IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6"

APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989

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.

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.

- [x] 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
- [x] 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
- [ ] 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 restoration 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.

- [ ] 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
- [ ] Continuous pagination/ Pagination continue
- [ ] Includes index(es)/ Comprend un (des) index

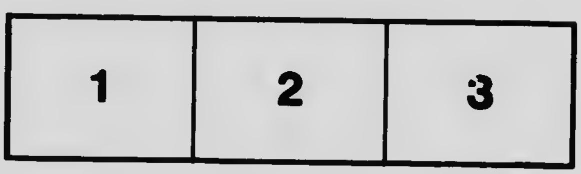
Title on header taken from:/ Le titre de l'en-tête provient:

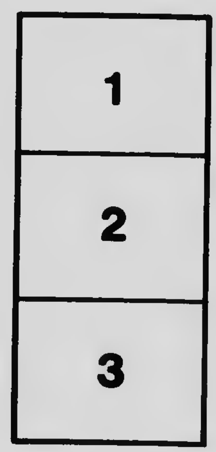
- [ ] Title page of issue/ Page de titre de la livraison
- [ ] Caption of issue/ Titre de départ de la livraison
- [ ] Masthead/ Générique (périodiques) de la livraison

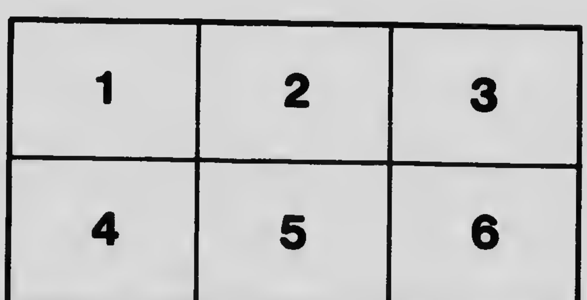
- [ ] Additional comments:/ Commentaires supplémentaires:

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

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


1
2
3


1
2
3


1
2
3
4
5
6

Can. Carmichael, Norman Ross.

PHYSICAL EXPERIMENTS

Physical Experiments

A MANUAL OF LABORATORY EXPERIMENTS TO
ACCOMPANY AN ELEMENTARY COURSE
IN GENERAL PHYSICS

BY

N. R. CARMICHAEL, M.A.

KINGSTON, ONTARIO
R. UGLOW & CO.
1904

The Jackson Press
KINGSTON, ONT.

PREFACE.

This book is intended for the use of students taking an experimental course in a Physical Laboratory under an instructor. It aims to state concisely the nature of the quantity to be measured in each experiment and the theory underlying the method suggested. Descriptions of instruments are entirely omitted as the students are expected to have the apparatus given them by the instructor. Details of experimental methods have also been omitted because in many experiments the methods may be varied to suit the apparatus available. Moreover, a few words from the instructor, directly applicable to the method employed, are more useful than any general description.

The object of this course is to give students who have but a limited time for laboratory work a practical acquaintance with as many physical quantities as possible. Therefore simple and direct methods have in all cases been preferred to more accurate ones which require elaborate instrumental adjustments or corrections. Several more advanced experiments have also been introduced because they illustrate important physical principles and can be performed with simple means.

Most of the experiments given are the standard ones found in books upon Experimental Physics with such modifications as have seemed in our experience to render them more suitable to the circumstances of this Laboratory. The book is therefore indebted, both directly and indirectly, to many previous works upon the subject. It is more particularly indebted to Professor Marshall and Mr. W. C. Baker, whose methods of making experiments I have not distinguished from my own, and who have both suggested many corrections and improvements during its preparation.

N. R. CARMICHAEL.

Physical Laboratory, School of Mining,
Kingston, Ontario,
November 1, 1904.

CONTENTS.

VI. MAGNETISM.

VII. ELECTRICITY.

INTRODUCTION.

Making an experiment in Physics involves (1) measuring certain quantities with suitable instruments, (2) making a record of all measurements and the methods by which they were obtained, (3) calculating the magnitude of some quantity, and (4) considering the meaning of the experiment and its relation to the principles of Physics. The measurements required are described under each experiment; a few general words may be said here regarding the records and calculations.

The record should be as brief as possible provided it contains the date, the object of the experiment, the general character of the apparatus used, all readings of instruments or other measurements, and the calculation of the desired quantity. But it should also be systematic, so that a glance will show the means of arriving at the result and the probable accuracy of the work. If the purpose of an experiment is understood before measurements are commenced, the plan of the record can be arranged so that readings may be entered as they are made. There is then no necessity for copying.

A tabular form can generally be used in which different measurements of the same quantity appear in a column. All measurements should be made before calculations are commenced. The agreement or disagreement of different measurements of the same quantity is frequently the only means of estimating the accuracy of the result.

All measurements are approximations and should be recorded in such a way as to show how close the approximation probably is. Thus, if a measured length is recorded as 24·3 cm., it is understood that no attempt has been made to measure the fourth figure and that the record means that the length is believed to be nearer 24·3 than 24·2 or 24·4, that is, that it lies between 24·25 and 24·35. Similarly 24·30 would mean that the fourth figure had been measured and that the length was believed to be between 24·295 and 24·305. From this point of view a 0 is as significant as any other figure, and it must therefore always be recorded if measured.

For the same reason numbers obtained by measurement must be treated in arithmetical operations somewhat differently from exact numbers. Thus if 4·36 cm. and 2·13 cm. were the exact length and breadth of a rectangle, its area would be found by multiplication to be 9·2868 sq. cm. But if these values of the length and breadth are the result of measurements made to 3 figures the area should only be calculated to be 9·29 sq. cm., also to 3 figures. Similarly the area of a rectangle whose sides were found to be 436 and 213 cm. should be written $9{\cdot}29 \times 10^4$ sq. cm., not 92868 sq. cm. since the latter would give a wrong idea of the accuracy of the measurement. Contracted methods should therefore always be used in the calculations, not only because they save time, but also because they give the proper number of figures. The slide-rule or 4 figure logarithms should also be used to save labour in calculations.

In most of the experiments in this book it is expected that the result will be given to 3 figures. An attempt should always be made to estimate the accuracy of each measurement and of the final result.

Where an experiment is designed to show the relation between two quantities which vary, the result is best expressed by plotting the measurements on co-ordinate paper. A smooth curve drawn among the points thus found shows to the eye the nature of the relation sought. The distances of the points from the curve also show the accuracy of the measurements.

I.

DYNAMICS.

(*A*)

1. Measurement of length.

Make two small crosses upon a sheet of paper 20 or 30 cm. apart and measure the distance between them several times in inches and centimetres in the following way. Place a scale on edge over the marks, with the graduated edge next the paper and read the position of each cross, estimating to tenths of the smallest division of the scale. Use a different part of the scale each time. Record the results in this way:

Measurement of the distance between two points A and B.

Reading at A	Reading at B	AB
4·36	16·19	11·83 inches
7·21	19·05	11·84 "
14·83	26·68	11·85 "
18·09	29·92	11·83 "
	Average	11·84 inches.

Make a similar measurement of the same distance in centimetres and divide one by the other to obtain the number of centimetres in one inch.

When a scale cannot be applied directly to a distance to be measured, the distance can frequently be transferred to the scale by dividers, or calipers, or a wire or string.

1. Draw a line a few centimetres long. Mark a point upon it and estimate how many tenths of the length of the line it is from one end. Test with the scale. This should be practised frequently, as a scale is always read to tenths of its smallest division.

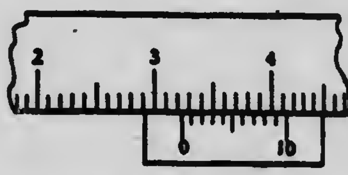
2. Why is it better to place the scale on edge than to lay it flat?

3. Why is it better to use a different portion of the scale each time?

2. Special means of measuring length.

(*a*) *The Vernier.*

The vernier is a common attachment to a scale, which enables us to estimate fractions of a scale division more accurately. It is placed so that its zero mark is opposite the point of the scale which it is desired to read.



In the diagram we see that the scale reading of the zero mark of the vernier is 3·2. To estimate the fraction we look at the vernier. We see that it has a graduated part equal to 9 scale divisions, divided into 10 equal parts. Let s be a scale division ($=0{\cdot}1$ inch say), v a vernier division.

$$\therefore\ 10\,v = 9\,s$$

$$v = \tfrac{9}{10}s$$

$$\therefore\ s - v = \tfrac{1}{10}s = 0{\cdot}01 \text{ inch.}$$

Looking along the vernier we see that division 3 of the vernier coincides with a scale division. The vernier reading is, therefore, 0·03 in. Hence the complete reading is 1·33 inches.

Verniers are divided in various ways according to the purpose for which they are to be used. In each case a calculation, similar to the one above, for $s-v$ must be made, to find how the vernier will read.

In the vernier calipers given you calculate $s-v$ for each of the three verniers. Test whether the zero marks of the verniers are correctly placed by closing the jaws. If not, what is the correction?

Measure the dimensions of the bodies given you in inches and centimetres.

1. If a scale is divided into twentieths of an inch how would a vernier be made to read thousandths of an inch?

2. A circular scale is divided into half-degrees. How would a vernier be constructed to read to minutes?

(*b*) *The Screw Gauge or Micrometer.*

In the screw gauge or micrometer, fractions of a scale division are read by the revolution of a screw, which has a graduated head. The screw is so constructed that two revolutions move it forward one millimetre and the scale is divided into millimetres. The head of the screw has 50 divisions, so that each division means 0·01 mm.

In using the screw gauge care must be taken not to apply force, which would injure the thread. The head should be turned gently until it just makes contact.

The head is graduated to 50 because one complete revolution is one-half of a millimetre. In the second revolution 50 must be added to the reading.

Screw up the head until the jaws close. Does the instrument read zero? If not, what is the correction? Measure the thickness of the objects given.

Some micrometers are made so that one revolution corresponds to one scale division. This must always be tested before readings are made. And sometimes the head is divided into a hundred parts.

(c) *The Length of a Curved Line.*

Draw as large a circle as convenient on smooth paper. Laying a scale across it measure the diameter. Do this several times in different directions. Then draw two diameters not at right angles. Straighten a piece of fine wire by drawing it round a pencil and measure the length of a semicircle by applying the wire to it a little at a time with the fingers. Then transfer the wire to a scale and measure it. Repeat with the other three semicircles. Divide the average semicircumference by the average semidiameter to obtain a value of π.

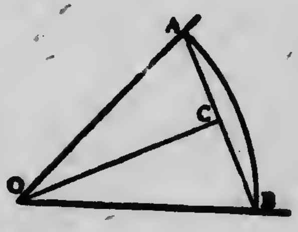
1. Why do you measure the diameter before drawing any diameters?

2. Why do you measure a different semicircle each time?

3. Why do you measure the semicircumference rather than the whole circumference?

3. Measurement of angle.

An angle may be measured directly with a circular scale or protractor. The following method is also frequently convenient.



Let AOB be any angle $(=\theta)$. With centre O and any convenient radius (10 cm. sometimes simplifies calculation) describe an arc AB. Measure the chord AB and AO. $AC=\frac{1}{2}AB$.

$$\sin \tfrac{1}{2}\theta = AC/AO.$$

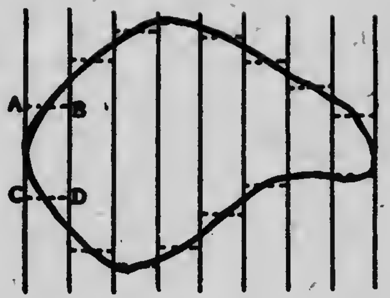
Hence $\frac{1}{2}\theta$ may be found by a table of sines and θ may be calculated.

Draw any angle upon a sheet of paper and measure it in this way. Also employ this method to lay off angles of 39°, 75°, 111°. Lay off a radian and find its value in degrees.

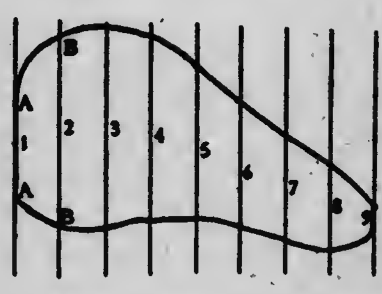
4. Measurement of area.

If the area has the shape of some regular figure its area can be calculated from its linear dimensions. If it is irregular one of the following methods may be used.

(1) Divide the area into a series of strips of equal breadth by drawing a series of equidistant parallel lines. Draw lines like the dotted ones *AB*, *CD*, etc. in the figure, converting each strip into a rectangle of as nearly the same area as possible. Add the lengths of all these rectangles and multiply by the common breadth.



(2) Simpson's Rule. Divide the area into an even number of strips by drawing an odd number of ordinates *AA*, *BB*, etc. at equal distances (x) apart. Measure the lengths of these ordinates. Call *A* the sum of the first and last (1 + 9), *B* the sum of the other odd ones (3 + 5 + 7), *C* the sum of the even ones (2 + 4 + 6 + 8). Then Simpson's rule is that the area is $\frac{1}{3}x(A + 2B + 4C)$.



(3) If the curve is drawn upon co-ordinate paper its area can be found by counting the number of squares enclosed, counting a square if more than half lies within the curve, neglecting it if less than half. The whole centimetres may be counted first,

then the square millimetres in the centimetre squares through which the curve passes.

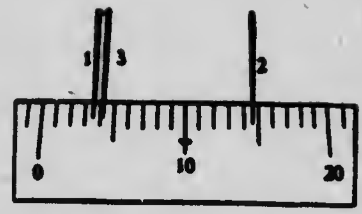
(*a*) Find the area of the curve given you by each of these methods.

(*b*) Describe a circle. Measure its diameter nd area, and calculate π.

5. Measurement of mass.

Mass is generally measured by weighing, *i.e.* comparing with standard masses by means of a balance. When the balance is not in use the beam is lowered until it rests upon supports and the scale pans rest upon the base. The beam must not be left free to swing longer than is absolutely necessary. On no account must weights be put on or taken off the pans while the beam is free. In using the balance proceed as follows: Level the balance by the screws under the base and brush off any dust from the scale pans. Gently raise the beam and see that the pointer swings freely. If the pointer does not swing to nearly equal distances on both sides of the centre of the scale, lower the beam and adjust the small weights at its ends. Watch the pointer swing past the scale and record the points at which it turns three consecutive times. Thus if 1, 2, 3, in the diagram on page 12 represent the positions at which the pointer turns, they would be read 3·6, 14·7 and 4·2 and recorded as follows so that the mean of the readings on the left is combined with the reading on the right.

Left.	Right.
8·6	
4·2	14·7
2 | 7·8	8·9
8·9	2 | 18·6
	9·3



This gives the position, 9·3, at which the pointer would come to rest. It is called the zero point. Five turning points might be taken instead of three to obtain the zero point more accurately. To wait for the pointer to stop swinging would waste a great deal of time and would not be so accurate.

Having found the zero point, place the object to be weighed in the left hand scale pan and the box of masses near the right hand pan. This allows the left hand to raise and lower the beam, while the right hand moves the masses. The masses must never be touched by the fingers but always lifted with the forceps. Place on the right hand pan a mass greater than that of the object being weighed. Raise the beam a very short distance and see that the pointer commences to swing to the left, which indicates that the mass placed in the scale is too great. Lower the beam immediately and remove the mass, placing upon the scale the next smaller one. Again raise the beam a short distance and note in what direction the pointer commences to swing. If the mass is too great remove it and try the next one. If it is too small leave it on and add the next one. Continue this until the smallest mass in the box, (1 centigram), has been tried. When the object is nearly balanced the first motion of the pointer does not show whether the masses are too great or too small. The beam must then be allowed to swing and the pointer observed as was done in finding the zero point. It is very important that the weights in the box be tried in order. Otherwise much time is lost.

Suppose the zero point has been found to be 9·3, and with the object in the left hand pan and 142·32 grams in the right hand pan the position of rest of the pointer is 7·8, while with 142·31 grams in the pan it is 11·5. If we only desire to know the mass to five figures we say that it is 142·32 grams, since 7·8 is nearer to 9·3 than 11·5 is. If we wish another figure we calculate that its mass is

$$142{\cdot}31 + \frac{11{\cdot}5 - 9{\cdot}3}{11{\cdot}5 - 7{\cdot}8} \text{ of } 0{\cdot}01 \text{ grams,}$$

that is 142·316 grams.

(*a*) Weigh some British standard mass in grams to the nearest centigram and calculate the number of grams in a pound.

(*b*) Weigh a light flask or beaker, then measure into it a known volume of water from a burette. Weigh again and calculate the mass of 1 cubic centimetre of water.

The gram is the mass of a cubic centimetre of water at 4° Centigrade. Hence the density of water at this temperature is unity. On account of this relation fluid measures are frequently graduated in grams instead of cubic centimetres, and volumes are frequently found by weighing, as in the next experiment.

6. Measurement of density.

(*a*) To find the density of a regular solid. Weigh the solid and measure its dimensions with calipers or a micrometer. Calculate its density.

(*b*) To find the density of a liquid with a specific gravity bottle. Weigh the bottle empty. Carefully fill with water to the top of the stopper, wipe off any which flows over and weigh again. The difference between these weights is the volume of the bottle. Fill with the liquid whose density is to be measured and weigh again. Calculate the density.

(*c*) To find the density of a finely divided solid. The density of a finely divided solid, such as shot or sand or crushed rock may also be found by a specific gravity bottle. Weigh out a convenient quantity of the solid, also fill a specific gravity bottle with water and weigh it. Pour the solid into the bottle and refill with water. Weigh again. Calculate the volume of water displaced by the solid and the density of the solid.

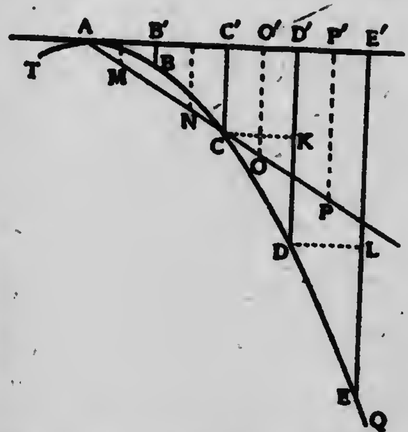
7. Uniformly accelerated motion.

The motion of a body starting from rest with a uniform acceleration is expressed by the equations

$$v = at,$$

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

A body falling freely is uniformly accelerated but its acceleration is so great that it is difficult to study its motion without elaborate apparatus for measuring small intervals of time. The same information may be obtained more simply by studying the form of a water jet. As the single particles all follow the same path the jet shows the path of each particle. Let TAQ be a jet of water, A being the highest point, and draw equidistant vertical lines $B'B$, $C'C$, etc. Since the horizontal motion is uniform B, C, D, etc. are the positions of the same particle at successive equal intervals of time. Thus $D'D$ is the distance the particle falls in 3 intervals, $E'E$ in 4, and so on.



LE $(=E'E-D'D,)$ is the distance fallen in the fourth interval and represents the velocity at the middle (P') of this interval. If we mark P so that $P'P=LE$ and points M, N, O, similarly, the curve $AMNOP$ (a straight line) gives us the vertical velocity of the particle at each instant. It is called the velocity curve. Since the velocity increases uniformly the difference between two successive ordinates to this curve (as $P'P-O'O$) should be a constant, the acceleration.

To verify these facts experimentally tack a sheet of paper to a drawing board and support it vertically a short distance from a jet of water. Place a strong light a few metres away, so that the shadow of the jet falls upon the paper. Hang a plumb line so that its shadow also comes upon the paper. Make marks on the paper in the centre of the shadow of the jet every few centimetres, and mark the shadow of the plumb line. Taking down the board draw freehand a smooth curve corresponding to *TAQ*. Draw a horizontal tangent by means of the shadow of the plumb line and a set square. Mark off equal distances every three or four centimetres, from the vertex along the tangent and draw vertical lines through these.

Taking the differences of these plot the velocity curve. Taking differences from the velocity curve find the acceleration. Also divide $B'B$ by $\frac{1}{2}$, $C'C$ by $\frac{1}{2}\cdot 2^2$, $D'D$ by $\frac{1}{2}\cdot 3^2$, and so on. The average value of the quotient should give the same value of the acceleration as before. Plot these curves on a suitable scale on a sheet of co-ordinate paper and fasten it in your notebook.

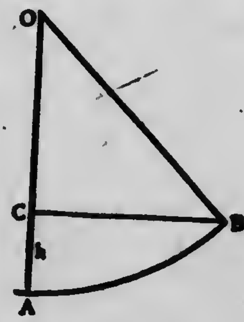
1. Assuming the acceleration due to gravity to be 980 cm./sec^2. calculate the interval of time used as a unit in this experiment.

8. Momentum.

When one body strikes another the law of conservation of momentum tells us that the total momentum of the system is not changed. Expressed in symbols

$$mv + MV = mv' + MV',$$

where m and M are the masses, v and V their velocities before impact and v' and V' their velocities after impact, all the velocities being measured in the same direction. This principle may be used to compare masses, the bodies being hung by long strings, forming two pendulums, and just touching one another when at rest. The velocities can be measured in the following way: If a pendulum, OA, is drawn aside to a position OB, so that the bob is raised to a height $AC(=h)$ and allowed to swing, the velocity (v) of the bob when it passes through the position A is given by the equation



$$v^2 = 2gh.$$

But $$BC^2 = h\,(2r - h)$$

$$= 2rh \text{ if } h \text{ is small compared with } r.$$

$$\therefore\; v^2 : BC^2 = g : r$$

or $$v : BC = \text{a constant},$$

so that BC may be taken to measure the velocity at A.

Keeping the mass M at rest so that $V=0$, draw aside the mass m a convenient distance $(=v)$ and allow it to fall. Measure V' and v'. Take a large number of measurements, as it is difficult to observe these quantities accurately. Substitute the average values obtained in the general equation and calculate the ratio of M to m. Repeat, allowing m to fall a different distance. Verify by weighing m and M with a balance.

1. By what factors must the velocities found in this experiment be multiplied to reduce them to cm./sec.?

2. Calculate the kinetic energy of the system before and after the impact. What has become of the difference?

9. Coefficient of restitution.

If a body falls from a height h its velocity is given by

$$v^2 = 2gh.$$

If it rebounds to a height h' the velocity with which it starts to rise (v') is given by

$$v'^2 = 2gh'.$$

If the falling body is small and the body it strikes so large as not to receive any appreciable velocity the coefficient of restitution e is given by

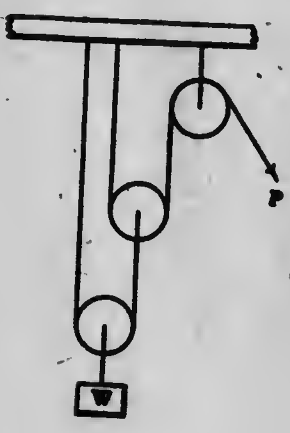
$$e = v'/v = \sqrt{h'}/\sqrt{h}.$$

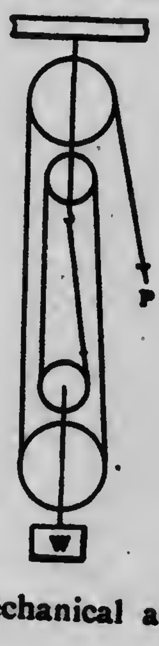
Allow balls of steel, ivory and wood to fall from a known height upon a glass block and measure the heights to which they rebound by a silvered glass scale. Calculate e for each ball.

10. Systems of pulleys.

By a system of pulleys a force P is able to raise a weight W which is greater than P. The ratio of W to P is called the advantage of the system.

If we neglect friction and the weights of the pulleys, the ratio of W to P is called the mechanical advantage. It can easily be calculated from the principle of conservation of energy. For the work done by P equals the work done upon W. $W : P$ = distance P moves : distance W moves. It is easily seen that with either of the arrangements of pulleys shown in the diagrams P moves





4 times as far as W. Hence the mechanical advantage of either system is 4.

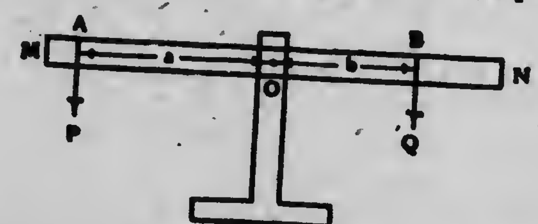
The ratio of $W : P$, when P is just able to raise W is called the kinetic advantage and is evidently always less than the mechanical advantage.

Build up any convenient system of pulleys and attach a series of different weights W, finding each time the weight P which will make it rise. Plot on co-ordinate paper a curve showing the relation between W and P. Draw also a dotted line showing $W : P =$ the mechanical advantage of the system.

11. The lever, moments.

If a rigid body is free to rotate about an axis it remains at rest if the sum of the moments about this axis of all the forces acting upon it is zero.

Let the rigid body MN, which can turn about an axis O at its centre of mass, be in equilibrium



under the action of forces P and Q at distances a and b from O, then

$$Pa = Qb.$$

The moment Qb is considered positive since it tends to give the body a righthanded rotation about O, while the moment Pa is negative.

(*a*) Support a metre bar upon a needle through a small hole at the 50 cm. mark and hang a mass from a box of weights on each end by a thread. Adjust until the bar is in equilibrium. Make a table of P, a, Pa, Q, b, Qb.

(*b*) Support the metre bar upon a fulcrum some distance from its centre of mass. Hang a mass upon each end as before and adjust until the lever is balanced. Calculate the mass of the lever and verify by weighing it.

(*c*) Turning the lever so that the axis about which it can rotate is vertical, apply horizontal forces by threads attached to spring balances or to weights hanging over pulleys at the edge of the table. The forces may now be inclined at any desired angles to the lever. Make a table as before, measuring the distances a and b not along the bar but perpendicular to the respective threads.

12. Composition of forces.

Fasten three threads together, lay them over a sheet of paper and stretch them to known tensions with spring balances or by attaching weights and hanging over pulleys. Mark on the paper the directions of the three threads and measure on each of these lines a segment proportional to the corresponding tension.

(*a*) Prove that these three segments taken in magnitude and direction form a triangle.

(*b*) Show that one of these segments is equal and opposite to the diagonal of the parallelogram of which the others are adjacent sides.

(*c*) Calling the segments A, B, and C, arrange so that B and C are at right angles. Call θ the angle between A produced and B. Make a table of values of A, B, C, $A\cos\theta$, $A\sin\theta$.

13. Centre of mass, Centre of gravity.

A solid body or a system of bodies is composed of parts, each of which has mass and weight. If m is the mass of any one particle at a distance x from any plane, the distance of the centre of mass from that plane is $\Sigma mx/\Sigma m$. By finding the distance of the centre of mass from three planes we know its position.

The weights of the parts of a solid body or system are parallel forces, since all are vertical. Their resultant is also a vertical force equal to their sum (the total weight), passing through a point called the centre of gravity. In order that a body may have a centre of gravity it must be small compared with the earth, so that the weights of all its parts are parallel. Since in this case the weight of any part is proportional to its mass the centre of gravity coincides with the centre of mass.

(*a*) Hang a piece of cardboard from a horizontal pin about which it can turn freely. When it is rest its centre of gravity must be vertically under the pin. Hang a plumb line beside the pin and mark the vertical direction on the card. This gives a line in which the centre of gravity lies. Find a number of such lines, and show that they are concurrent.

(*b*) Take a bar along which masses can slide. Find the mass of the bar, and of each sliding part. Place the sliding parts on the bar and find the centre of gravity by balancing upon an edge. Measure its distance from one end. Move one of the sliding masses some convenient distance. Calculate by the formula how far the centre of mass has moved and find by balancing how far the centre of gravity has moved. Repeat a few times.

(*c*) Draw a semicircle on co-ordinate paper, using an integral number of centimetres as radius. Its centre of mass evidently lies on the radius which is perpendicular to the diameter bounding the semicircle. It is only necessary to find how far it is from the centre. Suppose the semicircle divided into strips parallel to the diameter by the half centimetre lines. Estimate the average length of each strip. These lengths may be considered masses since all strips have the same breadth. Call them *a*, *b*, *c*, etc. The distances of the centres of these strips from the diameter are $\frac{1}{4}$, $\frac{3}{4}$ etc.

$$\therefore \quad \Sigma mx = \tfrac{1}{4}(a+3b+5c+\cdots),$$

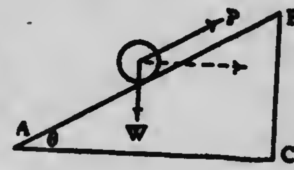
and $$\Sigma m = a+b+c+\cdots$$

Calculate the distance of the centre of mass of the semicircle from the centre as a fraction of the radius.

This method may evidently be used to find the centre of mass of any figure, regular or irregular. In general the distances of the centre of mass from two lines must be found to determine its position.

14. The inclined plane.

Suppose a body whose weight is W to be drawn up an inclined plane by a force P parallel to the plane. Then neglecting friction the work done by P is equal to the work done upon W. If the body moves from A to B, P acts through the distance AB, and W is raised through CB.



$$W(BC)=P(AB)$$
$$\therefore W:P=AB:BC$$

or

$$P=W\sin\theta.$$

Hence the mechanical advantage of the inclined plane is $1/\sin\theta$ if the power is parallel to the plane.

(*a*) Using a metal cylinder for W and a thread stretched by a spring balance for P, make a table of W, BC, P, AB, $W\cdot BC$, and $P\cdot AB$ for various angles. Weigh W by the spring balance used to measure P.

(*b*) If P is horizontal we have in the same way

$$W(BC)=P(AC)$$
$$\therefore W:P=AC:BC$$

or

$$P=W\tan\theta.$$

Make a similar table in this case of W, BC, P, AC, $W\cdot BC$, and $P\cdot AC$ for various angles.

15. The simple pendulum.

Any body hanging from an axis about which it can rotate may be regarded as a pendulum. A body like a metal ball hanging by a long thread or wire is called a simple pendulum, because its mass is practically all at the same distance from the point of suspension. The distance from the point of suspension to the centre of the ball is the length of the pendulum. The distance the bob moves to either side of its position of rest is called the amplitude of the swing; the motion from the centre to one side, back to the other side, and again to the centre is called a complete oscillation. The time taken to make an oscillation is called a period.

(*a*) Taking as long a pendulum as convenient, set it swinging with an amplitude of about 5 cm. Count the number of oscillations in two minutes and calculate the period. Repeat with double the amplitude. Double the amplitude again. Finally start the pendulum swinging with a very large amplitude (60° or more) and determine the period. It appears that if the amplitude is not too great the period is the same whatever the amplitude. That is, the oscillations of a pendulum through small amplitudes are isochronous. For very large amplitudes the period is somewhat longer.

A pendulum is always used with a small amplitude so that its period is not affected by changes in the amplitude.

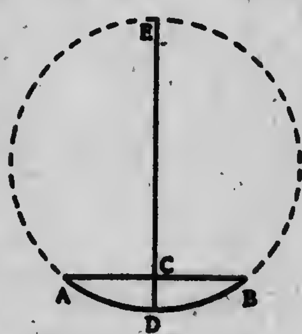
(*b*) Measure the length of the pendulum already used, then shorten it about 20 cm. and determine the period again, using small amplitudes. Continue to shorten by lengths of about 20 cm. until it is about 20 cm. long, then shorten 3 or 4 cm. at a time until it is as short as possible. Make a table of length, period, and length divided by square of period. The numbers in the third column should be nearly constant. Also plot upon co-ordinate paper the lengths and corresponding periods and draw a curve to show the relation between them.

(*B*)

16. The spherometer.

The spherometer stands upon three feet forming an equilateral triangle. A fourth foot moves perpendicularly to the plane of the other three, so that it can measure distances from this plane. It can be used to measure the thickness of a small object as well as a micrometer. But its greatest use, as its name indicates, is to measure the radius of curvature of a spherical surface.

Let *ADB* be a portion of a sphere, such as the surface of a lens, of which we wish to know the radius. The spherometer is placed first upon a plane surface such as a plate of glass. The centre foot is screwed down until it just touches the surface. This is accurately tested by rocking the instrument. The scale is read. Then the spherometer



is placed upon the spherical surface and the foot screwed into contact again and the scale read. The distance it has moved is $CD\,(=a)$. $AC\,(=b)$ is the radius of the circle which circumscribes the equilateral triangle formed by the fixed feet. If l is a side of this triangle

$$b=\tfrac{1}{3}l\sqrt{3}$$

but

$$AC^2=CD\cdot CE$$

or

$$b^2=a(2r-a)$$

$$\therefore\ \tfrac{1}{3}l^2=2ar-a^2$$

$$\therefore\ r=\frac{l^2}{6a}+\frac{a}{2}.$$

Generally $a/2$ may be neglected, as r is large compared to a.

Measure in this way the radius of curvature of a mirror or of one surface of a lens.

17. Calibration of a level.

Mount a level in forks upon a rod resting upon an end support at one end and having the other end resting upon a micrometer screw. Find the distance through which the micrometer must be raised or lowered to move the bubble through each division of the scale. Measure the distance from the point of the micrometer to the line about which the rod rotates and reduce the micrometer readings to angles by a table of sines, or tangents, or circular measures of angles. All three are the same for such small angles.

18. Coefficient of friction.

If the maximum friction between two surfaces is F and the normal pressure is R

$$F = \mu R$$

where μ is called the coefficient of friction.

(*a*) Place a block of wood upon a horizontal glass plate and attach a string which passes over a pulley at the edge of the table and carries a weight P. Adjust until the block will just move without acceleration when started. Then $P = F$. Calculate μ.

(*b*) Removing the string, incline the glass plate until the block will just slide down without acceleration when started. The inclination of the plane to the horizon is called the angle of repose. If it is a, $\mu = \tan a$.

(*c*) If a perfectly flexible wire is wrapped round a circular cylinder, the angle of contact being θ, a tension P in one end of the wire will just keep the wire from being pulled around the cylinder by a tension Q in the other end when

$$\frac{Q}{P} = e^{\mu\theta}$$

where $e = 2{\cdot}718$.

Hanging a weight upon one end of a wire and attaching a spring balance to the other, wrap the wire over a cylinder and observe the least pull of the spring balance, which will keep the weight from falling when θ is $\frac{1}{2}\pi$, π, $\frac{3}{2}\pi$, 2π, and so on. Calculate μ in each case.

19. The ratio of the arms of a balance.

The use of the balance in Experiment 5 assumes that the arms are of equal length. This cannot be absolutely true, and in an accurate weighing it is necessary to consider the inequality.

Let a and b be the lengths of the arms of a balance. Suppose a body placed in the left hand pan and balanced by m grams in the right hand pan. When the body is placed in the other pan suppose it to balance n grams. Then if its true mass is x grams

$$xa = mb$$

and

$$na = xb.$$

$$\therefore\ x^2 = mn$$

or

$$x = \sqrt{(mn)},$$

so that the true mass may be found by double weighing, however unequal the arms.

Also

$$na^2 = mb^2$$

$$a^2 : b^2 = m : n$$

or

$$\therefore\ a : b = \sqrt{m} : \sqrt{n}$$

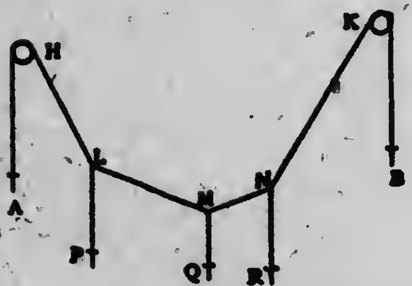
In any good balance m and n will be so nearly equal that the weighings must be made with great care to obtain the difference accurately. A 200 gram weight from the box can be used as the body.

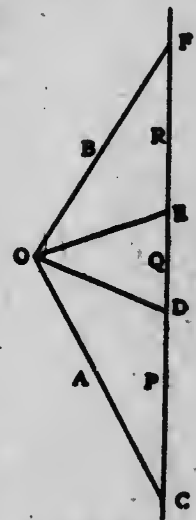
1. What error would be made in weighing 100 grams by neglecting the inequality of the arms of this balance?

2. What is the smallest quantity which can be detected with this balance with a load of about 100 grams in each pan?

20. The funicular polygon.

Hang a string over two pulleys, having weights *A* and *B* attached to the ends, and weights *P*, *Q*, *R* at various intermediate points. Transfer to paper the inclinations of the various parts of the string to the vertical, Then draw a vertical line *CF* and draw *OC* parallel to *HL* and proportional to the force *A*. On the same scale make *CD* proportional to *P*, *DE* to *Q*, *EF* to *R*. Join *OD*, *OE*, *OF*. Then by the triangle of forces *OD* is parallel to *LM*, and proportional to the tension of the string *LM*, *OE* is parallel to *MN* and proportional to the tension of *MN*, while *OF* is parallel to *NK* and proportional to *B*. Test all these facts.





1. What change if *P*, *Q*, *R*, are not parallel?

2. What is the form taken by the cable of a suspension bridge which carries 10 loads of 20 tons each at equal distances and has a horizontal tension of 200 tons weight?

21. The value of "g" by a simple pendulum.

If when a body is displaced a distance x from its position of rest, it has an acceleration kx towards the position of rest, its motion is simple harmonic, and its period is $2\pi/\sqrt{k}$.

If a simple pendulum of mass m and length l is displaced through an angle θ, that is $x=l\theta$, the force tending to make it return is $mg\sin\theta$. If θ is small, $\sin\theta=\theta$

$$\therefore \text{force}=mg\theta$$

$$\therefore \text{acceleration}=g\theta$$

$$=\frac{g}{l}x.$$

Hence the motion is simple harmonic and the period is $2\pi\sqrt{l/g}$.

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

Take a simple pendulum of convenient length. Measure its length and period and calculate g.

Since g depends upon T^2 it is necessary to measure the period as accurately as possible. The method used in Experiment 15 is not sufficiently accurate. The best way, if there are two observers, is to have one watch the pendulum, and give a signal every tenth period for one hundred or more periods. The other observer holds a watch and records the time of every signal. Subtract the time of the first signal from that of the sixth, the time of the second from that of the seventh and so on. Each difference is 50 periods. The average divided by 50 should give a single period fairly accurately.

22. The moment of inertia of a circle about its diameter

If m is the mass of a particle of a system, x its distance from any straight line, and I the moment of inertia of the system about that line,

$$I = \Sigma mx^2.$$

If $\Sigma m = M$ and $I = Mk^2$, k is called the radius of gyration of the system about that axis. As the moment of inertia is always expressed in terms of the total mass, finding the moment of inertia is equivalent to finding the factor k^2 or the radius of gyration k.

Draw a circle on co-ordinate paper with an integral number of centimetres as radius. Suppose it divided into strips of equal breadth by the half centimetre lines. Estimate the length of each strip. These lengths may be regarded as masses since the breadths are equal. Let them be a, b, c, etc. The distances of their centres from the diameter are $\frac{1}{4}$, $\frac{3}{4}$, etc.

$$\therefore\ M = \Sigma m = 2\,(a+b+c+\cdots)$$
$$\Sigma mx^2 = \tfrac{2}{16}(a+3^2b+5^2c+\cdots).$$

Dividing Σmx^2 by Σm we have k^2 which should be expressed as a fraction of r^2; so that I will be expressed as a fraction of Mr^2. The theoretical value of I is $\frac{1}{4}Mr^2$.

This method may be employed to find the moment of inertia of any plane figure. It is commonly used to find the moment of inertia of sections of beams. It is the only method available for irregular sections.

23. Moment of inertia of a loaded bar.

The bar should be provided with knife edges about which it can oscillate freely so that we may regard it as a compound pendulum. Suppose it to oscillate about an axis, A, at a distance h from its centre of mass. Let its moment of inertia about a parallel axis, O, through its centre of mass be mk^2. Its moment of inertia about the axis A is $m(k^2+h^2)$. If it is displaced through an angle θ from its position of rest the moment tending to restore it is $mgh \sin \theta$. If θ is small we may write

$$\text{moment} = mgh\theta$$

$$\therefore \text{ angular acceleration} = \frac{gh}{k^2+h^2}\theta.$$

Hence the motion is simple harmonic and the period is $2\pi\sqrt{(k^2+h^2)/gh}$.

Allow the pendulum to swing from one pair of knife edges and find the period. Find the centre of mass by balancing and measure h. Calculate k.

Swing the pendulum from the other pair of knife edges and repeat the calculation.

24. The value of "g" by a reversible pendulum.

If the compound pendulum when swinging about an axis at a distance h from the centre of mass has the same period as a simple pendulum of length $h+h'$,

$$\frac{k^2+h^2}{h} = h+h',$$

$$\therefore\ k^2 = hh'$$

$$\therefore\ k^2 + h'^2 = h'(h+h')$$

or

$$\frac{k^2+h'^2}{h'} = h+h'.$$

If we have a second axis at the distance h' on the other side of the centre of mass, the pendulum will swing about it with the same period. When the axes are adjusted to such positions the pendulum is called reversible and has the same period as a simple pendulum whose length is the distance between the axes.

Swing the compound pendulum from one axis and hold a simple pendulum in front. Adjust the simple pendulum until it has nearly the same period as the compound one. Then move the other axis of the compound pendulum to make the distance between the axes nearly equal to the length of the simple pendulum. The compound pendulum is then approximately reversible. The axes may be adjusted by observation of the periods about each until the periods are exactly equal. Then the distance between the axes may be measured and the value of g calculated.

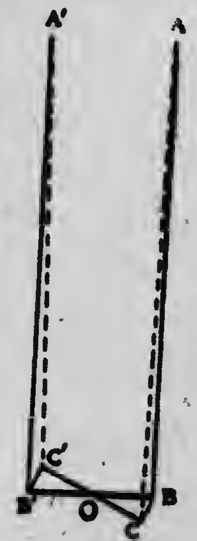
To adjust the axes until the periods are exactly equal is tedious and unnecessary. Leave one axis (A) stationary and find two positions of the other axis (B), say 1 cm. apart, such that at one the period about A is the longer while at the other it is the shorter. Plot on co-ordinate paper the periods opposite the corresponding positions of B. Joining corresponding points, the point of intersection of the joins gives the position of B at which the reversibility is exact and the corresponding period.

Instead of moving one of the axes, a sliding weight may be moved and the position of reversibility determined in the same way.

The axes should not be at the same distance from the centre of mass, since if $h=h'$ the periods are the same whether $hh'=k^2$ or not. That is, in this case the pendulum is reversible although the distance between the axes is not the length of the equivalent simple pendulum.

25. Moment of inertia by bifilar suspension.

The moment of inertia of a solid body may be found by hanging it by two threads and allowing it to vibrate. Suppose the body supported by two equal parallel threads AB and $A'B'$ so that its centre of gravity is vertically under O the middle point of BB'. Let $AB=l$ and $OB=a$. Suppose the body displaced so that BB' takes the position CC'. Let $\angle BAC=\varphi$ and $\angle BOC=\theta$.



$$\therefore\ BC=a\theta=l\varphi$$

$$\therefore\ \varphi=a\theta/l.$$

We may suppose each string to support half the weight so that the force acting vertically at C is $\frac{1}{2}mg$. The force acting in the direction CB is $\frac{1}{2}mg\sin\varphi$ which may be called $\frac{1}{2}mg\varphi$ if φ is a small angle. The moment of this force about O is $\frac{1}{2}mga\varphi$. There is an equal force at C' so that the total moment,

$$L = mga\varphi$$
$$= mga^2\theta/l$$
$$I = mk^2$$

$$\therefore \text{ ang. accel. } = \frac{ga^2}{lk^2}\theta.$$

Hence the motion is simple harmonic and the period,

$$T = 2\pi\sqrt{(lk^2/ga^2)}.$$

T, l and a can be measured, and k^2 calculated. If the body is sufficiently regular k^2 should also be calculated from its dimensions.

II.

PROPERTIES OF MATTER.

(*A*) GASES.

26. Atmospheric pressure. The barometer.

Take a clean, dry, glass tube at least 80 cm. long, closed at one end. Pour in mercury until it is nearly full, then pass a bubble of air backwards and forwards along the tube until any air bubbles which cling to the glass are removed. Fill the tube completely with mercury, and placing a finger over the open end, invert the tube in a dish of mercury. The mercury in the tube falls until its surface is at a definite height above the surface of the mercury outside. Upon inclining the tube more mercury flows into it so that its surface remains as nearly as possible at the same vertical distance above the surface outside.

If the space above the mercury is empty, the pressure at the top of the mercury column is zero. The pressure at its base is therefore ρgh, if h is its height and ρ the density of the mercury. This must be the pressure of the atmosphere at the surface of the mercury outside the tube. If π is the atmospheric pressure, $\pi = \rho gh$ dynes per square centimetre.

It is frequently more convenient to express atmospheric pressures in centimetres of mercury than in absolute units. Thus in the barometer just described the reading would be called h centimetres.

Measure the height of the mercury column thus obtained and compare with the standard barometer in the laboratory.

The pressure of a centimetre of mercury depends upon the density of mercury, which varies with temperature, and upon g which varies with the latitude and altitude of the place. Hence to make the statement of a pressure in centimetres of mercury definite it is necessary to state the temperature and place. Thus the observation of barometric pressure described above would be recorded as h cm. at t°C at Kingston ($g=980{\cdot}5$). To make observations taken at different times and places comparable it is necessary to reduce them to a standard temperature and latitude. Generally readings are reduced to centimetres of mercury at 0° at the sea level at latitude 45° ($g=980{\cdot}6$). If h' is the reduced reading

$$h'=\frac{980{\cdot}5}{980{\cdot}6}(1-0{\cdot}000182\ t)\ h$$

since mercury expands 0·000182 of its volume for each degree. This is approximately the same as

$$h'=h-0{\cdot}0138\,t-0{\cdot}01.$$

In the Canadian meteorological service barometer readings are reduced to inches of mercury at 32° F at the sea level at latitude 45°.

In places where many observations are made, tables are prepared which show the necessary reductions without calculation.

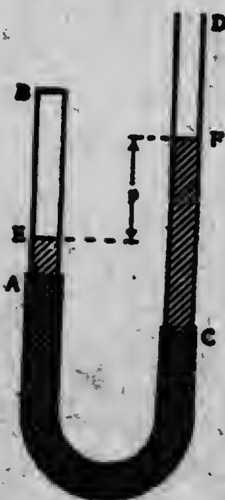
1. Read the pressure on the laboratory barometer and reduce it to cm. of mercury at 0° at the sea level at latitude 45°.

2. Reduce the atmospheric pressure to dynes per square centimetre.

27. Boyle's law.

Unlike a solid or liquid, a gas has no definite volume, but takes the volume of the vessel containing it. The pressure however varies with the volume. Boyle's law states that if the temperature is constant the product of the pressure and volume is constant.

The relation between the pressure and volume of air may be studied by connecting a glass tube *AB*, closed at *B*, to another *CD*, open at both ends, by a rubber tube and pouring in sufficient mercury to bring its surfaces to convenient positions *E* and *F* in the glass tubes. A definite quantity of air is enclos- in the tube *AB*, its volume (V) being measured by the distance *EB*. Its pressure is measured by the vertical distance *EF* plus the atmospheric pressure. By raising or lowering one of the tubes *EF* may be varied. Let $EF = p$. Then P, the pressure of the enclosed air, $= \pi + p$.



(*a*) Read the barometric pressure, π. Make a series of 15 or 20 measurements of V and p, varying p as greatly as the lengths of the tubes will allow. Then fill up a table of V, p, $P\ (=\pi+p)$, and VP. In accordance with Boyle's law the numbers in the last column should be nearly constant.

(*b*) Plot on co-ordinate paper the corresponding measurements of pressure and volume and draw a curve connecting them.

28. The density of air.

The last experiment shows that the density of a gas depends upon its pressure. It also depends upon the temperature. In recording the density of a gas it is therefore necessary to specify the temperature and pressure. It is customary to consider 0° and 76 cm. as the standard conditions and to reduce densities of gases to them. Gases expand $\frac{1}{273}$ of their volume at 0° for each degree above that temperature. Hence if d is the density of a gas at 0° and 76 cm. and d' the density at $t°$ and p cm.

$$d : d' = (273+t)\,76 : 273p.$$

The density of air may be measured by one of the following methods.

(*a*) From a glass globe of known volume (v) exhaust as much of the air as possible and measure the pressure of the remainder with a manometer. Let it be p. Weigh the globe carefully. Let its mass be m. Open the stop-cock and allow it to fill with air at atmospheric pressure, π. Weigh again. Let the mass be m'. Then $m'-m$ is the mass of v cubic centimetres of air at the temperature of the room and pressure $\pi-p$ cm. That is, its density under these conditions is $(m'-m)/v$. The density under standard conditions can be calculated by the formula given above.

(*b*) Compress as much air as possible into a glass globe. Weigh. Allow the compressed air to escape into a graduated jar over a pneumatic trough and measure it. Weigh again. The difference of the masses obtained is the mass of a known volume of air at atmospheric pressure and the temperature of the water in the trough. Reduce to standard conditions.

(*B*) Liquids.

29. Comparison of densities by balancing columns.

If the limbs of a U-tube are occupied by two liquids of different densities, ρ and ρ', and the heights of their free surfaces above their common surface are h and h' respectively

$$\rho g h = \rho' g h'.$$

For the pressure is the same in both limbs at the level of the common surface. It is also the same, namely the atmospheric pressure, at the free surfaces.

Supporting the tube so that the limbs are vertical measure h and h'. Then,

$$\rho : \rho' = h' : h.$$

If one of the liquids is water the density of the other is found directly. This method applies only to liquids which do not mix.

Find in this way the density of oil or mercury.

30. Comparison of the densities of liquids which mix.

If two liquids mix they cannot be poured into the same U-tube, but a method may be used depending upon the same principle. Place the liquids in two cups side by side. Connect two long glass tubes to two arms of a three way rubber tube. If the tubes are placed vertically in the cups containing the liquids and air drawn from them through the third arm of the three way tube, the liquids will rise to heights h and h' such that

$$\rho g h = \rho' g h'.$$

Draw the lighter liquid nearly to the top of the glass tube, close the rubber tube with a pinchcock, and measure h and h'. Using water as one of the liquids find in this way the density of some acid or solution.

31. The density of a solid by Archimedes' principle.

Archimedes' principle is that a solid immersed in a fluid is subject to a vertical, upward force equal to the weight of fluid displaced. Thus by measuring the loss of weight of a body immersed in water we are able conveniently and accurately to measure its volume. This is the basis of the ordinary method of finding the density of a solid body.

Place a bridge over one scale pan of a balance so that the pan swings freely under it and there is room to set a vessel of water on it. Hang the solid body to the hook which carries the scale pan by a fine thread so that its lowest point is a centimetre or two above the bridge. Weigh it. Let its weight be m grams. Set the vessel of water on the bridge so that the solid is completely immersed. Weigh again. If its weight is now n grams, the weight of water displaced is $m-n$. Hence the volume of the solid is $m-n$ and its density is $m/(m-n)$. Find in this way the density of the solid given you.

If the body is lighter than water as wood or cork, we require to employ a heavy body as a sinker. We need to weigh the body, m; the body and sinker in water, n; and the sinker alone in water, n'. Then, if we call the mass of the sinker m', the volume of the combination is $m+m'-n$, while the volume of the sinker is $m'-n'$, so that the volume of the body is $m+n'-n$, and its density is $m/(m+n'-n)$.

32. The density of a liquid by Archimedes' principle.

If a body whose mass is m grams weighs n grams when suspended in water, it displaces $m-n$ grams of water. If it weighs n' grams in another liquid it displaces $m-n'$ grams of the second liquid.

Since the volume displaced is the same the density of the liquid is $(m-n')/(m-n)$.

Weigh the solid used in the last exercise in another liquid and calculate the density of the latter.

Also read the density of the liquid directly with a hydrometer of variable immersion.

33. Nicholson's hydrometer.

In Nicholson's hydrometer, also called a hydrometer of constant immersion, the floating body has a very slender, vertical stem with a single mark. The stem carries a small pan in which weights are placed until this mark is at the level of the surface of the liquid. Thus a constant volume of the hydrometer is immersed. There is also a pan or cage at the lower end of the instrument in which small bodies may be placed. The immersed volume of the hydrometer may be determined once for all by weighing the hydrometer, then floating it in water and adding weights to the pan until it floats at the proper depth. If w is the mass of the hydrometer and m of the added weights, $w+m$ is the volume immersed. If m' is the weight required to sink the hydrometer to the mark in another liquid, the density of the liquid is $(w+m')/(w+m)$.

A hydrometer of this form may also be used to measure the density of a small solid. Place the solid in the upper pan and add weights (n) to sink it to the proper level. The mass of the solid is $m-n$. Place the solid in the lower pan. Let the weights now required to sink it be n'. Then $n'-n$

is the volume of the solid, and its density is $(m-n)/(n'-n)$.

Find in this way the density of the solids given you. This hydrometer may be used for bodies lighter than water, the same formula being used.

34. The surface tension of water.

When a capillary tube is dipped into water, the water inside rises to a height (h) above the surrounding water. If r is the radius of the tube a volume of water, $\pi r^2 h$, is supported by the surface tension of the water around the circumference of the tube. Let the surface tension be T dynes per centimetre. The circumference of the tube is $2\pi r$ cm. Hence the force is $2\pi rT$. The weight of the water supported is $\pi r^2 hg$ since $\rho = 1$.

$$\therefore\ 2\pi rT = \pi r^2 hg$$

$$\therefore\ T = \tfrac{1}{2} rhg.$$

Draw out a fine capillary tube. Wet the inside thoroughly, then support the tube vertically in a dish of water, and measure the height of the water in the tube above the surface outside. Break the tube off at the point to which the water has risen and measure its diameter with a reading microscope. Calculate the surface tension of water.

This formula assumes that the angle of contact of the water and glass is zero, that is, that the tube is thoroughly wet so that a film of water extends up the inside. For a liquid which makes a finite angle of contact (a) with the solid the formula would be

$$T = \tfrac{1}{2} rhg \sec a.$$

(C) Solids.

35. Hooke's Law. The Jolly balance.

One of the most important properties of solid bodies is elasticity. In consequence of this property any change of form or volume (strain) of a solid causes a force tending to restore it to its original form. This force per unit area of the body is called the stress. The strain is measured by the change of unit volume or length, or in case of a shear by the angle through which certain lines in the body are rotated. If the strain is small, lying within the limits of elasticity of the material, the stress is proportional to the strain, This is called Hooke's law.

In a spiral spring a small twist of the wire produces a large motion of the end of the spring. Thus, Hooke's law holds for comparatively great extensions of the spring. A spiral spring is used for weighing, and forms a spring balance. Bodies are hung from the end of the spring and their weights are measured by the extensions produced.

In the Jolly balance a delicate spiral spring carrying two scale pans, one under the other, hangs in front of a silvered glass scale. The eye is placed so that a coloured bead attached to the scale pan is in line with its image in the scale. By this means extensions of the spring can be read very accurately. This balance is used chiefly to determine the densities of small solids. A glass of water is placed so that the lower scale pan is completely immersed, while the upper is dry. The position of the bead is read on the scale (p). The solid is placed in the upper pan and the scale read (q). The solid is removed to the lower pan and the scale again read (r). Then on an arbitrary scale $q-p$ measures the mass of the solid and $q-r$ the mass of water it displaces. Hence its density is $(q-p)/(q-r)$.

Find in this way the density of the solid given.

36. Young's modulus by stretching.

By Hooke's law the ratio of the stress to the strain is constant for small deformations. It is called a coefficient of elasticity of the material strained. There is a different coefficient of elasticity for each different kind of strain, and they have special names. When the strain is an extension in one direction the coefficient of elasticity is called Young's modulus.

Fasten a wire at one end of a table and hang it over a pulley at the other end so that the wire lies along the surface of the table. Hang a weight on the end to keep it stretched. Make two marks on the wire near the ends of the table, and measure the distance (l) between them, and focus reading microscopes upon them. Hang an additional weight to the end of the wire and measure the extension with the microscopes. Add a series of weights and measure the corresponding extensions, then remove the weights one by one and measure again. If these measurements do not agree with the former ones the wire has been strained beyond its elastic limits. If they agree, calculate from each measurement by assuming Hooke's law the extension which would be produced by some definite force (f) such as 100 grs.-weight. Take the average (x) of these extensions. Measure the diameter of the wire in a great many places and take the average value. Let r be its radius. Then the strain observed is x/l, corresponding to the stress $f/\pi r^2$ dynes per sq. cm. If E is Young's modulus

$$E = \frac{\text{stress}}{\text{strain}} = \frac{fl}{\pi x r^2}.$$

37. Young's modulus by bending.

If a uniform bar of length l and cross-section A is clamped in a horizontal position at one end and loaded at the other with a force F, the depression δ of the loaded end is given by the equation

$$\delta = \frac{Fl^3}{3EAk^2}$$

where k is the radius of gyration of a section about its neutral axis.

If the section of the bar is a rectangle of breadth b and depth d, $A = bd$ and $k^2 = \frac{1}{12}d^2$,

$$\therefore\ \delta = \frac{4Fl^3}{Ebd^3}.$$

If the bar is a cylinder of radius r, $A = \pi r^2$ and $k^2 = \frac{1}{4}r^2$

$$\therefore\ \delta = \frac{4Fl^3}{3E\pi r^4}.$$

Find Young's modulus for the material of a given bar by loading one end and measuring the depression.

If the bar is supported at each end and loaded in the middle, the depression is that of a bar of half the length loaded at the end with half the weight. That is, the depression is one-sixteenth as great as for a similar bar loaded at one end.

Test by measuring the deflection of the same bar when loaded at the middle.

38. Rigidity.

The coefficient of elasticity involved when the strain is a simple shear is called the rigidity. If a cylinder such as a stout wire is held at one end while the other is rotated about the axis of the cylinder, the strain is a simple shear. Hence the coefficient of elasticity involved is the rigidity. If l is the length of the wire, r its radius, L the moment required to twist one end through an angle θ relatively to the other, and n the rigidity

$$\theta = \frac{2lL}{\pi n r^4}.$$

If the moment is applied in such a way that it can be measured, all the quantities in this equation may be measured except n. So that n can be calculated. Special care should be given to measuring r since it is to be raised to the fourth power.

39. Rigidity by vibration.

Instead of applying a known moment to the end of a wire as in the last experiment, we may attach a body of known moment of inertia (I) such as a heavy cylinder and allow it to vibrate. Then since

$$L = \frac{\pi n r^4}{2l}\theta,$$

the angular acceleration $= \dfrac{\pi n r^4}{2lI}\theta.$

Therefore the motion is simple harmonic and the period

$$T = 2\pi\sqrt{\frac{2lI}{\pi n r^4}}.$$

T can be measured in the usual way. I can be calculated from the mass and dimensions of the body. Hence n can be calculated.

40. Comparison of moments of inertia.

We may compare the moments of inertia of bodies by attaching them successively to the same wire and allowing them to vibrate. Let T be the period when a body of known moment of inertia I is attached, and T' the period when another body of unknown moment of inertia I' is attached. Then by the formula of the last experiment, since n, l, and r do not change,

$$T' : T = \sqrt{I'} : \sqrt{I}$$

or

$$I' : I = T'^2 : T^2.$$

III.

HEAT.

41. Testing the fixed points of a thermometer.

For scientific purposes thermometers are generally graduated according to the centigrade scale. On this scale the temperature of melting ice is 0°, and the temperature of water boiling at a pressure of 76 cm. is 100°. These are called the fixed points. If the bore of the tube is uniform the distance between the marks indicating the fixed points is divided into 100 equal parts to give the degrees. Before using a thermometer the fixed points should be tested, and if great accuracy is desired the tube should be calibrated.

(*a*) Fill a deep vessel with crushed ice. Pour over it enough water to make contact with a thermometer bulb. Insert the thermometer and leave it for several minutes until the mercury has become stationary. Read the end of the mercury column. This reading is the error of the freezing point. The error with its sign changed is the correction (c_1) which must be added to thermometer readings near the freezing point to make them correct.

(*b*) Suspend a thermometer so that it is surrounded by the steam from boiling water. The thermometer should be in a tube which is filled with steam and also surrounded by steam. Read the top of the mercury column after it has become stationary, and read the atmospheric pressure with a barometer. Correct the reading of the thermometer for the difference between the atmospheric pressure and 76 cm., assuming that the boiling point rises 0°·36 for each cm. increase of pressure. The corrected reading − 100° is the error of the boiling point. This error with its sign changed is the correction (c_2) which must be added to readings of the thermometer near the boiling point to make them correct.

If the corrections obtained are sufficiently large to affect experiments, all readings obtained with this thermometer should be corrected by adding

$$c_1 + \frac{1}{100} x (c_2 - c_1)$$

where x is the reading of the thermometer.

42. Effect of dissolved salt on the boiling point.

Take 3 or 4 slips of paper and weigh out on each 10 grams of salt (Na Cl). Boil 200 c.c. of water in a flask and arrange a thermometer so that the bulb may be either in the boiling liquid or in the steam above it. Read the temperature of each. Then add the salt, one paper at a time, and note after each addition the temperatures of the steam and of the boiling liquid.

Plot curves showing the relations between the quantity of salt and the temperatures of the liquid and steam.

43. Expansion of a solid.

If l is the length of a line segment on a solid at $t°$ and l' its length at $t'°$

$$l' = l\{1 + a(t' - t)\}$$

where a is called the coefficient of linear expansion of the solid. Solving this equation for a

$$a = \frac{l' - l}{l(t' - t)}.$$

As a is a very small quantity some care is required to measure the change of length accurately.

Take a long tube of metal or glass. Make two marks near its ends and measure their distance apart. Wrap the tube in non-conducting material, leaving the marks visible. Focus reading microscopes upon the marks. Pass a current of cold water from the tap through the tube until it has come to the temperature of the water. Set the cross hairs of the microscopes upon the marks. Then pass a current of steam through the tube until its temperature has again become stationary. Measnre the expansion with the microscopes and calculate a.

44. Expansion of a liquid.

Suppose a glass bulb completely filled with liquid. If its temperature is raised some liquid must flow out, since the liquid expands more rapidly than the glass. Such an instrument is called a weight thermometer, since it can be used to measure temperatures by weighing the liquid which flows out.

Let the bulb hold x grams at the first temperature and suppose y grams to flow out when the temperature is raised $t°$. Then if $3a$ is the coefficient of cubical expansion of glass and β that of the liquid

$$(x-y)(1+\beta t)=x(1+3at).$$

Hence if x and y are measured and a is known β may be calculated. y is measured by allowing the liquid to flow into a light beaker which has been weighed.

Find in this way the coefficient of expansion of mercury.

45. Expansion of a gas—Charles' law.

Since a gas has no definite volume it cannot have a definite coefficient of expansion like a solid or liquid. It is therefore usually studied under special conditions in which either the pressure or the volume is kept constant. Let v be the volume and p the pressure of a quantity of gas at 0°. Then if the temperature is raised to $t°$, while the pressure is kept constant, the volume becomes v' where

$$v'=v(1+\beta t).$$

If the volume is kept constant, the pressure becomes p' where

$$p'=p(1+\beta t).$$

β is found to be the same in both cases and for all gases, its value being about $\frac{1}{273}$. It is called in one case the coefficient of increase of volume at constant pressure, in the other case the coefficient of increase of pressure at constant volume.

(*a*) To measure the coefficient of increase of volume at constant pressure. Take a long tube of thin glass, having a small bore, closed at one end. Place a drop of mercury about one-third of the length of the tube from the open end. Attach a thermometer to the tube and place it centrally within a larger tube through which steam can be passed. The drop of mercury encloses a fixed quantity of air at atmospheric pressure. Measure the length of this column (v_1) at the temperature of the room (t_1). Then pass steam through the larger tube until its temperature is stationary (t_2). Let the length of the air column become (v_2).

$$\therefore\ v_1 = v\,(1 + \beta t_1)$$
$$v_2 = v\,(1 + \beta t_2).$$

From these v and β can be calculated. Since the glass tube containing the air has also expanded, the value of β obtained should be increased by $2a$, where a is the coefficient of linear expansion of the glass.

Allow the apparatus to cool slowly and make several readings of the volume and temperature. Plot a curve connecting them.

(*b*) To measure the coefficient of increase of pressure at constant volume. Apparatus similar to that used for verifying Boyle's law may be used to measure the pressure. The straight tube *AB* is replaced by a narrow tube bent twice at right angles and terminating in a large bulb which may be immersed in a vessel of water. The volume of air is kept constant by keeping the surface of the mercury at a fixed mark. The pressures p_1 and p_2 are read at two temperatures t_1 and t_2.

$$\therefore p_1 = p\,(1 + \beta t_1)$$
$$p_2 = p\,(1 + \beta t_2)$$

from which β can be calculated. This value of β should be increased by the coefficient of cubical expansion of glass ($3a$) to allow for the expansion of the bulb.

Take readings as the apparatus cools, and plot a curve connecting the pressure and temperature.

46. Specific heat.

Quantities of heat are expressed in terms of the calorie which is defined as the quantity of heat required to raise one gram of water from 10° to 11°C. As the specific heat of water varies but little with temperature we may in elementary experiments regard it as constant and consider the quantity of heat required to raise the temperature of one gram of water one degree at any temperature as a calorie. The specific heat of any substance is the number of calories required to raise the temperature of one gram of it one degree.

We measure a quantity of heat by allowing it to change the temperature of a mass of water and measuring this change. The water must be contained in a vessel, and generally a thin copper vessel is used. It is called a calorimeter. The calorimeter evidently changes its temperature with the contained water. If m is its mass and s its specific heat, the heat required to change its temperature one degree is ms, which is called the water equivalent of the calorimeter.

In experiments with heat it is impossible to prevent its continual escape by conduction, convection and radiation. This may be minimized by protecting the calorimeter with a jacket and by performing all operations as quickly as possible. When an operation lasts any considerable time, this time should be measured, and the rate of change of temperature should be observed both before and after the experiment, so that correction may be made. For the same reason it is generally desirable that the temperature of a calorimeter should not differ greatly from that of the room.

In order to find the water equivalent of the calorimeter we may first measure the specific heat of copper. Then, knowing the water equivalent of the calorimeter, the specific heat of any other substance may be found in a similar way.

Weigh a calorimeter. Half fill it with water and weigh again. Let m be the mass of the calorimeter and M that of the water. Place the calorimeter in a jacket and stand a thermometer in it. Weigh a mass (M') of copper wire cut into short pieces and place it with a thermometer in a test tube. Heat by exposing it to steam or hot water until its temperature is constant (T). Let the temperature of the calorimeter be t. Quickly pour the copper into the calorimeter, stir with the thermometer and read the temperature. Let it be t'. Then if s is the specific heat of the copper, the heat lost by the wire is $M's\,(T-t')$ calories. The heat gained by the water and calorimeter is $(M+ms)\,(t'-t)$ calories. These must be equal.

$$\therefore M's\,(T-t') = (M+ms)\,(t'-t),$$

from which s may be calculated.

47. Latent heat of water.

It requires a certain amount of heat to convert a gram of ice into water without changing its temperature. This is called the latent heat of water or the latent heat of fusion of ice.

Weigh a calorimeter. Half fill it with water and weigh again. Warm the calorimeter about 10° above the temperature of the room. Place a thermometer in it and read the temperature. Have ready some ice crushed into small pieces. Quickly dry a quantity and place in the calorimeter. Stir until the ice is all melted and read the temperature. It is best to use enough ice to make the final temperature about as much below that of the room as the original temperature was above it. Weigh the calorimeter again to find how much ice was added.

Let w be the water equivalent of the calorimeter, M the mass of water in it, M' the mass of ice added, t the original, and t' the final temperature of the calorimeter, and l the latent heat of water. Then the heat received by the ice was $M'(l+t')$ calories. The heat lost by the water and calorimeter was $(M+w)\,(t-t')$ calories.

$$\therefore M'(l+t') = (M+w)(t-t'),$$

from which l may be calculated.

48. Latent heat of steam.

The latent heat of steam is the quantity of heat required to convert one gram of water into steam without changing its temperature. The same quantity of heat is given out by a gram of steam in condensing.

Weigh a calorimeter. Partly fill it with water and weigh again. Cool the calorimeter considerably below the temperature of the room and measure its temperature. Boil some water in a flask. Let the steam pass through a trap, to catch any water which is carried over, and escape through a small glass tube. Let the steam escape into a cup of water until it has raised the water to 40° or 50°. Then lift the tube into the calorimeter and leave it there until the temperature of the calorimeter is about that of the water from which the tube was lifted. Lift it out, read the temperature of the water, and again weigh the calorimeter to find how much steam has been condensed.

Let w be the water equivalent of the calorimeter, M the mass of water in it, M' the mass of steam condensed, t the initial temperature of the calorimeter, t' its final temperature, T the temperature of the boiling point (nearly 100°), and l the latent heat of steam. Then the heat gained by the calorimeter is $(M+w)(t'-t)$ calories. The heat lost by the steam is $M'(l+T-t')$ calories.

$$\therefore M'(l+T-t') = (M+w)(t'-t),$$

from which l may be calculated.

49. Vapour pressure of water.

The pressure of a vapour varies rapidly with the temperature. When the vapour pressure is the same as the pressure of the surrounding atmosphere, the liquid is at its boiling point for that pressure. Thus the relation between vapour pressure and temperature may be studied by finding the relation between boiling point and pressure.

(*a*) Insert in a round bottomed flask containing water a thermometer, and a tube leading to a long vertical tube dipping into mercury and also to a filter pump. Heat the water nearly to the boiling point, then start the pump and observe the pressure and temperature when the water boils. Make a series of observations until the lowest pressure which the pump will give is reached.

Plot a curve connecting pressures and temperatures.

This method applies only to temperatures below 100°.

(*b*) To find the pressures at higher temperatures, a closed metal vessel having a loaded valve can be used. The pressure is increased gradually by increasing the load upon the valve and the temperature of the boiling point read at each pressure.

50. Humidity of the atmosphere.

There is always some water vapour in the atmosphere. If the temperature of the air is lowered, a point is reached at which the pressure of this vapour is the vapour pressure of water at that temperature. This temperature is called the dew point, as the vapour then begins to condense. At the dew point the air is said to be saturated with water vapour. If the dew point is t'° when the atmospheric temperature is t°, the ratio of the vapour pressure of water at t'° to its vapour pressure at t° is called the relative humidity. The relative humidity is thus the ratio of the quantity of water vapour present to the quantity which would saturate the air at that temperature.

To find the humidity we must measure the dew point. This may be done by partly filling a polished vessel with water and adding snow a little at a time until moisture begins to collect on the vessel. Read the temperature of the water. Then stir it until the dew disappears and again read the temperature. The mean of these readings may be taken as the dew point. From tables of the pressure of water vapour calculate the relative humidity.

Instead of water and snow ether may be used and a current of air blown through it to lower its temperature.

1. Assuming that water vapour has a density nine times that of hydrogen under the same conditions, calculate the density of the water vapour in the atmosphere.

2. Calculate the density of the air (including the water vapour) from this observation.

81. The mechanical equivalent of heat.

Heat is energy and therefore both can be measured in the same units. It is usually more convenient to measure quantities of heat in calories. In order to make such measurements comparable with other measurements of energy it is necessary to know the relation between the calorie and the erg. This is found most directly by converting a measurable quantity of mechanical energy into heat by friction within a calorimeter.

The calorimeter used is of a special form but it contains a measured quantity of water with a thermometer dipping into it so that the quantity of heat developed is measured just as in other calorimetric experiments.

The friction is sometimes applied by rotating a system of paddles within the calorimeter while the latter remains stationary. Sometimes the calorimeter consists of two cones one of which rotates inside the other. In either case the moment which keeps the stationary part from moving is measured. This is done by attaching to it a disc round which a cord is wound. The cord passes over a pulley and carries a weight. The moving part is rotated sufficiently rapidly to raise this weight until it hangs freely.

If r is the radius of the disc and m the mass of the hanging weight, the moment is mgr, and the work done in n revolutions is $2\pi nmgr$ ergs. If M is the mass of water, w the water equivalent of the calorimeter and thermometer, t_1 and t_2 the initial and final temperatures of the water, and J the number of ergs in a calorie,

$$J(M+w)(t_2-t_1)=2\pi nmgr.$$

A counter geared to the shaft enables n to be measured.

As the experiment takes some time it is necessary to make a correction for the heat lost by the calorimeter. To do this the time taken to raise the calorimeter from the temperature of the room (t_1) to the temperature (t_2) is observed. Then the calorimeter is allowed to stand with occasional stirrings and the rate at which the temperature falls is observed. It may be assumed as a first approximation that the heat lost during the experiment is half that which would be lost by the calorimeter if kept at t_2° for the same time.

IV.

SOUND.

52. The frequency of a note.

To determine the frequency of a note accurately is rather difficult, but it may be found approximately in a simple manner with a siren.

A circular disc has a row of equidistant holes. If the disc is attached to a whirling table and rotated, while a stream of air from a tube is directed against the holes, a note is given out whose frequency is the number of holes passing the tube per second. Adjust the speed until the note is in unison with a tuning fork or pipe, then count the number of rotations in a minute and calculate the frequency. Make several measurements.

53. To compare the frequencies of two forks.

Wrap a strip of smoked paper round a cylinder which can be rotated. Mount the tuning forks to be compared side by side in a block of wood and attach a light style to each. Rotate the cylinder and bring the styles in contact with the smoked paper for the greater part of a revolution. Mark off corresponding lengths of the two traces and count the number of vibrations of each fork included. Calculate the ratio of the frequencies.

54. The transverse vibrations of a wire.

The dynamical theory shows that the velocity of a transverse wave along a stretched wire is given by the equation

$$v = \sqrt{(T/m)},$$

where T is the tension of the wire and m the mass of unit length. If n is the frequency and λ the wave length

$$v = n\lambda$$

$$\therefore\ n\lambda = \sqrt{(T/m)}.$$

The length of wire which vibrates with a frequency n is $\frac{1}{2}\lambda$, since it is the distance between two nodes. If l is this length

$$2nl = \sqrt{(T/m)}.$$

This equation should be verified in the following cases.

(*a*) If m and T are constant, n varies inversely as l. Verify this by stretching a wire by a definite tension over two bridges. Vary the distance between the bridges to bring that portion of the wire into unison with various tuning forks. Show that the product nl remains constant. If the ear is unable to determine whether the wire is in unison with the fork, small paper stirrups may be hung upon the wire and the handle of the fork touched to the wire above a bridge. If the wire is in tune with the fork it will vibrate and throw off the paper.

(*b*) If m and n are constant, l varies as the square root of T. Verify by finding the lengths of wire in unison with the same fork under various tensions.

(*c*) Find m by weighing a few centimetres of the wire. Measure T and l and calculate n. Compare with the number on the fork.

55. The velocity of sound in air.

The velocity of sound in a gas is given by the equation

$$v=\sqrt{(E/D)},$$

where E is the elasticity of the gas for adiabatic changes of volume and D its density.

But
$$E=\gamma p,$$
and
$$p/D=RT,$$
so that this becomes

$$v=\sqrt{(\gamma RT)},$$

R being the gas constant and T the absolute temperature.

The velocity of sound in air may be determined by finding the length of a column of air which vibrates in unison with a tuning fork of known period. If a tuning fork is held over a tall jar containing water, the height of the water may be adjusted until the air column resounds in unison with the fork. The length of the air column is then $\frac{1}{4}\lambda$, since there is a node at the surface of the water and a point of maximum motion near the top. The length of this column should be measured from the surface of the water to the top of the jar and half the radius of the jar should be added since the loop is about this distance above the top of the jar. If l is this length

$$\lambda = 4l,$$

$$v = n\lambda.$$

Use several forks and take the average of the velocities obtained.

If the jar is long enough a second position of the surface of the water may be found at which there is resonance. This is $\frac{3}{4}\lambda$ from the top. The distance between the two positions is $\frac{1}{2}\lambda$. If this is measured the correction for the end of the jar is not required.

1. Note the temperature and reduce the velocity to 0°C by the formula given above, or by subtracting 60 cm. per sec. for each degree which is approximately the same.

2. Calculate the theoretical velocity by the formula given above. Assume that for air $\gamma = 1{\cdot}41$ and $R = 2{\cdot}88 \times 10^6$.

56. The velocity of sound in brass.

When a metal rod is clamped at the middle and stroked towards one end with a resined cloth it is thrown into longitudinal vibrations, the fundamental vibration being such that there is a loop at each end and a node at the middle. That is, the length of the rod is one half wave length of the note in the metal. If l is the length of the rod and v the velocity of sound in it

$$v = 2nl.$$

By inserting an end of the rod into a tube the air in the tube may be set in vibration with the same frequency. If some cork dust or other light powder is in the tube it is thrown into ridges near the loops and left unmoved near the nodes. If l' is the distance between two consecutive nodes and v' the velocity of sound in air at the temperature of the room

$$v' = 2nl'$$

$$\therefore\ v : v' = l : l'.$$

As v' is known from the last experiment v may be calculated.

1. Assuming that the velocity of a longitudinal wave is $\sqrt{(E/D)}$, where E is Young's modulus and D the density, calculate Young's modulus for brass.

2. Calculate the frequency of the note of the rod.

3. Obtain if possible the first overtone from the rod and calculate its frequency.

V.

LIGHT.

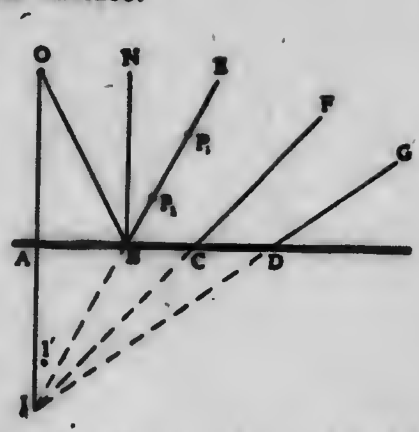
57. Parallax.

Stand two pins upright and place the eye nearly in the same line. If the eye is moved to the right, the more distant pin seems also to move to the right, that is, in the same direction as the eye. This apparent motion of an object caused by the motion of the observer is called parallax. It enables us to judge which of two objects is the more distant.

Stick a pin upright in the table and hold another in a support 5 or 10 cm. above the table. Keeping the eye at some distance away and at the level of the table, move the support about, noticing the parallax, until one pin is directly over the other.

On account of parallax our eyes see objects somewhat differently and we can form an idea of the relative distances of their parts. In the same way the sun, moon, and planets are displaced from the positions they would have if seen from the centre of the earth. This displacement is called parallax and when the body is on the horizon, horizontal parallax. Thus *e.g.* the sun's horizontal parallax is the angle subtended by the earth's radius at the sun. On a still larger scale the parallax of a star is the angle subtended at the star by the radius of the earth's orbit.

58. Reflection at a plane surface.



If an object is in such a position as *O*, in front of the plane mirror *ABC*, an eye placed at *E* and looking into the mirror sees an image of the object behind the mirror as at *I*.

Using a pin as the object and a strip of unsilvered glass held upright by a little soft wax as the mirror, place two pins, P_1 and P_2 in line with the image *I*. Moving the eye to other points, *F* and *G*, find other lines in the same way and show that they all meet at a point *I*. Show also that *OI* is perpendicular to the mirror and bisected by it.

Joining *OB* and drawing *BN* normal to the mirror, we see that a ray of light incident upon the mirror at an angle *OBN* is reflected at an equal angle *NBE*. The laws of reflection are (1) The incident and reflected rays and the normal to the surface lie in the same plane, and (2) The angle of reflection is equal to the angle of incidence.

The image *I* is called virtual because the rays of light do not actually come from it to the eye but only appear to do so.

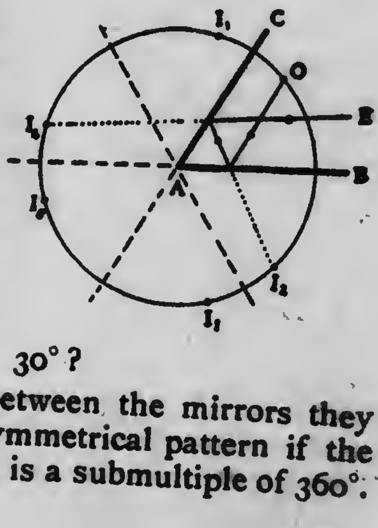
Verify that the image is the same size as the object, erect, but perverted, that is, differs from the object as the left hand does from the right.

The position of the image may also be found by parallax. Stand a pin at any point behind the mirror, as I', so that it can be seen over the mirror at the same time that the image of the pin at O is seen in the mirror. Determine by parallax whether it is nearer or farther than the image and move it about until it seems to occupy the same position. Is it then at the point I?

A pin or a pencil held in a support might also be arranged to point at the image, as in the last experiment.

59. The images formed by two mirrors.

Stand two strips of silvered glass at an angle of about 60° and locate the images of a pin seen in both. Show that they lie on a circle.



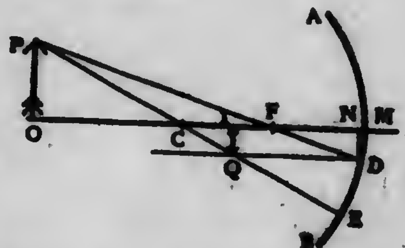
By placing pins at points marked with dots, trace the path of a ray forming one of these images.

Gradually decrease the angle between the mirrors and notice the number of images formed. What is the number of images when the angle is 45°? 36°? 30°?

If objects are placed between the mirrors they form with the images a symmetrical pattern if the angle between the mirrors is a submultiple of 360°.

The toy called the kaleidoscope is generally formed by placing coloured bodies between two mirrors at an angle of 36°, or between three mirrors forming an equilateral triangle.

60. Reflection at a spherical surface.



Let AB be a spherical mirror, M being the centre, and C the centre of the sphere of which the mirror is a part. CM is called the axis, and F, the middle point of CM, is called the focus. Usually only a small portion of a spherical surface is used as a mirror, so that CM is large compared to AM and NM.

All rays passing through C fall upon the mirror normally and are therefore reflected back in the same straight line. All rays parallel to the axis are reflected to pass through the focus and vice-versa.

If an object is in such a position as OP, the position of the image may be found by joining any point P upon it to C and F. A ray PCE is reflected back along the same path. A ray PFD is reflected parallel to the axis in the direction DQ. Both these rays diverge from the point Q, which is the image of the point P.

Let OM, the distance of the object from the mirror, $=u$, $IM=v$, $CM=r$, $FM=f$,

$$\therefore \frac{OC}{CI} = \frac{OP}{QI} = \frac{OP}{DN} = \frac{OF}{FN} = \frac{OF}{FM}$$

since NM may be neglected in comparison with FM.

$$\therefore \frac{OM - CM}{CM - IM} = \frac{OM - FM}{FM}$$

or
$$\frac{u - 2f}{2f - v} = \frac{u - f}{f},$$

which reduces to
$$fv + fu = uv,$$

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

This formula may be used to give the position of the image in all cases of reflection at a spherical surface, u and v being positive if they are measured in the same direction as f, negative if in the opposite direction.

Evidently $IQ : OP = CI : OC$,
or the sizes of image and object are proportional to their distances from the centre of curvature.

Hold the mirror in the hand and an object, such as the point of a pencil, close to it. Move the pencil gradually away from the mirror, noting the position of the image, its size, whether it is real or virtual, erect or inverted.

61. The radius of curvature of a concave mirror.

(*a*) Place a pin in a holder and adjust until, testing by parallax, its point appears to touch the point of its image. The point is then at the centre of curvature and its distance from the mirror may be measured with a scale.

(*b*) Carry the mirror as far as possible from a window or lamp and receive the image upon a strip of paper. It is formed at the focus.

(*c*) Using any bright object, place the mirror at various distances from it and make a series of measurements of u and v. Calculate f for each by the formula,

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

(*d*) Measure the radius of curvature directly with a spherometer as in Experiment 16.

62. The index of refraction of glass.

The laws of refraction are (1) The incident and refracted rays and the normal to the surface lie in the same plane, and (2) The sine of the angle of incidence bears a constant ratio to the sine of the angle of refraction.

If i is the angle of incidence and r the angle of refraction

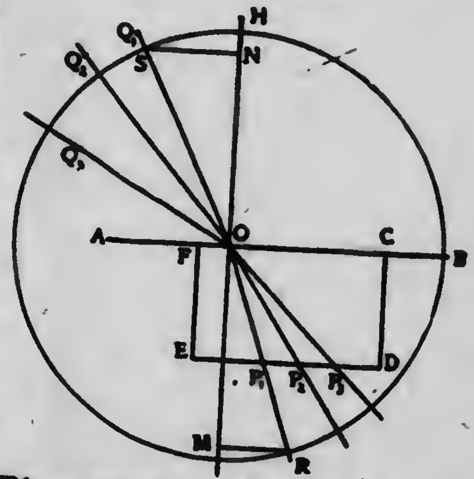
$$\frac{\sin i}{\sin r}=\mu,$$

where μ is the ratio of the velocities of light in the two media and is called the index of refraction of one with respect to the other.

To measure the index of refraction of glass relatively to air, we must measure the angles of incidence and refraction for a ray of light passing from air to glass. To do this accurately requires a mounted telescope and a carefully graduated circle.

The following methods, however, can be used to obtain the index to three figures.

(*a*) Using a rectangular block of glass.



On a sheet of paper draw a line AB and place the block of glass with one edge along this line as $CDEF$. Place a pin at any point O on the line and another at H so that it, its image by reflection, and the pin at O are in line. This line is perpendicular to AB. Place some pins as P_1, P_2, P_3, close to the edge of the block and place others, as Q_1, Q_2, Q_3, so that Q_1OP_1, Q_2OP_2, etc., appear straight lines. Then Q_1OP_1 is the path of a ray passing from air to glass, Q_1OH being the angle of incidence, and P_1OM the angle of refraction.

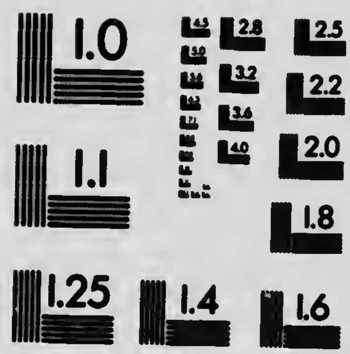
Describe any circle with centre O.

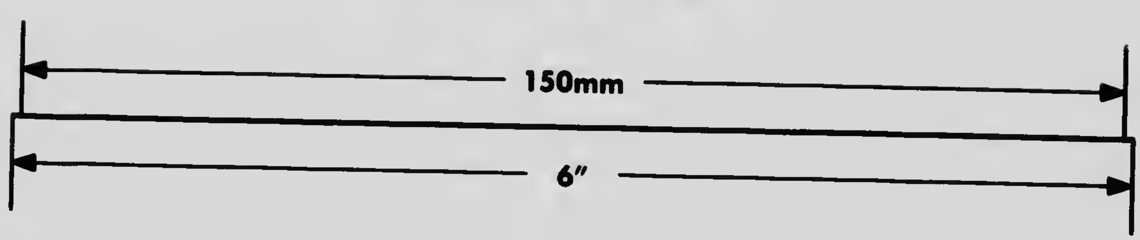
$$\sin i = \frac{SN}{OS}, \quad \sin r = \frac{RM}{OS}$$

$$\therefore \mu = \frac{SN}{RM}.$$

Calculate this ratio for each of the lines drawn.

IMAGE EVALUATION TEST TARGET (MT-3)

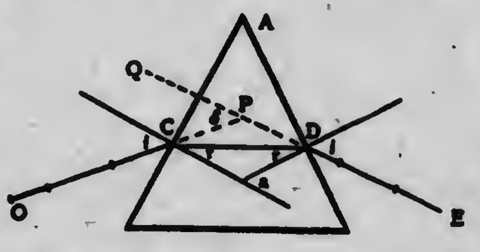




APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989

(*b*) Using a glass prism.

The deviation produced by a prism is least when the ray leaves the prism at the same angle as it enters. Call this angle i, and the angle which the ray within the prism makes with the normal to either face r, A the angle of the prism, and δ the minimum deviation = $\angle OPQ$.



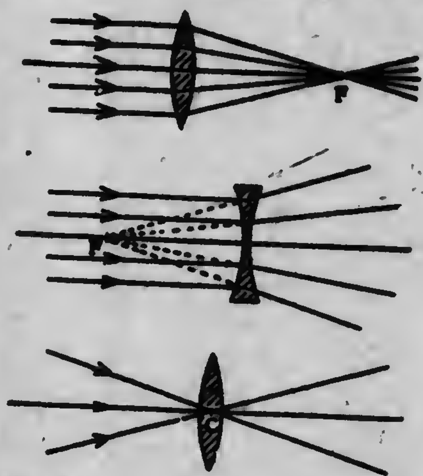
$$\therefore A = a = 2r$$
$$\delta = 2(i - r)$$
$$\therefore r = \tfrac{1}{2}A$$
$$i = \tfrac{1}{2}(A + \delta).$$

Placing a pin at O for the object, turn the prism until the deviation is least, then mark the path of the ray by pins. Measure the angles A and δ as in Experiment 3 and calculate r and i, and $\sin i/\sin r = \mu$.

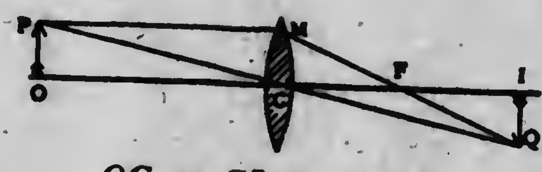
63. The focal length of a lens.

Lenses are of two principal kinds, convex and concave. Convex lenses are thicker at the centre than at the edge, concave lenses are thinner at the centre than at the edge. The nature of a lens is described by stating its focal length, that is, the distance from the lens to its focus.

The general theory of lenses is complicated but it will suffice here to take an approximate theory, which neglects the size and thickness of the lens. The properties of a lens and the meaning of its focus are described in the following statements: (1) Rays parallel to its axis falling upon a convex lens are bent so as to converge to its focus. (2) Rays parallel to its axis falling upon a concave lens are bent so as to diverge from its focus. (3) Rays passing through the centre of a lens are not deflected.



By drawing two rays from the object we are able to find where the image is formed, as in the case of a mirror.



If
$$OC=u,\ CI=v,\ CF=f,$$
$$\frac{OC}{CI}=\frac{OP}{IQ}=\frac{CM}{IQ}=\frac{CF}{FI}$$
$$\therefore \frac{u}{v}=\frac{f}{v-f}$$
or
$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f},$$

the same formula as for a mirror. We consider $u+$ if the object is on the side of the lens from which the light comes, that is, if the object is real; $v+$ if the image is on the side to which the light goes, that is, if the image is real. f is $+$ if the lens is convex, $-$ if it is concave.

Since $IQ : OP = CI : OC$, the sizes of image and object are proportional to their distances from the lens.

(*a*) With a convex lens form a real image of a bright object, such as a candle flame, on a paper screen. Measure u and v. Make a series of observations at various distances and calculate f for each.

(*b*) If $u = \infty$, $v = f$, so that the image of a distant object is at the focus. Form an image of the sun, or a distant window, which may be assumed to be at an infinite distance, and measure its distance from the lens.

(*c*) Using a concave lens, place a pencil in a holder pointing downwards. Look through the lens at some object and place the pencil directly over the image by parallax, being careful to look at the pencil *over* the lens. Measure u and v for various distances and calculate f for each, remembering that in this case v and f are negative.

1. How can you tell by looking through a lens whether it is convex or concave?

2. How can you judge approximately the focal length of a lens by looking through it?

64. **The telescope and opera glass.**

(*a*) Mount a convex lens so as to form an image of a distant building or other conspicuous object. Look at this image through a second convex lens. What is the distance between the lenses when vision is most distinct? What relation does it bear to the focal lengths of the lenses? Does the object appear erect or inverted? Does it seem larger or smaller than when looked at directly?

Replace the lens next the eye by one of a different focal length and answer the same questions.

This combination forms the simple astronomical telescope, the lens next the object representing the object glass, and the lens next the eye representing the eye piece. In an actual telescope both these lenses are compound to make the image more distinct.

(*b*) Use a concave lens as an eye lens and repeat the observations. The combination now represents an opera glass, or a field glass.

65. **The spectroscope.**

When a ray of white light passes through a prism of dense glass it is deflected owing to the refraction and it is also separated into its constituent colours. That is, the index of refraction has different values for different colours. This phenomenon is called dispersion. The resulting series of colours is called a spectrum. Any instrument for analyzing light into its constituent colours is called a spectroscope. A direct vision spectroscope will serve for the following experiments :

(*a*) Examine the spectrum of an incandescent solid, as a white gas flame, or the filament of an incandescent lamp. Notice that it is continuous, shading gradually from red through yellow and green to blue and violet. It is traditionally divided into seven colours, red, orange, yellow, green, blue, indigo, violet. There is little reason however for distinguishing seven colours rather than any other number.

(*b*) In a Bunsen flame place a platinum wire which has been dipped in common salt (sodium chloride). Examine the spectrum of the yellow flame. Notice that it consists of a single bright yellow line. In more powerful instruments this line is double. Place in the flame in the same way strontium chloride, lithium chloride or potassium chloride. Notice that in each case the spectrum consists of bright lines. The metal exists in the flame in the form of vapour and each metal gives its characteristic spectrum.

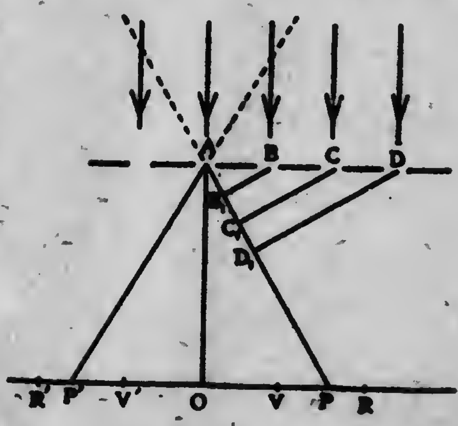
(*c*) Examine the spectrum of daylight (the solar spectrum). Notice that it is a continuous spectrum crossed by dark lines. The light from the body of the sun would give a continuous spectrum. The metallic vapours in the sun's atmosphere subtract the particular parts of the light which they themselves give out, causing the dark lines. These lines therefore tell us what substances are in the sun's atmosphere. Oxygen and water vapour in the earth's atmosphere also cause some of the dark lines.

(*d*) Look through the spectroscope at the sky or a bright cloud through a Bunsen flame. Then insert sodium in the flame. Does the sodium line coincide with one of the dark lines of the solar spectrum?

(*e*) Examine the spectrum of light from an incandescent lamp which has passed through a red glass. Has the glass added anything to the white light to make it red? Has it subtracted anything? Try a green, a blue, and a pink or a violet glass in the same way.

66. The wave length of sodium light.

The theory of the grating tells us that if light falls normally upon a grating in which the lines are *A, B, C,* etc., a portion travels on in the direction *AO.* Some, however goes in other directions, as *AP*, such that each of the distances, AB_1, B_1C_1, C_1D_1, etc., between the perpendiculars from the different openings is one wave length.

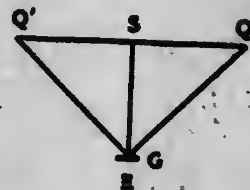


Call the wave length, λ, and the grating space AB, a,

$$\therefore \frac{OP}{AP} = \frac{AB_1}{AB} = \frac{\lambda}{a}.$$

Hence P is different for light waves of different lengths, that is for light of different colours, and we have the separate colours from violet to red forming the first spectrum on each side, VR and $V'R'$. Beyond these we generally have second and third spectra and so on.

If a sodium flame is placed as at S in the second figure and a grating a few metres away at G, an eye at E besides seeing the flame at S will see the first spectra, Q and Q', on each side, and perhaps the second and third spectra also. Retort stands may be placed at these points and adjusted until they coincide with the images of the flame. Then the distances QQ' and GQ may be measured. $SQ = \frac{1}{2}Q'Q$ and



$$\frac{\lambda}{a} = \frac{SQ}{GQ}$$

from which λ may be calculated.

If the second or third spectrum is used, 2λ or 3λ should be written instead of λ in the equation.

In the same way, cutting off the air from the Bunsen burner to get a white light, calculate the wave lengths of the extreme visible red and violet.

67. Intensity of light—the photometer.

The usual standard of light intensity or illuminating power is the candle power which is defined as the illuminating power of a sperm candle, one sixth of a pound, burning 120 grains per minute. Various other standards are also in use, such as the Carcel lamp which burns colza oil at a fixed rate, and the Hefner-Alteneck lamp which burns amyl-acetate with the flame adjusted to a fixed height.

If two surfaces are illuminated by light of the same colour the eye can judge whether they are equally illuminated with considerable accuracy. It has little power of judging the ratio of the brightnesses of unequally illuminated surfaces or of comparing illuminations of different colours.

To compare the intensities of two sources of light it is usual to arrange them so that they illuminate equally adjacent portions of the same surface. If light is incident at an angle i upon a surface at a distance r from a source of intensity I, the illumination is proportional to $I \cos i/r^2$. Hence if a surface is equally illuminated by light from two sources of intensity I and I',

$$\frac{I \cos i}{r^2} = \frac{I' \cos i'}{r'^2}$$

In comparing intensities it is usual to allow the light to fall normally upon the surface and to adjust r and r' until the illuminations are equal. Thus $\cos i = \cos i' = 1$

$$\therefore I : I' = r^2 : r'^2.$$

Various methods are used to make the comparison of the illuminated surfaces convenient.

By each of the following methods compare an incandescent lamp or gas flame with a standard candle.

(*a*) The shadow photometer. If an opaque rod stands a short distance in front of a sheet of paper and two lights are placed in front, two shadows of the rod are cast on the paper. By moving the lights the shadows may be brought side by side and made of equal brightness. Each shadow is illuminated by one of the lights. If the shadows are cast normally upon the paper, the intensities of the sources of light are compared by the formula above.

(*b*) The grease-spot photometer. Oil makes paper reflect less light and transmit more. If a sheet of paper having a grease spot is held between the eye and a strong light, the spot appears brighter than the surrounding paper. If the light is on the same side of the paper as the eye, the spot appears darker. Hence if a sheet of paper with a grease spot is placed between two lights, it may be adjusted until the spot has the same brightness as the pape. when looked at from either side. Both sides of the paper are then equally illuminated and the intensities of the lights may be compared by the formula above.

(*c*) The paraffin photometer. If two blocks of paraffin of equal thickness are placed side by side between two lights and looked at from the side, the more brightly illuminated block appears brighter than the other. Such a double block may be adjusted between two lights until its sides are equally illuminated. Then the intensities of the lights are compared as in the former methods.

68. Polarization.

Verify the following:

(*a*) Light which has passed through a Nicol prism will pass through a second prism if similarly placed, but is cut off if the second prism is rotated through a right angle.

Calling light which has passed through a Nicol prism polarized, how can you detect polarized light?

(*b*) Light reflected from glass at the polarizing angle is polarized.

Measure the polarizing angle of glass.

Is light reflected at other angles and from other objects partially polarized?

(*c*) Assuming that the plane of polarization of light polarized by reflection is the plane of incidence, what is the plane of polarization of light polarized by a Nicol prism? How is it related to the angles of the prism?

Is the light of the sky polarized? If so in what plane?

(*d*) If light falls at the polarizing angle upon a pile of glass plates the transmitted light is polarized.

How is its plane of polarization related to that of the reflected light?

69. Double refraction.

Make a dot on a sheet of paper and lay a crystal of Iceland spar upon it. Two images of the dot are seen, showing that light passing through the crystal is divided into two rays.

(*a*) How is the line joining the images related to the angles of the crystal?

(*b*) If the crystal is rotated one of the images (the ordinary) remains stationary while the other (the extraordinary) revolves round it.

(*c*) Which of the rays, ordinary or extraordinary, has the greater index of refraction?

(*d*) In what planes are the rays polarized?

VI.

MAGNETISM.

70. Fundamental properties of magnets.

Verify the following:

(*a*) A magnet attracts pieces of iron and steel but not paper, wood, copper, or most other substances.

(*b*) This attraction is to certain parts of the magnet (its poles). There is little attraction to the central parts.

(*c*) Magnetic attraction acts through wood, paper, copper, in fact all substances; though iron affects it considerably.

(*d*) A magnet tends to set itself in a definite direction. If only free to turn about a vertical axis it sets itself in a direction nearly north and south. The end which points north is called a north pole or + pole, the other end is a south pole or – pole.

(*e*) Small pieces of iron near a magnet but not near enough to be drawn to it tend to set themselves in definite directions. Show by laying a sheet of paper over a magnet and sprinkling iron filings upon it. These directions trace out lines of force. A line of force is understood to start from the + pole of a magnet.

(*f*) Unlike magnetic poles attract each other, like poles repel each other.

State a test by which the poles of any magnet may be distinguished.

(*g*) Pieces of steel may be magnetized by stroking with a magnet. One pole of the magnet is placed on one end of the piece of steel, drawn to the other, and removed. This is repeated several times. Or, two magnets may be used: opposite poles are placed together at the centre of the piece of steel and drawn apart several times. Determine the character of each pole of the magnetized piece of steel.

(*h*) When a magnet is broken across, each of the new ends thus formed is a pole, one being + and the other –. Each of the pieces is thus a complete magnet having both poles.

Place two similar magnets in line with the + pole of one a few centimeters from the – pole of the other. Show the lines of force and note how they change when these poles are brought together.

71. Declination and dip.

The fact that a freely suspended magnet assumes a definite position may be explained by the assumption that the earth is a magnet having its south magnetic pole in the Arctic regions and its north magnetic pole in the Antarctic regions. All magnets are in the earth's magnetic field and tend to take the direction of the lines of force passing through them. A magnet like a compass needle, which can rotate about a vertical axis, sets itself in the direction of the horizontal component of the line of force. The direction of the line of force varies from place to place. It is expressed by stating the declination and the dip. The declination is the angle which the horizontal component of the line of force makes with the geographic meridian. The inclination or dip is the angle which the line of force makes with the horizon.

(*a*) To measure the declination. Place a compass needle where it is away from the influence of other magnets or large masses of iron. Stretch a thread over it to mark its direction. Measure the angle which it makes with the geographic meridian as marked in the Laboratory. Express in degrees E. or W. (of north).

(*b*) To measure the dip. A needle is mounted upon a horizontal axis so that it swings in front of a vertical graduated circle. This is called a dipping needle. Adjust the circle until it lies in the plane of the magnetic meridian. Read the dip. Rotate the instrument through 180° and read again.

Reverse the needle in its bearings and make two more readings. The average of the four readings is the dip.

The four readings are taken to eliminate the effects of any error in placing the zero of the graduated circle and any lack of symmetry of the needle.

72. Induced magnetism.

Verify that:

(*a*) A piece of soft iron placed close to a magnet becomes a magnet, but loses this property when the magnet is removed. Show by filings or small pieces of iron.

(*b*) A piece of hard iron or steel in the same circumstances becomes less strongly magnetized but retains a considerable portion of its magnetism.

(*c*) A piece of soft iron held in the direction of the earth's magnetic force becomes a magnet. Test its polarity. Does its polarity change when it is rotated through 180°?

(*d*) A piece of steel held in the direction of the earth's magnetic force becomes magnetized if hammered. Test its polarity. Does its polarity change when it is rotated through 180°?

73. The lines of force of a magnet.

(*a*) Fasten a magnet to a large sheet of paper with soft wax or gummed paper and turn the sheet until the magnet lies nearly east and west Make a dot upon the paper near one pole of the magnet. Bring one pole of a compass needle over the dot and make a second dot to mark the position of the other pole. These two dots give the direction of a line of force at this place. Move the compass needle forward its own length and so continue the row of dots until it returns to the magnet or reaches the edge of the paper. Then draw a smooth curve among the dots, and mark it with arrows to show the directions in which the needle pointed. Trace two or three other lines in the same manner in different parts of the field.

The lines of force obtained in this way give the directions of the resultant of the forces due to the fixed magnet and the earth together.

(*b*) Fasten a thread about a centimetre above the table in the direction of the magnetic meridian, so that the sheet of paper carrying the magnet may be moved about under it. Plot lines of force as before, but turn the paper each time until the compass needle is parallel to the thread before marking its direction. The compass needle is then in the direction of the earth's magnetic field. Hence the force due to the magnet must have the same direction as that due to the earth. Thus the lines obtained show the directions of the magnetic force due to the magnet alone.

Compare the lines thus obtained with those found in (*a*).

(*c*) Taking any point, *P*, upon one of the curves found in (*b*), draw lines *PA* and *PB* joining it to the poles, *A* and *B*, of the magnet. Upon these lines mark points *C* and *D*, such that

$$PC : PD = \frac{1}{PA^2} : \frac{1}{PB^2}.$$

Show that *CD* is parallel to the tangent to the line of force at *P*. State the meaning of this relation.

74. Period of vibration of a magnet.

If the strengths of the poles of a magnet are $+m$ and $-m$ and their distance apart is l, the product ml is called the moment of the magnet (M). Let this magnet be suspended, so that it can rotate about a vertical axis, where the horizontal intensity of the earth's field is H. It is acted upon by two forces, each equal to mH, one acting north at the $+$ pole, the other south at the $-$ pole. If the magnet is inclined at an angle θ to its normal position and the moment of this couple is L.

$$L = mHl \sin \theta$$
$$= MH \sin \theta.$$

If I is the moment of inertia of the magnet about the axis of rotation, its angular acceleration is $MH \sin \theta / I$. If θ is small, this may be written $MH\theta / I$. Hence the motion of a magnet slightly displaced from its position of rest is simple harmonic and the p[illegible] (T) is given by

$$T = 2\pi\sqrt{(I/MH)}.$$

By allowing a magnet of regular form, for which I is known, to vibrate in the earth's field MH may be found. That is, H is determined in terms of M.

The magnet may be placed in a stirrup carried by a thread or fibre which has been freed from torsion by carrying for some time a body of the same weight as the magnet.

By allowing the same magnet to vibrate in different places variations of H may be determined. In this way determine how H varies in the laboratory, especially noting whether it is affected by the neighborhood of large masses of iron.

75. Comparison of magnetic moments.

If a magnet AB of length l and moment M $(=ml)$ is placed east and west with its centre r cm. east or west of a small magnet CD of length l' and

moment $M'(=m'l')$, a couple will act on the small magnet to deflect it from its normal direction. Suppose it deflected through an angle θ. We can calculate the moment of the couple acting upon it. The pole B repels the pole C with a force $mm'/(r-\frac{1}{2}l)^2$ and attracts the pole D with an equal force. These two forces form a couple whose moment is $mm'l' \cos\theta/(r-\frac{1}{2}l)^2$. The couple due to the pole A has a moment $-mm'l' \cos\theta/(r+\frac{1}{2}l)^2$. Writing M' for $m'l'$ the total moment acting upon the small magnet is

$$M'm \cos\theta \left\{\frac{1}{(r-\frac{1}{2}l)^2} - \frac{1}{(r+\frac{1}{2}l)^2}\right\} = \frac{2MM'r\cos\theta}{(r^2-\frac{1}{4}l^2)^2}.$$

If $\frac{1}{4}l^2$ is small in comparison with r^2, this may be written $2MM'\cos\theta/r^3$.

Arrange the two magnets, whose moments are to be compared, in line, one east and the other west of a suspended magnet, having their like poles turned in opposite directions. Adjust their distances until the effect of one upon the suspended magnet exactly neutralizes that of the other. Then their moments are proportional to the cubes of the distances of their centres from the suspended magnet.

76. Determination of "H" and "M."

From the theory given in the last two experiments it appears that a magnet of moment M placed east or west of a small suspended magnet of moment M' deflects it through an angle θ such that the couple due to the magnet is equal to that due to the earth's field.

$$\therefore 2MM' \cos \theta / r^3 = M'H \sin \theta$$
$$\therefore M/H = \tfrac{1}{2} r^3 \tan \theta.$$

The product, MH may be determined by observing the period of vibration of the deflecting magnet as in experiment 74. Hence M and H may be calculated.

1. From the value of H obtained and the dip calculate the total intensity of the earth's magnetic field.

VII.

ELECTRICITY.

77. Properties of electrified bodies.

Verify the following:

(*a*) An ebonite rod which has been rubbed with flannel attracts light bodies such as pieces of paper or a pith ball hanging by a silk thread. The rod is said to be electrified. A glass rod which has been rubbed with silk is also electrified.

If the electrified ebonite rod is suspended in a stirrup so that it can move freely, it is attracted towards the hand or any metal body held towards it.

(*b*) The electrified ebonite rod suspended as in (*a*) is repelled by a second electrified ebonite rod held near it but is attracted by a glass rod which has been rubbed with silk.

Hence, like magnetism, electricity is said to be of two kinds, and similarly charged bodies repel one another while those oppositely charged attract.

(*c*) A pith ball suspended by a silk thread illustrates the same fact. If an electrified ebonite rod is held near, it is drawn to the rod, but upon contact becomes electrified and is repelled from the ebonite but attracted to the glass rod.

The electricity produced upon glass by friction with silk is arbitrarily called positive. It will be shown in another experiment that the silk used to rub the glass is negatively electrified, and that both kinds of electricity are produced together in equal quantities.

Determine the kind of electrification when glass, ebonite, sealing wax, etc., are rubbed with fur, silk, flannel, etc.

(*d*) When a gold leaf electroscope is touched by an ebonite rod very slightly charged the leaves diverge. State the reason. (Care must be taken not to give the electroscope too great a charge or the leaves may be torn off.)

The gold leaf electroscope is thus a sensitive detector of electrification.

(*e*) A charged electroscope is discharged by touching it with the hand, or a piece of metal, or wet string held in the hand. It is not discharged when touched by dry glass, ebonite, sealing wax, or silk. State the difference between these classes of bodies. Touch the electroscope with a piece of "red fibre" held in the hand. To which class does it belong.

78. **Induction.**

Throughout this and the two following experiments make rough diagrams of the apparatus in every case, showing the positions of electric charges by + and − signs. Care must always be taken not to give an electroscope too great a charge or the leaves may be torn off.

(*a*) Rub an ebonite rod lightly with flannel and touch it to the disc of an electroscope so that the latter becomes negatively charged. Then charge the rod more strongly and bring it near the electroscope without touching. Note the motion of the leaves. State how to recognize the sign of a charge by an electroscope. Also how to determine the sign of the charge of the electroscope.

To study the charge upon any body an insulated metal ball or proof plane may be touched to it and then carried to the electroscope.

(*b*) Suspend a metal rod by silk threads and bring a charged body near one end. Test with a proof plane the charge induced upon each end of the metal rod. Test also the middle of the rod.

Keeping the charged body in the same position touch the metal rod with the hand and again test the charge upon each end.

(*c*) Hold a charged ebonite rod over an electroscope and momentarily touch the disc with a finger.

Explain the motion of the leaves as the rod is moved. How is the electroscope charged?

(*d*) Charge the ebonite plate of an electrophorus. Test the sign of the charge by a proof plane and electroscope. Holding the metal plate of the electrophorus by the insulating handle, lay it upon the ebonite. Remove it and test the sign of its charge.

Again lay it upon the ebonite and touch the knob with a finger. Remove it and test its charge with a proof plane. Explain.

(*e*) Explain the transformation of energy involved in using an electrophorus.

(*f*) Set a Leyden jar upon an insulating plate and charge its inner coating by several sparks from an electrophorus. Discharge it by touching with a finger.

Holding the inner conductor with the hand, charge the outer coating with the electrophorus and discharge it as before. Explain.

Hold the Leyden jar in the hand, holding it by the metallic coating. Charge the inner coating by several sparks from an electrophorus. Discharge by touching it with the finger. Explain.

Why is the Leyden jar called a condenser ?

79. Electric machines.

(*a*) Examine the working of any induction machine. Test the sign of each charged part with a proof plane and make a diagram showing the charges and the parts in which positive and negative electricities are separated by induction.

(*b*) Test the effect of the condenser of the electric machine upon the character of the sparks.

(*c*) Explain the transformation of energy involved in the action of the machine.

80. Properties of a closed conducting surface.

(*a*) Set an electroscope upon a metal plate and place over it a wire cage. Charge the cage by sparks from an electric machine. What is the effect upon the electroscope?

(*b*) Connect the disc of an electroscope to an insulated can at a little distance by a copper wire. Holding a metal ball by a silk thread, charge it by an electrophorus or electric machine and lower it into the can without allowing it to touch. Remove it. Explain the action of the electroscope. Draw a rough diagram indicating charges by + and − signs.

(*c*) As before lower the charged ball into the can, and while it is there touch the outside of the can with a finger. Remove the ball. Explain.

(*d*) Discharge the electroscope. Again lower the charged ball into the can and let it touch the bottom. Remove the ball and test by a second electroscope whether it is charged. Explain.

(*e*) Discharge the electroscope. Lower the charged ball into the can. Touch the outside of the can. Then touch the ball to the bottom of the can. Remove the ball and test its charge. Is the can now charged?

(*f*) Attach a piece of flannel to an insulating rod, and rub one end of an ebonite rod with it. Hold the flannel and the rubbed part of the ebonite rod inside the can. What is the effect upon the electroscope? Remove and replace first one and then the other without touching the can. What do you learn regarding the charges developed by friction?

81. The Voltaic cell.

Place a strip of zinc and a strip of copper in a dilute solution of sulphuric acid without touching one another. If the zinc is pure there is no effect until the zinc and copper are connected by a wire. Then chemical action commences and the zinc dissolves in the acid. At the same time the wire acquires the property of influencing a magnet in its neighborhood. An electric current is said to flow through the wire from the copper to the zinc and through the solution from the zinc to the copper. This combination is called a simple cell, the copper being called the positive and the zinc the negative pole.

In a simple cell the current soon dies away as the copper plate becomes coated with a layer of small bubbles of hydrogen displaced from the sulphuric acid by the zinc. This is called polarization. If the bubbles are removed with a brush the current is renewed.

The energy of the electric current is derived from the energy set free in the chemical action in which zinc displaces hydrogen from the sulphuric acid to form zinc sulphate. The copper plate, in this form of cell, takes little part in the chemical action but serves to convey the current from the solution to the wire. It may be replaced by platinum or hard carbon without affecting the action of the cell.

The simple cell is of little practical use because it polarizes so rapidly. To prevent polarization some agent which combines with hydrogen, as bichromate of potash, may be added to the solution. It is called a depolarizer. A great variety of useful cells is obtained by varying the chemical action and the means of depolarization.

Examine a few of the more common primary cells, noting the metals and solutions used, the chemical reactions which furnish the energy of the current, and the means of depolarization.

[Remarks upon the use of currents in experiments.

As a source of current in the following experiments any of the common forms of cell may be used, as a "dry cell," Daniell cell, bichromate cell, etc. When a constant current is required for some time an Edison-Lalande cell, or a storage cell, should be used.

In any case the current should not be allowed to flow any longer than is necessary, both because it wastes the materials of the cells, and also because the electromotive force of the cell changes on account of polarization. Generally in an experiment current is required for only a few seconds at a time. It is best therefore to have a key in the circuit by which connection can be made when required and broken as soon as the observation is made.

Cells must never be short circuited.

Another point must be kept in mind when using an electric current. Too great a current, even if lasting only an instant, will destroy electrical instruments such as galvanometers and resistance boxes. Care must therefore always be taken, before connecting any circuit, to see that the current will not be greater than the instruments can carry. This is specially necessary when using current from a dynamo or storage battery. But any form of cell will give sufficient current to destroy a millivoltmeter or sensitive galvanometer, if connected to it with insufficient resistance. Until a knowledge of the conditions which determine the magnitude of a current and of the currents which instruments can carry safely is acquired, it is best to consult an instructor before making connections.

In making connections the ends of wires should be scraped clean. Otherwise the film of grease and oxide offers sufficient resistance to interfere with accurate measurements. Binding posts, connectors, the plugs of resistance boxes, etc., may also require cleaning to make good contact.]

82. The magnetic effect of a current.

An electric current flowing through a straight wire creates a magnetic field in the surrounding space, such that the magnetic lines of force are circles having their centres in the wire. The sense of the magnetic lines is related to the direction of the current in the same way as the sense of the twist given to a right handed screw is related to the direction in which the screw advances. Thus a

right handed screw at *O*, rotated in the sense indicated by the arrow-heads, *A*, *B*, *C*, will advance downwards into the paper. If the downward direction is considered positive, the right handed rotation about it, *ABC*, is also considered positive. Then if a current flows through *O* vertically downwards into the paper, the magnetic lines have the sense *ABC*.

From this it follows that if a current flows round a loop of wire in the right handed sense (*ABC*) the lines of force inside are in the positive direction (downwards). Outside the loop the lines have the opposite direction.

In each of the following cases explain the direction of the magnetic force by the rule just given.

(*a*) Hold a wire carrying a current north and south over a compass. Hold the compass over the wire. Hold the wire east and west. Repeat with the current flowing in the opposite direction.

(*b*) Hold a portion of the wire vertical and examine the magnetic field near it. Repeat with the current flowing in the opposite direction.

(*c*) Bend the wire into a loop and placing it in the magnetic meridian hold the compass inside it. Reverse the loop in the same plane. Also hold it in a plane perpendicular to the magnetic meridian.

(*d*) Form a solenoid by winding a layer of insulated wire upon a glass tube. Show that the lines of force resemble those of a bar magnet. How is the north pole related to the sense of the current?

What is the effect upon a piece of soft iron placed inside the solenoid? How is an electromagnet formed?

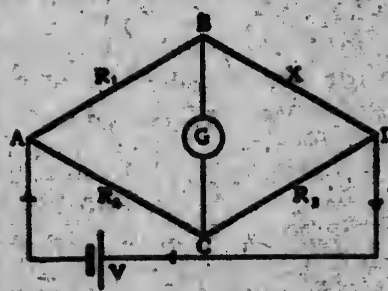
(*e*) Examine a simple galvanometer. How does it detect and measure currents?

82. Comparison of resistances—Wheatstone's bridge.

The function of a cell is to create a difference of potential or electromotive force. The current which flows depends upon the electromotive force and the resistance of the circuit. The relation between these three quantities is given by Ohm's law which states that if E is the electromotive force in a circuit, or in any portion of a circuit, R the resistance of the circuit or portion, and i the current, then

$$E = iR.$$

To compare resistances four conductors are connected as the sides, AB, BD, AC, CD, of a quadrilateral. The junctions A and D are connected to a cell (V) and the junctions B and C to the terminals of a galvanometer (G). This arrangement of conductors is called a Wheatstone's net. The resistances may be so adjusted that no current flows



through the galvanometer. In this case B and C are at the same potential. Let i_1 be the current through AB and BD, i_2 the current through AC and CD, V_1 the potential of A, and V_2 that of D. Also let R_1, R_2, R_3, and X, be the resistances of the corresponding sides of the quadrangle.

Then Potential at $B=V_1-i_1R_1=V_2+i_1X$

and " " $C=V_1-i_2R_2=V_2+i_2R_3$

But " " $B=$ Potential at C.

$$\therefore i_1R_1=i_2R_2$$

and

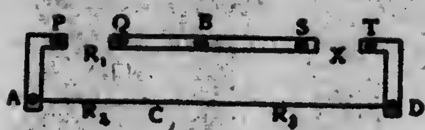
$$i_1X=i_2R_3.$$

$$\therefore \frac{X}{R_1}=\frac{R_3}{R_2}$$

or

$$X=R_1R_3/R_2.$$

In practice this arrangement is facilitated by the use of a metre bridge, which consists of a uniform wire (generally one metre long) stretched between two points A and D and a system of heavy copper strips AP, QS, and TD, with binding posts at A, P, Q, B, S, T, and D.



The battery is connected to A and D. The unknown resistance X is connected between the binding posts S and T, while the resistance R_1 with which it is to be compared is placed between P and Q. One terminal of the galvanometer is connected to B, while the other makes contact with the wire AD at such a point C that the galvanometer gives no deflection. Since the wire is uniform the resistance of any part is proportional to its length.

$$\therefore R_3 : R_2 = CD : AC.$$

$$\therefore X = \frac{CD}{AC} R_1.$$

If R_1 is a known resistance X is known.

Another form of Wheatstone's bridge consists of a box of resistance coils, arranged in three series corresponding to R_1, R_2, and R_3 so that any coils of the corresponding series may be placed in each arm of the bridge.[1]

There should be a key in the galvanometer circuit as well as one in the battery circuit, and the battery key should be closed first so that the current reaches a steady condition before connection is made with the galvanometer.

(*a*) Take three pieces of wire,—german silver, brass, or iron. Call their resistances A, B, and C. Measure B and C in terms of A. Join B and C in series and show that the resistance is $B+C$. Insert B and C in parallel and show that the resistance (D) of the pair is given by

$$\frac{1}{D} = \frac{1}{B} + \frac{1}{C}.$$

(*b*) Compare the resistances of two wires of different materials. Measure their lengths and diameters. Assuming that the resistance is proportional to the length and inversely proportional to the area of the cross-section, calculate the ratio of the resistances of two similar wires of these materials. This is the ratio of the specific resistances.

(*c*) Measure the resistance of a piece of wire by comparison with a resistance box or standard coil. Measure the length and diameter. Calculate the resistance of a block of the same material 1 cm. long and 1 sq. cm. in section. This is the specific resistance of the substance.

84. Comparison of electromotive forces.

In a galvanometer in which the magnet moves while the coil is stationary the tangent of the deflection is proportional to the current. In a galvanometer in which the coil moves while the magnet is stationary the deflection is more nearly proportional to the current. The latter condition may also be assumed to hold for a mirror galvanometer in which the deflections used are always comparatively small.

(*a*) The electromotive forces of two cells may be compared by comparing the currents they will send through the same circuit. Connect one of the cells in series with a galvanometer and sufficient resistance R to give a convenient deflection, θ_1. Connect the second cell in the same circuit. Let the deflection be θ_2. Then if E and F are the electromotive forces of the cells

$$E : F = \tan\theta_1 : \tan\theta_2.$$

Again change the resistance until the deflection is the same as that given by the first cell. Let it now be S.

$$\therefore E : F = R : S.$$

Each of these methods neglects the resistance of the cell and the latter neglects that of the galvanometer also. The results are therefore not reliable unless these are both small in comparison with the known resistance in the circuit. In the two following methods the effects of the resistances of the cell and the galvanometer are eliminated.

(*b*) Connect the two cells to be compared in series with a galvanometer and sufficient resistance to give a suitable galvanometer deflection. Let E and F be the electromotive forces of the cells, then $E+F$ is the total E.M.F. in the circuit. Let the galvanometer deflection be θ_1. Then reverse the connections of one cell, so that the total E.M.F. is $E-F$. Let the deflection be θ_2. Since the resistance of the circuit is unchanged,

$$\frac{E+F}{E-F}=\frac{\tan\theta_1}{\tan\theta_2}$$

from which $E:F$ may be found.

If the galvanometer has a moving coil, the angles should be used instead of their tangents.

(*c*) Connect one cell (E.M.F. $=E$) to a resistance box and galvanometer. Adjust the resistance until the deflection is a convenient angle (θ_1). Suppose the total resistance, including cell and galvanometer to be r, then the current is E/r. Add resistance (R) until the deflection becomes θ_2.

Connect the second cell (E.M.F. $=F$) in the same way. Adjust the resistance until the deflection is θ_1. Suppose the total resistance now to be s. Add resistance (S) until the deflection becomes θ_2.

$$\therefore \frac{E}{r}=\frac{F}{s}$$

and
$$\frac{E}{r+R}=\frac{F}{s+S}$$
$$\therefore E:F=R:S.$$

(*d*) Connect the cell of higher E.M.F. ($=E$) in series with two large adjustable resistances R and S. Call A and B the terminals of the resistance R. Connect the second cell (E.M.F. $=F$) in series with a galvanometer and resistance (T) to the points A and B so that it would tend to send a current through R in the same direction as E. The difference of potential between A and B due to the cell E is $RE/(R+S)$. If this is equal to F no current will flow through the galvanometer.

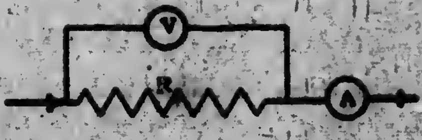
In making the comparison the cells are connected as described and R and S are adjusted until the galvanometer gives no deflection. Then
$$E:F=R+S:R.$$

The resistance T serves to protect the galvanometer from large currents before the resistances are adjusted. It should be reduced and finally cut out as the adjustment becomes nearly correct. The advantage of this method is that no current is flowing through the cell F when the comparison is made.

85. Measurement of resistance with ammeter and voltmeter.

A galvanometer may be arranged to read the current passing through it directly in amperes. It is then called an ampere-meter or ammeter, or, if designed for very small currents a milli-ammeter. A voltmeter is a similar instrument having a much higher resistance. The current flowing through it is proportional to the difference of potential of its terminals, and its scale is graduated to read this difference of potential directly in volts. On account of its high resistance very little current flows through it. A millivoltmeter is a similar instrument of greater sensitiveness and smaller resistance.

To measure a resistance the ammeter and voltmeter are arranged as shown in the diagram. If R is the coil whose resistance is to be measured,



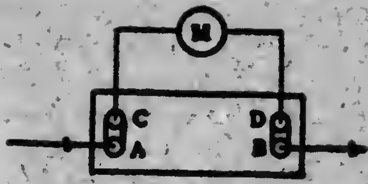
the ammeter, A, indicates the current (i) passing through it, while the voltmeter V indicates the difference of potential (E) at its terminals. The resistance R is given by the equation

$$E = iR.$$

This assumes that the resistance (V) of the voltmeter is very large compared with R. If this is not the case, the true resistance of the coil is S where

$$\frac{1}{S} = \frac{1}{R} - \frac{1}{V}.$$

A millivoltmeter with a suitable shunt is frequently used to measure currents instead of an ammeter. The shunt is a coil whose resistance is a certain fraction of that of the millivoltmeter, having two terminals at each end. The circuit is connected to one pair of terminals, *A* and *B* while the millivoltmeter is connected



to the other pair *C* and *D*. The resistance of the shunt is such that the scale of the millivoltmeter reads the current directly in amperes or fractions of amperes.

(*a*) Measure the resistance of the coils of a rheostat with ammeter and voltmeter, using current from a dynamo or storage battery.

(*b*) Measure the resistance of an incandescent lamp for various values of the current. Connect the lamp in series with a variable resistance and a shunted millivoltmeter reading to 1 ampere. Attach to the lighting circuit. Connect a voltmeter to the terminals of the lamp. Take a series of readings varying the current as greatly as possible. Plot a curve connecting the resistance of the lamp and the current through it. How is the resistance of carbon affected by change of temperature?

86. Measurement of E.M.F. and resistance of a cell with a millivoltmeter.

Let the E.M.F. of the cell be E volts and its resistance r ohms. Let m be the resistance of the millivoltmeter (as marked upon its certificate). Connect the cell in series with a resistance box containing coils up to 1000 ohms and the millivoltmeter. Adjust the resistance until the millivoltmeter reads some definite number of millivolts, say a. Let the resistance in the box be R. Change the resistance until the reading is b millivolts. Let the resistance now in the box be S ohms.

$$\therefore E : R+r+m=a : 1000\,m$$

and $$E : S+r+m=b : 1000\,m,$$

From which $$E=\frac{ab\,(R-S)}{1000\,(b-a)\,m}$$

and $$r=\frac{aR-bS}{b-a}-m.$$

To obtain the best results b should be nearly as large as the instrument reads and a should be approximately half as great.

87. The chemical action of a current.

The law of electrolysis is that the quantity of any ion liberated is proportional to the quantity of electricity which passes and to the chemical equivalent (atomic weight ÷ valency) of the ion. The ampere is defined as the current which deposits 0·001118 grams of silver per second from a solution of a silver salt. Since the chemical equivalent of silver is 107.94, the quantity of electricity which will deposit one gram equivalent of silver (107·94 grams) is 107·94 ÷ 0·001118 or 96550 coulombs. This quantity of electricity liberates a gram equivalent of any ion; for instance it liberates 1 gram of hydrogen from dilute sulphuric acid, or deposits 63/2 or 31·5 grams of copper from copper sulphate solution.

To measure the hydrogen liberated from a dilute solution of sulphuric acid, two platinum wires are sealed into a glass vessel, and a graduated glass tube filled with water is inserted over the kathode, in which the hydrogen is measured as it is generated. This tube may be changed as often as is necessary. The instrument is called a water voltameter.

To measure the copper deposited from a solution of copper sulphate a copper voltameter is used. This consists of a vessel of copper sulphate solution (to which a few drops of sulphuric acid have been added), with three parallel copper plates dipping into it. The centre plate should be the kathode, the outer plates being connected to form the anode. If the kathode is a new plate it should be cleaned with sandpaper, washed with caustic potash, then with dilute nitric acid, then with distilled water, and dried. It should then be weighed as accurately as possible and placed in the voltameter.

Connect water and copper voltameters in series with a millivoltmeter and shunt, a suitable resistance, and a few storage cells. Note the time of starting the current and read the current every minute or half minute for about half an hour. Note the time of stopping the current. Measure the hydrogen liberated, noting its temperature and pressure. Dry and weigh the copper kathode to find the amount of copper deposited. Calculate from each the number of coulombs which have passed and the mean value of the current. Compare with the mean of the millivoltmeter readings and calculate the correction factor which should be applied to the latter.

88. The heat produced by a current.

The heat produced in 1 second by a current of i amperes flowing between two points at a difference of potential of E volts is Ei joules or $10^7 Ei$ ergs. E and i can be measured with an ammeter and a voltmeter. The heat may be generated in a calorimeter and measured in calories. By comparing the measurements J, the number of ergs in a calorie, can be calculated.

Place in a metal calorimeter a thermometer and enough water to cover an incandescent lamp. Let m be the mass of the water and w the water equivalent of the lamp, calorimeter, and thermometer. Connect the lamp to the lighting circuit in series with an ammeter and switch, and connect a voltmeter to its terminals. Read the temperature of the water, T. Close the switch and note the time. Read the ammeter and voltmeter every half minute and stir frequently. When the temperature of the calorimeter has risen 10° or 20°, open the switch, and note the time and the temperature of the calorimeter, T'. Allow the calorimeter to stand for a few minutes, stirring and reading the temperature every half minute. Calculate the number of degrees (φ) it would fall at this rate during the experiment.

The average value of Ei multiplied by the time and by 10^7 is the number of ergs generated. The heat received by the calorimeter is

$$J(m+w)(T'-T+\tfrac{1}{2}\varphi) \text{ ergs.}$$

Calculate the value of J.

89. The polarization of a cell.

An open circuit cell, such as a Leclanché, which polarizes rapidly, should be used.

Arrange two circuits through the cell, one (A) containing a resistance of several hundred ohms and a galvanometer, the other (B) containing a resistance of a few ohms and a key. On account of the constant high resistance in its circuit, when the key is open the galvanometer deflection is proportional to the E.M.F. of the cell.

Connect the cell to circuit A and read the deflection. Then close the key in circuit B and let it stand for 1 minute. Then open the key, read the galvanometer as quickly as possible, and again close the key. Continue to read the E.M.F. at intervals of 1 minute until the readings become constant, keeping the current flowing through the low resistance circuit B except during the brief intervals required to read the galvanometer. Then open the key and read the E.M.F. every minute as the cell recovers. When the E.M.F. has risen considerably close the key again and take readings as before.

Plot curves connecting deflections and times to show the rates of polarization and recovery of the cell.

90. The temperature coefficient of resistance.

Place a coil of wire and a thermometer in a test tube of oil, connect it with heavy wire in one arm of a Wheatstone's bridge, and immerse the tube in a water bath. Measure the resistances of the coil at various temperatures. Plot the values of the resistance corresponding to the various temperatures and draw a straight line among them. From this line read the resistances R_1 and R_2 of the coil at temperatures t_1 and t_2. Then if R is the resistance of the coil at 0°, and a its temperature coefficient,

$$R_1 = R(1 + at_1)$$

and

$$R_2 = R(1 + at_2),$$

from which a can be calculated.

91. Induced currents.

Using a ballistic galvanometer find the direction of the current through it which corresponds to a deflection in each direction. This may be done by connecting the galvanometer terminals to two points of a wire through which a current is flowing in a known direction.

(*a*) Connect the ends of a coil of wire a few centimetres in diameter to the galvanometer terminals. Thrust the north pole of a magnet into the coil. In which sense does the induced current flow round the coil? Would the magnetic field due to the induced current have the same direction as that due to the magnet introduced or the opposite? Withdraw the magnet. How does the deflection compare with the previous one? Repeat with the south pole of the magnet.

(*b*) Connect with the same galvanometer a coil of greater area. Place the coil in the plane of the magnetic meridian and rotate it quickly through 180°. Place it in a vertical plane perpendicular to the magnetic meridian and rotate it through 180°. State in each case what change was made in the number of magnetic lines passing through the coil.

Place a paper arrow or other mark upon the inside of the coil to indicate one direction of the axis as positive. Also place an arrow upon the circumference to denote the corresponding right handed sense. (See Exp. 82.) When the number of magnetic lines passing through the coil in the positive direction is increased, does the current induced by the change flow round the coil in the right handed or in the left handed sense? Test this in all the above cases.

(*c*) Arrange two coils *A* and *B* so that one may be placed coaxially over the other. Connect *A* in series with a cell, resistance box, and key. Connect *B* with the galvanometer. Close the key in *A* and note the galvanometer deflection. Open the key again and note the deflection. What was the direction of the magnetic force through the coils produced by the current in *A*? What was the sense of the current in *B* induced by starting the current in *A*? Was the magnetic force due to the induced current in *B* in the same direction as that due to the current in *A*?

(*d*) Close the key. When the galvanometer has come to rest, remove the coil *B*. What is the direction of the induced current? Replace the coil.

(*e*) Add resistance to circuit *A* until the galvanometer deflection obtained on closing the key is as small as can be easily observed. Place a core of soft iron inside the coils and close the key. What is the effect of the iron core?

Describe the construction of an induction coil.

92. The distribution of magnetism along a magnet.

A small coil of wire surrounds a magnet and is arranged to slide along the magnet any desired distance. It is connected with a ballistic galvanometer, and moved, say 1 cm., along the magnet. The throw of the galvanometer measures the change in the number of magnetic lines threading the coil, that is the number of lines which leave the magnet in that centimetre. Neglecting damping, the quantity of electricity passing through a ballistic galvanometer is proportional to the sine of half the first deflection. If the deflection is comparatively small, as in a reflecting instrument, this is practically proportional to the deflection.

By attaching to the magnet a clamp of non-magnetic material which permits the coil to move 1 cm. and shifting it 1 cm. at a time along the magnet, the number of lines leaving or entering the magnet in each centimetre is measured. The number of lines leaving the magnet at the end is measured by placing the coil so as to encircle the end of the magnet and quickly removing it to a distance.

Plot a curve with distances from one end of the magnet as abscissae such that the area bounded by the curve and any two ordinates is proportional to the number of lines which leave or enter the magnet in the corresponding interval.

93. To map a current sheet.

Place a large glass bottomed vessel over a sheet of co-ordinate paper having the centimetre lines numbered in both directions from one corner of the vessel. Have a second sheet of co-ordinate paper with the lines similarly numbered and draw upon it the outline of the vessel. Level the bottom of the vessel and pour in enough acidulated copper sulphate solution to cover it to a depth of 2 or 3 millimetres. Connect the secondary of a small induction coil to two copper plates dipping into the solution at opposite ends or sides of the vessel. Mark their position upon the second sheet. Connect a telephone to two copper wires dipping into the solution. Leaving one of these wires at some marked point move the other about and find a series of points at which the telephone is silent. Mark these upon the second sheet of coordinate paper and draw a line through them. Points upon this line are always at the same potential. Plot a series of such lines. Also draw a set of lines cutting the former set at right angles.

94. The specific resistance of an electrolyte.

The electrolyte should be contained in a glass tube of known internal diameter. A stout wire should be passed through a cork at each end and carry a platinum disc which fits the tube loosely. The distance between the discs is thus adjustable. The wires are connected in one arm of a metre bridge. To avoid polarization an alternating current must be employed, so that a small induction coil is used instead of a cell, and a telephone instead of a galvanometer. The bridge is adjusted until the telephone is silent when the resistance is calculated in the usual way. The resistance obtained is divided by the distance between the discs and multiplied by the section of the tube to give the specific resistance. Since an alternating current is used all connecting wires should be short and straight to make their inductance as small as possible.

95. Comparison of electric capacities.

When two condensers are charged by the same battery their charges are proportional to their capacities. The ratio of their charges may be measured by discharging them through the same ballistic galvanometer.

Arrange a double throw switch to connect one condenser either with a number of cells in series, by which it is charged, or with a ballistic galvanometer, through which it is discharged. Charge the condenser, then discharge it through the galvanometer and observe the deflection. Treat the second condenser in the same way. The capacities are proportional to the sines of half the galvanometer deflections, or, if these are small, they are proportional to the deflections themselves.

1. Using different numbers of cells in series show that the charge of the condenser is proportional to the number of cells, that is, to the E.M.F. of the battery.

96. Thermo-electromotive forces.

Form a circuit of two wires of different materials. Place the junctions in baths by which they can be kept at any desired temperature. Connect in the circuit a sensitive galvanometer. When the baths are at different temperatures an electromotive force is produced, and if the circuit is closed a current will flow which may be measured with a galvanometer. But a galvanometer will detect a much smaller current than it will measure, so that it is better to balance the thermo-electromotive force by an adjustable electromotive force, and to use the galvanometer merely to show when the balance is exact. This may be done by leading the terminals of the thermo-electric circuit to two points, one fixed and one movable, upon a uniform wire carrying a constant current. The movable contact may then be adjusted until the galvanometer gives no deflection. The E.M.F. of the circuit is then proportional to the distance between the contacts.

Keeping one bath at a constant temperature, increase the temperature of the other, and read the E.M.F. every 10° until the highest available temperature is reached. Plot a curve connecting the electromotive force and the temperature of the hotter junction.

97. The permeability of iron.

If B is the magnetic induction in iron caused by a magnetizing force H, the ratio $B : H$ is called the permeability, and is denoted by the symbol μ. This ratio is not constant but varies with H. A curve must first be plotted connecting B and H. From it a curve may be calculated connecting μ and H.

A circular annulus of iron of radii r and R is uniformly wound with a primary coil of n turns of wire. When a current of i amperes flows through the coil, the magnetizing force is given by

$$H = \tfrac{4}{10}\pi ni / [\pi (R + r)]$$

or

$$H = 4ni / [10(R + r)].$$

This coil is connected in series with a source of current, an ammeter by which i is measured, an adjustable resistance, and a commutator by which the current in the coil can be reversed.

The iron ring is also wound with a secondary coil of m turns of wire connected in series with a ballistic galvanometer, an earth inductor, and a key. Any change in the magnetic induction in the iron ring is measured by the throw of the galvanometer. By comparison with the throw obtained by rotating the earth inductor, the number of lines (N) corresponding to any galvanometer throw is known absolutely. The change in B is obtained by dividing N by the area of the cross section of the iron.

Leaving the key open, so that the galvanometer is not affected, the commutator is rocked to and fro while the current is gradually decreased. The iron is thus demagnetized. The resistance is adjusted so that i has some small value and the commutator rocked a number of times. Then the key is closed, the commutator reversed, and the galvanometer deflection read. When the galvanometer has come to rest the commutator should be again reversed and the deflection read. The mean of these deflections represents a change of induction equal to twice the value of B corresponding to the magnetizing force $\frac{4}{10}ni/(R+r)$. The current should then be increased, the commutator rocked a number of times and the observation repeated as before. The object of rocking the commutator is to get the iron into a cyclic state.

The series of observations should be continued until the greatest current which can conveniently be used has been employed. The number of secondary turns, m, may be decreased as the current increases, to prevent the galvanometer deflections from becoming too great.

Plot a curve connecting B and H for the specimen of iron used. Also calculate the corresponding values of μ and plot a curve connecting μ and H.

98. The absolute measure of a current.

The measurements of current in previous experiments have been made either by direct reading of standard ammeters, or by determining the chemical action and comparing it with the commercial definition of the ampere. But the unit current in the c.g.s. electromagnetic system is defined by its magnetic effect. The ampere is one-tenth of the electromagnetic unit, and the fact that it deposits 0·001118 gram of silver per second has been found experimentally, and is adopted as a secondary definition because it is more convenient in practice. In opposition to this the direct measurement of a current in c.g.s. units by its magnetic effect is called absolute.

(*a*) The magnetic force due to a current i flowing round a circular loop of radius r, at a point on its axis x cm. from its plane is*

$$2\pi i r^2 / \sqrt{(r^2 + x^2)^3}.$$

The magnetic force due to a magnet of length l and moment M, at a point on its axis d cm. from its centre is

$$2Md / (d^2 - \tfrac{1}{4}l^2)^2,$$

or if l is small compared with d

$$2M/d^3.$$

Place a circular loop of wire in the plane of the magnetic meridian. Connect it in series with a galvanometer or ammeter, a constant source of current, and an adjustable resistance. Suspend a small magnet, having a mirror attached by which

*J. J. Thomson ; Elements of Electricity and Magnetism. § 218.

its deflection can be read, so that it is on the axis of the loop at a convenient distance (x) from its plane. Send a current (i) through the loop, and place a small bar magnet in the axis of the loop at such a distance (d) from the suspended magnet that it neutralizes the effect of the current upon it. Then

$$\frac{2\pi i r^2}{\sqrt{(r^2+x^2)^3}} = \frac{2M}{d^3}.$$

M is measured as in Experiment 76.

Calculating i from this equation, obtain the value of unit deflection of the galvanometer, or, if an ammeter was used, calculate the correction which should be applied to its readings.

(b) When the same current flows through two coaxial coils of radius r having n turns each and placed in parallel planes at a distance apart equal to the radius of either, the magnetic field near the axis halfway between the coils is nearly uniform and its intensity N is given by*

$$N = 32\pi n i/(r\sqrt{125})$$

or

$$N = 2{\cdot}862\pi n i/r,$$

Allow a small magnet to vibrate in this space and measure its period T. If the same magnet vibrates in the earth's field with period T'

$$N : H = T'^2 : T^2,$$

assuming that H is small compared with N.

Calculate N and i and determine the absolute value of the readings of the galvanometer or ammeter employed.

*Id. Th. § 211.

99. The E.M.F. induced in a rotating disc.

If a conducting circular disc of area A is rotated in a uniform magnetic field of intensity N with angular velocity ω, an electromotive force E is developed between its centre and circumference such that

$$E = AN\omega/2\pi,$$

E being expressed in c.g.s. electromagnetic units.

The uniform field may be obtained by placing the disc symmetrically between two parallel coils, each having n turns of radius r, r cm. apart. Its intensity N is proportional to the current through the coils or

$$N = Mi,$$

$$\therefore E = \frac{AM}{2\pi} i\omega.$$

A and M are constants and therefore E is proportional to $i\omega$.

E may be measured by forming a circuit from the axis and circumference of the disc through a galvanometer to two points B and C upon a wire carrying the current i. Adjust B and C until the galvanometer gives no deflection. Then if R is the resistance of BC in c.g.s. units,

$$E = iR.$$

(*a*) Rotating the disc at constant speed and varying the current, verify that R remains constant. That is, that the induced E.M.F. is proportional to the intensity of the magnetic field.

(*b*) By rotating the disc at various speeds, verify that R varies as ω. That is, that the induced E.M.F. is proportional to the speed.

100. The absolute measure of a resistance.

In the last experiment by equating the values of E, we have $R = AM\omega/2\pi$,
where, as in Experiment 98 (*b*),

$$M = 2{\cdot}862\,\pi n/r,$$

$$\therefore R = 1{\cdot}431\,An\omega/r.$$

Measure A, n, and r, and calculate the value of R, the resistance of the wire BC, in c.g.s. units. Compare with its value as found by comparison with standard coils.