Technical and Bibliographic Notes / Notes techniques et bibliographiques

The Institute has attempted to obtain the best original copy available for filming. Features of this copy which may be bibliographically unique, which may alter any of the images in the reproduction, or which may significantly change the usual method of filming are checked below.

- [ ] Coloured covers / Couverture de couleur
- [ ] Covers damaged / Couverture endommagée
- [ ] Covers restored and/or laminated / Couverture restaurée et/ou pelliculée
- [ ] Cover title missing / Le titre de couverture manque
- [ ] Coloured maps / Cartes géographiques en couleur
- [ ] Coloured ink (i.e. other than blue or black) / Encre de couleur (i.e. autre que bleue ou noire)
- [ ] Coloured plates and/or illustrations / Planches et/ou illustrations en couleur
- [ ] Bound with other material / Relié avec d'autres documents
- [ ] Only edition available / Seule édition disponible
- [ ] Tight binding may cause shadows or distortion along interior margin / La reliure serrée peut causer de l'ombre ou de la distorsion le long de la marge intérieure.
- [ ] Blank leaves added during restorations may appear within the text. Whenever possible, these have been omitted from filming / Il se peut que certaines pages blanches ajoutées lors d'une restauration apparaissent dans le texte, mais, lorsque cela était possible, ces pages n'ont pas été filmées.
- [x] Additional comments / Commentaires supplémentaires: Various pagings.

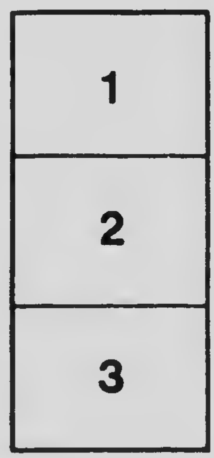
L'Institut a microfilmé le meilleur exemplaire qu'il lui a été possible de se procurer. Les détails de cet exemplaire qui sont peut-être uniques du point de vue bibliographique, qui peuvent modifier une image reproduite, ou qui peuvent exiger une modification dans la méthode normale de filmage sont indiqués ci-dessous.

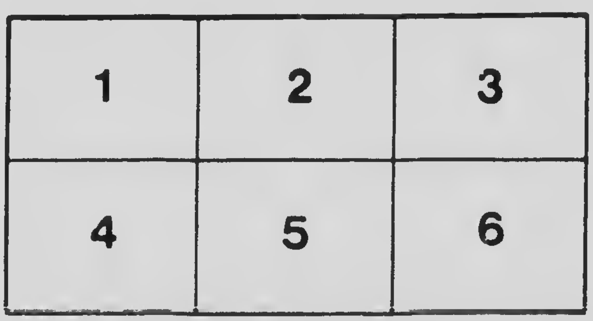
- [ ] Coloured pages / Pages de couleur
- [ ] Pages damaged / Pages endommagées
- [ ] Pages restored and/or laminated / Pages restaurées et/ou pelliculées
- [x] Pages discoloured, stained or foxed / Pages décolorées, tachetées ou piquées
- [ ] Pages detached / Pages détachées
- [x] Showthrough / Transparence
- [ ] Quality of print varies / Qualité inégale de l'impression
- [ ] Includes supplementary material / Comprend du matériel supplémentaire
- [ ] Pages wholly or partially obscured by errata slips, tissues, etc., have been refilmed to ensure the best possible image / Les pages totalement ou partiellement obscurcies par un feuillet d'errata, une pelure, etc., ont été filmées à nouveau de façon à obtenir la meilleure image possible.
- [ ] Opposing pages with varying colouration or discolourations are filmed twice to ensure the best possible image / Les pages s'opposant ayant des colorations variables ou des décolorations sont filmées deux fois afin d'obtenir la meilleure image possible.

This item is filmed at the reduction ratio checked below /
Ce document est filmé au taux de réduction indiqué ci-dessous.

10x		12x		14x		16x		18x		20x		22x		24x		26x		28x		30x		32x
															✓							

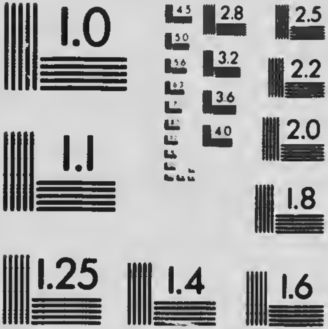

1
2
3


1
2
3


1
2
3
4
5
6

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc
1653 East Main Street
Rochester, New York 14609 USA
(716) 482 - 0300 - Phone
(716) 288 - 5989 - Fax

FIRST YEAR COURSE

IN

EXPERIMENTAL PHYSICS

ELEMENTARY SECTION

PREPARED FOR USE IN THE

MACDONALD PHYSICS BUILDING

McGILL UNIVERSITY

MONTREAL

RENOUF PUBLISHING COMPANY
MONTREAL

FIRST YEAR COURSE

IN

EXPERIMENTAL PHYSICS

ELEMENTARY SECTION

PREPARED FOR USE IN THE

MACDONALD PHYSICS BUILDING

McGILL UNIVERSITY

MONTREAL

RENOUF PUBLISHING COMPANY

MONTREAL

FIRST YEAR EXPERIMENTAL PHYSICS

INTRODUCTION

The purposes of a course in experimental physics are in general to familiarize students with the construction and operation of physical instruments and apparatus, to teach them the methods of determining physical constants, to train them to make accurate observations and to record the latter in a satisfactory manner.

Work in the Laboratory: The entire experiment which has previously been assigned should be read over carefully by the student *before coming into the laboratory.* When an experiment has been completed to the satisfaction of the demonstrator, another one should be assigned *before leaving the laboratory.*

All original observations should be recorded *in the laboratory note-book only* and preferably on the right-hand ruled pages, the left-hand pages being reserved for rough notes and calculations.

Original observations should *never be erased.* An erroneous entry should be neatly crossed out. The neatness with which the *original* observations are recorded, even if crossed out, forms an important factor in determining the student's rank.

The metric system is employed, and, unless otherwise directed, lengths should be measured in centimeters, masses in grams, intervals of time in seconds, and temperatures in degrees Centigrade. Estimate tenths of the smallest divisions on all graduated scales whenever the accuracy of the result will thereby be increased, using decimals and *not* fractions.

Record any numbers or distinguishing marks on the apparatus used.

When an experiment is completed, the apparatus should *always* be left in a neat, orderly condition, and any apparatus supplied by a demonstrator or assistant should be returned.

Reports: A report on each experiment is to be prepared from the original observations. The completed report should usually comprise the following:

NAME OF EXPERIMENT DATE

Apparatus: Include all numbers or distinguishing marks.

Observations: The original record of these should be in the book.

Results: Include formulæ with the values of various quantities substituted.

The reports are to be written on the right-hand ruled pages, and *all computations* on the left-hand pages. Use logarithms when possible. Use of the proper number of significant figures is important. In all computations, the first non-significant figure should be retained and then dropped in the final result.

Curve Plotting: The relation between two variable quantities may be clearly shown by plotting them on cross-section paper. The values of one quantity, usually the independent variable, are represented by *Abscissæ* or distances parallel to the Y or vertical axis, and of the other, the dependent variable, by *Ordinates* or distances parallel to the X or horizontal axis. The scales of abscissæ and ordinates, which need not be the same, should be chosen so that the range of values in each case extends at least more than half-way across the paper. The scales should be such that each large division on the paper will represent some factor or multiple of 10.

Each heavy line on the paper is then assigned a number, which should be a multiple of the scale adopted. The points may then be plotted, and a small circle drawn around each to indicate its position clearly. If two curves are plotted in the same space, the second set of points should be distinguished by crosses or squares instead of circles. The best-fitting curve should then be drawn through the *average position* of the points. If it appears that the function is linear, a straight line should be ruled in. All curves should first be plotted lightly in pencil, and then, if satisfactory, they should be inked in.

No.	Name of Experiment	Date
1.	The Balance	
2.	The Micrometer Caliper	
3.	The Vernier Caliper	
4.	The Spherometer	
5.	Composition of Forces	
6.	The Simple Pendulum	
7.	Law of Moments	
8.	Pulleys	
9.	Archimedes' Principle	
10.	The Jolly Spring Balance	
11.	Mohr's Balance	
12.	The Specific Gravity Bottle	
13.	The Constant-Weight Hydrometer	
14.	Boyle's Law	
15.	The Fixed Points of a Thermometer	
16.	The Air Thermometer	
17.	Coefficient of Expansion	
18.	Specific Heat	
19	Latent Heat of Fusion	
20.	Vapor Pressure	
21.	Latent Heat of Vaporization	
22.	Hygrometry	
23.	Mechanical Equivalent of Heat	
24.	Magnetic Fields of Permanent Magnets	
25.	The Deflection Magnetometer	
26.	The Electroscope	
27.	Magnetic Fields of Currents	
28.	Measurement of Current	
29.	Ohm's Law	
30.	The Potentiometer	
31.	The Wheatstone Bridge	
32.	Electrical Equivalent of Heat	
33.	Electro-Chemical Equivalents	
34.	Electric Cells	
35.	Induced Currents	
36.	The Sonometer	
37.	The Resonance Tube	
38.	Photometry	
39.	Reflection and Refraction of Light	
40.	The Prism	
41.	The Concave Mirror	
42.	The Convex Mirror	
43.	The Convex Lens	
44.	The Concave Lens	
45.	The Microscope and the Telescope	
46.	The Spectroscope	
47.	The Polariscope	

Name of Owner ....

Name of Partner ....

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

THE BALANCE

N.B.—Read carefully the entire experiment before attempting to use the balance.

Object of Experiment: To afford practice in the use of the analytical balance (1) by finding the sensitiveness of the balance, and (2) by weighing given objects by the "Method of Oscillations." Also to determine the number of grains in a gram.

Apparatus: A sensitive balance; a set of gram weights; a grain weight; a piece of brass.

Theory: The essential parts of the equal arm balance, which is one of the most important applications of the lever, are shown in Fig. 1.

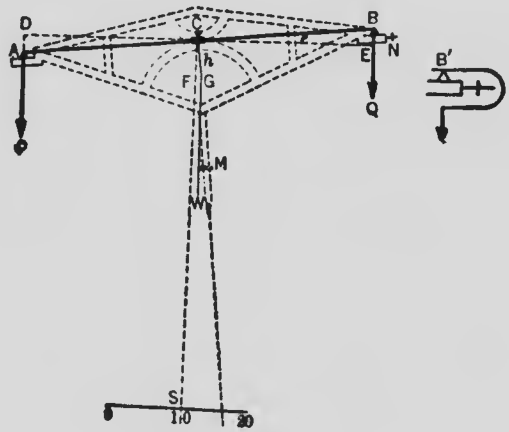


Fig. 1

The beam AB is supported at its middle point by means of the knife-edge C resting upon a plane. At the ends of the beam are the other knife-edges A and B, from which pans of nearly equal weight are suspended. Any slight inequality in the weights of the pans can be counterbalanced by moving the nut N.

A balance is said to have great sensitiveness when a large deflection is caused by a very

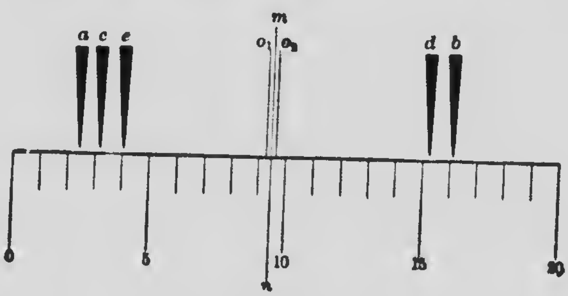


Fig. 2.

small difference of weights. In order that the sensitiveness of the balance may be constant under different loads, C must lie exactly on the line AB. Accordingly the beam is designed to combine maximum rigidity with the necessary lightness. Since no beam is perfectly rigid,

C is usually adjusted to lie on the line AB under one-half the maximum load for which the balance is designed.

By the position of rest is meant the point on the scale S over which the pointer would come to rest if given sufficient time. As this would take too long, the Method of Oscillations is employed. Suppose as the beam oscillates freely the pointer swings from a to b and back to c (Fig. 2). Owing to frictional resistance, each successive swing will be a little shorter than the preceding one. Therefore o_1, the middle point of ab, will lie nearer a than will the true position of rest mn. Similarly o_2, the middle point of bc, will lie on the opposite side of mn. However, the point midway between $\frac{a+c}{2}$ and b will lie practically on mn. Thus the effect of damping is to render it necessary to take into account an even number of swings across the scale, and therefore an odd number of successive readings. Hence it follows that the point midway between $\frac{a+c+e}{3}$ and $\frac{b+d}{2}$, i. e., the point given by

$$\frac{1}{2}\left(\frac{a+c+e}{3}+\frac{b+d}{2}\right)$$

may be taken as the true position of rest.

The *sensitiveness* of a balance is the change in the position of rest due to one milligram in either pan. It depends somewhat upon the load in the pans. If after the true position of rest has been found, one milligram is placed on one of the pans, the new position of rest will differ from the former by σ divisions. Then the sensitiveness is σ, and $1/\sigma$ is the fraction of a milligram which will change the position of rest by one division.

In weighing an object by the Method of Oscillations, suppose that sufficient weights have been placed in the pan to balance the object in the other pan so that the position of rest differs from the true position of rest by δ divisions, then $\delta \cdot 1/\sigma$ milligrams must be added to or subtracted from the weights in the pan to give the true weight of the given object.

Precautions to be observed:

(1) Handle the weights with the forceps, and when removing them from the balance, always return them to their proper places in the box.

(2) See that the beam is supported, off the knife-edges, whenever any weights are added to or removed from the pans or whenever the position of the rider is changed. The rider is the bent piece of wire which should be found on its support above the beam. The knife-edges, as well as the planes upon which they rest, are constructed of agate, a material which is brittle, though hard and otherwise desirable.

(3) Hence the beam should always be raised and lowered carefully, making the final turn when the pointer is opposite the middle of the scale.

(4) Never hit the pans with the forceps, nor set the beam swinging by suddenly lowering it upon the knife-edges. The beam may be set swinging by fanning one pan gently.

(5) All final adjustments of the rider, and all observations, should be made with the case closed.

Procedure: (1) *To Find the Position of Rest.* Release the beam and set it swinging. The pointer should move over at least 10 divisions but not off the scale.

Sitting directly in front of the balance determine the position of rest by reading the extreme position of the swings. Five consecutive readings should be taken, three on one side and two on the other. Read the scale from left to right, 0 at the left, 10 in the middle and 20 at the right. Estimate tenths of divisions, and record your observations as follows:

Left	Right
2.4	16.2
3.2	15.3
4.1	
3.23	15.75
15.75	
2)18.98	
9.49	

Position of rest with pans empty, 9.49.

Obtain at least three values of the position of rest which are in good agreement, and take the mean. Record all observations.

(2) *To Find the Sensitiveness.* Place the rider on division 1 of the scale of the beam. The weight of the rider is 10 milligrams. Hence when placed at division 1, it is equivalent to a weight of 1 milligram in the pan.

Determine the position of rest as before. From this and the previous determination the sensitiveness may be found.

(3) *To Weigh the Grain Weight.* With the beam supported, place the grain weight in the left-hand pan, and balance by putting gram weights in the right-hand pan.

Choose first a weight which you think is a little too large. Turn the key until the pointer just begins to move. The direction of motion will indicate whether the weight is too large or too small. After finding a weight which is too large, replace it by the next smaller one and continue to add units one by one till the total is again too large. Continue till the sum of the weights is too small by an amount less than 10 milligrams.

Now place the rider on such a numbered division that the position of rest will be near the true position of rest. Determine this position of rest as before, and find the number of milligrams to be added to or subtracted from the weight in the pan to give the precise weight.

From your result determine the number of grains in a gram.

(4) *To Weigh the Given Object.* Determine the weight of the given object in the same way in which the weight of the grain weight was obtained.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

THE MICROMETER CALIPER

Object of Experiment: To afford facility in the use of the micrometer caliper, and to find the number of centimeters in a foot.

Apparatus: Two micrometer calipers, one graduated in centimeters and the other in inches; a steel cylinder and a steel sphere.

Precaution: *Always turn the screw gently* so as to avoid straining the instrument when contact takes place. To do this, and also to insure better agreement between different settings, grasp the milled head very lightly so that the thumb and finger will slip over the barrel the instant contact is made.

Theory: One of the most convenient devices for measuring short distances, such as the diameters of a wire and the thickness of small objects, to a high degree of accuracy is the micrometer caliper. This instrument (Fig. 1) consists of a screw of uniform pitch one end of which is fixed to the inner end of the movable hollow barrel *B*, by means of which it can be turned back and forth in the nut *N*, which is firmly attached to the body of the instrument. On the nut *N* is graduated a linear scale corresponding to the pitch of the screw so that one revolution of *B* advances the cylinder *R* through just one or in some instruments one-half of a division on *N*. Fractions of a revolution are read from graduations on the barrel *B*, which are of such a size and number that the reading can be conveniently recorded *as a decimal.*

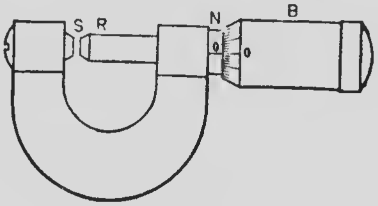


FIG. 1.

At *R* and *S* are plane polished surfaces perpendicular to the axis of the screw. *S* is adjusted so that the caliper reads nearly zero when *R* and *S* are in contact. As this reading is often not exactly zero, a "zero correction" is to be determined and applied to the *mean* of the readings taken in the measurement of any given distance.

The linear scale of one of the calipers is numbered in tenths of inches, each tenth being divided into four equal parts. Thus the value of one of the smallest scale divisions is .025 inch; and the amount to be added for one, two or three of these divisions is .025, .050 or .075 inch. Fractional parts of these smallest divisions are read by means of the micrometer screw. The pitch, or distance between threads of the screw will be found to be equal to one of the smallest divisions of the linear scale, i.e., to .025 inch. Hence it follows that the twenty-fifths of the turn graduated on the edge of the barrel correspond to .001 inch.

The pitch of the other screw is .050 cm., the barrel is divided into fiftieths of a complete revolution, and hence each division of the barrel corresponds to .001 cm. *Be careful to note* that it requires two revolutions of the barrel to move it through 1 mm. on the linear scale.

Procedure: In all readings, tenths of barrel divisions are to be estimated. Each tenth will be seen to correspond to .0001 inch in one instrument and to .0001 cm. in the other.

Turn the milled head of the screw until the end of the screw *R* is in contact with the end of the fixed cylinder *S*. This reading gives the "zero correction." It should be recorded with the proper sign showing whether it is to be added to or subtracted from the *mean* of the readings taken for any distance.

(OVER)

After familiarizing yourself with the method of reading the calipers, measure the diameter of the cylinder and of the sphere provided, being careful to measure the *same* diameter of each both in inches and in centimeters.

Each student is expected to take the entire set of readings. This can be done without loss of time, as one can use the inch caliper while the other is using the centimeter caliper.

Take at least five readings of each diameter and two "zero correction" readings both before and after each diameter is measured. From your readings find the number of centimeters in a foot.

Record your readings and results on the blank paper as follows:

	Inches	Centimeters
First zero correction readings	....	....
Readings of diameter of sphere	....	....
Mean reading for diameter of sphere	....	....
Second zero correction readings	....	....
Mean of first and second zero correction readings	....	....
Corrected diameter of sphere	....	....
Readings of diameter of cylinder	....	....
Mean diameter of cylinder	....	....
Third zero correction readings	....	....
Mean of second and third zero correction readings	....	....
Corrected diameter of cylinder	....	....
Number of centimeters in a foot deduced from measurements of sphere	....	....
Number of centimeters in one foot deduced from measurements of cylinder	....	....
Mean value of one foot expressed in centimeters	....	....

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

THE VERNIER CALIPER

Object of Experiment: To illustrate the principle of the vernier, and to afford practice in the use of the vernier caliper by finding the number of centimeters in an inch.

Apparatus: A vernier caliper; a magnifying glass; object to be measured.

Theory: The vernier, so called from its inventor, Pierre Vernier, is a device for reading with accuracy the fractional parts of the smallest scale divisions of a given scale. Its use in engineering and other scientific instruments has become very general, and hence the importance of thoroughly mastering its principle.

The principle of the vernier is as follows: Sliding along the main scale is a secondary scale, the vernier, divided into equal parts of such a length that the divisions of the vernier are equal to $n \pm 1$ of the smallest divisions of the scale. In this experiment we shall consider only the case where

$$n \text{ v.d.} = (n-1) \text{ s.d.},$$

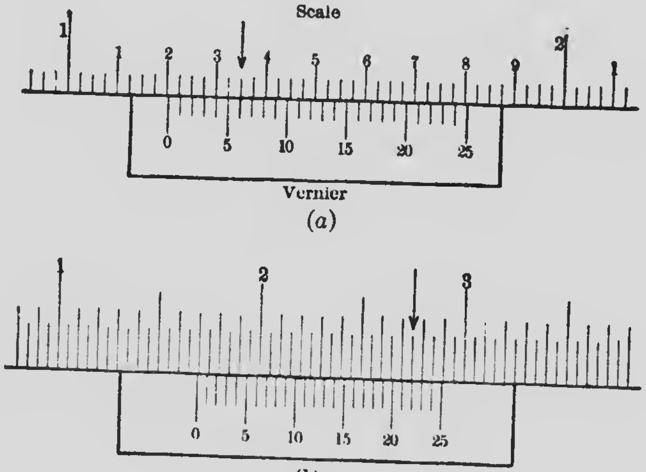
writing v.d. for vernier divisions and s.d. for scale divisions.

Hence

$$1 \text{ v.d.} = \frac{n-1}{n} \text{ s.d.}$$

and

$$1 \text{ v.d.} < 1 \text{ s.d. by } \frac{1}{n} \text{ s.d.}$$



(a)

(b)

FIG. 1.

Suppose $n = 25$ as in the vernier shown in Fig. 1 (*a*).

The 1 v.d. is less than 1 s.d. by $\frac{1}{25}$ s.d. Thus when division 6 of the vernier coincides with some scale division, the fractional part of the smallest division to be read at the *zero* of the vernier is $\frac{6}{25}$ s.d. for

$$6 \text{ v.d. are less than } 6 \text{ s.d. by } \frac{6}{25} \text{ s.d.}$$

Thus we see that this vernier reads to $\frac{1}{25}$ s.d. The next thing to find is the value of the smallest scale division. Examination shows that the scale is numbered in tenths of inches,

(OVER)

and that each tenth is divided into four parts. Hence 1 division is equal to $\frac{1}{40}$ or .025 inch, and the difference between 1 v.d. and 1 s.d. is

$$\frac{1}{25}\times.025=.001 \text{ inch.}$$

The reading of the position of the zero of the vernier in Fig. 1 (*a*) is 1.206 inches. It should be noticed that the vernier reads fractional parts of the *smallest scale division* only, and that if the zero of the vernier is opposite the second, third, or fourth division of a given tenth it is necessary to add .025, .050, or .075 inch as the case may be.

Procedure: In Fig. 1 (*b*) the scale and vernier of a centimeter caliper are shown as they appear when magnified.

Find, as above, the fraction of a centimeter to which one vernier division in the figure corresponds, and write out in detail the way in which you arrive at this value.

Examine the verniers of the caliper provided, and find to what fraction of an inch or a centimeter one vernier division corresponds. If the verniers are duplicates of those of Fig. 1, note that fact. If they differ, work them out in detail as for the vernier of Fig. 1 (*b*).

Having become familiar with the reading of the verniers, measure the diameter and the length of the cylinder provided. Take three to five readings for each linear dimension and find the means. Tabulate your results neatly in columns, leaving space to add the readings, and find the average by dividing by the number of readings taken.

The zero reading, i.e., the reading on the scale when the jaws of the caliper are closed, should be read and *recorded*. If this reading differs from zero, apply the proper correction to the means of the readings for the twelve measurements.

From the formula $\pi r^2 l$ where r is the radius and l the length, calculate the volume of the cylinder in cubic centimeters and in cubic inches. From these values obtain the number of cubic cm. in one cubic inch.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

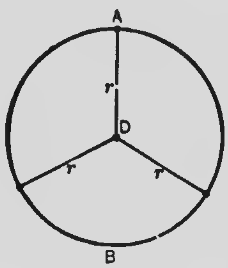
THE SPHEROMETER

Object of Experiment: (1) To measure the thickness of a piece of glass, and (2) to measure the radius of curvature of a spherical surface.

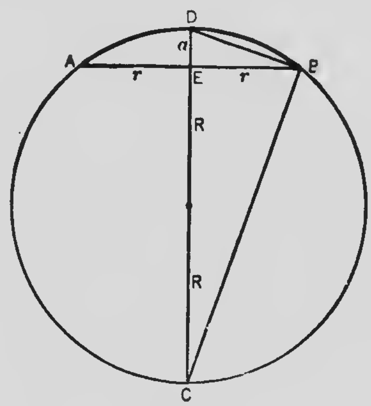
Apparatus: Spherometer; block of plate glass; piece of thin glass; centimeter scale; spherical surface.

Theory: The spherometer is a form of the micrometer screw. It consists of four legs, three of which form the vertices of an equilateral triangle while the fourth is at the center of the triangle. Attached to the central leg is a divided head which travels along a vertical scale. This vertical scale is divided into small divisions each of which equals .5 mm., which is also the pitch of the screw, so that the scale records the turns of the divided head. The divided head has 100 divisions, and since a complete revolution raises the foot .5 mm., each division corresponds to .0005 cm. That is, when the divided head is turned through one small division, the central foot is raised or lowered .0005 of a centimeter.

The spherometer, as its name indicates, may be used to measure the dimensions of a spherical surface, and hence to find the radius of curvature of a lens or a mirror. If the spherometer is placed on a spherical surface, the central foot must be raised or depressed by a small distance in order that all four feet may be in contact with the surface.



PLAN



SECTION

Let ADB = the section of the sphere $ACBD$ included between the feet;
r = the radius of the circle of the feet;
R = the radius of the sphere;
a = the elevation or depression of the central foot.

Suppose ABD to be small. Then DB approaches a straight line. Therefore $DB^2 = a^2 + r^2$. Triangle DEB is similar to triangle BDC.

Hence
$$\frac{BD}{DC} = \frac{DE}{BD}, \text{ and } BD^2 = DC \times DE = a \times 2R.$$
Therefore
$$a^2 + r^2 = 2aR,$$
so that
$$R = \frac{a^2 + r^2}{2a}.$$

Procedure: (1) *To Find the Thickness of a Piece of Glass.* The zero as marked on the divided head is probably incorrect. Determine the true zero position by placing the spherometer on

(OVER)

the plate glass and adjusting the position of the central foot until the point makes contact with the plane glass surface. This may be done by the sense of touch as follows: With one hand hold the spherometer firmly upon the plane surface, while with the other gently turn the milled head until it ceases to move. It will be noticed that the screw turns very easily just at the point of contact due to reduced friction. A little practice will determine this point very readily. Adjust the instrument and read the divided head. Repeat this five times and take the mean.

Now determine the thickness of the piece of glass. Place it directly under the central foot and adjust as before, taking five separate readings. While turning count the number of complete revolutions of the milled head and determine the fraction of a turn from the divided head. The difference between the last reading and that obtained on the plate glass gives the thickness.

(2) *To Determine the Radius of Curvature of a Spherical Surface.* The spherical surface provided is that of a lens. The radius of curvature of such a lens is the radius of the sphere of which the surface is a part. Having determined the zero position place the instrument on the curved surface. Adjust as before so that all four feet make contact. Make five separate determinations of the distance a.

Remove the spherometer to a piece of paper and adjust it so that all four feet touch. Press gently down so that an impression of the feet is left. Measure the distance from the center point to each of the other three points and take the mean. This equals the radius r of the circle of the [illegible]

Calculate R.

FIRST YEAR EXPERIMENTAL PHYSICS

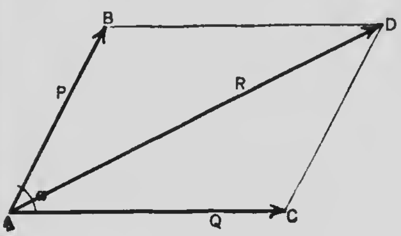
MECHANICS

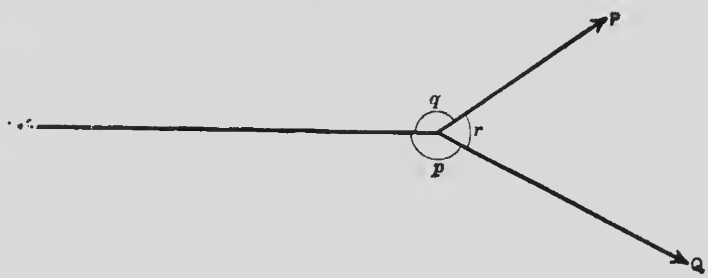
COMPOSITION OF FORCES

Object of Experiment: To verify Lami's Theorem and the Parallelogram Law.

Apparatus: Drawing board hinged so that it can be placed vertically or horizontally; large sheet of paper; thumb tacks; two spring balances; scale pan of known weight; brass weight; centimeter stick; square protractor.

Theory: Every force has magnitude and must act in a definite direction. Hence it can be represented by a straight line, the *length* of the line representing the *magnitude* of the force, and the *direction* in which it is drawn representing the *direction* of the force. Newton's Second Law of Motion implies that when several forces act on a particle at the same time, each force produces its own effect regardless of the action of the other forces. The single force which, acting alone, will produce the same effect as the combined action of these separate forces is called their *resultant*. The separate forces are called the *components*.





Suppose two concurrent forces P and Q act on a particle and that they are represented in magnitude and direction by the straight lines AB and AC. Then experiment shows that their resultant is represented both in magnitude and direction by AD, the diagonal of the parallelogram of which AB and AC form adjacent sides. This is known as the Parallelogram Law.

Analytically it can be shown that the magnitude of the resultant R is given by

$$R^2 = P^2 + Q^2 + 2PQ \cos \alpha,$$

where α is the angle between the lines of action of the two forces. If the forces act at right angles, then α equals 90° and

$$R^2 = P^2 + Q^2.$$

Also if the forces are parallel, then α equals 0° or 180° and

$$R^2 = P^2 + Q^2 + 2PQ,$$

or

$$R = P + Q.$$

Lines drawn to the right are by convention considered positive and to the left negative. The last formula must therefore be interpreted thus: The resultant of two parallel forces is equal in magnitude to the algebraic sum of the components, and the direction of the resultant is given by the sign of R.

If three forces P, Q and R are so arranged that their resultant is zero, they are said to be in equilibrium. It can be shown in this case that

$$\frac{P}{\sin p} = \frac{Q}{\sin q} = \frac{R}{\sin r},$$

(OVER)

where p, q and r are the angles between the forces. That is, the ratio of any force to the sine of the angle between the other two is a constant. This is known as *Lami's Theorem.*

Procedure: Pin the paper to the drawing board and raise it to the vertical position. Hang the balances from the pegs and tie a thread to the two hooks so that, hanging freely, the bottom of the loop is about half-way down the paper. At any point of this loop tie a second thread so that it will not slip. From the free end suspend the scale pan. Place the weight in the pan.

Beneath each of the three threads make *very carefully* two small dots, one near the knot and the other near the edge of the paper. Near the threads record the forces P and Q as indicated by the balances. Obviously the three forces are in equilibrium and any one force is in magnitude and direction the resultant of the other two.

Remove the weights and the balances and lower the board to the horizontal position. Draw the lines representing the *directions* of the forces. Using any convenient unit, mark off on the lines lengths to represent the two forces P and Q. Complete the parallelogram. Then verify the parallelogram law by measuring the diagonal of the parallelogram, and calculating the force represented by it, using the same scale as before.

Compare this resultant force with the total weight suspended by the third thread. If they are found to be equal, the law has been verified.

Find the sines by dropping perpendiculars and determining the ratios by measurement, and thus verify Lami's Theorem.

FIRST YEAR EXPERIMENTAL PHYSICS

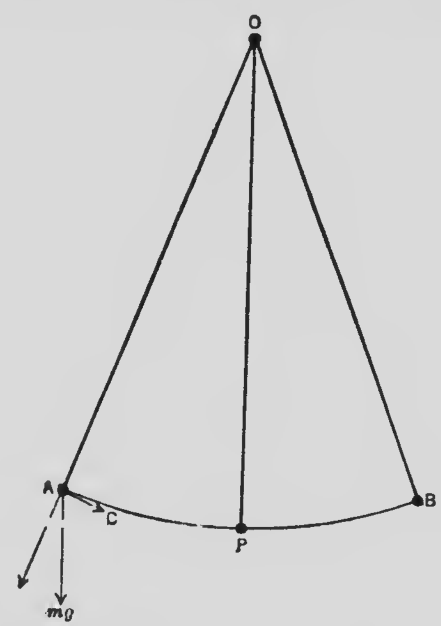
MECHANICS

THE SIMPLE PENDULUM

Object of Experiment: (1) To find the effect of amplitude of vibration, (2) to show that the time of vibration is proportional to the square root of the length, and (3) to find the value of "g."

Apparatus: Simple pendulum; two meter sticks; watch.

Theory: A heavy particle suspended by a weightless thread forms what is called a simple pendulum. Although it is impossible rigorously to construct a simple pendulum, we may closely approach the required conditions if we suspend a small metal sphere by a long and very thin thread. The distance between the point of support and the center of the bob is called the length of the pendulum. A double swing from one side to the other and back is called a *vibration.* The extent of the swing from the mean position is called the *amplitude.*



Let OP represent a pendulum consisting of a particle attached by a string to O. If left to itself, this pendulum will take up a vertical position through O. If drawn aside to position A and released, it will move towards P because of the component AC of the force of gravitation mg, where m is the mass of the body. As it approaches P this component grows smaller and becomes zero at P. The particle will gain kinetic energy in moving from A to P and in virtue of this it will pass P with a maximum velocity and rise to B, as far on the other side of P as A, provided there is no air resistance. The motion is *simple harmonic motion*, and the particle will continue to vibrate from side to side until it is brought to rest by the opposing frictional forces. If the amplitude of vibration is small, it can be shown that the time of one complete vibration is given by $T=2\pi\sqrt{\frac{l}{g}}$ where l is the length of the pendulum, and g is the acceleration due to gravity.

Hence
$$g=4\pi^2\frac{l}{T^2}.$$

(OVER)

Procedure: (1) *The Effect of Amplitude of Swing.* Adjust the pendulum so that it is exactly a meter long. Start it swinging through a small arc. One observer stands directly in front of the pendulum and counts aloud every time it passes in the same direction through the middle position, while the other observes his watch. When both are ready, one begins counting the transits out loud thus: -3, -2, -1, 0, 1, 2, etc. At 0 he taps with a meter stick on the floor while the other records the reading indicated by the second hand of his watch to half a second when the tap occurred. The first observer continues to count and marks 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 by a tap, while the other records the time at each tap.

Subtract the time at the 0th tap from the time at the 30th tap. This gives one value for the time of 30 vibrations. Do the same operation for 5 and 35, 10 and 40, 15 and 45, 20 and 50. These five values should agree fairly well. From their mean obtain T.

Do this for amplitudes of about 5° and 45°.

(2) *To Show that the Period is Proportional to the Square Root of the Length.* With the pendulum swinging through a small arc, determine the time of vibration as above for four other lengths, in this order: 140, 120, 80 and 60 cm. The time for the 100 cm. length has already been taken. Calculate T, T^2, and T^2/l for each of these five lengths.

Plot T^2 against l on squared paper. The fact that all the points lie on a smooth curve indicates that some law connects T and l and the form of the curve shows that T^2 is proportional to l. This is also shown by the fact that the quotients T^2/l are practically constant.

(3) *To Find the Value of "g."* Using the results obtained in (2), calculate g for each of the five different lengths, and compute the average.

Tabulate your results thus:

l	T	T^2	T^2/l	g
60				
80				
100 (5°)				
100 (45°)				
120				
140				

FIRST YEAR EXPERIMENTAL PHYSICS

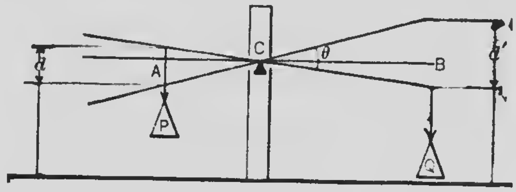
MECHANICS

LAW OF MOMENTS

Object of Experiment: To verify the law of moments, and to apply the principle of work to the lever.

Apparatus: Graduated bar mounted at its center of gravity; five scale pans of known weight; two 500-gram weights; 400-, 300-, and 200-gram weights; unknown weights; centimeter scale.

Theory: *The moment of a force* about a point is the product of the force and the length of the perpendicular from the point to the line of action of the force.



The lever is defined as a rigid bar free to turn about some point C, called its fulcrum. In this experiment, if the fulcrum is at the center of gravity of the bar, then the weight of the bar need not be considered. If weights are hung from each side of the fulcrum, the condition for equilibrium is that the sum of the moments on one side of the fulcrum equals the sum of the moments on the other side. That is $P \times AC = Q \times BC$.

Therefore $$\frac{Q}{P} = \frac{AC}{BC} \quad \text{. . . . .} \quad (1)$$

If, while the bar is in equilibrium, it is given an angular displacement θ, then the weight P moving through a vertical distance d will do work equal to Pd. Q will be raised by this displacement through a distance d', and the work done on it is equal to Qd'. From the figure it is clear that $\frac{AC}{BC} = \frac{d}{d'}$. Hence from (1) $\frac{Q}{P} = \frac{d}{d'}$ or $Pd = Qd'$, i.e., one force multiplied by its vertical displacement is equal to the other force multiplied by its vertical displacement. This proves that the work done on the lever by the applied force equals the work done by the lever on the resisting force.

Procedure: Balance the two 500-gram weights on each side of the bar. Measure their distances from the fulcrum. Verify the fact that their moments are equal. In every case the weight of the pan must be added to the weight it supports.

Place the 300-gram weight near the end of the bar and balance with the 500-gram weight on the other side. Verify the law of moments. Turn the rod through a moderate angle and measure the vertical displacements of each weight. This can be done by lowering one side until the pan rests on the table, and measuring the heights of the supports of the pans above the table. Then do the same thing with the other pan resting on the table. The vertical displacements are easily obtained by subtraction. Verify the fact that the work done by one weight equals the work done on the other. Express the work done in gram-centimeters and in ergs.

Balance two weights at different points on one side against one on the other. Also balance three weights on one side against two on the other. Verify the law of moments in each case.

Calculate the error in each case and the percentage error. Balance the unknown weight near the end of one arm against the 500-gram weight. Applying the law of moments, find the value of the unknown weight.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

PULLEYS

Object of Experiment: To study the pulley as a machine, and to find the mechanical advantage of different forms and combinations of pulleys.

Apparatus: Four single pulleys; two blocks of three pulleys each; two scale pans; spool of stout thread; meter stick; frame from which pulleys can be suspended; set of weights.

Theory: A pulley may be considered as a traveling lever of constant length. Let the pulley be fixed (Fig. 1). If a string passing over the pulley supports a weight W at one end, it can be balanced by a force P at the other. Since C is the fulcrum, then $P\times AC=W\times BC$ or $P=W$ if there is no friction. If P moves a distance X then W moves a distance X and the the work done is PX or WX. In this case the mechanical advantage is simply one of direction.

If the pulley is movable (Fig. 2), then at any instant $P\times AC=W\times BC$ where C is the fulcrum. Hence $W/P=2$. The ratio W/P is called the mechanical advantage. In Fig. 2, if P moves a distance X, W will move a distance Y. From the principle of the conservation of energy the work done by a machine must equal the work done on it, if there is no friction. Hence, neglecting friction, $WY=PX$. Or $W/P=X/Y=2$. It is thus evident that P will move twice as far as W. This is sometimes expressed as—"What is gained in force is lost in speed." If the weight w of the pulley is considered, then $(W+w)Y=PX$.

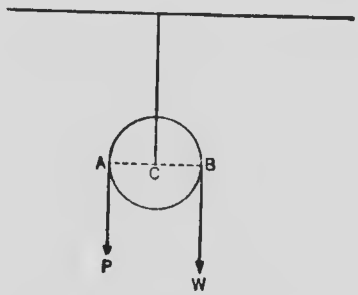


FIG. 1.

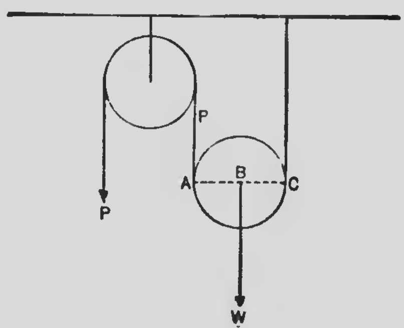


FIG. 2.

Let a system of pulleys be arranged as in Fig. 3. Let P move a distance X and W a distance Y. Neglecting the weight of the pulleys, $PX=WY$ and X is eight times Y. Considering the pulleys, let the weight of each be w. If pulley A moves a distance Y, pulley B will move a distance $2Y$ and pulley C a distance $4Y$. Hence, applying the principle of work $PX=(W+w)Y+2wY+4wY$ or $PX=(W+w)Y+6wY=WY+7wY$. Therefore the mechanical advantage $=\frac{W}{P}=\frac{X}{Y}-\frac{7w}{P}$.

For two blocks with three pulleys each (Fig. 4), the number of supporting strings will be six. If P is displaced a distance X, W will move over a distance Y such that X will be six times Y. If the weight of the block is w', then $(W+w')Y=PX$. The mechanical advantage $=\frac{W}{P}=\frac{X}{Y}-\frac{w'}{P}$.

Procedure: Suspend the pulley as in Fig. 1; pass a string over it and show that equal weights balance, and that one moves up as much as the other moves down.

Arrange a pulley as in Fig. 2. Place in a pan a 500-gram weight and suspend it from the hook of the pulley. Pass a string over the fixed pulley and attach the other pan to the free end. Add weights until a balance is obtained. Verify that the mechanical advantage

(OVER)

equals 2. Verify also that for any displacement of P, that of W is one-half as much. Giv P a displacement of 25 cms. Calculate in gram-centimeters and in ergs the work done o both sides. The weights of the pulley and the pan must be considered. The small differenc in the work done is due to friction. What percentage of the total work is spent in friction?

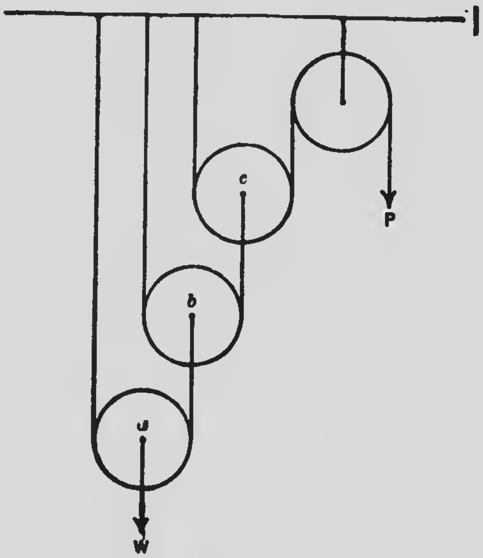


FIG. 3.

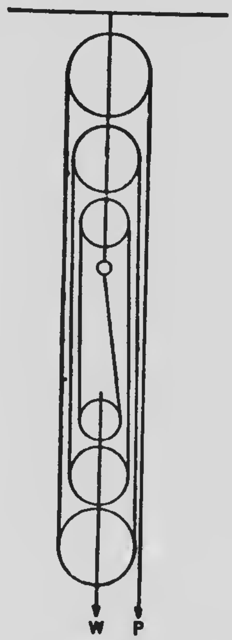


FIG. 4.

Arrange the pulleys as in Fig. 3. Suspend a pan with the 500-gram weight from the lower pulley. Repeat the above observations and verifications. The work done is given by $PX=(W+w)Y+6wY=WY+7wY$.

Pass a string around the two blocks as in Fig. 4 so as to include all the pulleys. Suspend a 500-gram weight from the lower block and repeat as in the last case, finding the mechanical advantage, the work done and the percentage of work spent in overcoming friction.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

ARCHIMEDES' PRINCIPLE

Object of Experiment: (1) To verify Archimedes' principle, and (2) to find the specific gravity of a solid.

Apparatus: Tin vessels; copper beaker; stone; wooden block; metal block; thread, balance and weights.

Theory: Archimedes' principle states that a body immersed in a fluid loses weight equal to the weight of the fluid displaced. If the body floats, the weight of the fluid displaced must equal the weight of the body.

The ratio of the weight of any body to the weight of an equal volume of water is called its *relative density* or *specific gravity*. By Archimedes' principle the specific gravity may be defined as:

$$\frac{\text{weight of body in air}}{\text{weight of water displaced}} \quad \text{or} \quad \frac{\text{weight of body in air}}{\text{loss of weight in water}}.$$

Procedure: (1) *To Verify Archimedes' Principle.* Weigh carefully the smaller of the two tin vessels, the stone and the wooden block. Fill the larger vessel with water until it overflows through the spout. As soon as it stops dripping place the smaller vessel beneath the overflow tube and carefully immerse the stone. Determine the weight of the displaced water. Repeat for the wooden block making sure that it floats upright. Using the copper beaker and the bridge weigh the stone immersed in water. Compare the weight of the block in air with the weight of the water it displaces. Also compare the loss of weight of the stone in water with the weight of the water displaced by it.

(2) *To Determine the Specific Gravity of the Stone and of the Metal Block.* The specific gravity of the stone can be calculated from the data already obtained by applying the formula. Determine the specific gravity of the metal by weighing it in air and in water.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

THE JOLLY SPRING BALANCE

Object of Experiment: To determine the specific gravity of (1) aluminum. (2) brass, (3) a saturated salt solution.

Apparatus: Jolly spring balance; piece of aluminum; piece of brass; saturated salt solution.

Theory: The density of any substance is defined as the mass per unit volume. Hence density $= \frac{\text{mass}}{\text{volume}}$.

The ratio of the mass of any volume of a substance to the mass of an equal volume of water is called the *relative density* or *specific gravity* of that substance. Thus specific gravity is expressed by the ratio

$$\frac{\text{weight of body}}{\text{weight of equal volume of water}}.$$

By Archimedes' principle a body immersed in a liquid loses weight equal to the weight of the liquid displaced. Since the volume of the liquid displaced must equal the volume of the solid, specific gravity may be defined as

$$\frac{\text{weight of body in air}}{\text{loss of weight in water}}.$$

Hence for a solution, the specific gravity is expressed by the loss of weight of a body immersed in the solution divided by the loss of weight when it is immersed in water, since the volumes displaced on both cases are equal.

Instead of expressing the weight in grams, in this experiment it is expressed in millimeters of extension of a spiral spring. By Hooke's law the extension of a spring (within certain limits) is proportional to the weight which it suspends. Hence instead of reading the weight in grams read the weight as millimeters of extension.

The Jolly balance consists of a spiral spring suspended vertically with two scale pans attached to the lower end, the lower one of which must always be immersed in water at such a depth that but a single wire emerges from the surface of the liquid. Behind the pans are a mirror and a millimeter scale. A small bead or a pointed wire serves as an index and its position on the scale should be read to one-tenth of a millimeter. There will be no error due to parallax if the reflected image of the index coincides with the index itself. The instrument should be adjusted so that the spring hangs parallel to the upright and the index comes directly in front of the scale.

Procedure: (1) *To Find the Specific Gravity of Aluminum.* With the lower pan immersed in water take the zero reading E_0. Lower the beaker to the bottom of the upright and place the aluminum in the upper pan. Raise the beaker until the lower pan is again immersed. Read the extension E_a produced by the body in air. Remove the body to the lower pan, taking care that no air bubbles adhere to it. Adjust the beaker and read the extension E_w produced by the body in water.

Calculate the specific gravity from the formula

$$\frac{E_a - E_0}{E_a - E_w}.$$

(2) *To Find the Specific Gravity of Brass.* Repeat the above procedure for the piece of brass.

(3) *To Find the Specific Gravity of the Saturated Salt Solution.* Replace the pans by the small glass sinker. Read the scale with the sinker suspended in air. Adjust the beaker so that the sinker is submerged and read again. Replace the water by the salt solution and with the sinker submerged take the reading.

Calculate the specific gravity of the salt solution.

Replace the salt solution in its container, rinse the glass and wash the sinker.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

MOHR'S BALANCE

Object of Experiment: To determine the specific gravity of solutions, using Mohr's balance.

Apparatus: Mohr's balance and fixtures; solutions of different densities.

Theory: The apparatus consists of a balance beam divided into ten parts. From one end is suspended a glass sinker, while the other end is so counterbalanced that the beam is in equilibrium when the sinker is suspended in air. With the balance are three riders, the unit, the tenth, and the hundredth riders. The largest is so made that its mass is exactly that of the volume of water displaced by the sinker in accordance with Archimedes' principle. If then the sinker is suspended while immersed in water, the balance will be in equilibrium when the unit rider is at division 10, i.e., suspended on the hook with the sinker. The tenth rider has a mass .1 of the mass of the displaced water, and the hundredth a mass .01 of the mass of the water displaced. Suppose in a particular case the unit rider is on division 8, the tenth rider on division 2, and the hundredth rider on division 5. The specific gravity would then be .825.

Precaution: Be very careful after using a solution to pour it back into its own bottle and rinse well the glass vessel and sinker before using another solution.

Procedure: See that the beam is level when the sinker is hung in air. Verify the weights. This can be done as follows: Suspend the sinker in water so that it is entirely immersed. Place the units rider on the hook. If it is correct, the balance will be at zero. To test the tenth rider, place the unit rider on division 9 and the tenth rider on the hook. Then $.9+.1=1$ and it should balance again. Place both the unit rider and the tenth rider on division 9 and the hundredth rider on the hook. Again it should balance since $.9+.09+.01=1$.

Now find the specific gravities of the solutions given.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

THE SPECIFIC GRAVITY BOTTLE

Object of Experiment: To determine the specific gravity of a liquid and of a solid in fragments by means of the pyknometer, or specific gravity bottle.

Apparatus: Specific gravity bottle; distilled water; salt solution; fragments of rock; balance and weights.

Theory: By definition the specific gravity of a body is the ratio of its weight to the weight of an equal volume of water. The specific gravity bottle is designed to hold a definite volume of a liquid. Of the many forms used, the one provided for this experiment secures its constant volume by means of a stopper with a capillary tube. Obviously the volume will be the same, whatever the liquid in the bottle may be. Hence the specific gravity of liquids can be obtained, since the masses of equal volumes are easily determined and compared. Also by the application of Archimedes' principle the specific gravity of a solid in fragments can be found.

Procedure: The volume and therefore the density of a liquid varies considerably with its temperature. Hence in comparing the given solutions with water, care should be taken that they are at the same temperature. For the same reason the bottle should not be held in the palm of the hand, but should be handled by the neck. All weighings should be made to the nearest milligram.

(1) *To Find the Specific Gravity of the Rock Fragments.* Weigh the empty bottle (B), being sure that it is clean and dry. Place not more than 100 gm. of rock fragments in the bottle and weigh again ($B+R$). Fill up the remaining space in the bottle with distilled water and insert the stopper. As some of the water will be forced out of the capillary tube, dry the bottle and weigh again ($B+R+w$). Empty out the water and the rock, rinse thoroughly, fill with distilled water and weigh ($B+W$). The symbols in brackets stand for the various weights obtained.

Now the specific gravity of the rock by Archimedes' principle is the weight of the rock divided by the weight of the water displaced by the rock, and is given by

$$\frac{R}{W-w}.$$

(2) *To Find the Specific Gravity of a Given Solution.* Fill the bottle with the salt solution, wipe dry and weigh. The weight of the bottle filled with distilled water has already been obtained. Calculate the specific gravity of the salt solution.

Precaution: Rinse out the specific gravity bottle thoroughly and wash the stopper at the end of the experiment.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

THE CONSTANT-WEIGHT HYDROMETER

Object of Experiment: To calibrate a hydrometer, and by means of it to measure the density of a given solution.

Apparatus: Ungraduated constant weight hydrometer; commercial hydrometer; distilled water; salt solution; solution of copper sulphate; tall glass jar; centimeter scale.

Theory: The principle of the hydrometer is that a floating body displaces its own weight of liquid. The commercial instrument consists of a hollow glass tube, uniform in cross-section and weighted at one end. A scale is marked upon it, graduated directly in density. In different liquids the hydrometer sinks to different depths, depending upon the density of the liquid. The smaller the diameter of the tube the greater the sensitiveness. In such a case a long tube would be required for a great range of densities, and a correspondingly large quantity of the liquid would be required. To avoid this, most hydrometers have a limited range, so that different liquids require different instruments. Thus there are lactometers, alcoholometers, etc.

Suppose a hydrometer is immersed in a liquid of density d_1, and the level l_1 of the surface of the liquid is marked on the stem. It is next placed in a liquid of density d_2, where d_2 is greater than d_1 and the level l_2 of the surface of the liquid is marked. Let w be the weight of the hydrometer. By Archimedes' principle $\frac{w}{d_1}$ and $\frac{w}{d_2}$ are the volumes of the liquids displaced in each case. Also $l_2 - l_1$ is the length of stem between the two marks. The volume of this length is $\frac{w}{d_1} - \frac{w}{d_2}$ and the volume v_0 per centimeter length is $\dfrac{\frac{w}{d_1} - \frac{w}{d_2}}{l_2 - l_1}$.

Therefore

$$v_0 = \frac{w}{l_2 - l_1}\left(\frac{1}{d_1} - \frac{1}{d_2}\right). \qquad (1)$$

Now let the hydrometer be immersed in a liquid of unknown density d and the level l of the surface of the liquid marked on the stem. Suppose d is greater than d_1. Then $l - l_1$ is the length of stem between the marks for these two densities.

Then

$$v_0 = \frac{w}{l - l_1}\left(\frac{1}{d_1} - \frac{1}{d}\right). \qquad (2)$$

d_1 is a known density, v_0 can be determined, and l_1, l_2, l and w can be measured. Hence d can be found.

Precaution: Return each solution to its proper bottle, and rinse the hydrometers and the jar each time they are used.

Procedure: Remove the lower cork and weigh the unmarked hydrometer which is to be calibrated. Fill the tall jar with distilled water and immerse the unmarked hydrometer. In this case $d_1 = 1$. Measure the length l_1 of the hydrometer tube which projects from the water. Pour back the distilled water and fill the jar with the salt solution. Its density d_2 may be found by the commercial hydrometer. Place the unmarked hydrometer in the salt solution and measure the exposed length l_2 of the tube. Pour back the salt solution and thoroughly rinse the jar and the hydrometers.

Calculate v_0 from formula (1).

The other receptacle contains a solution of copper sulphate of unknown density d. Fill the jar with some of this solution. Place the unmarked hydrometer in the solution and measure the exposed length l as before.

Calculate d from formula (2).

Verify your result with the commercial hydrometer.

FIRST YEAR EXPERIMENTAL PHYSICS

MECHANICS

BOYLE'S LAW

Object of Experiment: To verify Boyle's law.

Apparatus: Boyle's law apparatus; barometer.

Theory: Compressibility is one of the fundamental properties of gases. If the pressure on an enclosed mass of gas is changed, there is a marked change in volume. The relation between the change in pressure and the corresponding change in volume was first stated by Robert Boyle in 1662. "*At a constant temperature*, the volume of a mass of gas varies inversely as the pressure to which it is subjected."

Thus if V_0 = the initial volume of a mass of gas,
P_0 = the initial pressure,
V = some other volume of the same mass of gas,
P = the corresponding pressure.
Then $V_0P_0 = VP =$ a constant.

Or it may be written $V = \frac{K}{P}$, where K is the constant.

This simply means that if the pressure is doubled the volume will be halved.

In the apparatus provided, a mass of dry air is enclosed in the right-hand tube. Suppose that the level of the mercury in both tubes is the same (Fig. 1). Since there is equilibrium,

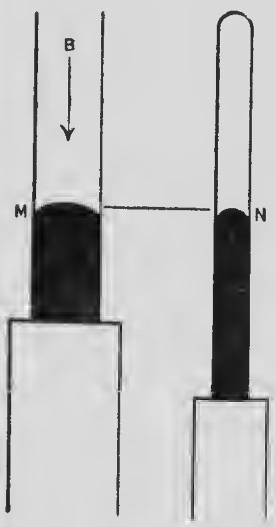


FIG. 1.

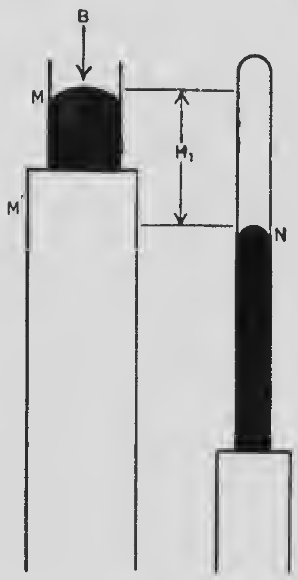


FIG. 2.

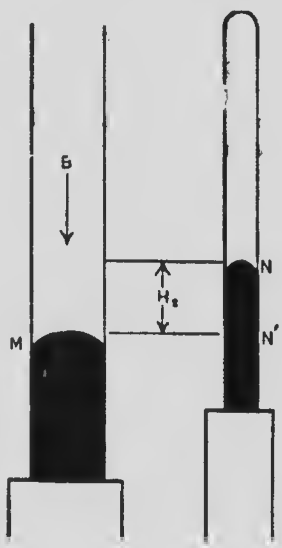


FIG. 3.

the downward pressure at M must equal the upward pressure at N according to Pascal's law. But the downward pressure at M is the atmospheric pressure B. Let V = the volume of gas enclosed. Then by Boyle's law $BV = K$.

Now suppose the open tube is raised so as to increase the pressure on the enclosed air (Fig. 2). By Pascal's law the upward pressure at N equals the downward pressure at M'.

(OVER)

But the downward pressure at M' is evidently composed of two parts—the atmospheric pressure on M and the weight of mercury of height H_1. Since the atmospheric pressure is measured in centimeters of mercury, the total pressure at M' can be written $B+H_1$. Let V_1 be the new volume, which will be smaller than V.

Then by Boyle's law $(B+H_1)V_1=K=BV$.

There is one other possible case (Fig. 3). Suppose the open tube is lowered until the level of the mercury in it is below that in the closed tube. Here the upward pressure at N' equals the downward pressure at M which is B. So the upward pressure on the gas is $B-H_2$. Let V_2 be this volume, which will be larger than V.

Then as before $(B-H_2)V_2=BV=(B+H_1)V_1=K$.

Procedure: Read the barometric pressure B. Adjust the closed tube until the bottom of the stopper is opposite the 100 cm. mark. Lower the open tube until the mercury level in the closed tube is very low. Read the two levels of the mercury.

Now adjust the open tube so that the mercury level in it is raised by about 12 cm., and read the levels for this new position. Continue to take readings by raising the open tube by intervals as indicated above until the upper limit of the scale is reached so that altogether at least ten sets of readings have been taken.

Record your results thus:

Level Open Tube	Level Closed Tube	H	$B \pm H$	V	K

The products $(B \pm H)V$ should agree fairly closely, since they are values of the constant K.

Plot a curve using pressures as ordinates and volumes as abscissæ. The curve obtained is a portion of an equilateral hyperbola. The fact that the points all lie on a smooth curve indicates that some law connects P and V. The verification of the particular law is obtained from the agreement of the curve with the theoretical one or, in this case, by the equality of the products.

FIRST YEAR EXPERIMENTAL PHYSICS

HEAT

THE FIXED POINTS OF A THERMOMETER

Object of Experiment: To determine the fixed points of a mercurial thermometer, and hence to deduce a formula for finding the true temperature corresponding to any reading of the thermometer.

Apparatus: Thermometer to be tested; a beaker filled with crushed ice; a steam hypsometer and a burner.

Theory: In accurate thermometric work it often becomes necessary to redetermine the fixed points of the thermometer used. By this is meant the determination of the readings corresponding to the freezing and boiling temperatures of water under a known barometric pressure.

Let the reading of the thermometer at the temperature of melting ice be denoted by t_i; and denote by t_s the observed reading when the thermometer is immersed in steam.

It is an experimental fact that, in the neighborhood of standard pressure, an increase of one centimeter of mercury in the pressure raises the boiling-point of water .37° C. Therefore, since the temperature of steam over boiling water under a pressure of 76 cms. of mercury is taken as 100° C., it follows that the true temperature T of steam is given by the equation

$$T = 100 + .37(B - 76).$$

where B is the barometer reading expressed in centimeters of mercury.

In Fig. 1, note especially that all actual thermometer readings are represented on the right, while only true temperatures are shown on the left of the mercury column. Then, by reference to the figure it is clear that $(t_s - t_i)$ thermometer divisions are equal to $(T - 0)$ true degrees. Hence, assuming that the capillary bore of the thermometer is of uniform cross-section, it follows that

$$\textit{One thermometer division} = \frac{T}{t_s - t_i} \textit{ true degees Centigrade.}$$

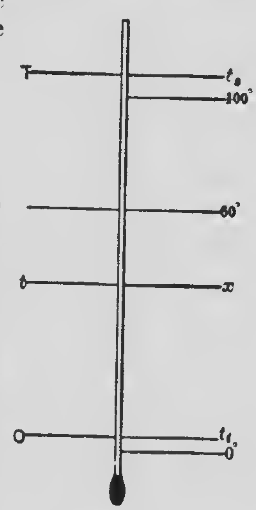


Fig. 1.

Procedure: Since a small residual contraction goes on in the bulb of the thermometer for a long time after it has been heated through any considerable range of temperature, the observations for the freezing-point should be taken before those for the boiling-point.

Fill the beaker with finely crushed ice and pour in sufficient water to nearly cover the ice, which should look white on top. Now carefully insert the thermometer into the ice. After the mercury column has become almost stationary, read the thermometer at one-minute intervals until five readings are obtained which show no systematic change. Take the readings with as little as possible of the mercury column exposed, being careful that the line of sight is perpendicular to the stem of the thermometer. Record *all* observations, and take the average of the last five as the value of t_i.

Having seen that the lower part of the hypsometer is about two-thirds full of water, remove the thermometer from the ice and, after warming it by holding the bulb in the hand, slowly insert it into the steam until the top of the mercury just appears above the stopper. Since the boiling-point of water is raised by impurities, the bulb of the thermometer should be above the surface of the water. The thermometer should also be clean, so that, as the steam condenses on it, it will be covered with a layer of pure water just at the boiling-point. Allow the steam to flow freely, regulating the gas, so that

(OVER)

the pressure within the hypsometer is not sensibly greater than without, as shown by the manometer tube. Obtain the thermometer readings as before, and denote the mean by t_1.

Read the barometer.

In your report include a diagram similar to Fig. 1, but with the values obtained for T, t_0 and t_1 inserted. Find the value of one scale division of the thermometer.

Problem: Suppose the thermometer reads 60° C. when placed in a certain solution. Find the true temperature of the solution (1) in degrees Centigrade, (2) in degrees Fahrenheit.

Write the formula for the true temperature t, corresponding to any reading x on the thermometer tested, inserting the special values found for t_0, etc. Hint: t=(true value of one division)×(number of divisions x is above true zero).

FIRST YEAR EXPERIMENTAL PHYSICS

HEAT

THE AIR THERMOMETER

Object of Experiment: To determine the coefficient of expansion of air by means of a Jolly constant-volume air thermometer.

Apparatus: A Jolly air thermometer with a quartz bulb; a hypsometer; a vessel for cracked ice.

Theory: By Charles' law the product of the volume V and pressure P of any given mass of gas is proportional to the absolute temperature T.

If P_0, V_0 and T_0 represent the values of these quantities at 0° C., then

$$\frac{PV}{T}=\frac{P_0V_0}{T_0}.$$

If we write (T_0+t) for T where t is the temperature on the Centigrade scale corresponding to T degrees absolute, then

$$\frac{PV}{T_0+t}=\frac{P_0V_0}{T_0},$$

from which we have

$$PV=P_0V_0\left(1+\frac{1}{T_0}t\right).$$

$\frac{1}{T_0}$ is the coefficient of expansion of the gas and is written α. Hence we have $PV=P_0V_0\,(1+\alpha t)$.

If either P or V is kept constant, when a gas is heated, α may be measured by observing the increase in either the volume or the pressure alone. In the Jolly air thermometer the volume of air enclosed in a quartz bulb and heated is kept constant by increasing the pressure to which the air is subjected. An adjustable mercury column is provided for this purpose.

Since V is constant, we have $P=P_0(1+\alpha t)$ which gives us

$$a=\frac{P-P_0}{P_0t}. \qquad \qquad (1)$$

No correction is necessary for the volume change of the quartz bulb, since the coefficient of expansion of quartz is very small; neither is [illegible] necessary for the volume of air in the tube connecting the bulb with the manometer column, since the volume of this tube is small compared with the volume of the bulb.

Procedure: Obtain some finely cracked ice, well moistened with water. Insert the quartz bulb of the thermometer in the vessel provided for the ice, and pack the ice well around the bulb. Adjust the manometer column until the mercury level comes to the arbitrary zero on the scale. Read the barometer carefully to find the air pressure on the open manometer tube.

The pressure P_0 in the bulb at 0° C., is equal to the barometer reading after adding or subtracting the difference in mercury level in the two arms of the manometer.

After the reading has become steady (about 15 minutes is sufficient) remove the bulb from the ice and place it in the hypsometer, where it is surrounded by live steam. Adjust the manometer column until the mercury level is brought to zero on the scale. Read the barometer again, and find the temperature of the steam from the formula

$$t=100+.37(B-76).$$

When the reading is seen to be steady, observe carefully the reading of the mercury level in the open arm of the manometer. To obtain the increase of pressure in centimeters of mercury due to the heating, subtract the reading of the mercury level when the bulb was at 0° C. This difference is equal to $P-P_0$.

Now calculate the coefficient of expansion a from formula (1).

Repeat the observations in ice and in steam. Take the barometer reading in centimeters. **Tabulate all results carefully.**

FIRST YEAR EXPERIMENTAL PHYSICS

HEAT

COEFFICIENT OF EXPANSION

Object of Experiment: To determine the coefficient of linear expansion of brass.

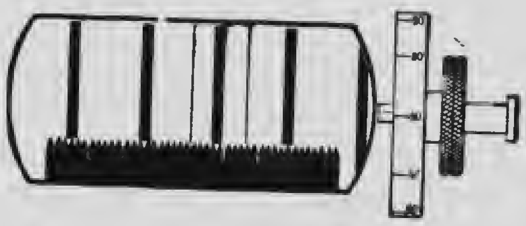
Apparatus: Expansion apparatus; boiler; micrometer microscope; steel centimeter scale; meter stick; thermometer.

Theory: The *coefficient of linear expansion* of any substance is defined as the increase in unit length of that substance when heated one degree. This definition assumes the coefficient to be constant at all temperatures, which is nearly true for most solids between 0° C. and 100° C.

Let l indicate the length of a rod at t° C., and α be the coefficient of expansion. Suppose the rod is heated to a temperature of t_1° C., and the new length is l_1. The increase in length is $l_1 - l$, and the increase in unit length for a temperature change of $t_1 - t$ degrees is $\frac{l_1 - l}{l}$. Hence the increase in unit length for an increase in temperature of one degree is

$$\alpha = \frac{l_1 - l}{l(t_1 - t)} = \frac{\lambda}{l(t_1 - t)},$$

which is the coefficient of linear expansion.



Note on Micrometer Microscope. The main difficulty in the determination of α arises in measuring the increase in length λ. The expansion is much too small to determine accurately by direct measurement. Hence a micrometer is used, in the form of a micrometer microscope. A screw with a divided head carries in the eye-piece a cross-hair, which can be arranged to be coincident with the image. By turning the screw the cross-hair can be made to pass across the field of vision. Perpendicular to the cross-hair, and fixed in the microscope so as to form one boundary of the field, is a jagged edge over which the cross-hair moves. The teeth are so made that each one corresponds to a complete turn of the screw, that is, the distance between the teeth is the pitch of the screw. Suppose the microscope is focused on the object and the cross-hair is set over a particular mark. If the object moves at all, the image moves with it and away from the cross-hair. By turning the screw until the cross-hair is again over the same mark and counting the number of whole turns and the fraction of a turn by the divided head, the displacement of the mark can be very accurately determined.

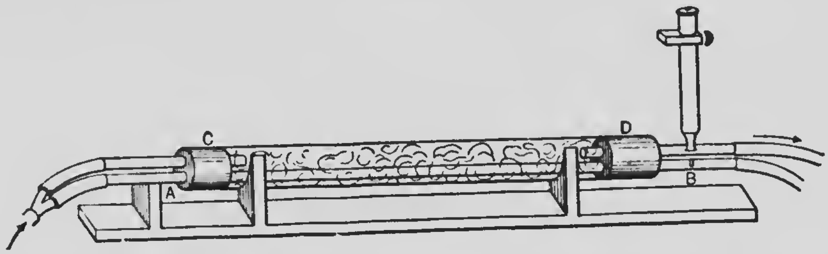
Procedure: Disconnect the boiler from the apparatus by removing the stopper. Fill it to the shoulder with water and light the gas under it.

The rod whose expansion coefficient is to be determined is fixed near one end, and practically the whole length enclosed in an air jacket through which steam can be passed. Focus the microscope upon some distinct mark at the free end, taking care that the image appears in the side of the field of view next to the free end of the rod, since the direction of travel will apparently be reversed by the microscope. Turn the micrometer screw until the cross-hair is directly over the chosen mark. Notice its position relative to the teeth and also read the divided head. The temperature of the rod will be given by a thermometer placed inside it.

(OVER)

Having removed the thermometer, replace the stopper and allow steam to pass through the apparatus, taking every precaution not to move the rod or the microscope. Let the steam flow freely through the apparatus until the temperature has become steady. Read the barometer, and find the temperature t_1 of the steam corresponding to the barometric pressure B from the formula $t_1 = 100 + .37(B - 76)$.

It will be noticed that the mark has moved across the field of view of the microscope. With the steam still flowing, turn the divided head until the cross-hair again coincides with



the mark. Count the number of whole turns passed over. Estimate the fraction of a turn from the two readings of the divided head.

This gives the expansion in terms of turns of the micrometer screw. To get it in millimeters remove the microscope and focus it on a millimeter mark of a steel scale placed on the stand. Determine the number of turns required to move the cross-hair one millimeter. Calculate from this the expansion λ in centimeters. With the meter stick measure to the nearest millimeter the length l of the rod from the mark to the place where it is fixed.

Calculate the coefficient of expansion.

FIRST YEAR EXPERIMENTAL PHYSICS

HEAT

SPECIFIC HEAT

Object of Experiment: To determine the specific heat of copper by the Method of Mixtures.

Apparatus: A suitable calorimeter and cylindrical heater, which is a modification of Regnault's apparatus; a mass of copper wire; two thermometers.

Theory: By the specific heat of a substance is meant the number of calories required to raise the temperature of one gram of the substance one degree Centigrade, the calorie being defined as the amount of heat necessary to raise one gram of water from 14.5° to 15.5° C.

Suppose a known mass of copper W_1 is heated to a temperature t_c, and then quickly lowered into a mass of water W_w contained in a copper calorimeter of mass W_k.

Let the initial temperature of the water be t_1 and the final uniform temperature of the water and copper be t_2. Then the quantity of heat lost by the mass of copper W_1 will be equal to $sW_1(t_c-t_2)$ calories, s being the specific heat of copper; and the quantity gained by the water will be equal to $W_w(t_2-t_1)$, and that gained by the calorimeter will be equal to $sW_k(t_2-t_1)$, since the calorimeter is of copper. Hence, assuming no gain or loss of heat externally, we can write

$$sW_1(t_c-t_2)=W_w(t_2-t_1)+sW_k(t_2-t_1).$$

Therefore

$$s=\frac{W_w(t_2-t_1)}{W_1(t_c-t_2)-W_k(t_2-t_1)}.$$

The quantity sW_k is called the "water equivalent" of the calorimeter.

Procedure: First fill the steam generator about to the shoulder, and start heating the water. Be sure to have a sheet of asbestos under the burner to protect the shelf or table.

Weigh carefully the mass of copper wire W_1. Suspend it by a thread inside and nearly half-way down the cylindrical heater. Insert a thermometer into the center of the mass of copper wire so that it does not touch the inner sides of the cylinder and read too high.

Connect the steam generator, and let the steam flow through the cylindrical heater till the copper has been raised to a high temperature, which should be about 95° C.

While the steam is flowing, determine the weight W_k of the calorimeter (the inner copper beaker only).

Fill the calorimeter with water to 1 cm. from the top, being careful to take enough water so that it will completely cover the copper wire without overflowing. Again determine the weight, and deduce the weight of water W_w. The water in the calorimeter should be cooled to about 5° C. below room temperature.

Place the calorimeter inside the felt-lined vessel.

Just before lowering the heated copper into the calorimeter, stir the water in the calorimeter and read its temperature t_1.

Read the temperature of the copper wire t_c.

Now place the calorimeter under the cylindrical heater, and quickly but carefully lower the mass of copper into it. Carefully stir the water with the thermometer and read the highest temperature t_2 reached by the mixture.

Substitute these values in the formula, and calculate s.

FIRST YEAR EXPLRIMENTAL PHYSICS

HEAT

LATENT HEAT OF FUSION

Object of Experiment: To determine the latent heat of fusion of ice.

Apparatus: A calorimeter consisting of a copper beaker in a box to reduce errors due to radiation; a second copper beaker to contain ice; thermometer; filter paper; forceps; broken ice; balance and weights.

Theory: *The latent heat of fusion* of any substance is defined as the number of calories required to convert one gram of the solid at the melting-point into liquid at the same temperature.

Suppose a quantity of ice of weight W_i be dropped into a quantity of water W_w at a temperature t_1 and the mixture be stirred until the ice is melted and the water is of uniform temperature t_2. The heat absorbed by the ice without change of temperature will be LW_i, where L is the latent heat of fusion of ice. The mass W_i will furthermore be raised to a temperature t_2, so that the total heat absorbed is equal to $LW_i+W_it_2$ calories.

Denoting the specific heat of the calorimeter by s, and its weight by W_k, its water equivalent is sW_k, so that the heat lost by the water and calorimeter is $(W_w+sW_k)(t_1-t_2)$.

Hence assuming no gain or loss of heat externally,

$$LW_i+W_it_2=(W_w+sW_k)(t_1-t_2),$$

and therefore

$$L=\frac{(W_w+sW_k)(t_1-t_2)}{W_i}-t_2.$$

Procedure: Weigh carefully the empty metal calorimeter containing the thermometer, which is to be used as a stirrer. Fill the calorimeter with water to 2 cm. from the top, and weigh it. Heat the water by means of a burner to about 30° to 32° C. Place the calorimeter in the box and read the temperature accurately.

Using the forceps drop in chips of ice, which have been well dried by folding them in filter paper. The ice chips should be about the size of your thumb. Try to keep a fairly constant quantity of ice present in the water, but do not allow the temperature to go below 10° C. Stir thoroughly with the thermometer until the last bit of ice is melted and then read the temperature accurately.

Again weigh the calorimeter with its contents. The increase in weight gives the weight of the ice added. The specific heat of the calorimeter may be taken as .095.

Calculate the latent heat of fusion of ice. Express your answer in calories, in joules and in ergs.

FIRST YEAR EXPERIMENTAL PHYSICS

HEAT

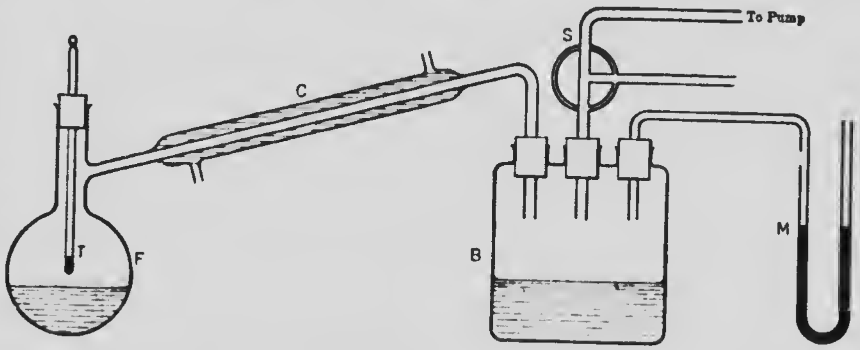
VAPOR PRESSURE

Object of Experiment: To determine the boiling-point of water at different pressures; and hence to find the pressure of saturated water vapor at different temperatures.

Apparatus: The apparatus consists of a flask *F*, from which a tube leads through a condenser to the bottle *B*. Cold water is circulated through the outer tube *C* to condense steam passing over from *F*. From *B* a second tube leads by means of a three-way stopcock *S* to a mercury manometer *M* and to an exhaust air-pump. The thermometer *T* gives the temperature of the vapor over the water in *F*.

Theory: At any definite temperature, a pure liquid can exist in equilibrium with its vapor at one and only one pressure. This is the pressure of its *saturated vapor.*

If the external pressure be greater than that corresponding to any temperature, the temperature of the liquid may be gradually raised until the pressure of its vapor is equal to the external pressure, when it will begin to boil. The pressure at which the liquid boils is therefore the pressure of its saturated vapor at that temperature, and the determination of the boiling-point of a liquid under different pressures is a convenient method of finding the pressure of its saturated vapor at different temperatures. This method, known as the *Dynamical Method*, is more accurate than the *Statical Method*, in which the liquid is introduced into the top of a barometer tube and the depression of the mercury column noted at known temperatures. This is especially so in the case of traces of very volatile impurities in the liquid.



Procedure: Read the barometric pressure *H*. If at any time the difference of level of the the two arms of the manometer is *h*, then the pressure in *F* is $(H-h)$.

Turn *S* so that *B* is connected with the air of the room. Start the water flowing slowly through *C*, and light the gas under *F*. After boiling commences reduce the flame so that the tube leading from *F* to the condenser is nowhere *completely* filled with condensed steam. Otherwise the pressure in *F* may not be equal to that in *B*, which is the pressure measured. Carefully read *T* to one-tenth of a degree, after making sure that it has become constant.

Next start the water flowing through the pump, and turn *S* so as to exhaust the apparatus until the manometer indicates a decreased pressure of 3 or 4 centimeters of mercury. Turn *S* so as to close the apparatus both from the pump and from the outside air. After seeing that the flame is sufficiently reduced and the temperature and pressure are remaining nearly steady, take three or four readings of each.

Continue decreasing the pressure by steps of 3 or 4 centimeters of mercury, and take readings until the boiling-point is in the neighborhood of 70° C.

Shut off the water pump and, turning *S* carefully, admit a small amount of air, and take readings thus in the reverse order.

Tabulate *all* readings taken.

Plot a curve with temperatures as abscissæ and pressures as ordinates.

Calculate the change in the boiling-point for a change of one centimeter in pressure near (1) 100° C. and (2) 75° C. by taking two points on the curve near each other at each of these temperatures.

FIRST YEAR EXPERIMENTAL PHYSICS

HEAT

LATENT HEAT OF VAPORIZATION

Object of Experiment: To determine the latent heat of vaporization of water.

Apparatus: A calorimeter consisting of a copper beaker in a box to reduce errors due to radiation; boiler; water trap; thermometer; balance and weights.

Theory: *The latent heat of vaporization* of any substance is defined as the number of calories required to convert one gram of the liquid to a vapor at the same temperature under a specific pressure.

Suppose a quantity of steam W_s be passed into a quantity of water W_w at a temperature t_1 contained in a calorimeter of weight W_k and specific heat s. Let the resulting temperature of the mixture be t_2. The heat given out by the steam in condensing at a temperature t_s will be LW_s, where L is the latent heat of vaporization of water. The mass W_s in cooling to the final temperature t_2 will furthermore give out $W_s(t_s - t_2)$ calories, so that the total amount of heat given out by the steam in reaching the temperature t_2 will be $LW_s + W_s(t_s - t_2)$, and the amount received by the water and the calorimeter will be $(W_w + sW_k)(t_2 - t_1)$.

Hence
$$LW_s + W_s(t_s - t_2) = (W_w + sW_k)(t_2 - t_1),$$

and therefore
$$L = \frac{(W_w + sW_k)(t_2 - t_1)}{W_s} - (t_s - t_2).$$

Procedure: Fill the boiler to the shoulder with water, and start it heating. Weigh carefully the empty metal calorimeter containing the thermometer. Fill the calorimeter to 2 cm. from the top with water which has been cooled to about 5° or 6° C., and weigh it. Place the calorimeter in the box and read the temperature accurately just before steam is passed into the water.

Having allowed steam to pass freely through the tubing for about a minute, insert the steam tube into the water nearly to the bottom. Stir continually with the thermometer until a temperature of about 30° to 32° C. is reached. Stir the water and read its highest temperature. Again weigh the calorimeter with its contents. The increase in weight gives the weight of the steam added. The temperature of the steam may be obtained from the formula $t_s = 100 + .37(B - 76)$ where B is the barometric pressure. The specific heat of the calorimeter may be taken as .095.

Calculate the latent heat of vaporization of water.

FIRST YEAR EXPERIMENTAL PHYSICS

HEAT

HYGROMETRY

Object of Experiment: To determine the dew-point and the humidity of the air by means of a hygrometer.

Apparatus: A standard wet- and dry-bulb hygrometer.

Theory: If an inclosed space is partly filled with water, some of the water will evaporate and fill the space above. This will continue until a definite amount of water vapor, depending on the temperature, is present. The space is then said to be *saturated*. If the temperature is raised, the space becomes unsaturated and more water will evaporate until it becomes saturated. If, however, the temperature is lowered, some of the water vapor will be condensed but the space still remains saturated. Hence at any temperature there is a maximum amount of water vapor which a given space can contain.

Now water vapor behaves like a gas and consequently exerts a pressure which conforms to the relations expressed by the ordinary gas laws. It follows that the water vapor pressure in a given space varies as the amount present and hence at any temperature there is a *maximum water vapor pressure* or vapor tension as it is sometimes called.

All the above facts are still true even if the space also contains any gas or gases which do not act chemically on water vapor. This is the case in the earth's atmosphere where a certain amount of water vapor is mixed with the air. The varying amount of water vapor in the air is closely associated with the weather, and also affects the drying power of the air. The healthfulness of air also depends greatly on the amount of water vapor in it.

When saturated air is cooled, condensation occurs in the form of dew, fog, mist, hoar frost, rain, snow or hail. The temperature at which condensation occurs is called the *dew-point*. The ratio, expressed as a percentage, of the amount of water vapor present under given conditions to the amount necessary to cause saturation is called the *relative humidity*. This ratio is also given by the vapor pressures corresponding to these amounts. The mass of water vapor in unit volume is called the *absolute humidity*. It is the object of hygrometry to determine the aqueous state of the air by determining the three quantities defined above.

The most satisfactory instrument for the purpose is Mason's hygrometer, which is usually known as the wet- and dry-bulb hygrometer. It consists of two similar thermometers mounted side by side, the bulb of one being covered with muslin which is connected to a dish of distilled water by an absorbent wick. The water which reaches the muslin evaporates and in so doing cools the bulb of the thermometer. The bulb of the other thermometer is kept dry and it indicates the temperature of the air. It is evident that the amount of evaporation and the amount of the consequent cooling of the wet-bulb thermometer will depend in some inverse manner on water vapor already present in the air.

The following empirical formula shows the relation between the actual water vapor pressure, p cm., at the air temperature $t°$ C., and the saturated water vapor pressure, P_w cm., at the wet-bulb temperature $t_w°$ C.

$$p = P_w - .052(t - t_w) \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

If P is the saturated water vapor pressure at $t°$, the relative humidity is equal to

$$\frac{100\,p}{P} \text{ per cent.} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

The dew-point may also be defined as that temperature at which the saturated water vapor pressure is equal to p.

To find the mass of water vapor per cc., i.e., its density ρ, use is made of the following form of Charles' law:

$$\frac{p}{\rho T} = \frac{P_0}{\rho_0 T_0}.$$

(OVER)

Solving for ρ and substituting for the other factors, the absolute humidity is given by

$$\rho=\frac{.000804\times p\times 273}{76\times(273+t)}=\frac{.00289\,p}{273+t}\quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (3)$$

Procedure: See that there is water in the receptacle and that the muslin is moist, but do not handle the muslin or the wick. Be sure that the other thermometer is dry.

Fan the air across the thermometers continually, so that a steady current of air removes the moisture from the neighborhood of the wet bulb. The wet bulb thermometer will slowly diminish in temperature until a steady state is reached. The reading of the other thermometer will probably remain constant.

Record the steady temperatures t and t_w indicated by the thermometers. Obtain the values of P_w and P from the chart in the laboratory. Substitute these values in formulæ (1) and (2), and find p and the relative humidity.

Find the dew-point from the chart.

Calculate the absolute humidity from formula (3). Express it also in grams per cubic meter. Calculate the amount of water vapor in a room 14 by 8 by 6 meters under the above conditions.

FIRST YEAR EXPERIMENTAL PHYSICS

HEAT

MECHANICAL EQUIVALENT OF HEAT

Object of Experiment: To determine the mechanical equivalent of heat.

Apparatus: Grace's apparatus as shown in Fig. 1; an accurate thermometer; hand wheel or motor; balance.

Theory: Grace's apparatus consists essentially of a hollow cylindrical brass box C, over which is passed a non-conducting ribbon R. One end of this ribbon is attached to a spiral spring S, while from the other end is suspended the weight W. This weight must be of such a mass that it will be raised from the base of the apparatus when the box C is rotated by means of the pulley P in the direction indicated by the arrow. At A is shown a side tube which permits the insertion of a thermometer at the beginning and the end of the experiment for finding the temperature of the water contained in C. At B is placed a small Veeder counter from which the number of revolutions of C during the experiment can easily be obtained.

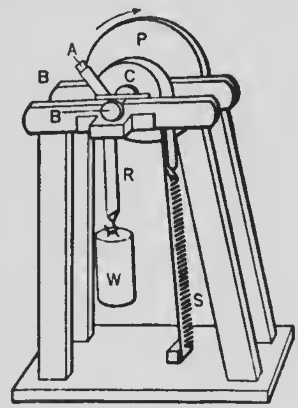


FIG. 1.

Work is done against the friction between R and C, and as is always the case an equivalent quantity of heat is produced. As R is practically a non-conductor of heat, and as C is attached to the spindle by means of non-conductors, i.e., boxwood and ebonite, almost the entire quantity of heat generated goes to heat the brass calorimeter C and the water contained therein.

Denoting the weight of the water by W_w and that of C by W_b, the number of calories of heat to raise them 1° C. will be

$$W_w + .095W_b,$$

where .095 is the specific heat of the brass and .095 W_b is the water equivalent of the calorimeter. If t_1 denotes the initial temperature and t_2 the final temperature, then the number of calories of heat developed will be

$$(W_w + .095W_b)(t_2 - t_1).$$

The number of ergs of work done can be found as follows: Let W denote the number of grams suspended from R, and w the number of grams of force exerted on the opposite end of R by S, then the resultant force exerted by R will be $(W-w)$ grams, or $(W-w)g$ dynes, where g denotes the force with which gravity acts on a mass of one gram. Let n be the number of revolutions of C and d be the diameter of C in centimeters. Then the total distance through which the force $(W-w)g$ dynes acts will be $n\pi d$ centimeters. Therefore, since, by definition, one dyne acting through one centimeter does one erg of work, the total work done against friction will be

$$(W-w)gn\pi d \text{ ergs.}$$

Now if J is taken as the number of ergs which are equivalent to one calorie, we can write

$$(W_w + .095W_b)(t_2 - t_1)J = (W-w)gn\pi d,$$

and therefore

$$J = \frac{(W-w)gn\pi d}{(W_w + .095W_b)(t_2 - t_1)}.$$

Procedure: Remove the calorimeter C from the spindle, see that it contains about 100 grams of water, and weigh to one-tenth of a gram. Having cooled the water and calorimeter about 8° C. below room temperature replace C on the spindle and clamp it in position.

(OVER)

Now observe the temperature of the water in C. In order to be able to insert the thermometer into A without loss of water, turn C until the tube A is nearly horizontal and above the water. Then replace the stopper in A. The time at which the temperature is read should also be recorded.

Immediately read the counter, place R and W in position, and rotate C. At regular intervals during the time that work is being done against the frictional force due to W, the position of the upper end of the spring S should be carefully read and recorded at least ten or fifteen times. Assuming that approximately 475 revolutions are required to raise the temperature 1° C., calculate what the final reading of the counter should be in order that the final temperature may be about as much above that of the room as the initial temperature is below. When this number is reached, note the temperature, the time, and the final reading of the counter.

Using a small spring balance, or a scale pan suspended by a thread passing over a pulley, find the force required to pull the end of S up to its average position during the time that C was rotated under friction.

From your readings, which should be repeated if time permits, calculate J.

The values of d and of W_t are marked on the apparatus.

FIRST YEAR EXPERIMENTAL PHYSICS

MAGNETISM

MAGNETIC FIELDS OF PERMANENT MAGNETS

Object of Experiment: To study the distribution of the magnetic lines of force around magnets and groups of magnets by means of iron filings.

Apparatus: Two bar magnets; a horseshoe magnet and keeper; a disk of soft iron; iron filings; sifter; a board with grooves to hold the magnets; sheet of paper.

Theory: The space in the neighborhood of a permanent magnet is characterized by this property, that it acts with a mechanical force on a magnetic pole when placed in it. The old idea of action at a distance has been discarded and the space is considered as being altered in some way not as yet clearly understood. That it must be to some extent a property of the ether is at once evident as magnetic effects are able to penetrate vacua. This region about a magnet is called a *magnetic field*. The direction of a magnetic field is taken *by convention* to be that in which a north-seeking pole is urged. The *strength* or *intensity* of the field at a given point is defined as the force in dynes which would be exerted on a unit north pole placed at that point. A field of unit intensity is therefore one which would exert a force of one dyne on a unit pole placed in it. Such a unit field is said to contain one tube of force per sq. cm. of surface taken at right angles to the direction of the field. The number of tubes is always chosen so that the product of the area of cross-section of each tube and the field-intensity is equal to unity.

Lines of force, as defined quantitatively, are obtained by replacing each tube by a line passing along its axis. A uniform field is of course represented by parallel straight lines.

A magnetic line of force is always a continuous closed curve. Thus, in the case of an isolated bar magnet, by convention, each line of force leaves the magnet from the north pole, passes around to the south pole and then through the material of the magnet back to the north pole.

Substances differ greatly in permeability, which is the ease with which, as compared with a vacuum, they allow the passage of magnetic lines. Those substances like iron and nickel, which possess a permeability greater than that of a vacuum, are said to be paramagnetic. For some, the permeability is slightly less than that of a vacuum and these are said to be diamagnetic.

When an iron filing is placed on a sheet of paper in the field of a permanent magnet, the lines of force crowd into it and it becomes a magnet by induction. On tapping the paper to reduce friction, the filing accordingly sets itself with its longer axis parallel to the direction of the magnetic field.

Magnetic lines of force act as though possessing a real physical existence in the ether and tend (1) to contract longitudinally and (2) to repel one another laterally. Many of the phenomena of the interaction of magnetic poles can be explained on these two simple hypotheses. Thus the force of attraction exerted between two unlike poles is explained by the first. According to the second hypothesis the lines from an isolated north pole should radiate in all directions and the pole should be in equilibrium, as is the case. Now suppose a second north pole is brought up. The symmetrical arrangement of the lines about both poles is destroyed and the tension along them tends to pull the poles away from each other. Thus they appear to repel each other and for convenience are usually spoken of as actually repelling each other.

The importance of a detailed knowledge of the fields about magnets is at once evident when it is remembered that the efficient operation of electrical machinery requires that the magnets of dynamos be designed to give strong magnetic fields where needed.

Procedure: Place the magnet or magnets in the grooves as near the center of the board as possible, cover with a sheet of paper, and sift iron filings evenly over the paper.

Obtain a representation of the field in each of the following cases and explain the points noted in each case and any others that occur to you as being of interest. Tap the paper

(OVER)

gently and draw neat diagrams of what you see. Indicate the stronger parts of the field which can be done more readily if the paper is not tapped too much. Make your diagrams as true to nature as possible.

(1) Single bar magnet; explain the collecting of the filings around the poles.

(2) Horseshoe magnet; explain the concentration and straightness of the lines between the poles and the fact that the stronger part of the field appears to extend to a greater distance from the poles in one direction than in the other.

(3) Two parallel bar magnets with like poles together; explain the formation of neutral points and the nature of the field as to whether it is strong or weak.

(4) Same as in (3) but with unlike poles together; explain as in (3).

(5) Both magnets in the same groove with like poles about two centimeters apart; explain.

(6) Same as in (5) but with unlike poles; explain.

(7) Bar magnet with disk of soft iron in its field; explain the effect of the soft iron on the distribution of the lines of force.

(8) Horseshoe magnet with keeper about 2 cm. from poles; explain as in (7).

(9) The end of a bar magnet held vertically; explain the radially uniform distribution of the lines of force.

While doing the various parts of the experiment, try to form a clear mental picture of the configuration of the lines of force in the three-dimensional space about the magnets, from the two-dimensional diagrams of these horizontal sections.

FIRST YEAR EXPERIMENTAL PHYSICS

MAGNETISM

THE DEFLECTION MAGNETOMETER

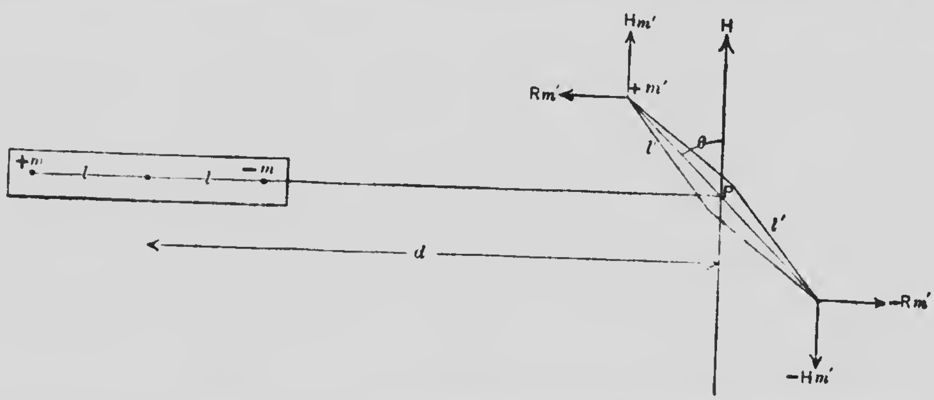
Object of Experiment: To determine the moment of a magnet with the deflection magnetometer.

Apparatus: Magnet; magnetometer.

Theory: The intensity of a magnetic field at any point is defined as the force in dynes exerted on a unit pole placed at that point. When the field is that of a bar magnet, the problem of finding the intensity is complicated by the presence of the two poles, both of which must be considered. If, however, the point taken is on the prolongation of the axis of the magnet, the two forces are parallel and the resultant is simply their algebraic sum.

A small compass needle placed at such a point will be acted upon by two sets of forces, (1) the earth's magnetic field, tending to make it point north and south, and (2) the resultant force due to the magnet, tending to cause the needle to point along the axis. If the bar magnet is placed with its axis east and west, the needle will take up a position of equilibrium at an angle θ from the meridian.

By equating the couples acting on the needle, the moment M of the magnet can be found if H, the horizontal component of the earth's field, is known. The compass needle is supposed



to be so small in comparison with its distance from the magnet, that the force on either pole is the same as that at its center.

Let R be the resultant force due to the magnet, and H the horizontal component of the earth's field. Then when equilibrium exists,

$$2Hm'l' \sin\theta = 2Rm'l' \cos\theta, \text{ or } R = H \tan\theta.$$

R, the force on unit north pole placed at P is made up of two parts;

$$\text{that due to } -m \text{ is } \frac{-m}{(d-l)^2}, \text{ and that due to } +m \text{ is } \frac{m}{(d+l)^2},$$

where d is the distance to the middle of the magnet and l is half its magnetic length. The magnetic length of the magnet is $\frac{5}{6}$ of the total length and is the distance between its poles.

From the above,

$$R = \frac{-m}{(d-l)^2} + \frac{m}{(d+l)^2} = \frac{-4dlm}{(d^2-l^2)^2}. \quad (1)$$

(OVER)

The minus sign indicates that the direction of the resultant force is towards the magnet. The pole strength multiplied by the magnetic length of a magnet is called its *magnetic moment* and is generally written M. Hence $M = 2ml$. Omitting the minus sign,

$$R = \frac{2Md}{(d^2 - l^2)^2} = H \tan \theta.$$

Therefore,

$$M = \frac{H(d^2 - l^2)^2 \tan \theta}{2d} = \frac{H[(d+l)(d-l)]^2 \tan \theta}{2d} \quad \ldots \ldots \ldots \quad (2)$$

d, l and θ can be measured and H is given. Hence M can be determined.

A suitable magnetometer for this experiment consists of a short magnetic needle provided with long pointers and mounted over a mirror surrounded by a circular scale graduated in degrees, whose center lies at the zero of two scales graduated in millimeters in opposite directions.

Procedure: Adjust the magnetometer so that its linear scales are at right angles to the magnetic meridian.

Place the magnet whose moment is to be determined along one of the linear scales with the distance of its middle point from 20 to 50 cm. from the needle. When possible, adjust it so that the angular deflection of the needle will be between 30° and 60°, because the tangent of an angle near 45° varies less rapidly with the angle than when the angle is near 0° or 90°, and hence smaller errors will be introduced in the results. This also applies, of course, to the use of needle galvanometers of the sine or the tangent type.

Read the position of both ends of the needle, making use of the mirror beneath to eliminate errors due to parallax. Carefully estimate tenths of degrees.

Now turn the magnet end for end and again read the deflection. Repeat with the magnet on the other side of the needle and at the same distance away.

In taking these eight readings, it is always best to read the circular scale opposite two definite edges of the needle, as e.g., the right-hand edge of the needle at the end toward you and the left-hand edge at the further end, as this can be done more accurately than the position of the *middle* of the end of the needle can be estimated.

The main object of taking the eight readings is to eliminate errors due to the needle not being straight, the pivot being out of center, and the magnet being unsymmetrically magnetized. Another advantage is that taking the mean of even eight readings, tends to eliminate accidental errors which are likely to be serious in the case where a single reading is taken.

Take $2l$ as $\frac{5}{6}$ of the length of the bar magnet, and obtain H from the magnetic chart of the laboratory. Substitute these values together with the mean angular deflection θ in (2) and calculate M.

Repeat using a different value for d and take the mean of the two results as the final value of M.

In your report note the number of the station at which your work is done as well as that of the magnet used.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

THE ELECTROSCOPE

Object of Experiment: With the electroscope to show that (1) when two different bodies are rubbed together, equal and opposite charges are produced, (2) the induced charge equals the inducing charge, (3) a free charge does not reside on the inside of a closed conductor.

Apparatus: Electroscope; ebonite rod; glass rod; tin can; block of paraffin; electrophorus; mounted ebonite disk and a similar wooden disk with c face fur-lined; piece of fur; piece of silk; metal ball suspended by a silk thread.

Theory: If a rod of ebonite is rubbed with fur, it acquires special properties, one of which is the ability to attract to itself light bodies. It is then said to be electrified. A glass rod rubbed with silk acquires the same property. Examination shows, however, that the kinds of electrification in the two cases are different. To distinguish between the two, that developed on ebonite by rubbing with fur is called *negative*, and that produced on glass by rubbing with silk is *positive*.

Electricity itself is probably of one kind, which is negative. In its ultimate form it is supposed to consist of exceedingly small negatively charged bodies called electrons. These mutually repel each other. Every body has associated with it a normal number of these free electrons, when it is uncharged. If there is an excess number it is negatively charged, and if a number less than the normal it is positively charged. Rubbing ebonite with fur means an accumulation of electrons on the ebonite and a consequent subtraction from the fur. The "charges" should then be equal.

In a conductor the electrons are free to move about, and when an electric force is applied they are urged to move in a definite direction. If a negatively charged rod is brought near an uncharged conductor, the free electrons in it are repelled to the far end, and hence the end nearer the rod is positively charged. If a positively charged body is brought near an insulated uncharged electroscope, the free electrons in the latter accumulate on the near end, as if the conductor would share its electrons with the other, which has too few. The number of electrons which appear at one end in such a case will depend on the degree of positive or negative electrification, and the nearness of the two conductors.

If when the positively charged rod is presented, the insulated conductor is touched with the finger, contact is made with the earth through the body. The electricity accumulated on the near end cannot go to the earth, since it is held attracted by the positive charge. On the other hand, electrons will pass from the earth to the end from which electricity has been drawn until it is again normal. If now, the hand, and then the positively charged body are removed, there will be an excess of negative electricity on the conductor due to that which has passed in from the earth. This is called charging by *induction*. The following experiments will show that the induced charge is equal to the inducing charge.

Procedure: Rub the ebonite rod with the fur. Bring it near the electroscope and observe the result. Explain by a diagram showing the location and signs of the charges. Rub the plate of the electroscope with the rod and explain the result by a diagram. Discharge the electroscope by touching it with the finger. Repeat the two experiments with the glass rod rubbed with silk.

Again rub the ebonite with fur and bring it near the electroscope. Touch the plate of the electroscope with the finger. Remove the finger and then the rod. The electroscope is charged positively by induction. Explain what happens by appropriate diagrams. Now bring near the charged electroscope the glass rod rubbed with silk. Explain why the divergence of the leaves is increased. Bring near the charged ebonite rod again and explain the tendency of the leaves to collapse.

Place the tin can on the paraffin block and connect it to the uncharged electroscope by a wire, taking care that the wire does not touch any other object. See that the ebonite disk

(OVER)

and the fur-lined wooden disk are uncharged by lowering them successively into the can. Place them both in the can and rub the ebonite against the fur. No effect should be produced on the leaves by this action. Remove the fur and observe the deflection. Place the fur back and remove the ebonite. Notice that the deflection is the same. What does this show?

Disconnect the metal can and charge the electroscope positively. Rub the ebonite disk of the electrophorus with the fur and place the metal disk upon it. Touch the metal with the finger and after withdrawing the hand remove the disk by the insulating handle. Bring the knuckle of the hand near the metal. It will be found to be highly charged. Charge again in the same way. Bring the brass ball in contact with the metal disk, holding the ball by the silk thread. The ball will acquire the same charge as that on the disk. Test the charge with the electroscope. It is positive. Explain the action of the electrophorus by diagrams.

Discharge the electroscope and connect it to the can. Charge the ball with the electrophorus and lower it well down into the can, taking care that it does not touch the sides or bottom. Observe the deflection. Move the ball about inside. What effect is produced on the gold leaf? Withdraw the ball and the leaf collapses. Explain. Again introduce the charged ball and allow it to touch the bottom of the can. Watch the leaf closely at the instant of contact. No change in the divergence is produced. With diagrams show the location of the charges just before and after the ball has touched. Remove the ball and keeping it carefully insulated, discharge the electroscope and disconnect the can. Bring the ball in contact with the plate of the electroscope. It will be found to be uncharged. This shows that the induced charge equals the inducing charge, the positive charge on the ball being just neutralized by the induced negative charge on the inside of the can.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

MAGNETIC FIELDS OF CURRENTS

Object of Experiment: To study the distribution of the magnetic lines of force about currents flowing in conductors of certain standard shapes.

Apparatus: A vertical wire, two coaxial coils, and a helix mounted on separate wooden stands; compass needle; iron filings; suitable lamp rheostat; 110-volt D.C. circuit; connecting wires.

Theory: In 1820, Oersted, of Copenhagen, published the results of an investigation of the behavior of a magnetic needle in the presence of an electric current. He found that a needle turns so as to set itself as nearly as possible at right angles to a wire carrying a current, although the direction of rotation depends on the relative position of the wire and the needle and on the direction of the current.

This peculiar behavior indicates that a magnetic field exists in the space surrounding an electric current, and it is evident that the magnetic lines of force in a plane perpendicular to a long straight conductor must have the form of concentric circles whose center lies in the conductor. The direction in which a needle would rotate when brought near a conductor

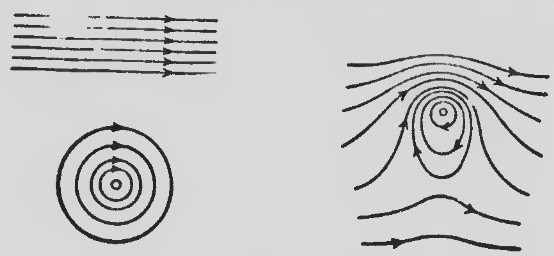


FIG. 1

carrying a current, i.e., the direction of the magnetic field, can be determined by applying the well-known rule of Ampere, or that of Maxwell, or the "right hand" rule, provided that the direction of the current is known. The converse of this statement is true.

When the conductor is not straight, the lines of force are no longer circles, but they are still closed curves. If the conductor is bent into a circle or into a flat helix or coil, the lines of force enter one face of the space inclosed by the coil, and leave by the other, completing their path around the outside of the coil. Hence the two faces of the coil are of opposite polarity and the entire coil behaves as if it were a broad flat magnet.

When the magnetic field of a vertical conductor carrying a current is superposed on a uniform magnetic field such as the horizontal component of the earth's field, the character of the resultant field is shown in Fig. 1. The tendency of the resultant lines of force to become as short as possible accounts for the mechanical force acting on the conductor.

The direction of this force is evident from the figure and is also given by Fleming's left hand or motor rule which may be stated as follows:

If the thumb, first and second fingers of the left hand are held at right angles to one another, and if the First finger represents the direction of the magnetic Field and the Center finger that of the Current, the direction of the mechanical force on the conductor, i.e., of its Motion or tendency to Motion, will be that in which the thuMb points. (Note the mnemonic use of F, C and M.)

As described in the experiment on the Magnetic Fields of Permanent Magnets, a compass needle moves because the magnetic forces acting on its poles produce a mechanical effect on the needle. Moreover, the force on a unit magnetic pole, i.e., the intensity of the magnetic field, near a conductor carrying a current can be calculated.

(OVER)

In the case of an infinitely long straight conductor, it can be shown that the intensity at any point P outside the conductor is given by

$$F_p = \frac{2i}{r}, \quad \ldots\ldots\ldots\ldots \quad (1)$$

where i is the value of the current in electromagnetic units, and r is the perpendicular distance of P in centimeters from the axis of the conductor.

In the case of a flat coil of wire, the intensity at any point P on the axis is given by

$$F_p = \frac{2\pi n i a^2}{(a^2 + d^2)^{3/2}}, \quad \ldots\ldots\ldots\ldots \quad (2)$$

where n is the number of turns of wire, a is the mean radius of the coil, d is the distance of P from the center, and i is defined as before.

Procedure: Before connecting any apparatus to the D.C. circuit be sure that the switch is open (i.e., turned off).

Connect the lamp rheostat in series with the conductor to be examined. Draw a neat diagram of the horizontal section of the magnetic field about the conductor in each of the following cases. Indicate the direction of a current flowing upward by the point of an arrow within a circle thus ⊙, and of a downward current by the tail of an arrow thus ⊕. Write a brief discussion explaining the main features exhibited by each case.

(1) Place a piece of paper on the stand supporting the vertical wire and turn on the lamps. Using the compass needle, map the magnetic field around the wire and estimate the position of the neutral point. From an inspection of the resulting field, indicate the direction in which the wire is urged. Verify this by applying Fleming's rule.

Making use of equation (1), and of H, the horizontal component of the earth's field, calculate the value of the current in electromagnetic units and also in amperes.

(2) Obtain a representation, by means of iron filings, of the field about a single coil of wire. Place the needle at the center and determine the direction of the current.

Now turn the stand until the plane of the coil is at right angles to the meridian and its field opposes that of the earth. Using a meter stick find the two neutral points on its axis with the compass needle and measure their distances from the center.

Using equation (2), calculate the value of the current. The value of n is given on the stand.

(3) Include the other coil in series in the circuit. Observe the distribution of the filings, and explain the formation of any neutral points. Determine the direction of the current in each coil, and indicate the character of the force between them.

(4) Reverse the current in one coil only and repeat as in (3).

(5) Connect in the helix. Sprinkle on iron filings and tap gently. Obtain the direction of the field with the compass. Mark the direction of the current and the polarity of the helix in a sectional diagram.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

MEASUREMENT OF CURRENT

Object of Experiment: To measure the current used by different incandescent lamps, and to find the resistance of each lamp, and its illuminating value.

Apparatus: Tangent galvanometer; two 16-candle-power carbon lamps and two 25-watt tungsten lamps; 110-volt D.C. circuit; four lamp sockets suitably mounted as shown in Fig. 2; reversing switch and connecting wires.

Theory: To measure the current a tangent galvanometer is used, the theory of which is based on the fact that the magnetic field at the center of a circular coil of n turns of radius r carrying a current of i electromagnetic units is equal to

$$\frac{2\pi n i}{r} \qquad \text{(1)}$$

The *absolute electromagnetic unit of current* is defined as that current which, flowing through a circular arc of length 1 cm. and radius 1 cm., produces at its center a magnetic field of unit intensity. The resulting field is perpendicular to the plane in which the arc lies, and it can easily be shown that equation (1) is in agreement with the above definition.

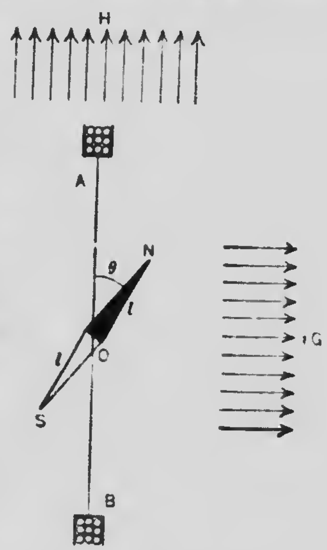


Fig. 1.

In Fig. 1, which shows diagrammatically a horizontal section of a tangent galvanometer, NS represents the magnetic needle of length $2l$ (l must be so small that the magnetic field acting on the poles at N and S will not differ appreciably from that at O, the center of the coil, although the needle is represented on a larger scale in Fig. 1 for greater clearness). A and B represent the section of the galvanometer coil of n turns. As indicated in the figure, the galvanometer must be placed so that the plane of the coil AB contains the earth's magnetic meridian, θ being the angle between NS and the plane of AB.

The couple due to the horizontal component of the earth's magnetic field H acting on the needle of pole strength m is $Hm \cdot 2l \sin\theta$.

If the field at O, due to one absolute electromagnetic unit of current, be G, then for a current strength i the field set up at right angles to the magnetic meridian is iG. Hence the couple tending to deflect the needle away from the magnetic meridian is $iGm \cdot 2l \cos\theta$.

Since the needle is in equilibrium when deflected through the angle θ, $iGm \cdot 2l \cos\theta = Hm \cdot 2l \sin\theta$,

$$i = \frac{H}{G} \tan\theta. \qquad \text{(2)}$$

But from (1) the field G produced by unit current flowing in the n turns of the circular coil of the galvanometer is equal to $\frac{2\pi n}{r}$.

Hence

$$i = \frac{Hr}{2\pi n} \tan\theta. \qquad \text{(3)}$$

Since the *ampere*, the practical unit of current is defined as one-tenth of the electromagnetic unit of current, it follows that

$$I = \frac{10Hr}{2\pi n} \tan\theta, \qquad \text{(4)}$$

where I is the current expressed in amperes.

(OVER)

Hence the current can be measured by noting n, reading θ, and measuring r, the value of H for the given location being found from the magnetic chart of the laboratory.

Since the resistance of the galvanometer and connecting wires is very small in comparison with that of the lamps, the resistance of the latter can be calculated from Ohm's law, $I=\frac{E}{R}$, where E is the electromotive force applied to the lamp and is to be taken as 110 volts and R is the required resistance in ohms.

The power used in a circuit is equal to EI and is expressed in watts. The illuminating value of various kinds of lamps may be compared if the rates are known at which electrical energy is consumed in the production of light, i.e., if the number of watts per candle-power for each lamp is known.

Procedure: Connect the tangent galvanometer through a reversing switch S to the terminals D and E. The lamps to be tested are to be placed in the sockets marked L. See that the galvanometer G is placed at one of the points for which the value of the horizontal component of the earth's field is given on the magnetic chart of the laboratory, and adjust it so that the plane of its coil contains the magnetic meridian.

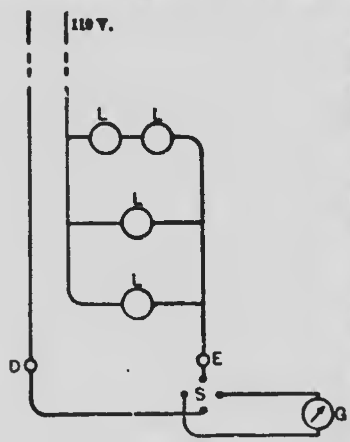


Fig. 2.

Before turning on the current make sure that the connections correspond to those of Fig. 2. See that none of the wires are in contact with gas or water pipes, as this might result in a short circuit.

In using the tangent galvanometer, choose such a number of turns, when possible, that the value of θ will lie between 25° and 65°. In order to eliminate errors due to the needle being bent and the pivot possibly out of center, always reverse the current and read both ends of the needle and take as θ the mean of the four values thus read.

If only 5 turns are used, note whether the inside or outside radius is to be used. If more than 15 turns are used, use the mean of the inside and outside radii.

Measure the current (1) through each lamp separately, (2) through the two tungsten lamps in series, and (3) through the two carbon lamps in parallel.

Record all readings, as they are obtained, in tabular form; and also tabulate your results for the resistance, power-consumption and illuminating value of the lamps tested.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

OHM'S LAW

Object of Experiment: To show that the strength of the electric current flowing in a circuit is proportional to the total electromotive force applied to the circuit.

Apparatus: Five similar storage cells; group of commutators mounted as shown in Fig. 1; resistance box; tangent galvanometer; reversing switch.

Theory: In 1827, Dr. G. S. Ohm published an account of his investigation in which he had found experimentally that a simple relation exists between the electromotive force applied to a circuit and the current flowing in it; and in the case of a conductor forming a *part* of a circuit the same relation holds between the current flowing through the conductor and the potential difference between its ends. This fact, that the current in a circuit is proportional to the e.m.f. or the P.D. producing it, is known as *Ohm's Law*. Although Dr. Ohm did not have the refined apparatus necessary to establish this law with any great certainty, later experimenters have verified it to a high degree of accuracy.

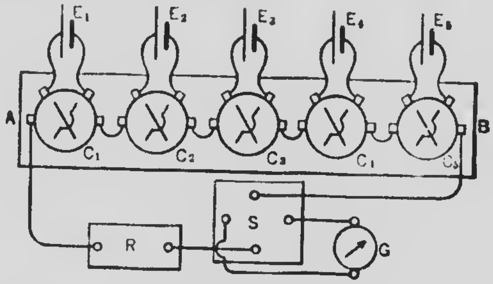


FIG. 1.

The name *resistance* has been given to this ratio of the e.m.f. to the current, which is always found constant for metals provided that the size, material and physical state of the conductor do not vary.

Ohm's law may be verified by the use of the apparatus shown in Fig. 1, where E_1, E_2, E_3, E_4, E_5, represent five similar storage cells connected in series through the commutators C_1, C_2, C_3, C_4, C_5, the two ends of which are joined to a constant length of wire R and, through a reversing switch S, to a tangent galvanometer G.

Suppose the e.m.f.'s of all the cells are exactly equal, then it follows that, if E_1 is reversed the effective e.m.f. in the circuit becomes $3E$ where E is the e.m.f. of a single cell, while if two cells are reversed the effective e.m.f. becomes E. Thus we are able to alter the e.m.f. applied to the circuit without appreciably changing its resistance.

By means of the tangent galvanometer the current in the circuit can be measured by a method which does not depend on Ohm's law, for from the equation of the tangent galvanometer,

$$I = \frac{10Hr}{2\pi n} \tan\theta = K \tan\theta, .$$

where K is a constant for a given galvanometer in a given position.

If values of $\tan\theta$ are plotted as ordinates against the effective e.m.f. as abscissæ, and the points obtained fall on a straight line passing through the origin, Ohm's law is verified.

In practice, however, E_1, E_2, etc., may not be exactly equal, but any errors which might thus invalidate the work can be eliminated as follows:

Consider the case when one cell only is reversed. Call the average value of the e.m.f.'s

(OVER)

of the cells E_a. Then, if readings are taken first with E_1 reversed, then with E_2 reversed, etc., the effective e.m.f. in the several cases will be expressible as follows:

$$5E_a - 2E_1,$$
$$5E_a - 2E_2,$$
$$\text{———}$$
$$5E_a - 2E_5.$$

Adding and dividing by 5, we obtain the average value which is $5E_a - 2E_a$, or $3E_a$.

If groups of two consecutive cells are similarly reversed, the effective e.m.f. in the several cases will be

$$5E_a - 2E_1 - 2E_2,$$
$$5E_a - 2E_2 - 2E_3,$$
$$\text{———}$$
$$5E_a - 2E_5 - 2E_1.$$

The average value in this case is E_a.

Procedure: Connect the five cells to the commutators as in Fig. 1, with like poles in the same direction. Connect the galvanometer G through the reversing switch S and the resistance box R to A and B, having first unplugged 100 ohms in R. Keep the reversing switch S open except when readings are being taken.

With all the commutator rockers similarly placed and using the greatest number of turns in the galvanometer, adjust R until the galvanometer deflection lies between 65° and 70°. Take five complete sets of readings of the deflection. The reason for taking such a large number of readings is that the effect of accidental errors may thus be largely eliminated. One complete set of readings for a tangent galvanometer consists of the four readings obtained from both ends of the needle with the current direct and then reversed. The mean of the above twenty readings gives the value of θ corresponding to an applied e.m.f. of $5E_a$.

Without altering any of the adjustments, take a complete set of four readings, first with E_1 only reversed, then with E_2 only reversed, etc. The mean of these twenty readings gives the value of θ corresponding to an applied e.m.f. of $3E_a$.

Finally, take five sets of readings with two consecutive cells reversed, successively reversing E_1, and E_2 and E_3, . . . , E_5, and E_1. The mean of these twenty readings gives the value of θ corresponding to an applied e.m.f. of E_a.

Show that the tangents of the three mean values of the angles are proportional to the applied e.m.f.

Plot a curve showing the relation between $\tan\theta$ and E_a.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

THE POTENTIOMETER

Object of Experiment: To afford practice in the use of the potentiometer for the accurate determination of the electromotive force of cells.

Apparatus: A 500-cm. wire potentiometer; sensitive galvanometer; high resistance; storage battery; standard Clark or Weston cell; cells to be tested.

Theory: Suppose the terminals of a battery of constant electromotive force E (Fig. 1) are connected to the ends of the uniform wire AB of resistance R per centimeter length. Let I be the constant value of the current which flows along AB.

Then it follows from Ohm's law that the drop in potential along AB is equal to IR per cm. length, and that the drop in potential from A to K along the length l_s of the wire is equal to l_sIR.

Suppose that a standard cell of e.m.f. E_s, a galvanometer G, and a high resistance M which can be short-circuited by a plug key P, are connected in series between A and the sliding

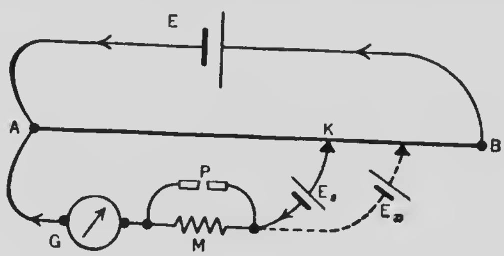


FIG. 1.

contact K. If K has been adjusted so that no current flows through the galvanometer when K is depressed, it follows that the total e.m.f. around AKE_sA is equal to zero, or that, numerically,

$$E_s = l_sIR. \qquad (1)$$

Suppose that E_s is replaced by a cell whose e.m.f. E_x is to be measured and that a balance point is found which is l_x centimeters from A. Then

$$E_x = l_xIR. \qquad (2)$$

Dividing (2) by (1), we obtain

$$E_x = \frac{l_x}{l_s}E_s. \qquad (3)$$

If the Clark cell is used as the standard then its e.m.f. in volts at a temperature $t°$ C. should be found from the following equation,

$$E_c = 1.434 - .0012(t° - 15°) \text{ volts}. \qquad (4)$$

If the Weston standard cell is used, the following equation for its e.m.f. should be employed:

$$E_w = 1.0190 - .00004(t° - 20°) \text{ volts} = 1.019 \text{ volts}. \qquad (5)$$

Care is necessary, in the construction of these standard cells, to obtain very great purity in the materials of which they are composed, and they must be guarded against carrying more than an extremely small current. Under these conditions the e.m.f.'s expressed by the above equations are accurately reproducible.

(OVER)

The Weston cell has the advantage of having a much smaller temperature coefficient than the Clark cell.

Procedure: Connect the storage battery to the ends of the potentiometer wire. Connect the dry cell through the galvanometer to the sliding contact and to one end of the potentiometer wire in such a way that like poles of the batteries are joined together.

Adjust the position of the sliding contact until on closing the circuit the galvanometer shows no deflection. Note the length l_x of wire between the sliding contact and the end where the batteries are joined.

Replace the dry cell by the standard cell and find the length l_s corresponding to its e.m.f. The balance point in this case is fairly close to the previous one. Advantage is taken of this fact to protect the standard cell from being subjected to an excessive current, which would introduce errors. An alternative method is to introduce in series with the standard cell, a high resistance which can be short-circuited when the final adjustment is to be made.

Find E_s for the standard cell used from formula (4) or (5), and calculate the e.m.f. of the dry cell from formula (3).

Using the same method find the e.m.f.'s of the Leclanché and the Daniell cells.

Also, neglecting the small resistance of the wires connecting the storage battery to the potentiometer, calculate the approximate e.m.f. of the storage battery. Why is it only approximate? Why need not the resistance of the galvanometer and of the wires connecting the standard cell be taken into account?

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

THE WHEATSTONE BRIDGE

Object of Experiment: To measure resistances by means of the B.A. or slide-wire form of the Wheatstone bridge, and to find the equivalent resistance of resistances in series and in parallel.

Apparatus: Slide-wire meter bridge; sensitive galvanometer; storage battery; rheostat; resistance box; two unknown resistances.

Theory: The Wheatstone bridge is an arrangement of conductors whereby it is possible to compare resistances. In Fig. 1, B is a battery connected to the opposite corners of a Wheat-

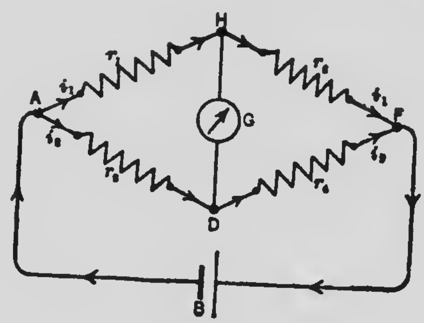


FIG. 1.

stone net. Whenever a current flows in a wire there is a drop of potential along the wire. The amount of the drop between two points is proportional to the resistance included between the two points by Ohm's law, which states that the current $= \frac{\text{electromotive force}}{\text{resistance}}$. Between A and F the current will split into two parts, a part i_1 going by the upper circuit AHF and a part i_2 by the lower circuit ADF. The drop of potential from A to F must be the same for the two circuits, since A and F are points common to the two circuits, and two different potentials cannot exist at the same point. Hence for every point on the circuit AHF there must be a corresponding point on the circuit ADF at the same potential.

Let H and D be two such points. A galvanometer G connected between H and D will show no deflection, since no current will flow between two points at the same potential.

Let H divide the upper circuit into two parts, the resistances of which are r_1 and r_2. In the same way D divides the lower circuit into two resistances r_3 and r_4.

Let E_1 be the potential difference between A and H. It will also be the potential difference between A and D, since H and D are at the same potential.

Let E_2 be the difference of potential between H and F. It will also be the potential difference between D and F.

By Ohm's law

$$E_1 = i_1 r_1 = i_2 r_3,$$

and

$$E_2 = i_1 r_2 = i_2 r_4.$$

Dividing.

$$\frac{r_1}{r_2} = \frac{r_3}{r_4}. \qquad \ldots\ldots\ldots\ldots \quad (1)$$

Usually one ratio is known. Hence the other two resistances can be compared.

Fig. 2 represents the slide-wire form of the bridge, and is lettered to correspond to Fig. 1.

The shaded parts represent large brass straps whose resistances are so small that the drop of potential across them may be neglected. Between A and F is stretched a German silver

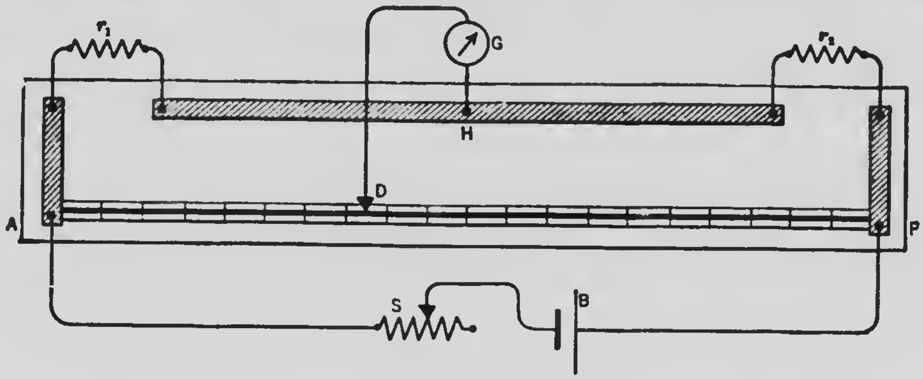


FIG. 2.

wire whose resistance σ per unit length is uniform. r_2 is an unknown resistance and r_1 a set of resistances which can be easily adjusted to the same order of magnitude as r_2.

Again suppose H and D to be the equipotential points. D divides the wire into two lengths l_1 and l_2 whose resistances are σl_1 and σl_2.

As before,
$$\frac{r_1}{r_2}=\frac{\sigma l_1}{\sigma l_2}=\frac{l_1}{l_2}. \qquad (2)$$

l_1 and l_2 can be measured, r_1 is known and hence r_2 can be calculated.

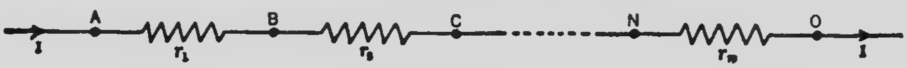


FIG. 3.

Resistances in Series. Let Fig. 3 represent n resistances in series.

Let e_1 be the potential difference between A and B,
e_2 — B and C,
e_n — N and O,
and E — A and O.

Then $E=e_1+e_2+\ldots+e_n$. The same current I must flow through each. Let R be the equivalent resistance, i.e., the single resistance which will replace them all, without altering the current. By Ohm's law,

$$IR=Ir_1+Ir_2+\ldots+Ir_n.$$

Hence
$$R=r_1+r_2+\ldots+r_n. \qquad (3)$$

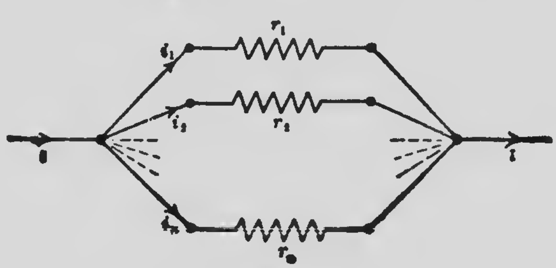


FIG. 4.

Resistances in Parallel Let Fig. 4 represent n resistances in parallel.

Let E be the drop of potential across each resistance, which will be the same for all. Let R be the single resistance equivalent to the n resistances. The current I will divide into n parts so that

$$I = i_1 + i_2 + \dots + i_n.$$

By Ohm's law,

$$\frac{E}{R} = \frac{E}{r_1} + \frac{E}{r_2} + \dots + \frac{E}{r_n}.$$

Hence

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \dots + \frac{1}{r_n}. \qquad (4)$$

Procedure: Connect up the bridge as shown in Fig. 2, using either one of the two coils as the unknown resistance. Adjust the rheostat S so that the sliding switch makes contact in the middle. Keep this sliding switch open except when making measurements. Make sure that all wire connections are tight.

Adjust the resistance in the box to 10 ohms. With D at about the middle of the bridge wire, depress the contact key. A quick tap is sufficient and will show the direction in which the galvanometer mirror turns. Alter the position of the contact key on the bridge wire until on depressing it only a slight deflection of the mirror is observed. Calculate to the nearest ohm the approximate resistance of the coil from the lengths l_1 and l_2 of the bridge wire, using formula (2), and adjust the resistance in the box to this value.

Now carefully adjust the position of the contact key until no deflection is obtained. The balance point should be near the middle of the bridge wire. Interchange the coil and the box and balance again. From the mean values of l_1 and l_2, calculate the resistance of the coil.

Repeat the above procedure for the other coil.

Connect the two in series and find the equivalent resistance.

Connect them in parallel and find the equivalent resistance.

Calculate the values of the equivalent resistances from formulæ (3) and (4), and compare them with the experimental values. This comparison is a verification of Ohm's law.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

ELECTRICAL EQUIVALENT OF HEAT

Object of Experiment: To verify Joule's law and to find the electrical and hence the mechanical equivalent of heat.

Apparatus: A Callendar and Barnes continuous-flow calorimeter; constant-level water tank; 110 volt D.C. circuit; suitable lamp rheostat; tangent galvanometer or ammeter; 500 cc. graduated flask; copper beaker; watch; two thermometers.

Theory: The Callendar and Barnes calorimeter, shown in Fig. 1, is designed for the rapid and fairly accurate determination of the electrical and hence of the mechanical equivalent of

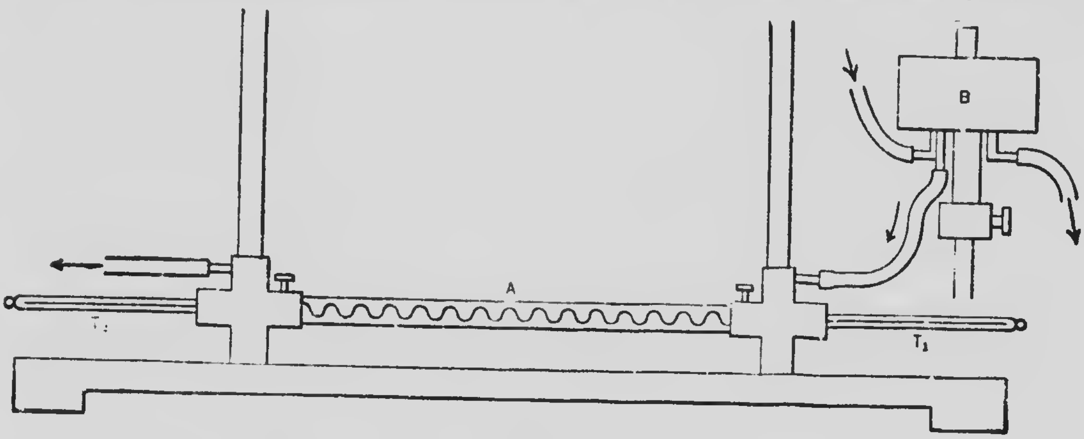


FIG. 1.

heat. It consists of a glass tube A, along which a helical coil of manganin wire passes, and in the ends of which are placed two mercurial thermometers T_1 and T_2, graduated to one-tenth of a degree. A stream of water flowing through the tube A is heated by an electric current passing along the helix of wire.

A uniform flow of water is secured by means of a constant-level water tank, the one in the figure being shown at B.

Joule's law states that in a simple circuit, i.e., a circuit which is not doing any mechanical work by moving relatively to the surrounding magnetic field, the heat generated is proportional to (1) the square of the current, (2) the resistance, and (3) the time during which the current flows. Joule's law applies equally well to the whole or to a part of the circuit.

According to this law it follows that $H = I^2Rt$, where H is the number of calories developed, I the current in amperes, R the resistance in ohms, and t the time in seconds; or we may write $H = I^2Rt/K$, where I/K is the proportionality factor. Therefore

$$K = \frac{I^2Rt}{H} = \frac{QE}{H}, \quad \quad (1)$$

where Q is the quantity of electricity in coulombs, and E the difference of potential in volts.

If we find experimentally that I/K is a constant, then we have verified Joule's law. Moreover, we see that K is the number of (ampere)²-ohm-seconds or volt-coulombs necessary for the development of one calorie of heat. This quantity K may be called the *electrical equivalent of heat energy*, since it gives the relation between units of heat energy and units of electrical energy.

To find the relation between mechanical energy and electrical energy we have only to

(OVER)

recall our definitions connecting the electrical with the mechanical units. Going back to the absolute electromagnetic definitions, we find that *unit difference* of potential exists between two points when it requires one erg of work to convey a unit positive charge *against* the electrical forces from the point of lower potential to the point of higher potential; or that one erg of work is done by the electrical forces when a unit positive charge, as it moves along a wire, passes through two points between which there exists unit difference of potential.

Remembering that the coulomb is 10^{-1} absolute unit of quantity and the volt is 10^8 absolute units of potential difference, we have $w(\text{ergs}) = (Q \times 10^{-1})(E \times 10^8) = QE \times 10^7$. Therefore

$$W(\text{joules}) = QE. \quad \quad (2)$$

Combining (1) and (2), we obtain $W = KH$. But the first law of thermodynamics states that $W = JH$, where J is the *mechanical equivalent of heat energy.*

Therefore $$K = J.$$

Hence the electrical and the mechanical equivalents of heat energy are equal.

The value of K, and hence of J, can be determined as follows: Suppose that, in t seconds, a mass M grams of water flows through the calorimeter, and is heated from $t_1°$ to $t_2°$ C. Then $H = M(t_2° - t_1°)$, since H is taken to be the quantity of heat developed in t seconds. Hence substituting in (1) and solving for K, we obtain

$$K = \frac{I^2Rt}{M(t_2° - t_1°)}. \quad \quad (3)$$

Procedure: Connect the tangent galvanometer and reversing switch in series with the lamp rheostat and the resistance wire in the tube A (Fig. 1).

Before turning on the current, allow the water to pass through the apparatus, gently overflowing from the constant-level tank B, and read the thermometers T_1 and T_2 to one-tenth of the smallest division. To correct for any gradual change which may take place in the temperatures, the thermometers may be read alternately, an odd number of readings being taken at regular intervals, thus T_1, T_2, T_1, T_2, T_1, etc., and the means of T_1 and T_2 taken. The difference of these means is to be applied as a zero correction to the temperature difference obtained during the course of the experiment.

Never turn on the current without water flowing through the calorimeter as the wire is likely to be injured.

Now adjust the current to give a rise of from 5° to 10° C. in the water as it flows through A. After the temperatures have become steady, read the thermometers as before while collecting about 500 cc. of water in a copper beaker. Also note the length of time t during which the water is being collected.

Determine the mass M of water collected by measuring it in the graduated flask provided, taking 1 cc. as equivalent to 1 gm.

Substitute in (3) and calculate K and J.

Repeat the experiment for two other current strengths or positions of the constant-level tank and find the mean of the three values obtained.

If the values of K (and hence of $1/K$) determined under different experimental conditions are found to be constant, then Joule's law is verified within the limits of experimental error.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

ELECTRO-CHEMICAL EQUIVALENTS

Object of Experiment: To measure the E.C.E. of hydrogen and to calculate that of copper.

Apparatus: Tangent galvanometer; gas voltameter; 16 candle-power carbon lamp with socket and plug for connecting to the 110 volt D.C. circuit; reversing switch; thermometer.

Theory: Liquid conductors of electricity may be divided into two classes: (1) those which are not decomposed when a current passes through them, such as mercury and other pure metals in the molten state, and (2) those compounds, either fused or in solution, which are decomposed by the passage of the electric current. These latter are termed *electrolytes*.

When a substance which forms an electrolyte on solution is dissolved in a liquid, it appears to some extent to dissociate into simpler portions, which wander about as charged atoms or groups of atoms called ions. This process of *ionization* seems to be essential to conduction in most liquids. The extent to which a substance is ionized in solution depends largely on the solvent, water being very effective in this respect. The forces to be overcome by the solvent in producing dissociation are probably of the nature of an electrical attraction between the parts of the molecule which form the positively and negatively charged ions.

Suppose two inert electrodes, say of platinum, are placed in a dilute solution of sulphuric acid (H_2SO_4) in water, the *primary action* taking place on the passage of current will be the movement of the $SO_4(-)$ ions to the anode (+) and of the hydrogen (+) ions to the kathode (−), due to the attraction of oppositely charged bodies and to the apparent repulsion of similarly charged bodies.

A *secondary action* at the anode takes place between the discharged SO_4 groups and a molecule of water, which may be represented by the equation,

$$2H_2O + 2SO_4 = 2H_2SO_4 + O_2.$$

Thus the water is decomposed and oxygen is given off at the anode.

At the kathode no secondary action takes place because hydrogen does not combine with either platinum or water; so hydrogen appears at the kathode. The result is that the water molecules are broken up into H_2 and O_2, while at the end of the experiment there remains the same quantity of H_2SO_4.

In the case where the electrolyte consists of a metallic salt in solution, as $CuSO_4$, the copper is deposited on the kathode when a current passes. The processes of electroplating and electrotyping depend on this fact.

Since each ion, of the same kind, carries the same charge, which is a simple multiple of the charge of the negative electron, it is evident that a definite amount of the substance forming the ion will be deposited by the passage of a definite quantity of electricity through the electrolyte. The mass in grams of a substance thus deposited by the passage of one coulomb of electricity is called its *electro-chemical equivalent*.

If we denote the electro-chemical equivalent of hydrogen by z_h we can write

$$m = Itz_h, \qquad (1)$$

where m is the mass in grams of hydrogen liberated by the passage of I amperes for t seconds, i.e., of It coulombs of electricity.

If a tangent galvanometer having a coil of n turns of radius r cm. is joined in series with the gas voltameter, then

$$I = \frac{10Hr}{2\pi n} \tan\theta, \qquad (2)$$

(OVER)

where H is the horizontal component of the earth's magnetic field and θ is the mean angular deflection of the galvanometer needle.

Solving (1) and (2) for z_h, we have

$$z_h = \frac{2\pi nm}{10Hrt \tan\theta}. \quad \text{. . . . .} \quad (3)$$

To find the value of m, calculate the volume of hydrogen at N.T.P. and multiply by the density of hydrogen at N.T.P., viz., .0000900 gram per cc.

By Charles' law we have

$$\frac{PV}{T} = \frac{P_0 V_0}{T_0},$$

where P and V denote the pressure and volume of the given mass of hydrogen at the absolute temperature T; and P_0, V_0, T_0 denote corresponding quantities at 0° C. By putting P_0 equal to 76 cm. of mercury V_0 becomes the volume at N.T.P. and we have

$$V_0 = \frac{VPT_0}{76T} = \frac{VPT_0}{76(T_0 + t^\circ)}, \quad \text{. . . . .} \quad (4)$$

where t° is the temperature in degrees Centigrade.

The pressure P consists of the atmospheric pressure B, plus that due to the head h of dilute acid of density 1.1, minus the pressure of saturated water vapor p in the hydrogen tube. Hence the value of m is given by the following equation,

$$m = V_0 \times 0.0000900 = \frac{V\left(B + \frac{h \times 1.1}{13.6} - p\right)273}{76(273 + t^\circ)} \times 0.0000900. \quad \text{. . . . . .} \quad (5)$$

The quantity 13.6 is, of course, the density of mercury, and the pressure is expressed in terms of centimeters of mercury.

Procedure: Connect the apparatus as indicated in Fig. 1 where G denotes the tangent galvanometer, V the hydrogen voltameter, S a reversing switch and L a 16-candle-power lamp joined to the 110-volt D.C. circuit. See that the electrolyte completely fills the U-tubes of the voltameter and that the stopcocks at the top are properly closed.

Read the galvanometer deflection and reverse the current at least every two minutes, taking the same number of readings with the current flowing in each direction. Allow the current to flow until from 45 to 50 cc. of hydrogen is collected, but be sure to open the circuit before the hydrogen column reaches the top of the electrode or extends below the graduated scale.

Note the time during which the hydrogen is being collected.

Read the temperature of the electrolyte at the time that the volume V is read, and find, from tables or from the chart in the laboratory, the value for the saturated water vapor pressure.

Read the barometer.

Determine the radius of the galvanometer coil. If only five turns are employed, note whether the outside or the inside radius should be used.

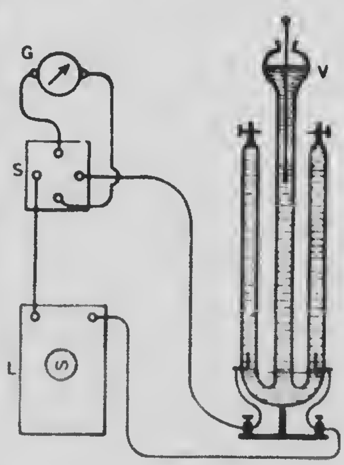


Fig. 1

Substitute the values of these quantities in equations (5) and (3), and calculate z_h.

Problem: Remembering that the charge carried by any ion is proportional to its valency, i.e., to the number of hydrogen atoms which it combines with or replaces, calculate z_c the E.C.E. of copper. Take the atomic weight of copper as 63.6 and that of hydrogen as 1.008 and use the value as determined above for the E.C.E. of hydrogen.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

ELECTRIC CELLS

Object of Experiment: (1) To observe the effect of polarization in a primary cell; (2) to measure the internal resistance of a primary cell, and (3) to discover under what condition cells should be connected in series and in parallel to give the greater current.

Apparatus: A Leclanché cell; four Daniell cells; voltmeter; tangent galvanometer; reversing switch; two coils of known resistance; tapping key.

Theory: The chief difficulty in using a primary cell is that of polarization. This is due to the accumulation of hydrogen on the kathode. The positively charged hydrogen ion, in contact with the copper plate of a simple cell, gives to the plate its positive charge and becomes free hydrogen gas with a tendency to stick to the plate, forming a gaseous film. This decreases the action of the cell for two reasons: (1) it increases the internal resistance, thereby decreasing the current, and (2) hydrogen being electro-negative to zinc, it tends to decrease the e.m.f. of the cell by setting up a counter e.m.f.

Polarization is avoided in two ways as illustrated by the Leclanché and the Daniell cells. The Leclanché cell consists of carbon and zinc plates immersed in a solution of ammonium chloride. Mixed with the carbon is manganese dioxide, which tends to combine with the hydrogen as it appears, forming water. The action is slow, however, so that when the cell is used for any length of time polarization will result. Left to stand on open circuit the cell will soon recover. The Daniell cell has a zinc plate in dilute sulphuric acid and a copper plate in copper sulphate. In the latter the copper is the positive ion so that copper is deposited and no polarization is possible. This cell can be used on "closed circuit" work.

With any external resistance in the circuit a single cell will give only a small current. If larger currents are required, several cells can be used. There are two general ways in which

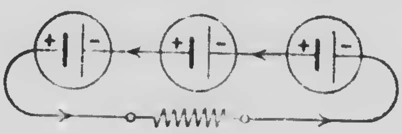


Fig. 1

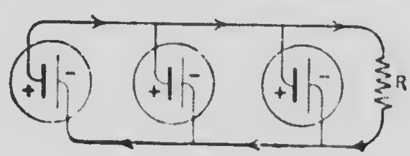


Fig. 2.

a number of cells can be arranged, and the currents thus obtained depend on the relative magnitudes of the external and the internal resistances.

In Series. The positive plate of one cell is connected to the negative of the next and so on. If E is the e.m.f. of one cell the total e.m.f. will be nE where there are n cells, all of which are supposed to be identical. If r is the internal resistance of one cell, nr is the total internal resistance. Applying Ohm's law, $I = \frac{nE}{R + nr}$ where R is the external resistance.

In Parallel. The positive and the negative plates are all connected so as to form one large positive plate and one large negative plate. Since the e.m.f. is independent of the size of the plates, the resultant e.m.f. will be E. The equivalent internal resistance, however, will be less than that of one cell and is given by $\frac{r}{n}$. Then

$$I = \frac{E}{R + r/n} = \frac{nE}{nR + r}.$$

If the cells are not identical, their e.m.f.'s and resistances must be separately determined. From an inspection of the formulae it is obvious that if *R is greater than r*, the greater current

(OVER)

will be obtained with the cells *in series*, but that if R is less than r then they should be in *parallel*.

Procedure: Be careful to connect the positive pole of the battery to the positive pole of the voltmeter.

(1) Connect the voltmeter across the terminals of the Daniell cell. The resistance of the voltmeter is so large that very little energy is drawn from the battery and the reading given is practically the e.m.f. of open circuit according to Ohm's law. Connect the terminals of the cell to a tapping key. Close the circuit by depressing the key. The e.m.f. will be observed to fall due to the fact that energy is now being consumed in the circuit in the form of heat. Release the key, and the e.m.f. returns to its former value. Measure and record the e.m.f. of each Daniell cell on open circuit.

Connect the voltmeter to the Leclanché cell and measure its e.m.f. on open circuit. Short-circuit it through the tapping key as before. Keep the circuit closed for two or three minutes and observe the falling off of the e.m.f. Release the key so that the cell is again on open circuit. Observe that the e.m.f. does not return to its former value. This is due to polarization. Place the cell aside to be tested later.

(2) Measure the internal resistance of each Daniell cell separately, as they will probably all differ. To do this connect in the circuit of a cell one of the resistance coils R (Fig. 3).

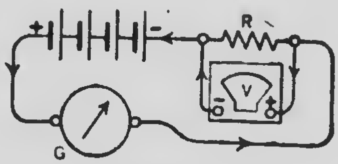


Fig. 3.

With the voltmeter V measure the drop of potential across the terminals of this resistance and denote it by e. The e.m.f. E of the cell has been determined in (1).

By Ohm's law, $I = \frac{E}{R+r} = \frac{e}{R}$. R, E and e are known. Hence determine r. Repeat for each cell.

(3) *Best Arrangement of Cells for a Large Current.* From the theory of the tangent galvanometer, the current in amperes through the galvanometer is

$$I = \frac{10Hr \tan\theta}{2\pi n},$$

where θ is the angle of deflection, r the radius of the coil, n the number of turns of wire, and H the horizontal component of the earth's field. At any given place all these factors except θ are constant. Hence with this instrument currents may be compared by merely comparing the tangent of the angles of deflection which they produce.

Connect the four Daniell cells in series (Fig. 3) and place in the circuit the galvanometer G and one of the resistance coils R. The galvanometer should be set so that the plane of its coil is in the magnetic meridian. Read and record the deflection produced. Repeat for the other resistance.

Connect the cells in parallel and determine the deflection for each resistance. It will be seen that the greater current will depend on whether the external resistance is larger or smaller than the internal. Compare the experimental result with the deduction arrived at from the formulæ.

Using the formula for the tangent galvanometer calculate the current in amperes in each case. Hence state in the results the rule by which a given number of cells may be connected so as to give a large current.

Redetermine the e.m.f. of the Leclanché cell and record its value with the others.

FIRST YEAR EXPERIMENTAL PHYSICS

ELECTRICITY

INDUCED CURRENTS

Object of Experiment: (1) To show that the value of the induced e.m.f. in a coil depends on the rate at which the flux through the coil changes.

(2) To verify Lenz's Law.

(3) To study the construction of the induction coil.

(4) To study the principle of the transformer.

Apparatus: Storage cells; source of alternating e.m.f.; bar magnet; D'Arsonval galvanometer; two concentric cylindrical coils, one free to slide within the other; soft iron core to fit the smaller coil; detachable interrupter; iron ring wound with four separate coils each of a known number of turns; 16 c.p. lamp in stand; tapping key; condenser; resistance coil.

Theory: Whenever a conductor cuts lines of magnetic force, an induced e.m.f. is set up between the ends of the conductor, the magnitude of the induced e.m.f. depending on the rate at which the cutting takes place. The conductor may be fixed and the field changing, in which case the effect is the same. If the conductor is in the form of a loop, the law may be stated thus: Whenever the total flux threading a coil changes, an induced e.m.f. is set up; the *direction* of the induced current depends upon whether the flux is increasing or decreasing,

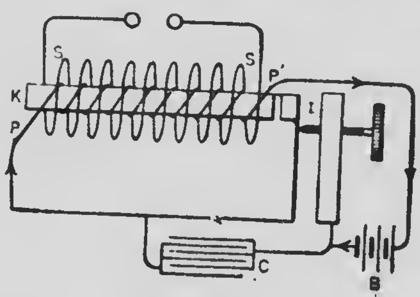


Fig. 1.

and the *magnitude* of the induced e.m.f. depends upon the rate of change of the flux. The law connecting the direction of the induced current and the change in flux was given by Lenz, and may be stated as follows: *The e.m.f. induced is such that it always opposes the force which produces it.*

The *Induction Coil* consits of two coils, the primary PP' and the secondary SS'. The primary is made up of a few turns of thick insulated wire, and the secondary of a large number of turns of fine wire. The primary also includes an iron core K which becomes a magnet when an electric current flows through the coil. An interrupter is attached, by which the current through the primary coil can be made and broken many times per second. The making and breaking of the current causes an increasing and decreasing flux through the secondary in which an alternating e.m.f. will be produced. Since each turn of wire participates in the cutting of the lines the greater the ratio of the number of turns of wire in the secondary to the number in the primary, the greater the e.m.f. induced.

A *transformer* consists in principle of an iron ring around which may be wound several separate coils of wire. If a current is sent through one coil, lines of magnetic induction are set up in the iron, threading each of the coils. If the current should be alternating, the lines of induction will alternate with it. Thus an alternating induced e.m.f. will be established in each of the other coils. It can be shown that the ratio of the e.m.f. induced in any coil to the e.m.f. of the primary is very nearly the same as the ratio of the number of turns of wire in the two coils.

Procedure: (1) Observe that, with no current through the galvanometer, the image of the scale is seen approximately at the middle of the mirror.

Connect the terminals of the larger cylindrical coil to the galvanometer, so that the terminal marked A is joined to the right-hand galvanometer terminal. Thrust the N pole of the magnet into the coil. The deflection of the galvanometer indicates that an e.m.f. has been set up. Notice and record whether the deflection is to right or left. Allow the magnet to remain at rest and it will be observed that the mirror will return to its zero position. This indicates that the induced e.m.f. exists only so long as the field inside the coil is changing. Draw the magnet out quickly, and the deflection is in the opposite direction. Repeat with the other pole of the magnet. Thrusting in a south pole is equivalent to drawing out a north pole. Explain. Thrust the magnet into the coil at varying rates of speed. How does this verify the law?

(2) Connect in series the battery B, resistance coil R and galvanometer G in such a way that the positive pole of the battery is joined to the right-hand terminal of the galvanometer (Fig. 2). Notice and record whether the deflection is to right or left. From the observations made in (1) determine the direction in which the current flows through the coil when

(*a*) the north pole of the magnet is advancing;
(*b*) the south pole of the magnet is advancing;
(*c*) the north pole of the magnet is receding;
(*d*) the south pole of the magnet is receding.

The current will establish a magnetic field within the coil which will oppose the field of the magnet. The coil exhibits a polarity. Draw a diagram for each of the above cases

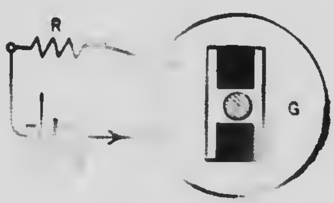


Fig. 2.

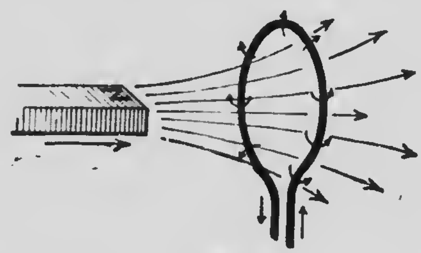


Fig. 3.

similar to Fig. 3, marking the polarity of the coil, the direction of the induced currents, and the direction of motion of the magnet.

(3) Whereas the larger coil has a large number of turns of fine wire, the smaller has a comparatively small number of turns of heavy wire. Connect the smaller coil to the storage battery. When a current is flowing through it, the coil is equivalent to a magnet. Observe that it produces the same effects as the magnet when thrust into and withdrawn from the larger coil. Place the small coil completely within the larger. Connect a tapping key in the circuit. Close the circuit by depressing the key. Observe the direction of the deflection of the galvanometer. Keeping the circuit closed the mirror returns to its initial position, showing that the field within the large coil is no longer changing. Release the key and a deflection will be obtained in the other direction. Upon closing the circuit a magnetic field is suddenly established which disappears again when the circuit is broken. Place the iron core inside the coils and repeat the above experiments. The iron increases the effect due to the fact that the number of lines of induction is increased by the presence of the core. The smaller coil around the iron is called the primary and the outer coil the secondary.

If the current through the primary is made and broken rapidly, an alternating e.m.f. will be set up in the secondary. If too rapid, no effect will be observed on the galvanometer, since it will not have time to be deflected appreciably in one direction before the e.m.f. in the opposite direction is impressed upon it. Disconnect the galvanometer and tapping key and replace them with the mechanical interrupter I. The current through the primary is now made and broken many times a second and a large alternating e.m.f. is induced in the secondary. To observe this bring a wire from one terminal of the secondary near to the other terminal. The value of the voltage between the terminals of the secondary can be approximately estimated, since it is known that a potential difference of about 27,000 volts is required to cause a spark 1 cm. long in air. Estimate the value of the induced e.m.f. from the length of the spark.

(4) The induced e.m.f. between the terminals of large induction coils may reach a value of more than a million volts. The quantity of electricity flowing in the secondary is, however, quite small, since the energy produced in the secondary can never be equal to that expended in the primary.

In order to obtain such high electromotive forces, it is clear from the equation $E = \frac{\phi}{t}$ where E is the induced e.m.f., ϕ the total change in the magnetic flux in the time t, that this end may be attained by increasing ϕ or by decreasing t. The change in the magnetic flux may be increased by using a large current in the primary and by using iron of high permeability in the core. The value of t may be greatly reduced by using some form of interrupter whereby the current may be made and broken with great rapidity. This may be accomplished by means of some form of automatic interrupter acting on the principle of the hammer in the electric bell.

Owing to the fact that the carriers or electrons, which constitute an electric current, have momentum, their inertia tends to cause them to jump across the gap made by the interrupter at each break. This interferes with the sudden interruption of the current. This spark would not only burn off the contact point and ruin the automatic break, but it would also prolong the fall of the current to zero. In order to suppress this spark a condenser C is placed in parallel with the spark gap. This serves a two-fold purpose. First, the current at the break, instead of jumping the gap in the form of a spark, is diverted into the condenser and charges it to a high difference of potential. By this means the spark and the burning of the contact are both avoided, and t the time of breaking is greatly reduced. Second, the condenser immediately after the break and before the next make of the current, discharges backward through the battery and the primary coil, thus sweeping out all lines of induction remaining in the core and inserting others in the opposite direction. In this way ϕ is greatly increased.

Connect the terminals of the condenser so as to place the latter in parallel with the spark gap of the primary coil, as indicated in Fig. 2. Set the induction coil in operation and observe the increased length of spark obtainable. Estimate, if possible, the increase in the length of the spark and calculate the induced e.m.f.

(5) Connect in series the source of alternating e.m.f., the lamp and coil No. 3 of the ring. With the A.C. voltmeter measure the drop of potential across the coil chosen. The coils are so wound that the ratio of the turns are as 1 : 2 : 3 : 4 : 5 : 6, the exact number of turns being marked in each case. Determine the voltage across each of the other coils and verify that the ratio of the e.m.f. of the secondary is to that of the primary as that of the number of turns of wire in the two coils.

FIRST YEAR EXPERIMENTAL PHYSICS

SOUND

THE SONOMETER

Object of Experiment: To determine the vibration frequency of a tuning fork by means of a sonometer.

Apparatus: A sonometer; a tuning fork, provided with a resonator; a rubber hammer for exciting the fork.

Theory: If a string stretched under a tension T, so great that the action of gravity may be neglected in comparison with it, is made to vibrate by drawing it aside at one point and then suddenly freeing it, the disturbance will be transmitted along the string as a wave motion, the velocity of the wave being given by the equation

$$v=\sqrt{\frac{T}{m}}, \quad \ldots \ldots \quad (1)$$

where m is the mass of the string per unit length.

If l is the length of the vibrating portion of the string, and n the vibration frequency of the fundamental note, then

$$v=2ln,$$

and therefore,

$$n=\frac{1}{2l}\sqrt{\frac{T}{m}}. \quad \ldots \ldots \quad (2)$$

In formula (2) all the laws of the transverse vibration of strings are included.

If the length of the vibrating portion of the string is adjusted till the emitted note is the same as that of a tuning fork, the vibration frequency of the fork can be calculated from formula (2).

Procedure: We shall assume that the usual form of sonometer, provided with weights for altering the tension, and with a movable bridge for altering the length of the vibrating portion of the string, is used.

A piece of piano-wire of small diameter is generally suitable for the purpose of the experiment.

If the weight m of the unit length of the wire is not given, the wire must be weighed before attaching it to the sonometer box, and m calculated.

Fasten one end of the wire to the sonometer box, and the other to the attachment for holding the weights.

Excite the fork by a blow from the hammer.

Vibrate the wire by plucking it at the middle point with a finger.

Continue the process, adjusting the length of the vibrating wire by means of the movable bridge, until the string and the fork are apparently in unison, no beats being heard. This point cannot be accurately determined in this manner because the wire is damped before very slow beats can be distinguished, so an indirect method must be used. Find two points on opposite sides of the unison point where the beats have the same frequency of about one or two per second. Midway between them is the unison point required.

If it is found that less than one-third of a meter of wire is used in the vibrating portion the tension should be increased so that the length of the string can be increased; otherwise the string will vibrate for such a short time that it will be almost impossible to make the comparison.

Having adjusted for unison, measure the length of the vibrating segment.

Read the stretching weight including the scale pan and reduce it to dynes.

Calculate n from formula (2).

Find the frequency using three different sets of weights, making three separate determinations for each.

Remember that 1 pound = 453.6 grams and 1 gram = 981 dynes.

FIRST YEAR EXPERIMENTAL PHYSICS

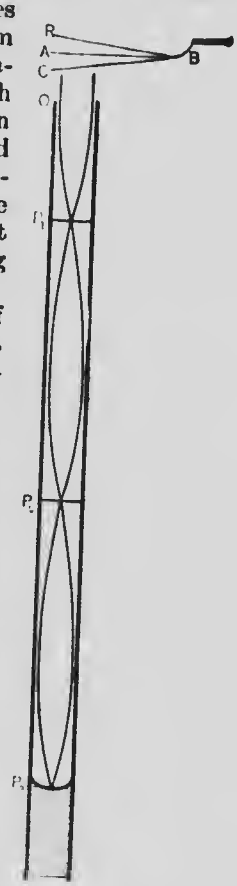
SOUND

THE RESONANCE TUBE

Object of Experiment: To determine the velocity of sound in air at 0° C.

Apparatus: Resonance tube; tuning fork; rubber hammer; meter stick.

Theory: Every elastic body has a natural period of vibration which depends on the nature of the body. If any such body is placed in a medium through which a train of waves is passing and if the natural period of vibration of the body coincides with that of the waves, the body will gradually absorb energy from the waves until it is in full vibration. This is known as "*The Principle of Resonance.*" If two similar tuning forks are placed near each other and one is made to vibrate, the other begins to vibrate also in accordance with the above principle. The second fork may be replaced by a column of air. If a vibrating tuning fork is held over an air column, and *the air column* is of proper length, it starts vibrating and the intensity of the sound is much increased. This last is due to the fact that the vibrating air column effectively increases the area of the sounding body.



It is possible to calculate from such an arrangement the velocity of sound in air. Let AB represent one prong of a tuning fork held in front of a cylindrical tube. As the vibrating prong moves from R to C a condensation will be sent down the tube. Since a condensation is reflected as a condensation, this will travel the length of the tube to P_1 and will be there reflected back as a condensation. If the natural period of vibration of the air column coincides with that of the fork, the reflected wave will arrive at the open end in time to join the condensation sent out in the direction CR, at the same time reflecting back into the tube a rarefaction which unites with that caused by the fork on its backward swing. Thus the vibrating air column will reinforce the fork and the intensity of the sound will be much increased. It is evident that the fork will be reinforced not only when the time corresponds to the first half-vibration, but also if the length of the tube is such that the time it takes the vibration to travel to the closed end and back is equal to the time of a complete vibration and a half or any odd number of semi-vibrations of the fork.

There are therefore several resonance points in a long tube, called the first, second, and third resonance points, and so on. The distance from the open end of the tube to the first point is *approximately* equal to a quarter of a wave-length of the fork, the distance to the second point three-quarters, and to the third point one and a quarter wave-lengths. The distance between the first and third points is accurately equal to one whole wave.

(1) While the prong moves from R to C the condensation travels from O to P_1 and back to O. Let n represent the frequency of the fork; then the time for the fork to go from R to C is $t=\frac{1}{2n}$.

Also if l is the length OP_1 and v represents the velocity of sound, $t=\frac{2l}{v}$.

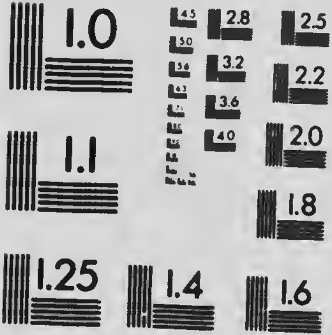
Hence
$$\frac{2l}{v}=\frac{1}{2n} \text{ or } v=4ln.$$

On account of the form of the wave surface and the friction of the air on the walls of the

(OVER)

MICROCOPY RESOLUTION TEST CHART

(ANSI and ISO TEST CHART No. 2)



APPLIED IMAGE Inc
1653 East Main Street
Rochester, New York 14609 USA
(716) 482 - 0300 - Phone
(716) 288 - 5989 - Fax

tube, a correction is necessary for l. This correction nearly equals the radius of the tube. So the formula becomes

$$v = 4(l+r)n. \qquad (1)$$

The velocity of sound increases with temperature. It can be shown that the velocity at 0° C. is given by $v_t = v_0\sqrt{1+\alpha t}$ where $\alpha = .003665$.

Therefore

$$v_0 = \frac{v_t}{\sqrt{1+\alpha t}}. \qquad (2)$$

(2) Suppose the end of the tube at P_1 to be removed to P_2 where $OP_2 = l'$. It is easily seen that while a condensation is traveling from O to P_2 and back to O the prong has made one and a half vibrations.

Hence $\frac{3}{2n} = \frac{2l'}{v}$ or $v = \frac{4l'n}{3}$, since $l' = 3l$.

Corrected, this becomes

$$v = \frac{4(l'+r)n}{3}. \qquad (3)$$

(3) In the same way a distance OP_3 may be obtained such that $l'' = 5l$. Then

$$v = \frac{4(l''+r)n}{5}. \qquad (4)$$

Procedure: Two adjustable tubes, connected by rubber tubing at the bottom, are partially filled with water. By raising either tube the water level in the other can be changed, increasing or decreasing the length of the air column above. Adjust so that the water level is within a few centimeters of the top of one tube. Set the tuning fork vibrating by striking it with the rubber hammer. Hold it horizontally over the end of the tube and gradually increase the length of the air column by lowering the other tube. The intensity of the sound will increase, reach a maximum and then gradually diminish. When the intensity is a maximum there is complete resonance. Determine this point carefully and measure the length of the air column. Make three separate determinations. Take the temperature of the room as the temperature of the air column. Applying the necessary corrections, calculate the velocity of sound at 0° C. from formulæ (1) and (2).

In the same way find the next two points of maximum intensity and calculate the velocity at 0° C. for each from formulæ (1), (3) and (4). Record all your observations and the mean result.

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

PHOTOMETRY

Object of Experiment: To determine the candle-power of an electric light when the filament is (1) broadside on, (2) edge on, (3) end on.

Apparatus: Photometer; standard candle; electric lamps; meter stick.

Theory: The illuminating power of a light is its value considered with reference to certain standard lights. The brightness or illumination produced by a light is the intensity of illumination per unit of area.

Let L = the illuminating power of a source of light, *i.e.*, the amount of light emitted per second, and I = the intensity of illumination.

Then $I = \frac{L}{A}$, where A is the area receiving the light L.

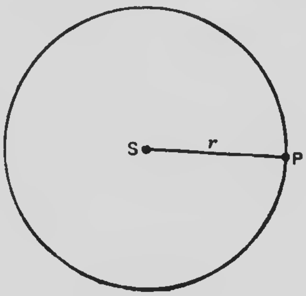


FIG. 1.

Suppose light is emitted uniformly from a small source S. It is required to find the illumination at a point P distant r from the source. Through P with S as center, construct a sphere of radius r. All the light from S must pass through the sphere, and the amount passing in each second is L.

Then
$$I = \frac{L}{A} = \frac{L}{4\pi r^2},$$
where $4\pi r^2$ is the area of the sphere.

The illumination at a given distance from a small source of light is therefore inversely proportional to the square of the distance.

Let L_s = the illuminating power of one source of light. The amount of light passing per second through unit area at a distance r_s from the source $= \frac{L_s}{4\pi r_s^2}$.

Let L_x = the illuminating power of another source. The amount of light passing through unit area at a distance r_x due to this source $= \frac{L_x}{4\pi r_x^2}$. Suppose a screen is placed between the two so as to be equally illuminated by both. Then

$$\frac{L_s}{4\pi r_s^2} = \frac{L_x}{4\pi r_x^2}.$$

Therfore

$$L_x = L_s\left(\frac{r_x}{r_s}\right)^2. \qquad (1)$$

The illuminating power is thus *directly* proportional to the square of the distance.

In order to measure the illuminating power of a light it is necessary to have a standard to measure it by. The British unit of illuminating power is the candle. A "candle power" is the illuminating power of a sperm candle burning 120 grains per hour.

The Joly photometer, shown diagrammatically in Fig. 2, consists of two rectangular blocks of paraffin wax of equal dimensions placed side by side but separated by a strip of tinfoil, and in such a position that light from each of the two sources to be compared falls normally on a face parallel to the tinfoil. Paraffin wax, being translucent, has the property of scattering (in all directions) the light that penetrates it. When the photometer has been properly adjusted in position, the two blocks should appear of the same shade.

Procedure: Assume that the candle employed is a standard candle. In the conditions under which the experiment is conducted, the candle flame is imperfectly protected, and hence

(OVER)

will be very variable. So instead of using the candle throughout the whole experiment, first standardize a small-power electric lamp and use it for determining the candle-power of the other lamp in the three positions.

To standardize the small lamp. Light the candle and allow it to burn for several minutes until it has a steady flame 4.5 cm. high. Place the lamp which is to be standardized at a distance of two meters from the candle. The other lights in the room will, of course, be out. Move the paraffin screen along the bench several times until both sides are equally illuminated. Call the distance from the screen to the candle r_1 and from the screen to the electrical light r_2.

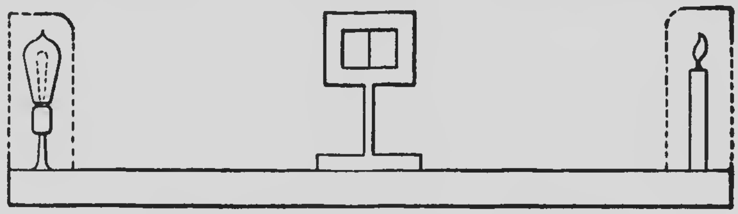


FIG. 2.

Measure these distances and record them. Repeat the settings twice more, and from the mean values of r_1 and r_2 calculate L_2 from formula (1).

Repeat the above procedure for distances of 175 cm. and 150 cm. Take the mean of the three results as the true candle-power.

Now replace the candle by the other electric lamp. Determine the candle-power of the other lamp in terms of the known lamp. Adjust the unknown lamp so that its filament is broadside on, that is when the plane of the filament is perpendicular to the photometer bench, and determine its candle-power when distant 200 cm., 175 cm. and 150 cm. from the known light, using the same method as in finding the candle-power of the "standard." Do the same for the unknown lamp when its filament is edge on, and finally when its filament is end on.

Calculate the mean value of the candle-power for each position of the filament.

Record all results in tabulated form.

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

REFLECTION AND REFRACTION OF LIGHT

Object of Experiment: To verify the laws of reflection and refraction of light, and to find the refractive index of glass.

Apparatus: Drawing board; piece of silvered glass about 10 centimeters long and 1 centimeter wide; blocks to hold it in a vertical position with its lower edge a few millimeters above the paper; thick glass plate with parallel edges; centimeter scale; set square; paper and pins.

I. Reflection of Light

Theory: The laws of reflection of light are:

(1) The reflected ray lies in the plane of incidence, i.e., in the plane determined by the incident ray and the normal to the reflecting surface at the point of incidence.

(2) The angle of reflection is equal to the angle of incidence.

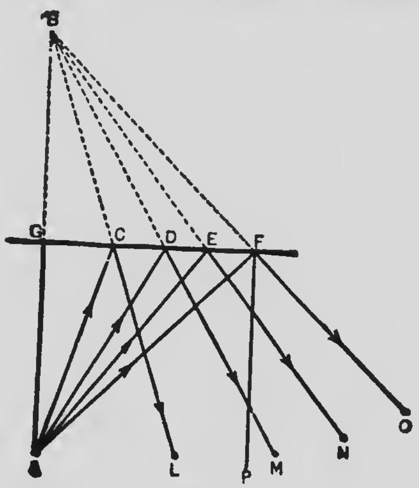


Fig. 1.

If a plane mirror is held in a vertical position, and a luminous point *A* (Fig. 1) is placed in front of it, an image of *A* will be seen formed behind the mirror, no matter from what point of the mirror light from *A* may be reflected.

Suppose light from *A* is reflected from the points *C*, *D*, *E*, *F* on the mirror.

If the lines *LC*, *MD*, *NE*, *OF* are drawn marking the directions in which the image is seen from the successive points, it will be found that they all pass through a common point behind the mirror, the point where the virtual image of *A* is formed. Denote this point by *B*.

Draw *AB*, intersecting the mirror at *G*. Then by measurement it may be shown that *AG* is equal to *BG*, and that *AB* is perpendicular to *FG*.

From this it follows geometrically that the angle of incidence must be equal to the angle of reflection; e.g., the angle *PFA* is equal to the angle *PFO*, where *PF* is perpendicular to *FG*.

Procedure: (1) Fasten a sheet of laboratory note-book paper on the drawing board. Stick a number of pins vertically into the board along a horizontal line near the middle of the page. Let their positions be represented by the points *C*, *D*, *E*, *F* in Fig. 1.

Place the mirror in a vertical position with its *silvered face* touching the pins and with its lower edge a few millimeters above the paper.

Stick another pin at a point corresponding to *A* in the diagram, and at least 10 cm. from the mirror.

Observe the image of this pin as it is reflected successively at the points *C, D, E, F,* and stick pins at points corresponding to *L, M, N, O* in line with the image and the pins *C, D, E, F* respectively.

Now remove the mirror, join *LC, MD, NE, OF* and produce them till they meet. Complete the diagram as in Fig. 1, and explain fully how it follows that the angles of incidence and of reflection at *C, D, E, F* are equal.

(2) If the angle of incidence is equal to the angle of reflection it follows geometrically that the image is as far behind the mirror as the object is in front of it, and that the line joining the object and image is perpendicular to the mirror. Consider the point *G* (Fig. 1) where the angle of incidence is equal to zero, and any other point *F* where the angle of incidence is *PFA*, and show that this is always the case. Remember that the construction to find the image of *A* in this case is to produce *AG* and *OF* till they intersect.

Hence the law of reflection can be verified by measuring the distances of object and image from the mirror and showing that the line joining them is perpendicular to the mirror.

Stick a pin vertically at a distance of 10 to 15 cm. in front of the mirror.

Now, while observing the image of the pin behind the mirror, adjust another pin so as to coincide with this image. In order to test the coincidence move the eye back and forth at right angles to the direction of the line joining the two pins. If the second pin coincides with the image, the two will appear to remain together, otherwise they will appear to move away from each other. This is known as the parallax method.

Measure the distances of the two pins from the silvered side of the mirror, and verify the fact that the line joining them is perpendicular to the mirror.

Take observations for four different distances of the pin from the mirror, and tabulate your results.

II. Refraction of Light

Theory: The laws of refraction may be stated as follows:

(1) The refracted ray lies in the plane of incidence.

(2) The ratio of the sine of the angle of incidence to the sine of the angle of refraction

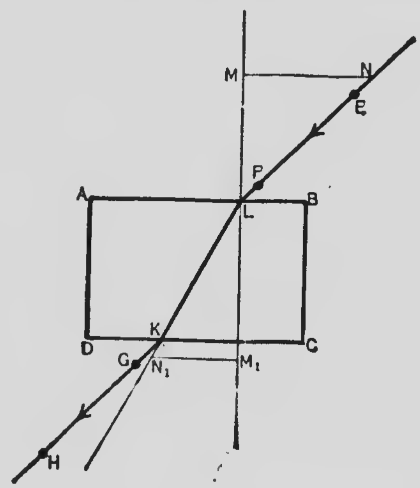


Fig. 2.

for any two given media is a constant for light of a given wave length, for all possible values of the angle of incidence.

The value of this constant, which is called the index of refraction, depends only on the nature of the two media at whose interface refraction takes place, and to a slight degree on the wave length of the light.

If a ray of light *EF* is incident on a plate of glass *ABCD* at *L* (Fig. 2), then on passing into the glass it is bent toward the normal MM_1, and passes along a line *LK*.

Denoting the refractive index of glass by μ, the angle of incidence MLE by i, and the angle of refraction M_1LK by r, we have by the laws of refraction

$$\mu = \frac{\sin i}{\sin r}.$$

If i and r are determined, μ can be calculated.

The laws of refraction may be verified by finding μ for different angles of incidence.

Procedure: Fasten a sheet of note-book paper on the drawing board and place the plate of glass flat on it, marking the outline of its position on the paper.

Stick two pins, E and F, vertically into the board so that they are at least 10 cm. apart and the line joining them makes an angle of about 45° with the normal MM_1.

On looking into the opposite edge of the plate, the refracted images of the two pins may be seen. Mark the direction of the emergent ray by sticking two other pins, G and H, also at least 10 cm. apart, so that they are in line with the refracted images of E and F.

Remove the glass plate.

Draw EF, and produce it to meet the edge AB of the glass in L.

Draw GH, and produce it to meet the edge CD of the glass in K.

Join L and K. Thus a ray of light falling on the glass at L along EF is refracted through the glass along LK and emerges along HG.

Measure 10 cm. along LE to the point N, and by means of the set square drop a perpendicular from N on the normal MM_1.

Then

$$\sin i = \frac{NM}{10}.$$

Now measure 10 cm. along LK, produced if necessary, to the point N_1, and drop the perpendicular N_1M_1 on MM_1.

Then

$$\sin r = \frac{N_1M_1}{10}.$$

Therefore

$$\mu = \frac{NM}{N_1M_1}.$$

Repeat the observations for three different values of i, and find the mean value of μ.

All diagrams should be preserved, and the readings and results recorded.

t

t

b

N

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

THE PRISM

Object of Experiment: (1) To measure the angles of a prism, (2) to verify the law that when a ray of light is refracted through a prism the angle of incidence *plus* the angle of emergence is equal to the deviation *plus* the angle of the prism, and (3) to find the refractive index of the glass of which the prism is constructed.

Apparatus: A prism; pair of dividers; centimeter scale; pins; set square.

PART I

To Measure the Angles of a Prism

Theory: Suppose from a luminous point P a ray of light falls upon the edge of a prism ABC (Fig. 1), and that it is reflected from the side AB at the edge A along the line AQ, and

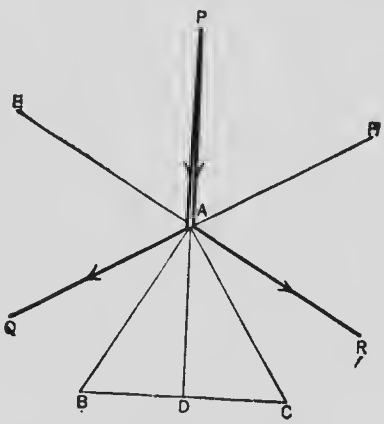


Fig. 1.

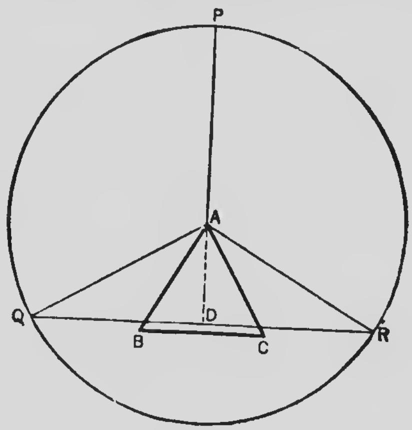


Fig. 2.

from the side AC along the line AR. Then since the angle of incidence is equal to the angle of reflection,

$$\angle PAE = \angle EAQ \text{ and } \angle PAF = \angle FAR,$$

EA being perpendicular to AB, and FA to AC.

If PA be produced to D, it is evident geometrically that $\angle QAB$ is equal to $\angle BAD$, and that $\angle RAC$ is equal to $\angle CAD$.

Therefore $\angle QAR$ is double $\angle BAC$, that is, double the angle of the prism. Hence if $\angle QAR$ is measured, the angle of the prism is found.

Procedure: Describe a circle with a radius of 10 cm., center A (Fig. 2). Place the prism with the angle to be found at the center of the circle. Stick a pin vertically at a point P on the circumference, so that the line PA approximately bisects the angle of the prism.

Mark the direction of the reflection of the pin P by sticking a pin at Q, so that Q and the image of P and the edge A are in a straight line. Mark the point R in the same way.

Now $\angle QAR$ is equal to twice $\angle BAC$. If QR be bisected at D and joined to A, then AD bisects $\angle QAR$, and is also perpendicular to QR. Hence $\angle QAD$ is equal to $\angle BAC$.

Now

$$\sin QAD = \frac{QD}{QA} = \frac{QR}{2QA}.$$

Hence measure QR, divide by twice QA, and the result is the sine of the angle BAC. By reference to the table of natural sines the angle may be found. Measure the three angles of the prism.

PART II

To Verify the Law that When a Ray of Light is Refracted through a Prism the Angle of Incidence Plus the Angle of Emergence is Equal to the Deviation Plus the Angle of the Prism.

Theory: If a ray of light falls upon the prism ABC (Fig. 3), from a luminous point P, at the point R, and is bent through the prism along a direction RS, emerging along SQ, $\angle PRE$

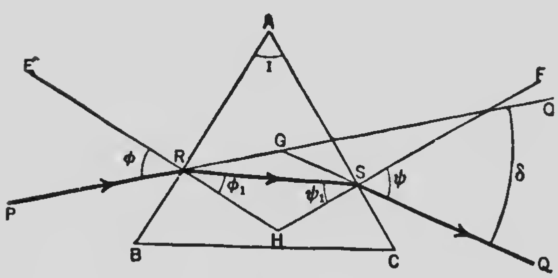


Fig. 3.

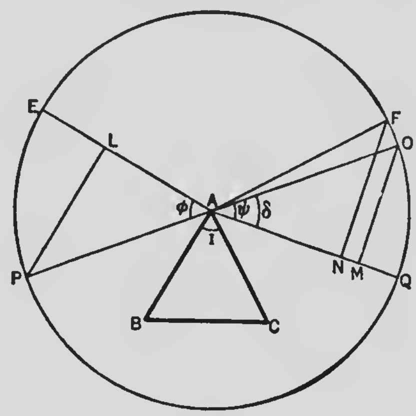


Fig. 4.

is the angle of incidence, and $\angle FSQ$ the angle of emergence, where ER and FS are perpendicular respectively to AB and AC.

Denote $\angle PRE$ by ϕ, $\angle FSQ$ by ψ, $\angle BAC$ by I, and $\angle OGQ$ by δ. Since PR and QS meet in G, $\angle OGQ$ is the angle of deviation, and

$$\angle RGS = 180° - \delta,$$

$$\angle RHS = 180° - I,$$

$$\angle GRH = \phi,$$

$$\angle GSH = \psi.$$

Hence
$$180° - \delta + 180° - I + \phi + \psi = 360°,$$

and therefore
$$\phi + \psi = \delta + I. \qquad (1)$$

If the incident ray falls so that RS is parallel to BC, then $\phi = \psi$, and in that case $2\phi = \delta + I$, or $\phi = \frac{\delta + I}{2}$.

Now if μ is the refractive index of the prism,

$$\mu = \frac{\sin \phi}{\sin SRH} = \frac{\sin \phi}{\sin \phi_1}.$$

When $\phi=\Psi$, $\angle SRH=\angle RSH$, or $\phi_1=\Psi_1$, and since $\phi_1+\Psi_1+180°-I=180°$, therefore $2\phi_1=I$, or

$$\phi_1=\frac{I}{2}.$$

Hence

$$\mu=\frac{\sin\frac{\delta+I}{2}}{\sin\frac{I}{2}}. \qquad (2)$$

It may be shown geometrically that when $\phi=\Psi$, the deviation δ is a minimum.

Procedure: (1) Describe a circle with a radius of 10 cm. (Fig. 4).

Place the prism with its edge at A, the center of the circle. Stick a pin vertically at a point P, such that the angle which PA makes with the face AB is less than a right angle. Observe the direction of the refracted image along the line AQ.

Stick a pin at Q, in such a position that the image of the pin at P is in a line with the edge of the prism A and with Q.

Draw EA perpendicular to the face AB, and FA perpendicular to the face AC. Join PA and QA, and produce PA till it cuts the circle in O. Then

$$\angle PAE=\phi,$$

$$\angle FAQ=\Psi,$$

$$\angle OAQ=\delta.$$

Draw PL perpendicular to EA, FN and OM to AQ. Then

$$\sin\phi=\frac{PL}{r},$$

$$\sin\psi=\frac{FN}{r},$$

$$\sin\delta=\frac{OM}{r},$$

where r is the radius of the circle.

Measure PL, FN, OM, and calculate the values of the angles ϕ, Ψ and δ from th[illegible]

Measure I, the angle of the prism, by the method of Part I.

Substitute the values in formula (1), and verify the law.

PART III

To Find the Refractive Index of the Prism

(2) Now adjust for minimum deviation. To accomplish this, turn the prism around through a succession of small angles, with the edge at the center as axis, and observe each time whether the deviation increases or decreases by observing whether the direction AQ of the refracted ray makes a larger or smaller angle with the direction AO of the incident ray. If the angle is decreasing, continue to turn the prism in the same direction; if not, reverse the process, when, if the position is not already one of minimum deviation, the angle will decrease.

If the process be continued, it will be found that the angle OAQ reaches a minimum value and then increases no matter which way the prism is turned.

Adjust for the exact position of minimum deviation, and measure δ as before.

Calculate μ from formula (2).

at
th
ra
th
fo

se
in
of
po
pri
on

and

In
pos
a c

is c

plan

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

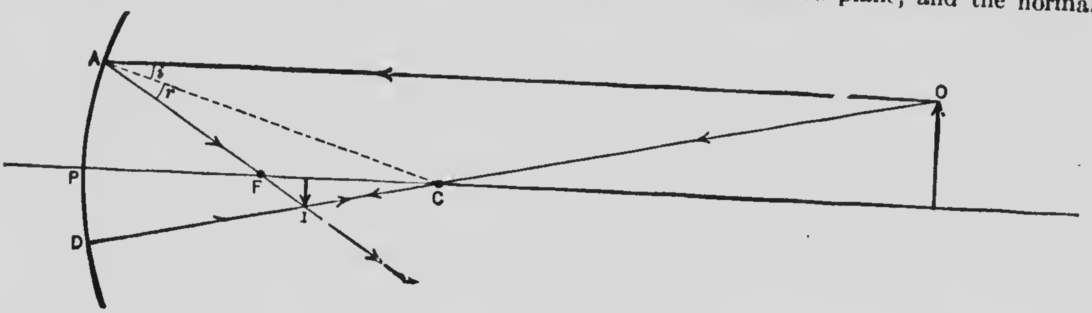
THE CONCAVE MIRROR

Object of Experiment: To study the formation of images in a concave mirror, and to find the focal length of a given mirror.

Apparatus: Concave mirror with a narrow strip of silver removed at the pole; a pin, a candle and a ground-glass screen, mounted on stands; meter stick.

Theory: A concave spherical mirror may be considered to be a portion of the surface of a sphere, the convex side of which is silvered. The point P, the center of figure of the mirror, is called the *pole*, and the center of the sphere of which the mirror forms a part is called the *center of curvature*. The straight line passing through the pole and the center of curvature is called the *principal axis*.

Suppose a ray of light parallel to the principal axis falls on the mirror at A. The surface of the mirror in the immediate neighborhood of A may be considered plane, and the normal



at A will be the radius of the sphere, i.e., the line AC. According to the laws of reflection, the angle of reflection r must equal the angle of incidence i. It can be shown that the reflected ray in this case will cut the principal axis at a point F such that $PF=FC=r/2$, where r is the radius of curvature. The point F is called the *principal focus* and the distance PF the *focal length*.

If any two rays are drawn from any point O of a source of light, the point of their intersection after reflection will be the position of the corresponding point of the image. For instance the point I of intersection of the two rays OA and OD when reflected, is the image of the point O. For convenience the two rays generally used for locating the image of any point are (1) a ray parallel to the principal axis which after reflection passes through the principal focus and (2), a ray passing through the center of curvature which is reflected back on itself.

If the distance from the mirror to the object is u, and from the mirror to the image is v, and if f is the focal length, it can be shown that, $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}=\frac{2}{r}$ for mirrors of small aperture. *In this formula distances measured from the mirror towards a real focus or image are considered positive and distances measured towards a virtual focus or image negative.* The focal length of a concave mirror is always positive.

If O is the length of the object and I is the length of the image, then $I/O=v/u$. This is called the *magnification*.

If the source is at a great distance from the mirror, the incident wave front is practically plane (parallel beam) and u is infinite. The above equation then becomes

$$\frac{1}{\infty}+\frac{1}{v}=\frac{1}{f} \text{ or } v=f.$$

(OVER)

If $u>r$ then $v<r$, and the image is between C and F. If $u=r$ then $v=r$, and the image is at C. If $u<r$ then $v>r$, and the image is beyond C. If $u=f$ then $v=\infty$, and the reflected light is parallel. If $u<f$ then v is a negative quantity, i.e., the image is virtual, erect, enlarged, and situated behind the mirror.

Procedure: *Method* 1. Take the mirror to the window and using a note-book as a screen, obtain as sharp an image as possible of some distant object. If the object is far enough away the image will be formed very nearly at the principal focus. The distance from the mirror to the book will be an approximate determination of the focal length.

Method 2. Using the value just obtained, place the candle well beyond the center of curvature and adjust its height so that its top is approximately on the axis of the mirror. Place the ground-glass screen between the center of curvature and the focal length at the point where the most distinct image is formed. Measure u and v accurately.

Keeping u constant make three separate determinations of v. Using the mean of these values, calculate f from the formula. Make a diagram using a convenient scale and as large as possible [illegible] to show the relation between the object and its image. By measuring the lengths of object and image in your diagram, calculate the magnification, and describe the image.

It may be clearly seen from the diagram that the positions of image and object are interchangeable. One position is said to be the conjugate focus of the other.

Method 3. Adjust the mounted pin so that it is bisected by the principal axis of the mirror. Slide it back and forth until the object and the image coincide. The coincidence of object and image can be determined by the method of parallax. This consists in observing both object and image until by moving the head slowly from side to side the pin and its inverted image appear to be together from whatever angle they may be viewed. Measure the distance from the center of the mirror to the pin. This gives the radius of curvature of the mirror. Make three separate determinations and calculate the focal length. Describe the image.

Method 4. Place the object within the focal length of the mirror. The image will now be seen behind the mirror enlarged, upright and virtual. Place the pointer behind the mirror and looking through the transparent portion, find the position of the image by the parallax method. Calculate f. **Draw a diagram as before.**

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

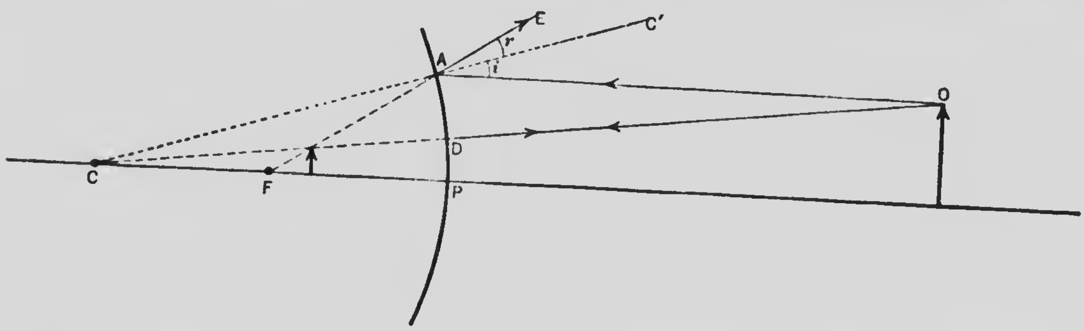
THE CONVEX MIRROR

Object of Experiment: To study the formation of images in a convex mirror, and to find the focal length of a given mirror.

Apparatus: Convex mirror with a narrow strip of silver removed at the pole; two vertical steel pins mounted on adjustable stands; meter stick.

Theory: A convex mirror may be considered as a portion of the surface of a sphere, the concave side of which is silvered. The point P, the center of figure of the mirror, is called its *pole*, and the center of the sphere of which the mirror forms a part is called the *center of curvature*. The straight line passing through the pole and the center of curvature is called the *principal axis*.

Suppose a ray of light parallel to the principal axis falls on the mirror at A. The surface of the mirror at A may be considered plane, and the normal at A will be AC', the prolongation



of CA, the radius of curvature. By the laws of reflection, the reflected ray must make with this normal an angle equal to the angle of incidence. It can be shown that in this case if the reflected ray is produced backwards, it will cut the principal axis at a point F where $CF = FP = r/2$, where r is the radius of curvature. The point F is called the *principal focus* and the distance PF the *focal length*. To an observer looking into the mirror, the light will appear to come from F. Such a focus is called a *virtual* focus.

If two rays are drawn from any point of a source of light, the point of their intersection after reflection will fix the position of the corresponding point of the image. Any two rays will do, but for convenience the following two are usually chosen, because their course after reflection is easily determined: the ray OA parallel to the axis, which after reflection appears to come from the principal focus F, and the ray OD normal to the mirror which is reflected back upon itself. The image I of the source O is formed where the two reflected rays AE and DO appear to meet. Hence the images formed by convex mirrors are virtual.

If the distance from the mirror to the object is u, and from the mirror to the image is v, and if f is the focal length, it can be shown that

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}=\frac{2}{r}.$$

In this formula, distances measured from the mirror towards a real focus or image are considered positive and distances measured towards a virtual focus or image negative. Hence v, f and r are *always negative* for a *convex* mirror.

(OVER)

Procedure: Place the object about a meter away from the mirror, and adjust its height so that it is approximately bisected by the principal axis. The image will be upright, diminished and virtual. Place the second upright pin behind the mirror and adjust its position so that, looking along the axis, the part of the needle seen through the transparent slit forms a straight line with the image of the object. Move the eye horizontally and they will shift with respect to one another. Keeping the object fixed in position slide the second needle back and forth until it occupies the same position as the image. This can be done by the *method of parallax*. Moving the eye horizontally, if the needle is in front of the image, the former will appear to move the faster. If the needle is behind the image, the latter will move the faster. When they occupy the same position, they will keep together however the eye is moved. Measure u and v and determine f. At least three separate settings should be made and the means taken.

Place the object about 50 cm. from the mirror and again determine the position of the image, and find f.

Repeat with the object about 20 cm. from the mirror.

Draw diagrams to scale to illustrate the formation of the images in the three cases.

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

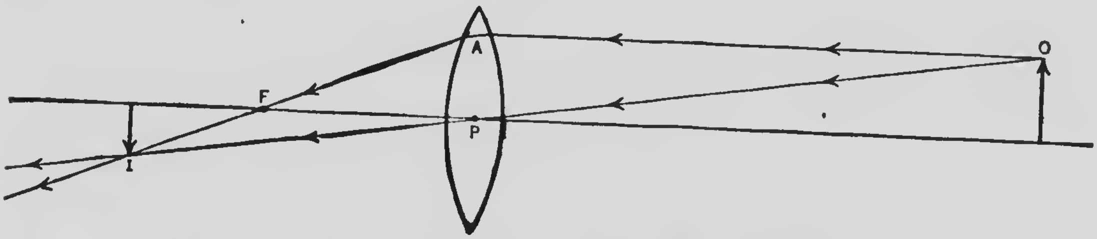
THE CONVEX LENS

Object of Experiment: To determine the focal length of a convex lens by various methods.

Apparatus: An elementary optical bench; ground-glass screen; convex lens; telescope, lamp and fine wire grating or other suitable object for source of illumination.

Method I

Theory: A convex lens may be considered to be a portion of refracting matter bounded by two adjacent intersecting spherical surfaces. The straight line joining the centers of the spheres is called the *principal axis* and passes through the *optical center* P of the lens.



Suppose a ray of light parallel to the principal axis falls upon the lens at A. The region in the immediate neighborhood of A may be considered to be a prism with sides tangential to the surface. The rays will be twice bent, and emerging from the lens, will be bent towards the principal axis. Such a lens is called a *converging* lens. All rays parallel to the principal axis after passing through the lens cut the axis at F which is called the *principal focus*. The distance FP is called the focal length of the lens and is *positive*.

Suppose a source of light is placed at O. All rays of light from O after passing through the lens will intersect at some point I. I is called the image of O and is real. Similarly if I is the source, O will be the image of I. O and I are called conjugate foci.

(*a*) If f is the focal length of the lens, and u and v the respective distances of object and image from the center of the lens, then since real distances are assumed to be positive and virtual distances negative,

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}. \qquad (1)$$

If the incident rays are parallel, i.e., if the source of light is at a great distance from the lens, $\frac{1}{u}=O$, and hence

$$v=f. \qquad (2)$$

It is only necessary therefore to determine v.

(*b*) Another method involving the same principle is as follows: If a telescope is carefully focused on a very distant object, and afterwards used to view a near object through a convex lens, the distance between the lens and the object will be equal to the focal length of the former, if a sharp image of the object is seen in the telescope.

For, only parallel rays will come to a focus in the telescope, and the rays after traversing a lens from a given object are parallel when the distance between lens and object is equal to the focal length of the lens. In this as in the preceding case only one observation is necessary.

Procedure: (*a*) Mount the lens on its stand with its axis along the bench. Mount the ground-glass screen behind it, with the plane of the screen at right angles to the direction of the bench. Point the apparatus to an open window so that an image of a distant object may be obtained on the screen.

Slide the lens along the bench until a clearly defined image of the object is obtained. The image is best viewed from behind the screen. Read the distance between the indexes carried by the lens and the screen. This distance is the focal length of the lens.

(*b*) Select an ordinary reading telescope and focus it through an open window on a very distant object.

Place the telescope on the optical bench close up to the lens in question, so as to look through it in the direction of the bench.

Move the ground-glass screen along the bench until a clear image of it is seen in the telescope. Read the distance between the indexes carried by the lens and the screen. This is the focal length f of the lens.

Method II

Theory: As before, u and v being the respective distances of object and image from the lens, we have

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f},$$

from which f may be readily calculated, if u and v are observed.

Procedure: Mount on one of the stands the fine wire grating with the plane at right angles to the bench. Mount the lens on the second or middle stand, so that its axis lies along the bench in a horizontal line with the center of the hole. The third stand carries the ground-glasss screen, mounted at right angles to the bench, so as to receive the image of the wire gauze. The object, lens, and ground-glass screen should occupy the same positions in relation to the indexes carried by them.

Adjust the positions of the lens and the screen along the bench until a clearly defined image of the illuminated object is obtained. If the focal length of the lens is less than one-fourth the available length of the bench, an image of the illuminated wire grating can in this manner be readily obtained. Measure u and v. Make two more settings of the screen without moving the lens, and from the mean value of v calculate f.

In the same way determine f for two other values of u, and take the mean of the three. Draw a diagram illustrating the formation of the image by this method.

Method III

Theory: If the distance between the object and screen is more than four times the focal length of the lens, the lens can occupy two positions where a clearly defined image of the object will be obtained on the screen.

Let the distance between object and screen be l, that between the two positions of the lens a, and, as before, f the focal length. Then we have

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}, \text{ for the first position,}$$

and

$$\frac{1}{u_1}+\frac{1}{v_1}=\frac{1}{f}, \text{ for the second.}$$

Further, it is clear, since l is constant, that $u=v_1$; that is, the lens will be at the same distance from the screen in the second case as it was from the object in the first.

The magnifying power of a simple microscope may be calculated approximately from its focal length. If d is the distance of most distinct vision, then the magnification is d/f, where f is the focal length of the lens.

The magnifying power of a telescope may be taken as equal to the ratio of the focal length of object-glass and eye-piece, or as the ratio of the size of the image to that of the object when the telescope is focused so that these are at the same distance from the eye, provided this distance is fairly large.

Procedure: Find the approximate focal lengths of the lenses provided, by Method I of the experiment on The Convex Lens.

Simple Microscope. Place one of the lenses of shorter focal length close to a printed page. A magnified erect image will be seen. Note how the magnification varies as the lens is moved away from the page. What relation does the distance at which the image blurs bear to the focal length of the lens?

Astronomical Telescope. Turn the lens of greater focal length towards the vertical scale on the wall. Place your eye so as to view the real inverted image of the scale, and put the wire gauze between your eye and the lens, and move it till it occupies the same position as the image which can be tested by the method of parallax. Now put the other lens between your eye and the gauze, and adjust it till the erect magnified image of the gauze is seen. You should see at the same time an inverted image of the scale through the gauze.

Looking through the lens with one eye and observing the unmagnified scale with the other, adjust the position of the eye-lens until the image appears to coincide with the scale. Read the number of magnified divisions between the two ends of the scale. Calculate the magnification, and compare it with the ratio of the focal lengths of the lenses.

Compound Microscope. Focus the micrometer microscope upon the millimeter scale provided. The height of the microscope is such that the scale can be conveniently viewed with one eye while looking through the microscope at its image with the other. Adjust the scale till image and scale appear to coincide.

Find the number of scale divisions covered by as many magnified divisions as can be accurately observed. Take two or three sets of readings, and calculate the mean value of the magnifying power of the microscope as a whole.

The magnifying powers of the eye-piece and the object-glass may be found separately by a similar method, if the microscope contains in the eye-piece a micrometer scale the value of whose divisions are known.

Focus the microscope on the millimeter scale, and note the number of divisions of the image, which is magnified by both eye-piece and object-glass, covered by a number of divisions of the micrometer scale, which is magnified by the eye-piece only. The ratio of the two, expressed in the same units, gives the magnifying power of the object-glass.

Observe now, with one eye along the side of the microscope, the number of divisions of the scale covered by a definite number of divisions of the micrometer scale as seen by the other eye through the microscope. Since the micrometer scale is magnified by the eye-piece only, the ratio of these two, when expressed in the same units, gives the magnifying power of the eye-piece.

Find the product of the magnifying powers of object-glass and eye-piece and compare it with the value found above for the complete microscope.

Place one of the lenses of shorter focal length in front of the millimeter scale at a distance a little more than its focal length. As before, locate the position of the image with the wire gauze, and adjust the other lens of shorter focal length in front of the gauze. Observe and record how the magnification changes as the position of the lens is altered.

i

b
sp

in

—

to
the
len
div
to
is
neg

the
Wh
posi
erec

the
and

lens,

focal

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

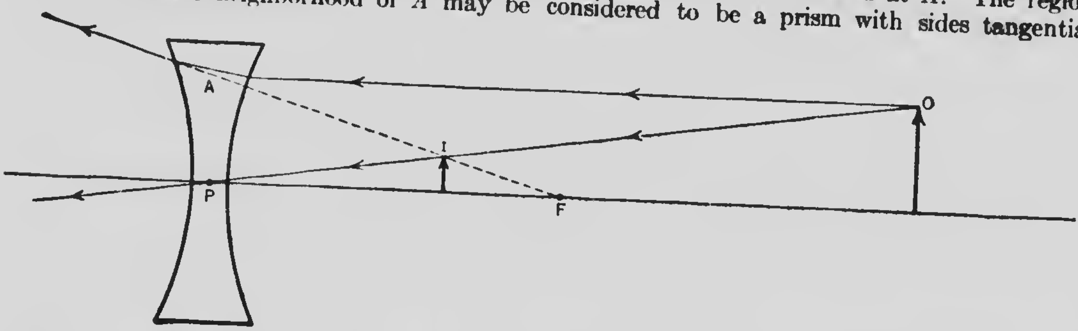
THE CONCAVE LENS

Object of Experiment: To determine the focal length of a concave lens by various methods.

Apparatus: Concave lens; convex lens of shorter focal length; vertical pin; inverted pin; illuminated object; vertical glass plate; ground-glass screen; meter stick.

Theory: A concave lens may be considered to be a portion of refracting matter bounded by two adjacent non-intersecting spherical surfaces. The straight line joining the centers of the spheres is called the *principal axis* and passes through the *optical center* P of the lens.

Suppose a ray of light parallel to the principal axis falls upon the lens at A. The region in the immediate neighborhood of A may be considered to be a prism with sides tangential



to the surface. The rays will be twice bent, and emerging from the lens, will be bent away from the principal axis. Such a lens is called a *diverging* lens. To an observer looking through the lens, the light will appear to come from the point F, which is the point on the axis where the diverging rays would cut it if produced backwards. In the same way all rays of light parallel to the principal axis after passing through the lens appear to have their source at F, which is called the *principal focus.* The distance FP or f is called the *focal length* of the lens and is *negative.*

Suppose a source of light is placed at O. All rays of light from O after passing through the lens if produced backwards would intersect at I. I is called the image of O and is virtual. When O is against the lens near P, the image will coincide with the object. Hence for any position of O between infinity and the lens, the image will be between F and the lens, virtual erect and diminished.

If f is the focal length of the lens, and u and v the respective distances of the object and the image from the center of the lens, then since real distances are assumed to be positive, and virtual distances negative,

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f}. \qquad (1)$$

If the incident rays are parallel, i.e., if the source of light is at a great distance from the lens, $\frac{1}{u}=O$, and hence

$$v=f. \qquad (2)$$

If two lenses of focal lengths f_1 and f_2 are placed close together, it can be shown that the focal length of the combination is given by

$$\frac{1}{F}=\frac{1}{f_1}+\frac{1}{f_2}, \qquad (3)$$

(OVER)

being careful to give each focal length its proper sign. The reciprocal of the focal length in meters is known as the dioptric power. Hence the last formula may be written $D=d_1+d_2$ where D,d_1 and d_2 stand for the dioptric powers.

Procedure: *Method* 1. Place the concave lens before the window. Looking through the lens the image of some distant object will be seen at the focus. Place the glass plate vertically about 20 cm. in front of the lens. Place the illuminated object about 50 cm. in front of the plate glass.

Looking through the glass and the lens, the image of the distant object will be seen at the focus of the lens, and near it the virtual image of the illuminated object as seen in the glass as a mirror. Slide the glass back and forth until the two images coincide in position. This can be judged by the method of parallax.

The image formed by the glass plate is as far back of the glass as the object is in front. Measure this distance d_o. Measure the distance d_v from the glass plate to the lens. The focal length is obviously given by $f=d_o-d_v$.

Make three determinations of f and take the mean.

Method 2. Place the *vertical* pin about 60 cm. away from the lens and adjust its height so that on looking through the lens from the opposite side along the axis the image of the top of the pin comes nearly to the top of the lens. Still looking through the lens, adjust the position and height of the *inverted* pin so that its pointed part just comes down to the top of the lens in a straight line with the image. If the eye is moved horizontally, the two will in general shift relatively to each other.

Slide the inverted pin back and forth until it occupies the same position as the image as indicated by the method of parallax. Measure u and v and determine f.

Repeat with the pin 40 cm. from the lens. Draw a diagram to some convenient scale, locating the position of object and image for either distance.

Method 3. Find the focal length f_1 of the convex lens by one of the methods described in the manuscript on the convex lens.

Next place the convex and concave lenses face to face and adjust them in the holder. Treating the combination as a new convex lens, place the illuminated object about a meter from the lens. With the screen on the other side of the lens, adjust its position until a clear image is obtained. Measure u and v and calculate F.

Make three determinations of F at different distances, and take the mean.

Calculate the focal length of the concave lens from formula (3).

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

THE MICROSCOPE AND THE TELESCOPE

Object of Experiment: To illustrate the principle and to find the magnifying power of a simple and a compound microscope and an astronomical telescope.

Apparatus: Two double convex lenses of about 5 cm. and one of about 15 or 20 cm. focal length, mounted on stands; mounted millimeter scale and wire gauze; micrometer microscope and millimeter scale.

Theory: 1. *The Simple Microscope.* Fig. 1 illustrates the formation of a magnified erect

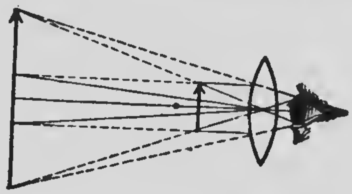


FIG. 1.

virtual image by means of a converging lens. The necessary condition for the simple microscope is that the object should be less than the focal distance from the lens.

2. *The Compound Microscope.* To obtain the greatest magnification the compound micro-

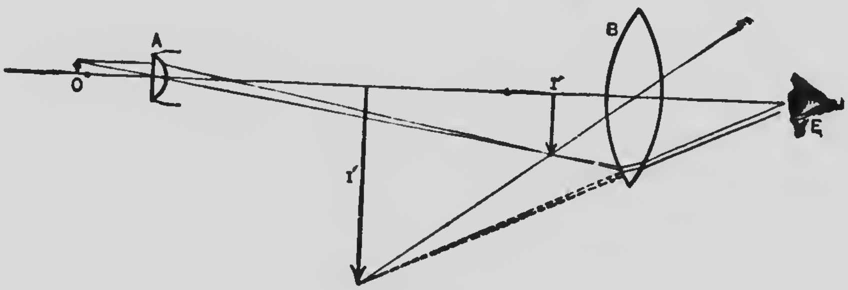


FIG. 2.

scope is used, the optical system of which is shown in Fig. 2. The object O to be magnified is placed just outside the focus of the short-focus lens A called the *objective* or *object-glass*, which forms a real image at I. Back of this image is placed a convergent eye-piece B at a distance slightly less than its focal length so that it forms a virtual image of I at I' which may be seen by the eye at E.

Since O is nearly at the principal focus of the lens A the image I will be as many times greater than the object O as the distance AI is greater than the focal length of A. The distance AI in an ordinary microscope is about 150 mm. so that if the focal length of the objective is 5 mm., the image I will be 30 times as large as the object, and if the eye-piece has a magnifying power of 10, the power of the combination is 30×10 or 300 diameters.

3. *The Astronomical Telescope.* In this instrument the eye-piece is a convergent lens or system of lenses. The eye-piece, as shown in the diagram, is placed at a distance slightly less than its own focal length back of the image at I formed by the object-glass, so that a virtual enlarged image of I is formed at I'. It will be noted that the pencil of rays from the upper part of the distant object comes to the eye as if from the lower part of the image I. Since this instrument produces an inverted image, it is used chiefly for astronomical observations.

The various pencils of rays coming to the eye from different points in the virtual image all intersect at S, forming a bright spot known as the *eye spot*. If the pupil of the eye is held

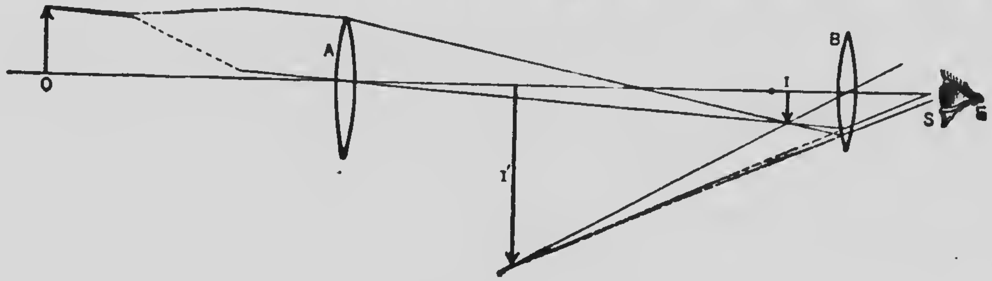


FIG. 3.

at this point, all parts of the virtual image can be seen simultaneously, and the field of view is large, being limited only by the size of the lens B.

4. *The Micrometer Microscope.* In the case of telescopes provided with cross-hairs, and used extensively in surveying instruments, as well as in the micrometer microscope, which

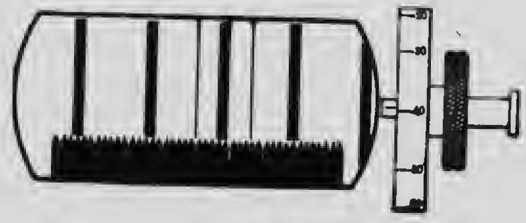


FIG. 4.

is used to measure very short lengths, the cross-hairs are adjusted to lie in the plane of the inverted image I, and are magnified together with the image by the eye-piece.

The cross-hairs of the micrometer microscope can be moved across the image by means of a screw of uniform pitch, to which is attached a milled head and a divided circle. In the figure are shown diagrammatically the cross-hairs and the magnified image of a scale. The micrometer scale below (shown in black) corresponds to the pitch of the screw, so that the number of complete revolutions of the screw can be read from it as the cross-hairs are moved across the image.

If the cross-hairs do not lie exactly in the same plane as the image, moving the eye across the aperture of the eye-piece will cause the cross-hairs to appear to shift across the scale and make accurate measurements impossible. This shift is known as *parallax*. In order to eliminate parallax the eye-piece is first focused on the cross-hairs and then the whole instrument focused on the object. In using the instrument, care should always be taken to make sure that parallax has been eliminated before making any measurements.

The micrometer microscope can be calibrated by finding the number of revolutions, read to one-thousandth of a revolution by means of the divided circle, necessary to move the cross-hair across one or two millimeter divisions of a good steel scale. The instrument can then be used to measure short lengths, such as the dimensions of small objects and the thermal expansion of rods of various materials.

5. *Magnifying Power.* The apparent size of an object depends on the visual angle which it subtends at the eye. The function of a microscope or a telescope is to change the directions of the rays coming from the object so that they enter the eye with increased angular separation. The *magnifying power* of such an instrument is the ratio of the angle subtended at the eye by the image to that subtended by the object viewed directly, and is of course equal to the magnification of the object-glass multiplied by that of the eye-piece.

The magnifying power of a microscope may also be defined as the ratio of the size of the image to that of the object when the object is placed at the distance of most distinct vision. (This distance is about 25 cm. for the normal eye, but varies with different eyes.)

Hence we have

$$u+v=l,\ u-u_1=a,\ u_1=v,$$

and therefore

$$u=\frac{l+a}{2},\ v=\frac{l-a}{2}.$$

Substituting these values of u and v in equation (1), we obtain

$$f=\frac{l^2-a^2}{4l}. \qquad (3)$$

Procedure: With the distance from object to screen equal to about 90 cm., find two places where a good image is obtained. Measure the distance through which the lens is moved. Repeat this setting twice more and from the mean value of a calculate f.

Repeat for two greater distances and take the mean of the three values of f.

sc

pi
al

kn
va
lyi
Wl
of
len
orc
wa

inc
The
wav
sho

forn

lens C
a teles
E. P
of the
In
can ex
If
instead

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

THE SPECTROSCOPE

Object of Experiment: To examine in detail the construction and operation of a spectroscope, to study the light emitted by various incandescent substances, and to map their spectra.

Apparatus: Spectroscope; incandescent lamp; Bunsen burner; solutions of different salts; pieces of colored glass; an induction coil with hydrogen and oxygen tubes should be available; also a spectrometer for demonstration purposes.

Theory: Energy which can be propagated from one place to another through the ether is known as radiant energy. This energy is transmitted in the form of transverse waves which vary in wave length from a few millionths of a millimeter to several kilometers. Wave lengths lying between .0004 mm. and 0007. mm. affect the sense of vision and are called light waves. When light waves of all wave lengths fall on the eye they produce white light. A wave train of a definite wave length, however, produces the sensation of a definite color. Every wave length produces a characteristic color. Hence if any of the wave lengths are removed from ordinary white light, the remainder will be colored, the particular color depending on the wave lengths left.

The velocity with which these waves travel decreases as the density of the medium increases. Moreover, in a transparent medium such as glass, the longer waves travel the faster. Therefore, if a parallel beam of white light falls obliquely on one face of a prism, the shorter waves will be bent more than the longer, and the emergent beam will if caught upon a screen show a series of overlapping colors called a spectrum.

An instrument for examining a spectrum is called a spectroscope. The plan of the ordinary form of spectroscope is shown in Fig. 1. The essential parts are: A narrow slit *S*, a collimating

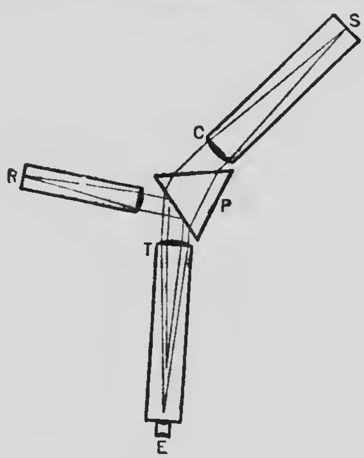


FIG. 1.

lens *C* which converts the rays of light into a parallel beam, a prism *P* to disperse the colors, a telescope lens *T* with which real images of the slit are produced at the focus of the eye-piece *E*. Positions in the spectrum may be referred to the image of a scale *R* reflected from the side of the prism.

Incandescent solids, liquids and compressed gases give all the colors which a spectrum can exhibit. Such a spectrum is called a *continuous spectrum.*

If gases and vapors are made incandescent, and viewed through a spectroscope, then instead of a continuous spectrum, a number of separate colored bright lines will appear, the

(OVER)

number and position of these lines depending upon the particular gas or vapor. Each bright line represents a definite wave length, the energy of which is produced by vibrations within the atoms. Each substance gives its own *bright-line spectrum*. The identification of substances by their spectra is known as spectrum analysis.

If light from any source is made to pass through sodium vapor, then it is found that where sodium vapor itself would give a bright yellow line, a dark line appears in the same place, indicating that that particular wave length has been absorbed. In general when radiant energy passes through any medium, those wave lengths will be absorbed which the medium itself would emit if incandescent. Such spectra are called *dark-line* or *absorption spectra*. The solar spectrum is a dark-line spectrum. The sun itself gives out a continuous spectrum, but in the cooler atmosphere of the sun are the vapors of the elements which it contains. Consequently in passing through this atmosphere, the characteristic light of each element in the sun's interior is absorbed by the surrounding vapor of that element. These dark lines are

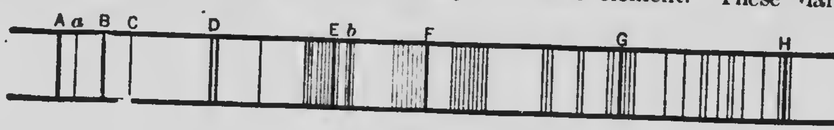


FIG. 2.

called Fraunhofer lines, after the name of their first investigator, and some of them are shown in Fig. 2.

Procedure: Examine the demonstration spectroscope, and study the function of each part.

Turn on an incandescent lamp and view the glowing filament through the assigned spectroscope. A continuous spectrum will be seen. Taking the red end to the left, map out in your note-book the approximate position and extent of the following colors: red, orange, yellow, blue, indigo, violet.

Interpose between the lamp and the slit of the spectroscope a piece of colored glass. An absorption spectrum is observed. Map the resulting colors beneath the first drawing. Replace it by another glass; observe and map the spectrum. Place the two pieces of glass together between the source and the slit. Map and explain the result.

Light the Bunsen burner and adjust it until it is non-luminous. Take the cork from the NaCl solution. While one student holds the platinum wire in the flame, let the other student view the light through the spectroscope. The spectrum obtained is a bright-line spectrum and is characteristic of sodium. Map the spectrum and record the color of the line of the flame. *Be sure to replace each cork in its own bottle.* Repeat for solutions of other salts. Hold a glass rod in the flame until begins to melt. View the light above the glass with the spectroscope. What substance is present in glass?

Tubes of hydrogen and oxygen gas are provided which can be made incandescent by means of an induction coil. View these illuminated tubes with the spectroscope. Map the characteristic spectrum of each.

Turn the spectroscope to the sky. The solar spectrum will be seen crossed by many fine dark Fraunhofer lines. These are the absorption lines caused by the vapors in the sun's atmosphere. Map as many of these lines as you can.

FIRST YEAR EXPERIMENTAL PHYSICS

LIGHT

THE POLARISCOPE

Object of Experiment: To observe the rotation of a beam of plane polarized light due to a solution of sugar; to calibrate the instrument as a saccharimeter; and to determine the concentration of an unknown solution.

Apparatus: Saccharimeter; sodium light; solutions of cane-sugar of known concentrations; distilled water; pipettes; solution of sugar of unknown concentration.

Theory: Light is propagated through a medium in the form of transverse waves, the vibrations taking place in a plane perpendicular to the direction of propagation. These vibrations are not in general confined to any one line in the plane, but take place in all possible directions. Some media, however, such as tourmaline, allow these vibrations to take place *in one direction only*. Hence if light is incident on such a substance, the vibrations parallel to this direction pass through freely. Other vibrations can be resolved into two components, one component passing through, the other being blocked. Consequently the emergent light has all its vibrations in one direction and is said to be plane polarized. Iceland spar allows two directions of vibration, mutually perpendicular. A ray of light incident on such a crystal is split up into two rays, polarized in planes perpendicular to one another. One of these rays obeys the ordinary laws of refraction and is called the *ordinary* ray; the other does not and is called the *extraordinary* ray.

In a Nicol prism a rhomb of Iceland spar (Fig. 1) is cut obliquely and cemented together again with Canada balsam, the refractive index of which is less than that of the Iceland spar

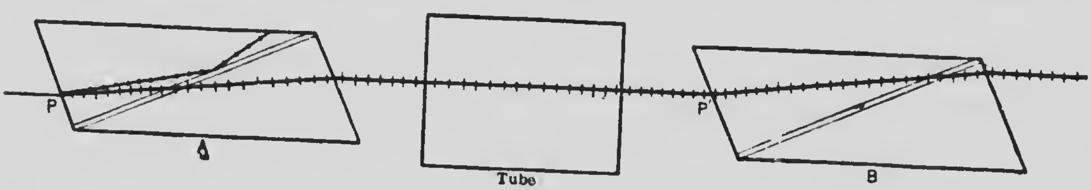


FIG. 1.

for the ordinary and greater for the extraordinary ray. The oblique section is so taken that when the ordinary ray meets the balsam it is totally reflected, while the extraordinary ray is transmitted.

The polariscope is an instrument for obtaining and analyzing polarized light. In the instrument provided there are two Nicol prisms, A for polarizing the light and B for analyzing it. The light incident on A is rendered parallel by a lens. A ray incident on A at P will be split into two rays, the extraordinary ray with its vibrations in the plane of the paper passing through. The ordinary ray will suffer total internal reflection and arriving at the external surface of A will be absorbed by a coating of lampblack. The ray incident on B at P' will be plane polarized and will pass through freely or be stopped according as B is arranged similarly to A or turned through 90°. For any intermediate position only part of the light will pass through.

If a tube containing a solution of cane-sugar is placed between A and B, then the plane of polarization will be rotated, and instead of the vibrations taking place in the plane of the paper, they will be inclined at some angle α, which for cane-sugar depends only on the length of the column of liquid and its concentration.

If B was originally arranged for extinction when no solution was present, it must now be rotated through the angle α to produce extinction again. Hence if the length of the column is constant, concentrations may be compared by noting the angles of rotation.

(OVER)

Procedure: Place the screen and lamp about five centimeters in front of the polariscope. Remove the tube and wash it thoroughly. Fill it with distilled water, taking care that no air bubbles remain. In screwing on the caps, *take care not to break the glass disks.* A very moderate tightening of the screw will be sufficient. The glass tube should be encased in its metal cover to shut out all light from the side. Place the tube in position and look through the eye-piece at an illuminated screen. The field will in general be bright. By means of the handle rotate the analyzer until extinction is procured. This is the zero position. Read this position by means of the vernier, taking readings to the left as negative and to the right as positive. Repeat ten times and take the mean as the zero reading.

Remove the tube, unscrew the caps and shake out the water. Run a little of the 2N solution into the beaker, shake it up in the tube and pour it out. This is to avoid the dilution which would result from the film of water adhering to the glass. Then fill the tube with the solution, taking the same precautions as before, and place it in position. Observe that though the instrument was formerly set for extinction, light now passes through. Rotate the analyzer to produce extinction again. Make ten separate settings and take the mean. The difference between this and the zero reading gives the rotation produced by the 2N solution. Pour out this liquid and wash the tube thoroughly. Fill the tube with the 1½ N solution and proceed as before. Do the same for the N and the ½ N solutions.

Plot a curve, using the concentrations as abscissæ and the rotations as ordinates. The graph should be a straight line. Why?

Now find the rotation produced by the unknown solution and determine its concentration from the curve.

Wash the tube and pipette thoroughly before leaving the apparatus.