidity from Wet and Dry Bulb Thermometer Readings

Dry bulb thermometer	Difference between dry and wet bulb thermometer readings											
°C.	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°
—12	62	7	--	--	--	--	--	--	--	--	--	--
— 9	70	39	9	--	--	--	--	--	--	--	--	--
— 6	74	49	25	2	--	--	--	--	--	--	--	--
— 3	78	57	36	17	--	--	--	--	--	--	--	--
0	81	64	46	29	13	--	--	--	--	--	--	--
3	84	69	54	40	25	12	--	--	--	--	--	--
6	87	73	60	47	35	23	11	--	--	--	--	--
9	88	76	65	53	42	32	22	12	3	--	--	--
12	89	78	68	58	48	38	30	21	12	4	--	--
15	90	80	71	62	53	44	36	28	20	13	4	--
18	90	82	73	65	57	49	42	35	27	20	13	6
21	91	83	75	67	60	53	46	39	32	26	19	13
24	92	85	77	70	63	56	49	43	37	31	26	21
27	93	86	79	72	65	59	53	47	41	36	31	26
30	93	86	79	73	67	61	55	50	44	39	35	30
33	93	86	80	74	68	63	57	52	47	42	37	33
36	93	87	81	75	70	64	57	54	50	45	41	36

LINEAR EXPANSION. The *coefficient of linear expansion* of a substance is the fractional change of length per degree Centigrade.

Aluminum	0.000023	Gold	0.000014	Marble	0.000012
Brass	0.000019	Hard Rubber	0.000069	Nickel	0.000013
Copper	0.000017	Ice	0.000069	Platinum	0.00009
German silver	0.000018	Irin (cast)	0.000010	Quartz glass	0.0000003
Glass	0.00008	Lead	0.000012	Silver	0.000019

MANOMETERS. The manometer is an instrument for measuring fluid pressure. There are several types of manometers, but the only one which we will consider is the open-tube form.

The *open-tube* manometer is used when the pressures are not excessive. It consists of a piece of glass tubing, open at both ends and bent into the shape of a *U*. A meter stick is placed upright between the two arms of the U-tube, so that the difference in levels of the liquid in the two arms can be measured, (Fig. 59). This liquid is generally mercury, though for rather small pressures, oil, gasoline or water is often used.

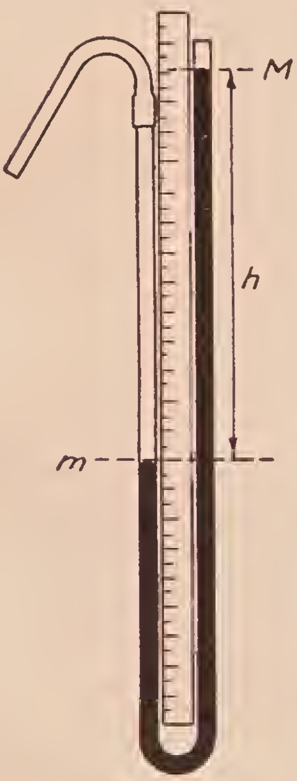

Fig. 59. Open-tube manometer.

Before a pressure is applied, the levels of the liquid in the two arms are at the same height, since the air presses down equally on both liquid surfaces. If, however, the pressure on *m*, Fig. 59, is increased, a difference of levels *h* results, which depends only upon the added pressure and upon the liquid used in the tube. The size of the tube will have no effect on the difference of levels in the two arms. Hence the cross-section of the tube may be thought of as being 1 square centimeter, and the pressure may be found by calculating the pressure in grams per square centimeter of a column of the manometer liquid equal in height to the difference in levels *h*.

The pressure so found is called the *gage* pressure, and it is given by the formula

$$p = h \times d.$$

When h is in centimeters and the density d is in grams per cubic centimeter, the pressure p is in grams per square centimeter.

RESISTANCE. The *specific resistance* of a substance is the electrical resistance in ohms of one centimeter length of a cylinder of the substance having a cross-sectional area of one square centimeter.

Aluminum	2.7×10^{-6}	Magnesium	42.0×10^{-6}
Brass	7.0×10^{-6}	Mercury	94.0×10^{-6}
Constantan (6% Cu. 40% Ni.)	49.0×10^{-6}	Nickel	7.0×10^{-6}
Copper	1.7×10^{-6}	Platinum	10.0×16^{-6}
German silver	33.0×10^{-6}	Silver	1.5×10^{-6}
Gold	2.0×10^{-6}	Tungsten	6.0×10^{-6}
Iron	10.0×10^{-6}	Zinc	6.0×10^{-6}
Lead	20.0×10^{-6}		

SPECIFIC HEAT. The following specific heats are given in calories per gram per degree Centigrade.

Aluminum	0.2	Iron	0.11
Brick	0.2	Lead	0.03
Copper	0.09	Mercury	0.03
Earth	0.2	Nickel	0.1
Gold	0.03	Soapstone	0.2
Glass	0.16	Zinc	0.09
Ice	0.5		

USEFUL CONSTANTS AND FORMULAS.

1 cm^3 of water at 4°C has a mass of 1 g.

1 cu. ft. of water at 4°C has a mass of 62.4 lbs.

1 atmosphere of pressure = 1033.6 g per cm^2.

1 atmosphere of pressure ≐ pressure of 76 cm of mercury.

$\pi = 3.1416 \qquad \sqrt{2} = 1.414$

$\pi^2 = 9.8696 \qquad \sqrt{3} = 1.732$

Circumference of circle = $2\pi r = \pi d$.

Area of circle = $\pi r^2 = \frac{1}{4}\pi d^2$.

Surface of sphere = $4\pi r^2 = \pi d^2$.

Volume of sphere = $\frac{4}{3}\pi r^3 = \frac{1}{6}\pi d^3$.

Volume of right cylinder = $\pi r^2 l = \frac{1}{4}\pi d^2 l$.

VOLTMETERS. Voltmeters are similar to ammeters in their internal construction except that they have a high resistance. The current which passes through them is equal to the voltage divided by the resistance of the instrument. Consequently the reading of a voltmeter is proportional to the voltage applied to its terminals. Voltmeters are always connected in parallel with that part of a circuit over which the potential drop is to be measured.

Position of Voltmeters. If a voltmeter is connected around an ammeter, as in Fig. 53, the voltmeter reading includes not only the potential drop in the circuit but also the drop in the ammeter. This, of course, introduces an error, but with alternating current voltmeters it is usually much smaller than the error which would result if the voltmeter were connected directly to the lamp terminals. The reason is that A. C. voltmeters take a considerable amount of current, sometimes as much as 0.1 ampere; consequently, if the ammeter reading is small, this additional current introduces an appreciable error.

In Fig. 50 the voltmeter is shown connected *inside* the ammeter, with the ammeter reading not only the current in the circuit but also the current taken by the voltmeter. This form of connection is permissible with D. C. voltmeters since they seldom require a current of more than .02 ampere. Either form of connection may be used with D. C. voltmeters but connections as shown in Fig. 53 are usually to be preferred when A. C. instruments are used.

LIST OF APPARATUS

The second column, under "Apparatus," contains a complete list of the apparatus reuqired for each of the experiments in this manual. In the third column, under "suggestions," substitute apparatus is suggested and home-made equipment is described.

Exp. No.	Apparatus	Suggestions
1-I	Beam or platform balance.	
	Set of slitted iron weights, 10-500g.	
	Meter stick.	
	3 rectangular blocks of different kinds of woods.	
1-II	Steel or glass ball, ¾ in.	
	Micrometer caliper, with rachet.	Meter stick, two blocks and an additional ball.
	Beam or platform balance and set of weights, Part I.	
2-I	Aluminum cylinder, 7.5x2.5 cm. with hook.	A spherical or rectangular piece of metal, about 40 cm.^{3}
	Battery jar, 5x7 in.	Beaker, Exp. 17, or calorimeter vessel, Exp. 15.
	Thread.	
	Balance, Exp. 1, fitted with a support for the above jar.	Spring balance, Exp. 6. If the beam balance of Exp. 1 is not fitted with a jar support, use a home-made wooden bench, Fig. 3.
	Vernier caliper or the micrometer caliper of Exp. 1.	Meter stick and two blocks, Exp. 1.
2-II	Brass weight, coal, rock, etc. and thread of Part I.	
	Balance, weights, jar support, jar and thread of Part I.	
3-I	Constant weight hydrometer tube, 50 cm.	
	Glass tube, 110x4cm, with rubber stopper.	
	Clamp for above tube.	May be omitted.
	Tripod base, rod and right angle clamp.	
	Rubber bands.	The length immersed in the liquid is more conveniently measured on a paper metric scale placed isside the tube.
	Theremometer, 10 to 110° C.	
	Universal hydrometer.	May be omitted.
	Gasoline.	
	Lead shot.	
	Meter stick, Exp. 1.	

Exp. No.	Apparatus	Suggestions
3-II	Water proof wooden block.	Large piece of wax, paraffin or cork.
	Lead sinker with hook.	A balance weight.
	Balance, support and weights, Exp. 2.	Spring balance, Exp. 6.
	Battery jar, Exp. 2.	Beaker or calorimeter cup.
	Thread, Exp. 2.	
4	Boyle's law tube, J-tube form, 100 and 20 cm arms.	
	Support for above tube.	
	Barometer.	
	Mercury, 1 lb.	
	Thermometer, Exp. 3; meter stick.	
5-I	Alcohol, denatured.	
	Constant weight hydrometer tube, Exp. 3.	
5-II	2 tumblers.	Use tumblers of demonstration cell, Exp. 24, or beakers, Exp. 17.
	Hydrochloric acid.	
6	2 spring balances, flat back 2000 g.	
	2 weight hangers.	Bags filled with sand or shot may be substituted for the weight hangers and weights. Each weight should be a little less than 1 kg.
	Fish line or strong cord.	
	Meter stick and weights, Exp. 1.	
7-I	Weight, about 1.5 kg.	Bag filled with sand or shot.
	Support for spring balances.	Hang from nails in wall or from table crossbar.
	Two spring balances and cord, Exp. 6.	
7-II	Spring balance, flat back, 2000 g.	**Note.** Part II may be performed with the apparatus of Part I. The weight **L** must be known and the supports **A** and **B** should be placed far enough apart to stretch the two balances to about half their full range. A smooth vertical board, on which to fasten the notebook paper, should be placed behind the cords.
	Three "Stone" tension clamps or a force board.	
	Dividers or pencil compass.	
	Ruler, metric and English.	
	Two spring balances, Exp. 6; wooden block, Exp. 1 or 14; cord.	

Exp. No.	Apparatus	Suggestions
8	Pendulum clamp, wood.	A nail in the wall, or a split cork held in a burette clamp or fitted into a hole in a board.
	Ball, iron, 2.5 cm, drilled.	Steel ball, Exp. 1, and sealing wax.
	Ball, hard wood, 2.5 cm, drilled.	Used only in Part I.
	Watch with second hand.	
	Magnifying glass.	Use reading glass, Exp. 35, or linen tester, Exp. 36.
	Meter stick and thread.	
9-I	Stop watch or watch with second hand.	**Note.** A wire with hook and turnbuckle, on which runs a car equipped with cone-bearing pulleys, can be purchased. Some instructors prefer to use a grooved inclined plane and steel ball for this experiment. Both of these forms of apparatus can be used indoors.
	Cord, fine quality, about 75 ft.	
	Glass awning ring or a metal ring.	
	Drilled iron ball, Exp. 8, or other weight.	
	Meter stick.	
9-II	Stop watch, meter stick and long cord.	
10	2 single pulleys.	
	Support for pulley.	Hang from table crossbar or from ring stand.
	Fish line or cord.	
	Weight hanger and spring balance, Exp. 6; weights; meter stick.	**Note.** The experiment may be continued with more than two pulleys, but time will be saved and less apparatus required if the instructor demonstrates such additional experiments in the presence of the class as a group.
11-I	Empty wooden crayon box.	A wooden block.
	Smooth board, about 120x15 cm.	Inclined plane, Exp. Add. 3, or the top of the table.
	Spring balance, Exp. 6.	If desired, substitute for the spring balance: pulley, Exp. Add. 3; weight hanger, Exp. 6; balance, Exp. 1.
	Cord, Exp. 6; weights.	**Note.** It is more satisfactory to use paper for the two surfaces in contact. Fasten large sheets of paper to the board and also around the box.
11-II	Same as above plus sheets of tin, brass, etc.	

Exp. No.	Apparatus	Suggestions
12	Steam generator. Bunsen burner or alcohol stove. Co-ordinate paper, millimeter ruled. Ice or snow. Tumbler, Exp. 5.	Calorimeter cup, Exp. 15.
13-I	Salt. Calorimeter cup, Exp. 15. Thermometer, Exp. 3; tumbler, Exp. 5; ice or snow.	Any vessel with a polished surface.
13-II	Cotton gauze. Calorimeter cup, Exp. 15. Thermometer, Exp. 3.	Cheesecloth or other piece of cloth. Tumbler or beaker.
14	Metal tube, pointer and mirror scale with support. 2 wooden blocks, 20x9x9cm. 2 ft. of rubber tubing, 3/16 in. Steam generator, Exp. 12. Micrometer caliper or Vernier caliper, Exp. 1. Thermometer, Exp. 3; Bunsen burner, Exp. 12; meter stick.	Any standard linear expansion apparatus may be used. A flask, or an ether or syrup can, with one hole stopper and delivery tube.
15	Calorimeter, complete. Steel shot, copper shot, lead shot, glass beads, aluminum pellets. Balance and weights, Exp. 2; thermometer, Exp. 3; steam generator and Bunsen burner, Exp. 12.	No one student is expected to use all of these substances.
16	Cardboard tube, length about 120 cm. Cork for above tube, bored for thermometer. Plug. Lead shot, 2 kg. Balance and weight, Exp. 1; thermometer, Exp. 3; cord.	Lead pencil.

Exp. No.	Apparatus	Suggestions
17	Acetamide. Watch with second hand. Beaker, glass, 500 cc. Test tube, 5x5/8 in. Wire gauze, iron, 6x6 in. Burette clamp. Tripod base, rod and right angle clamp, Exp. 3. Iron ring, 5 in.; for above. Thermometer, Exp. 3; Bunsen burner; co-ordinate paper.	Boiler of steam generator, Exp. 12.
18	Balance and weights, Exp. 1; thermometer, Exp. 3; calorimeter, Exp. 15; ring stand and wire gauze, Exp. 17; Bunsen burner.	
19-I	Pistol and blank cartridges. A measuring rod or cord. Thermometer, Exp. 3; stop watch, Exp. 9.	A toy cannon or a sheet of tin and an iron rod. The distance can be gotten from a large scale map of the region, if one is available.
19-II	Hammer or iron bar.	
20	2 tuning forks, say 256 and 512. Large flat cork or a strip of leather or rubber. Glass tube, 110x4 cm, Exp. 3. Piston for above tube with 110 cm handle. Clamp, tripod base and rod, Exp. 3. Thermometer and rubber bands, Exp. 3; meter stick.	2 wooden support blocks for the tube.
21	2 bar magnets. Piece of soft iron or an iron washer.	The magnets furnished with the St. Louis motor, Exp. 31 may be used. In storing magnets, always place them so that the unlike poles touch each other.

Exp. No.	Apparatus	Suggestions
22-I	Small bits of glass, iron, steel, granulated tin, common "tin," nickel, copper, lead, zinc, wood, paper, sand, etc.	The materials of Exp. 15 may also be used.
	Sheets about 8 cm square or larger, of cardboard, sheet iron, common tin, glass, copper, lead, brass, thin wood, etc.	The sheets of metal of Exp. 11-II may also be used.
	Iron filings.	Small iron tacks, Exp. 26.
	Bar magnet Exp. 21; Bunsen burner; copper wire.	
22-II	Half of a hardened steel knitting needle.	12 cm piece of watchspring.
	Compass, graduated, 5 cm diameter.	**Note.** If a knitting needle is used, render it brittle by heating it to a bright red and then dropping it into water.
	Thread; copper wire; Bunsen burner.	
23-I	Pith balls.	Bits of cork.
	Silk thread.	
	Glass friction rod.	
	Ebonite friction rod.	Sealing wax may be used in place of the ebonite rod.
	Silk pad.	
	Flannel pad.	
23-II	Stirrup replaces the pith balls and thread of Part I.	Make a stirrup out of heavy wire.
23-III	Leaf electroscope, flask form.	
	Proof plane.	A cent fastened to a stirring rod or stick with sealing wax.
23-IV	Metal balls, Exp. 8; electroscope, ebonite rod and flannel pad of Part I.	
24-I	Demonstration cell with zinc and copper elements.	A complete set of elements for this cell will be needed in Exp. 28.
	Galvanoscope frame.	
	Sulfuric acid.	
	Connecting wire (No. 18 insulated copper wire).	
	German silver wire, No. 36.	
	Compass, Exp. 22; mercury.	

Exp. No.	Apparatus	Suggestions
24-II	Porous cup.	
	Copper sulfate.	
	Demonstration cell, compass and galvanoscope frame, Part I.	
25	Knife switch, double pole, double throw.	Commutator. If a switch is used it will be found convenient to have it mounted on a heavy wooden base.
	Daniel cell.	Dry cell, Exp. 26.
	Copper wire, No. 18, insulated.	
	Compass, Exp. 22.	
26-I	Soft iron core.	Spike or bolt.
	Soft iron horseshoe core.	Bent spike or rod.
	Small iron tacks.	Brads, small nails or iron filings, Exp. 22.
	Dry cell.	
	Compass, Exp. 22; connecting wire; Exp. 24; knife switch, Exp. 25.	
26-II	D'Arsonval galvanometer.	
	Dry cell, Part I; connecting wire, Exp. 24.	
27	Electric bell or buzzer.	
	Some form of cell.	Dry cell, Exp. 26, is most convenient.
	Push button or knife switch of Exp. 25.	May be omitted.
	Small compass, Exp. 21; connecting wire, Exp. 24.	
28-I	Complete set of elements for demonstration cell.	
	Nitric acid.	
	Copper sulfate.	
	Zinc sulfate.	
	Sulfuric acid.	
	Hydrochloric acid.	
	Galvanoscope frame and compass, Exp. 24.	Voltmeter, Exp. Add. 6. is more desirable.
	Demonstration cell, No. 36 German silver wire and connecting wire, Exp. 24.	

Exp. No.	Apparatus	Suggestions
28-II	Galvanoscope frame and compass, Exp. 24.	Voltmeter, Exp. Add. 6.
	Demonstration cell, zinc, copper elements, sulfuric acid, No. 36 German silver wire and connecting wire, Exp. 24.	An automobile storage battery should be examined by the class.
28-III	2 dry cells.	
	Galvanoscope frame and compass, Exp. 24.	Voltmeter, Exp. Add. 6.
	Connecting wire, Exp. 24.	
29-I	Wire nails.	
	Tumbler, Exp. 5.	
	2 dry cells, Exp. 28; sulfuric acid and connecting wire, Exp. 24.	2 or 3 cells are usually needed to cause gas to appear at carbon plate.
29-II	Nickel (coin).	
	Tumbler, Exp. 5; copper sulfate and connecting wire, Exp. 24; carbon rod from demonstration cell and 2 dry cells, Exp. 28.	
30	2 coils for induction.	Home-made coils are very satisfactory. Use about 40 turns of No. 30 insulated copper wire. Bind the wire with friction tape, leaving a 3 cm opening.
	D'Arsonval galvanometer, Exp. 26.	A galvanoscope may be used, although it is less sensitive.
	Soft iron core, Exp. 26.	One or more large spikes.
	Dry cell, Exp. 28.	Two if available.
	Bar magnet, Exp. 21; connecting wire.	
31	St. Louis motor.	
	Electromagnet attachment.	
	German silver wire, No. 36, Exp. 24.	A small rheostat is more convenient.
	D'Arsonval galvanometer, Exp. 26.	Galvanoscope, Exp. 24.
	Dry cell, Exp. 28.	Two may be needed.
	Thread; connecting wire.	

Exp. No.	Apparatus	Suggestions
32	Plane mirror, blackened. Pins. Dividers, Exp. 7. Wooden block, Exp. 1 or Exp. 14. Rubber bands, Exp. 3; ruler, Exp. 7.	Blacken one side of a piece of glass with soot from burning camphor or a candle. Protractor. **Note.** Each student should work alone on this experiment.
33	Plate glass prism, euqilateral, with sharp edges and corners. Dividers and ruler, Exp. 7; pins.	**Note.** Each student should work alone.
34	Screen, unglazed white cardboard or paper, with support. Dividing screen, cardboard or beaverboard. 5 similar candles. Tripod base and rod, Exp. 3; meter stick.	
35-I	Reading glass of about 15 cm focus. Tripod base, rod and right angle clamp, Exp. 3; meter stick.	**Note.** If a good optical bench is available, Part II may be performed as a group experiment, with the teacher demonstrating.
35-II	Screen with a 1 cm circular opening covered with wire netting or cross wires, mounted on base. Source of light consisting of keyless porcelain receptacle, an 8 c. p. frosted bulb and an extension cord with plug. White cardboard screen, Exp. 34; reading glass and other apparatus of Part I.	If the laboratory already possesses a screen of wire netting mounted on a base, cover the screen with a sheet of paper containing a 1 cm circular opening. Any other source of light.
36	Linen tester. Tripod base and rod, Exp. 3; burette clamp, Exp. 17; meter stick.	Substitute for the linen tester a pocket magnifier and a black screen containing a 1 cm opening.
37	Tripod base, rod and right angle clamp, Exp. 3; wooden block, Exp. 14; white screen, Exp. 34; reading glass, Exp. 35; linen tester, Exp. 36; meter stick.	

Exp. No.	Apparatus	Suggestions
Add. 1	Open-tube manometer, 100 and 25 cm arms, unmounted.	
	Glass tube, 110 cm, with rubber stopper and support, Exp. 3; mercury, Exp. 4; rubber bands; meter stick; co-ordinate paper; gasoline.	
Add. 2-I	Open-tube manometer, 25 and 50 cm arms.	Manometer tube, Exp. Add. 1.
	Support for above manometer.	Tripod base, rod and cord.
	Glass mouthpiece.	An 8 cm piece of glass tubing with one end rounded in flame.
	2 in. length of 3/16 in. rubber tubing.	
	Barometer and mercury, Exp. 4; meter stick.	Omit barometer, if necessary.
Add. 2-II	U-tube, 25 cm arms.	Manometer, Exp. Add. 1 or Add. 2-I.
	Support for U-tube.	Grooved block or tripod base, rod and clamp.
	30 cm length of 5 mm glass tubing.	
	Glass tube with stopper and support, Exp. 3; barometer, Exp. 4; rubber tubing, Exp. 14; meter stick.	Omit barometer, if necessary. **Note.** If practicable, allow the student to choose between Part I and Part II.
Add. 3	Smooth board, about 120x12 cm.	Board, Exp. 11.
	Cone-bearing pulley for inclined plane.	**Note.** A spring balance may be used in place of the weights, hanger and pulley, to measure **F**. A correction is made for the position of the spring balance and, in Part II, the effect of friction is eliminated by taking the average of the two balance readings obtained, first when the car is pulled up, and then when it is allowed to roll down.
	Balance and weights, Exp. 1; weight hanger, Exp. 6; cord.	
Add. 4	Mercury gage for steam generator.	Glass tubing bent in U form.
	Pinch cock, screw compressor.	
	Steam generator, Exp. 12.	Flask with a three hole stopper.
	Thermometer, Exp. 3; mercury; Bunsen burner; meter stick.	
Add. 5	Sonometer, complete.	
	2 or more tuning forks and a large flat cork, Exp. 20.	

Exp. No.	Apparatus	Suggestions
Add. 6	Lengths of Nos. 24 and 30 German silver wire, No. 30 iron wire and No. 30 copper wire, mounted on a board.	Loose wire may be used but it is more convenient to have the wires strung between 4 pairs of binding posts mounted on a 1-m board as in Fig. 50.
	D.C. voltmeter, 5 volt.	**Note.** Because of the cost of the apparatus, this experiment may be performed by the class as a group, with the instructor demonstrating. Note that Exp. Add. 7 practically duplicates B and C of this experiment.
	D.C. ammeter, 5 amperes.	
	Knife switch, Exp. 25; 2 dry cells, Exp. 28.	
Add. 7	Wheatstone bridge.	See footnote to experiment.
	Resistance box, plug type.	
	Resistance wires, Exp. Add. 6.	These wires may be loose, mounted on a board, or wound on blocks or spools.
	Knife switch, Exp. 25; D'Arsonval galvanometer, Exp. 26; dry cell, Exp. 28; connecting wire.	
Add. 8	2 tungsten lamps, 25-watt and 40-watt.	60-watt, 100-watt or 200-watt lamps.
	2 carbon filament lamps 16 c. p. and 32 c. p.	
	Keyless porcelain receptacle and extension cord, Exp. 35.	
	A. C. Voltmeter, 150-75 volts.	
	A. C. Ammeter, 7.5 amperes.	
Add. 9	Electric irons, toasters, grills, curling irons, fans, sewing machine motors, etc., to be borrowed locally.	Students should be encouraged to bring electrical appliances from their homes.
	Immersion coil.	May be omitted.
	Thermometer, Exp. 3; knife switch, Exp. 25; A. C. ammeter and A. C. voltmeter, Exp. Add. 8; connecting wire.	
Add. 10	Bunsen photometer screen and support or a Bunsen photometer box.	See footnote to this experiment.
	Candle holder, single.	
	Candle holder, quadruple.	
	Support blocks for meter stick.	
	5 similar candles, Exp. 34; meter stick.	