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Elements of Physics
For Medical Students

Frederic Jas. M. Page, B.Sc.(Lond.) F.I.C.

ELEMENTS OF PHYSICS
FOR
MEDICAL STUDENTS
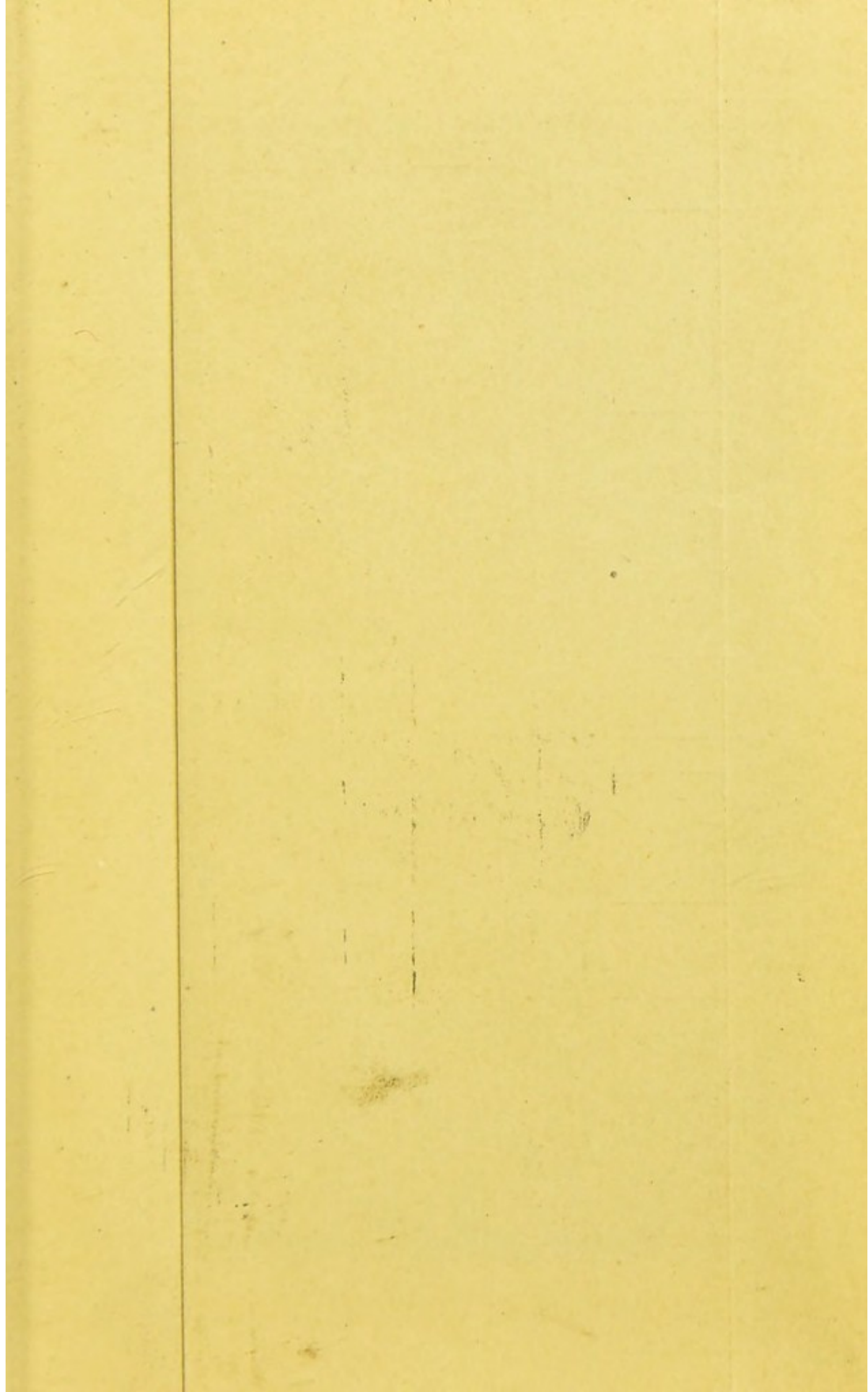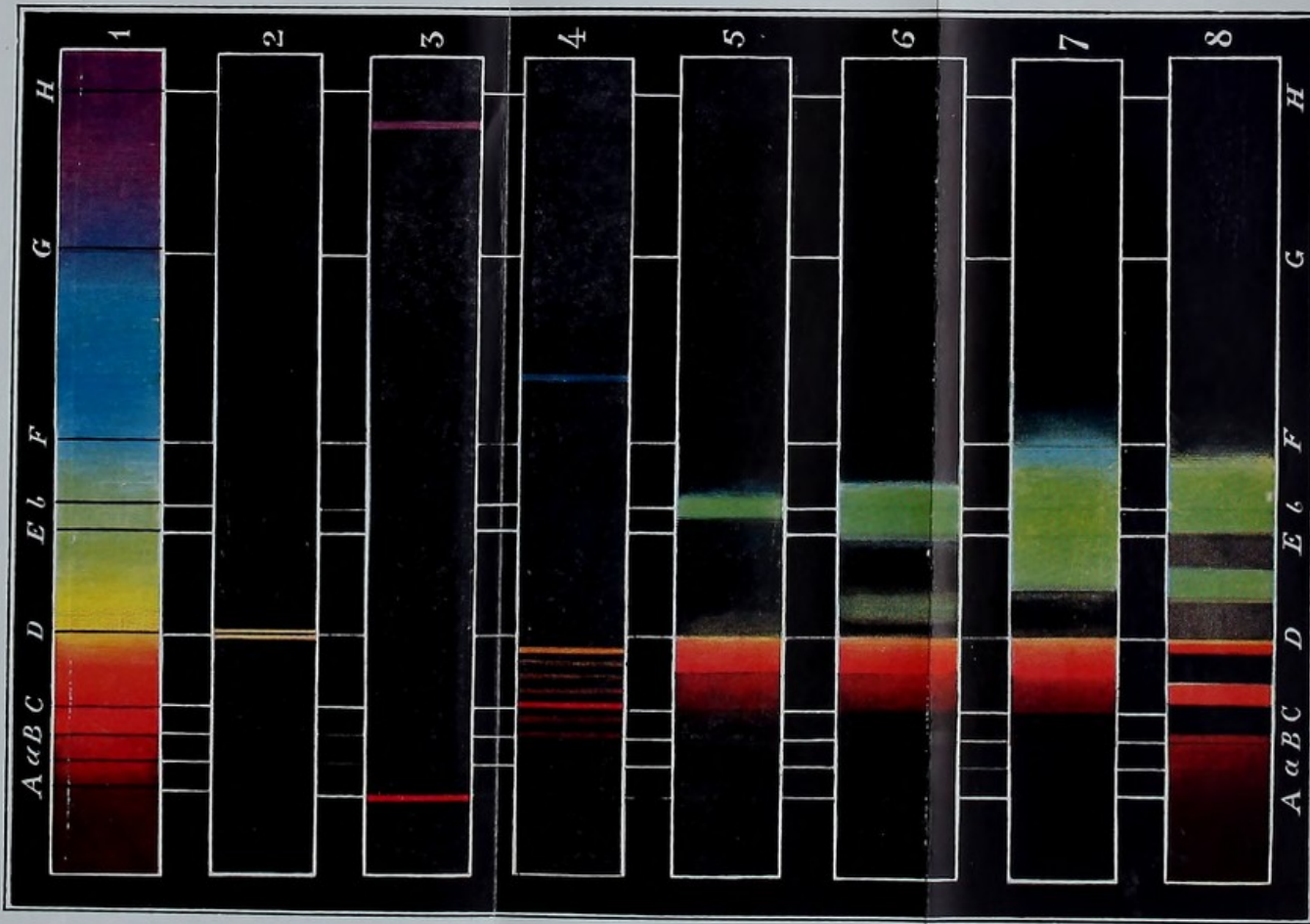
VARIOUS TYPES OF SPECTRA.

1, Continuous Spectrum with Fraunhofer's lines ; 2, Spectrum of Sodium ; 3, Do. of Potassium ; 4, Do. of Strontium ; 5, Absorption Spectrum of Arterial blood, diluted 1 in 250 ; 6, Do. diluted 1 in 400 ; 7, Same as No. 6, but deprived of Oxygen ; 8, Absorption Spectrum of Chlorophyll in Alcohol.
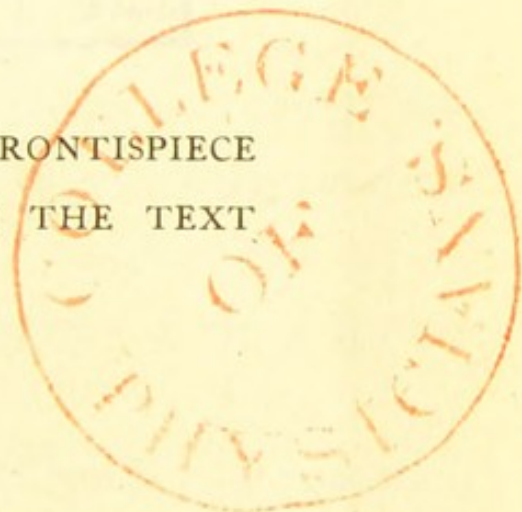
ELEMENTS OF PHYSICS

FOR MEDICAL STUDENTS

BY

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Apothecaries, London, etc.*

WITH A COLOURED FRONTISPIECE
AND 230 FIGURES IN THE TEXT

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MCMVII

PREFACE.

DURING some years' experience in teaching Physics at the London Hospital Medical College to the students intending to present themselves for the examinations of the Conjoint Board and the Society of Apothecaries, I have felt greatly the need of a suitable text-book which, while covering the syllabus of the above examinations, should bring into prominence those branches of Physics which might be useful to the student in his future career. The present work is an attempt to supply this need.

I have purposely endeavoured to keep the numerous illustrations as simple and diagrammatic as possible, so as to encourage the student to reproduce them when describing the various instruments and methods.

As it is essential to an intelligent understanding of the subject that the student should be brought into actual contact with the apparatus, and should practise the various measurements for himself, a short Practical Course has been added as Part VI.

The work is intended as a companion volume to the Manual of Chemistry by Dr. Luff and myself, and it is believed that the two books include all the Chemistry and Physics, both theoretical and practical, required by the Conjoint Board and the Society of Apothecaries.

F. J. M. P.

LONDON HOSPITAL MEDICAL COLLEGE,
TURNER STREET, E.

March, 1907.

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ELEMENTS OF PHYSICS.

Part I.

GENERAL PHYSICS.

CHAPTER I.

DISTINCTION BETWEEN PHYSICS AND CHEMISTRY—
THE THREE STATES OF MATTER—UNITS—VER-
NIER — MICROMETER SCREW — SPHEROMETER —
MEASUREMENT OF LIQUIDS.

Difference between Physics and Chemistry.
—If we take a bar of iron we can alter its appearance
and properties in several ways.
Thus (1) if we make it red
hot it acquires the property
of firing gunpowder, scorch-
ing wood, etc. (2) If we
wind a cotton-covered cop-
per wire round it (Fig. 1),
and pass a current of electri-
city through the copper wire,
the iron bar becomes mag-
netic, attracting iron nails.
(3) If we heat the end of

Fig. 1.—Electro-magnet.

the bar with an oxyhydrogen jet the iron obviously

B
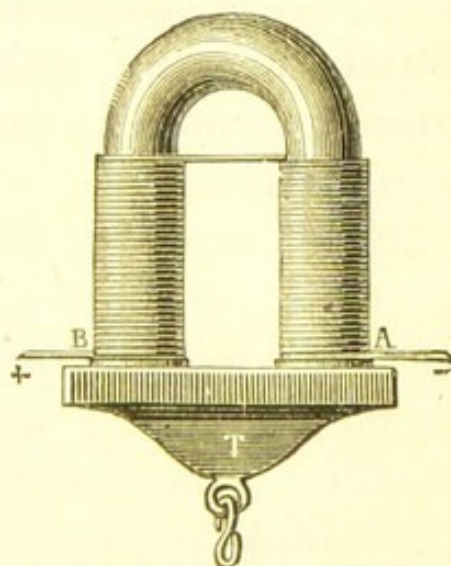
begins to burn, giving off sparks and forming scales of black oxide of iron. In this last experiment some of the iron has disappeared, and we have in its place black scales of a new substance. If we collect all the scales formed, they will be found to have a weight greater than the weight lost by the original bar of iron ; in fact, the iron has *combined* with the oxygen, and has been converted into the black or magnetic oxide of iron. This change is called a chemical change, and its study belongs to the domain of chemistry, because there has been a *change in the composition* of the iron.

After experiments 1 and 2 the iron remains practically unaltered. When a substance changes its properties, without any alteration in its chemical composition, such a change is termed a physical change, and we may define Physics as **an accurate study**, or, in its higher development, **an accurate measurement of all changes which matter undergoes, as long as such change produces no alteration in its chemical composition**.

Matter may be defined as that which occupies space. If we survey the various forms of matter presented to our senses, such as wood, iron, water, alcohol, air, etc., we find that it assumes three principal forms : *solid, liquid,* and *gaseous.*

A **solid** requires the exercise of some force to separate it into pieces, as in sawing wood, cutting iron ; a **liquid** separates with the exertion of a minimum force, as in passing the hand through

water; whilst in a **gas** the particles repel each other, so that they only approach when under the influence of some external force. Thus the particles of air in a popgun are at a certain distance from each other, this distance being determined by the weight of the atmosphere. If we close one end with a cork and force the piston in, we apply extra pressure, and the particles come closer together
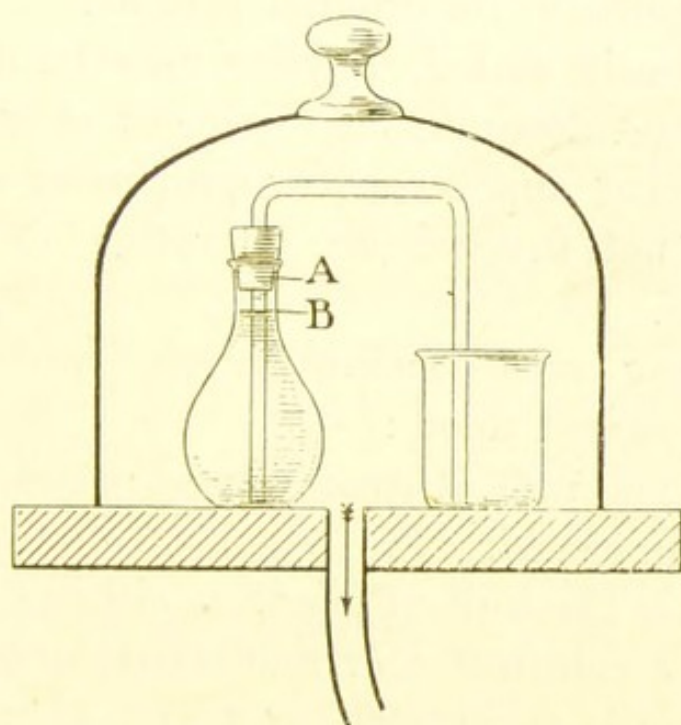
Fig. 2.—Experiment to show the expansion of a gas.

until the cork flies out, when, the pressure being relieved, the particles regain their original distance from each other. That the volume of a gas depends upon the pressure to which it is exposed can be well seen in the experiment shown in Fig. 2. A small volume of air is contained in a flask between A and B; the flask is furnished with a cork, through which passes a doubly-bent glass tube, one leg of which

reaches to the bottom of the flask, which is filled with water. The other leg reaches to the bottom of an empty beaker. The whole apparatus is placed under the bell-jar of an air-pump. If the pump be worked, the pressure on the confined air in the flask is removed and the volume of gas A B expands until it fills the whole of the flask, driving the water over into the beaker. If we let the air into the bell-jar the gas shrinks to its original volume.

As previously stated, Physics may be defined as the study and accurate measurement of all changes in the outward appearance or properties of matter which do not involve an alteration of chemical composition.

In making such measurements, various units have been agreed upon :—

Time.—The unit of time in most physical phenomena is the *second*.

Length.—The unit of length is either a metre (or sometimes a centimetre or millimetre) or a foot.

The metre is the length, at 0° C., of a platinum bar kept in the Bureau des Archives in Paris, and is equal to 39·37 inches. The centimetre is one-hundredth of this = ·3937 inch.

Weight.—The unit of weight is either the gram, the kilogram, or the pound.

The weight of a cubic centimetre of water, at 4° C., is 1 gram. A litre contains 1,000 c.c., so that the weight of a litre of water is a kilogram.

Mass.—The mass of a given substance is the amount of matter in it. It will be well to explain

the difference between mass and weight, although, in ordinary life, the terms are used indiscriminately. The mass of a substance does not vary, but its weight does, because the latter varies with the distance of the substance from the centre of the earth. In other words, the weight of a body is the pull of the earth on the mass of that body, so that a given substance weighs more at the poles than it does at the equator (although its mass is the same), because, the earth being flattened at the poles, the body, at the poles, is nearer to the centre of the earth. If we weigh out 1 lb. of shot on an ordinary balance with weights, we shall have the same quantity of shot wherever it is weighed, because the pull of the earth on the weights varies *pari passu* with the pull on the shot ; but if we weigh out 1 lb. of shot at the equator with a spring balance, we shall find that it weighs in London (with the spring balance) $\dfrac{32 \cdot 2}{32 \cdot 09}$ lbs.

Velocity is measured by the number of feet or centimetres traversed per second.

Acceleration is measured by the change of velocity per second.

Momentum is Mass × Velocity.

Force is that which tends to produce motion in a body. Its unit is either the *dyne* in the C.G.S. (centimetre gram second) system or the *poundal*.

A *dyne* is that force which produces a velocity of 1 centimetre per second, on a mass of 1 gram, acting on it for one second. The weight of a gram = 981 dynes.

A *poundal* is that force which would produce a velocity of 1 ft. per second in a mass of 1 lb. after acting on it for one second.

Work done is measured by the force × distance moved in the direction of the force.

One unit is the *erg*, which is the work done by one dyne acting through 1 centimetre. The work done in lifting 1 gram 1 centimetre = 981 ergs.

A more practical unit is the *joule* = 10,000,000 ergs.

A third unit is the *foot poundal* = work done by a force of one poundal, acting through 1 ft., in its own direction. This is rather less than the weight of $\frac{1}{2}$ oz.

It will be convenient here to describe some of the instruments and methods used for measuring accurately lengths, volumes, etc.
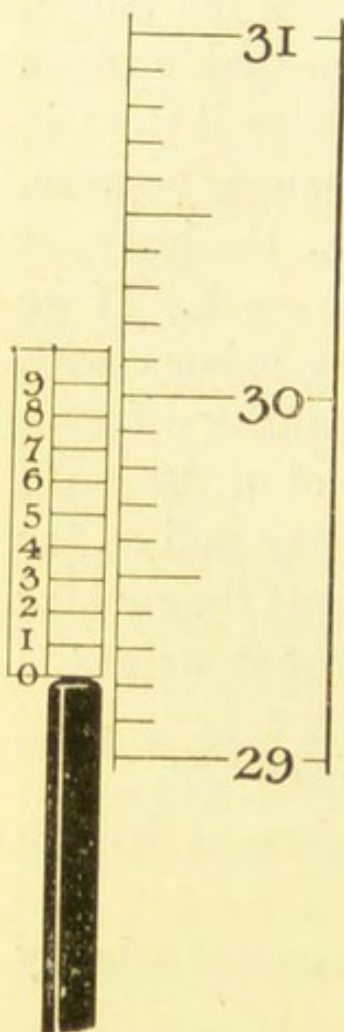
The Vernier.—A simple form is used for reading hundredths of inches on a scale divided into tenths (or tenths of millimetres on a millimetre scale). It consists of a small sliding scale, ten divisions of which are equal to nine of the original (Fig. 3). As each division on the vernier is obviously $\frac{1}{100}$ in. less than $\frac{1}{10}$ in., two divisions will be $\frac{2}{100}$ in. less than $\frac{2}{10}$ in., five will be $\frac{5}{100}$ in. less than $\frac{5}{10}$ in., and so on.

Fig. 3.—Vernier.

Suppose we wish to read the exact height of a mercury column in a barometer tube, at the side of which is fixed the scale with a sliding vernier. The zero of the vernier is adjusted so as to be level with the top of the mercury. We note that the zero of the vernier cuts the main scale a little above 29·2, and that the first division of the vernier co-incides with a division on the main scale. In other words, one vernier division + the height of the mercury above 29·2 $= \frac{1}{10}$ in. or $\frac{10}{100}$ in. Now, one vernier division $= \frac{9}{100}$ in., therefore the top of the mercury column is $\frac{10}{100}$ in. $- \frac{9}{100}$ in. above 29·2, and the reading is 29·21. If the sixth division of the vernier coincided with a division on the main scale, the reading would have been 29·26.

To sum up the method of using the vernier : having adjusted the zero to the top of the mercury, take the reading on the main scale, then note which division on the vernier coincides with a division

Fig. 3*a*.—Vernier of standard barometer.

on the main scale—this gives the next place of decimals.

A more *complex vernier* is used on standard

English barometers. The main scale is divided into inches and twentieths. Twenty-five divisions of the vernier scale = 24 of the smaller divisions of the main scale, so each vernier division is one-twenty-fifth of a twentieth, $= \frac{1}{500}$ in., less than the scale divisions. The twenty-five divisions of the vernier are divided into five parts, each of which is divided into five small divisions (see Fig. 3a). Each small division $= \frac{1}{500}$ in. or ·002 in. The reading shown in the figure is 29·25 on the main scale and ·024 on the vernier = 29·274 in.
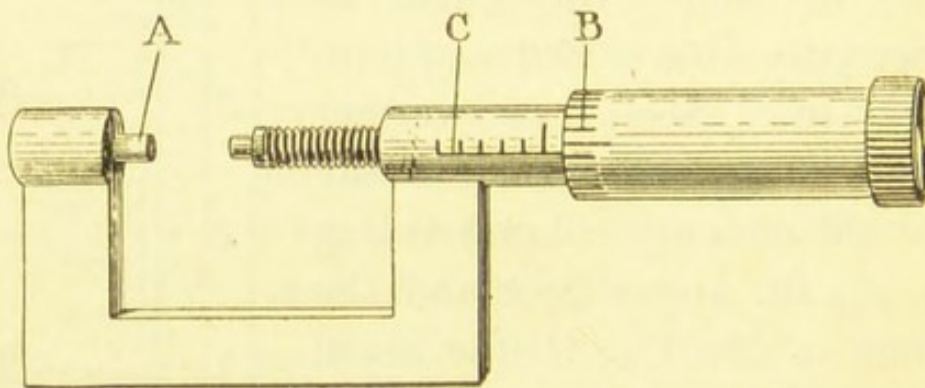
Fig. 4.—Micrometer screw gauge.

The Micrometer Screw. — This is a perfectly made screw with a divided head. The screw advances or recedes from a fixed bar of metal. The screw is usually so cut that a complete turn advances or recedes the end half a millimetre = 0·5 mm; a half-turn causes a movement of 0·25 mm., and a fiftieth of a turn = ·01 mm. The screw is gently turned until contact is felt between the end of the screw and the fixed piece A (Fig. 4) ; the zero of the graduations on the head of the screw B should then be opposite the line C.

Suppose we wish to ascertain the thickness of a cover glass. The screw is withdrawn until we can introduce the glass between A and the end of the screw; the graduated head is turned until the pressure of the screw is just sufficient to support the weight of the glass; the thickness is then ascertained by reading off the scale at B. One-fiftieth of
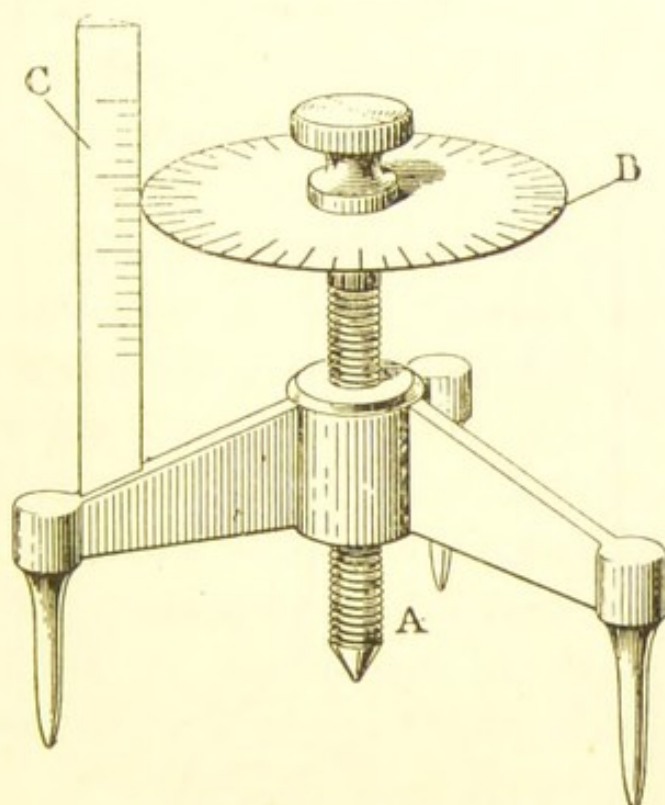
Fig. 5.—Spherometer.

a turn = one-hundredth of a millimetre. The number of complete turns is given by the scale at C, which is uncovered as the screw is withdrawn.

The Spherometer.—This is a little tripod, the micrometer screw A (Fig. 5) forming a fourth leg. When the micrometer screw projects beyond the three legs the instrument rocks when touched. By gently withdrawing the screw the rocking ceases, so that this rocking forms a delicate test as to when

the micrometer screw and the three legs all touch
the surface on which the instrument rests.

20cc

500 cc

Pipette

Measuring
flask
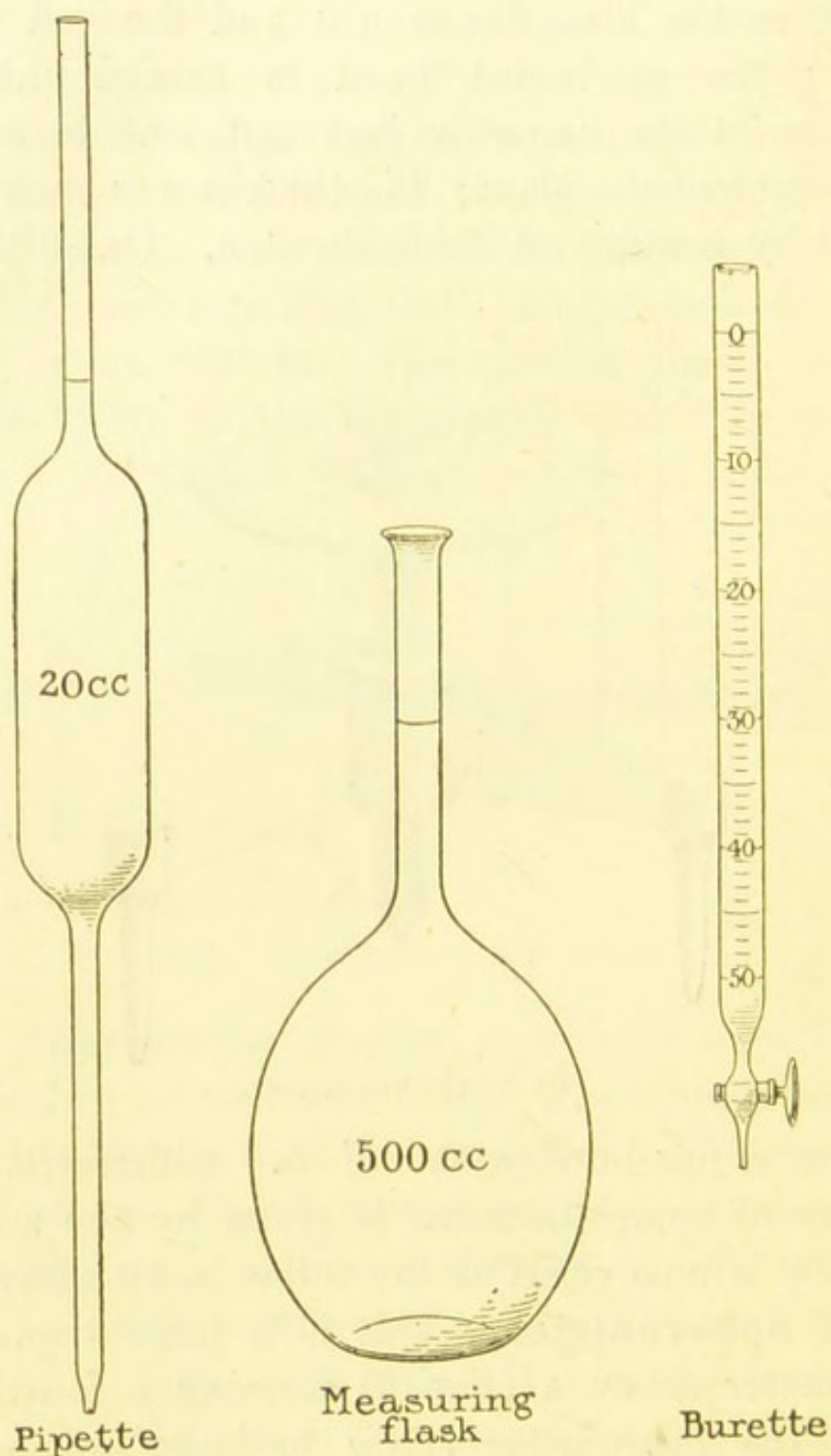
Burette

Fig. 6.—Pipette, measuring flask, and burette.

The spherometer is first tested by placing it on a
flat surface, such as a piece of good plate glass. When

the micrometer screw is withdrawn so that the rocking just ceases, the zero of the divided head B should be opposite the knife edge of the scale C. Usually two complete turns raise the screw one millimetre, so that one turn = 0·5 mm. The head is divided into 50 divisions, so that each division = ·01 mm., and each of these 50 divisions into five smaller ones, each of which = 0·002 mm.

In order to determine the thickness of a plano-convex lens, the screw is withdrawn, so that the lens can be placed on the plate glass on which the instrument rests ; the micrometer screw is then gently advanced until the rocking indicates contact, when the height of the screw above the plate glass is read off on the two scales.

Measurement of Liquids.—The accurate measurement of liquids is effected by means of **pipettes,** or **measuring flasks,** which deliver fixed quantities, usually marked on the vessels, or by a **burette,** which enables any quantity of fluid to be measured (Fig. 6).

If the specific gravity of a fluid is known, accurate quantities can be obtained by weighing. Thus, the specific gravity of a fluid being 1·27, if we weigh out 12·7 grams we have exactly 10 c.c.

CHAPTER II.

DIFFUSION OF SOLIDS, LIQUIDS, AND GASES—DIALYSIS
—OSMOTIC PRESSURE.

Diffusion of Solids in Solution.—If a strong solution of common salt contained in a small jar is placed at the bottom of a deeper and larger jar, the small jar covered with a glass plate and the large jar then gently filled up with water by a funnel, on removing the cover from the small jar we have a heavy solution of brine in contact with the pure water above (Fig. 7). It might be supposed that the heavy brine would remain for ever at the bottom without mixing with the water, but it is not so. The molecules of the salt seem to repel each other, just as the molecules of a gas, when the pressure is diminished and the molecules of salt begin to spread or diffuse into the water. This process of diffusion proceeds until, after the lapse of some time, the salt is evenly distributed through the water. The rate at which this diffusion of a substance takes place depends (1) on the nature of the substance ; (2) on the strength of the solution, a 3 per cent. solution diffusing three times
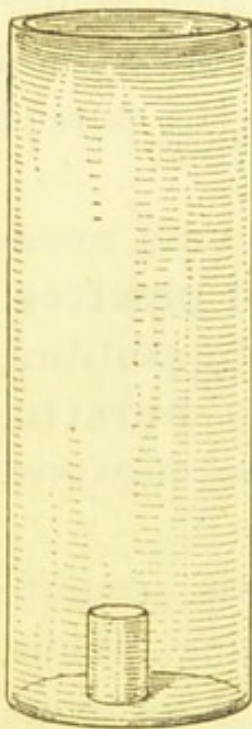
Fig. 7.
Diffusion of
brine.

as quickly as a 1 per cent. solution; (3) on the temperature, the rate increasing as the temperature rises.

Relative *times* of diffusion of equal amounts of—

Albumen	49·00 units.
Magnesium sulphate . .	7·00 ,,
Sodium chloride . . .	2·33 ,,
Hydrochloric acid . .	0·1 unit.

So that hydrochloric acid diffuses 490 times as quickly as albumen.
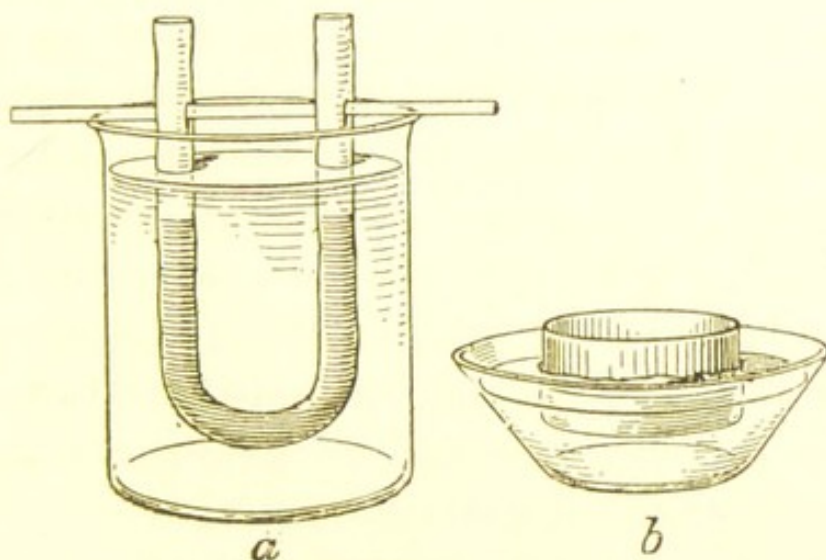
Fig. 8.—Diffusion of salt and albumen, (*a*) through parchment tube suspended from glass rod, (*b*) through layer of vegetable parchment stretched over hoop.

Graham observed that substances which diffused quickly were crystalline, and that those which diffused slowly were not, so he divided substances into *crystalloids*, such as salt, and *colloids* (from κολλώδης = viscous or glue-like), such as gelatin, albumen, etc.

If a water-tight membrane, such as a bladder or vegetable parchment, be tied tightly over the little jar in the previous experiment, the salt will still diffuse

into the water, in spite of the bladder. If we mix a crystalloid, such as salt, with some white of egg (albumen) and place the mixture in a tube of vegetable parchment, suspended in water, or in a drum of bladder stretched over a hoop floating in water (Fig. 8), the salt will diffuse rapidly, the albumen very slowly, through the membrane. Now, it is obvious that the process can be stopped at a time when nearly all the salt has passed through with but little albumen. If we evaporate the water we recover the salt almost pure, and if we repeat the process of diffusion with the residual albumen, we can remove practically all the salt, and on allowing the solution of albumen to evaporate in the sun we obtain the albumen free from salt. So, by taking advantage of the different rates at which substances diffuse through membranes, we can separate them from each other. This process of separating substances by diffusion is called **dialysis.**

This movement of solids in solution, if resisted, tends to continue in spite of the resistance. So much pressure is, in fact, developed that few membranes will sustain the pressure without leaking.

The most successful membrane was prepared by a botanist, Pfeffer, during his investigations on the rise of sap in plants. A small vessel of porous earthenware, after thorough washing and drying, was soaked first in a solution of copper sulphate, and then in a solution of potassium ferrocyanide. As the solutions came into contact in the pores of the pot, a gelatinous precipitate of copper ferro-

cyanide was thrown down, and this gelatinous precipitate, supported by the porous structure of the earthenware, formed an almost perfect membrane. The open mouth of the porous pot was closed by a glass tube A (Fig. 9) firmly cemented in ; the glass tube had a T tube B connecting it with a long bent U tube c containing mercury. By filling the porous pot with various solutions and immersing it in pure water it was found that the water passed in much more rapidly than the salt solution came out. Pressure was thereby developed and the mercury rose in the tube to considerable heights. Such pressure is termed **osmotic pressure,** and the process **osmosis.**

Thus, with a 6 per cent. solution of sugar, a height of over 10 feet (307·5 centimetres) of mercury was attained.

Fig. 9.—Pfeffer's apparatus for estimation of osmotic pressure.

It is generally believed at the present time that solids in dilute solutions obey the three great gas laws of Boyle, Gay Lussac,

and Avogadro. Thus, by Pfeffer's results, it was shown—

(1) That the osmotic pressure increases with the strength of the solutions. If you double the strength of the solution, the osmotic pressure is also, roughly, doubled, thus—

1 per cent. cane sugar gave o.p. = 53·5 centimetres.
2   ,,   ,,   ,,   ,,   101·6   ,,
4   ,,   ,,   ,,   ,,   208·2   ,,

This is really Boyle's law (p. 50); *i.e.*, if you squeeze twice as many molecules into the same space you double the pressure.

(2) That the osmotic pressure varies with the absolute temperature. A solution of cane sugar gave—
At 32° C. or 305 absolute temp. an o.p. of 54·4 cms.
,, 14·1 C. or 287·1   ,,   ,,   51·2 cms.

And $\dfrac{54\cdot4 \ \times \ 287\cdot1}{305} = 51\cdot2.$

This is the law of Charles and Gay Lussac (p. 73).

(3) That molecular weights of various substances give the same o.p.

Thus, cane sugar ($C_{12}H_{22}O_{11}$) has a molecular weight of 342.

Alcohol (C_2H_6O) has a molecular weight of 46, and it was found that a solution containing 3·42 per cent. of cane sugar gave the same osmotic pressure as one containing 0·46 per cent. of alcohol. In other words, equal volumes of liquid which give equal osmotic pressures contain the same number of molecules. This is Avogadro's law.[*]

[*] See Luff & Page's " Chemistry," p. 17.

Diffusion of Gases.—If a jar of hydrogen be placed mouth downwards over a jar of oxygen (Fig. 10), notwithstanding the fact that oxygen is sixteen times as heavy as hydrogen, the heavy oxygen does not remain in the lower jar, but mixes with the light hydrogen, and the latter passes downwards and mixes with the heavy oxygen, so that if, after an hour, a light be applied separately to each jar, it will be found that each jar explodes.

Graham discovered the law which governs the rate at which diffusion takes place with different gases. The velocity of diffusion of a gas varies inversely as the square root of its density. Thus hydrogen and oxygen will diffuse with relative velocities of $\dfrac{1}{\sqrt{1}} : \dfrac{1}{\sqrt{16}}$, or, in other words, hydrogen diffuses four times as fast as oxygen.

Fig. 10.—Diffusion of oxygen and hydrogen.

This diffusion takes place when the gases are separated by a porous partition of clay or dry plaster-of-Paris, and thus pressure may be developed, as in the experiment shown in Fig. 11.

A Woulffe's bottle, containing some coloured liquid, is fitted with two corks. Through one passes a long glass tube A to the bottom of the bottle. Through the other passes a short tube B which, at its upper end, is corked firmly into a porous pot C. The whole is, of course, full of ordinary air. C is

C

covered with an inverted beaker D, which can be filled with hydrogen by the tube H. As soon as the hydrogen enters the beaker D, diffusion is started through the porous pot C, air passes into the hydrogen, and hydrogen passes into the air; but four times as much hydrogen passes in as air passes out, so pressure is developed in the Woulffe's bottle, and the coloured liquid is forced up the tube A.

Diffusion of solids takes place slowly, at temperatures far below their melting points. Thus, when a bright sheet of lead was laid on an ingot of gold and the two maintained at the temperature of boiling water for some months, analysis proved that some lead had diffused into the gold and some gold into the lead.

Fig. 11. — Pressure produced by diffusion of hydrogen into air.

CHAPTER III.

THE **specific gravity** or **relative density** of a sub-stance gives the relative weight of a volume of the substance as compared with the weight of an equal volume of a standard substance (water for solids and liquids, hydrogen or air for gases). Thus the sp. gr. of iron is 7·8, so that if we take a volume of water weighing 1 lb., an equal volume of iron will weigh 7·8 lbs.

Relative density must be carefully distinguished from *density*. The latter is a term used by engineers, and gives the mass of a substance per unit volume. Thus 1 cubic foot of water weighs 1,000 ozs., its density is 1,000 ozs. per cubic foot ; a litre of hydrogen weighs ·0896 gram, its density is ·0896 gram per litre ; a cubic foot of iron weighs 488 lbs., its density is 488 lbs. per cubic foot.

Specific Gravity of a Liquid.—Take a flask with a mark on its neck, fill it with alcohol up to the mark, and weigh it. By subtracting the weight of the empty flask, we get the weight of the alcohol which it contains. Repeat the experiment with water, and we get the weight of water which it contains. In one experiment the weight of the

alcohol (not absolute) was 422 grams, and the weight of water 500. Taking the sp. gr. of water as 1, the sp. gr. of the alcohol is $\dfrac{422 \times 1}{50} = 0\cdot84$.

Instead of a large flask, especially when the quantity of fluid at our disposal is small, a *specific gravity bottle* holding 20 to 100 c.c. is used, furnished with a stopper (Fig. 12) carefully ground in, and perforated by a small hole. The bottle is rinsed out
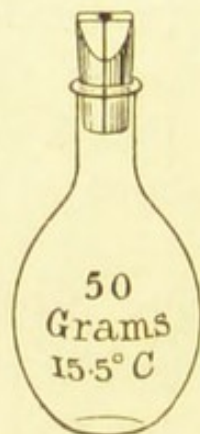
Fig. 12.—Specific gravity bottle.
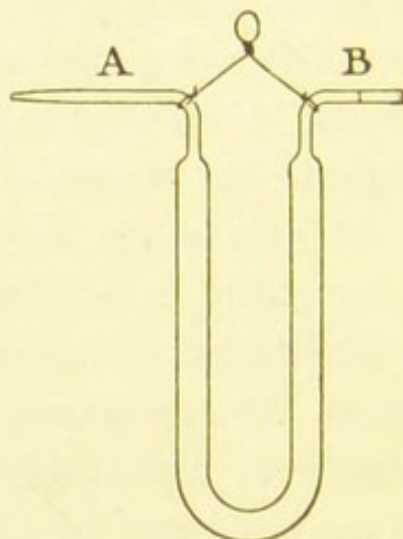
Fig. 13.—Sprengel tube.

with the fluid, then filled, and the stopper inserted, avoiding air bubbles, the excess of fluid spurting out through the perforated stopper. The bottle is then carefully wiped dry and weighed. The calculation is as before.

A still more delicate means of obtaining an accurate volume of fluid is the Sprengel tube (Fig. 13), a light glass **U** tube. The two ends are drawn out and bent as shown, a mark is made at B, and A is drawn out into a capillary tube, the end of

which is broken off. It is filled by dipping the end
A in the liquid, and sucking at B till the tube is filled
and the liquid is sucked beyond the mark B, the
volume being adjusted finally by holding a piece of
filter paper at the end A, when the excess of liquid is
sucked out by the filter paper and the level adjusted
exactly to the mark B. The tube is then carefully
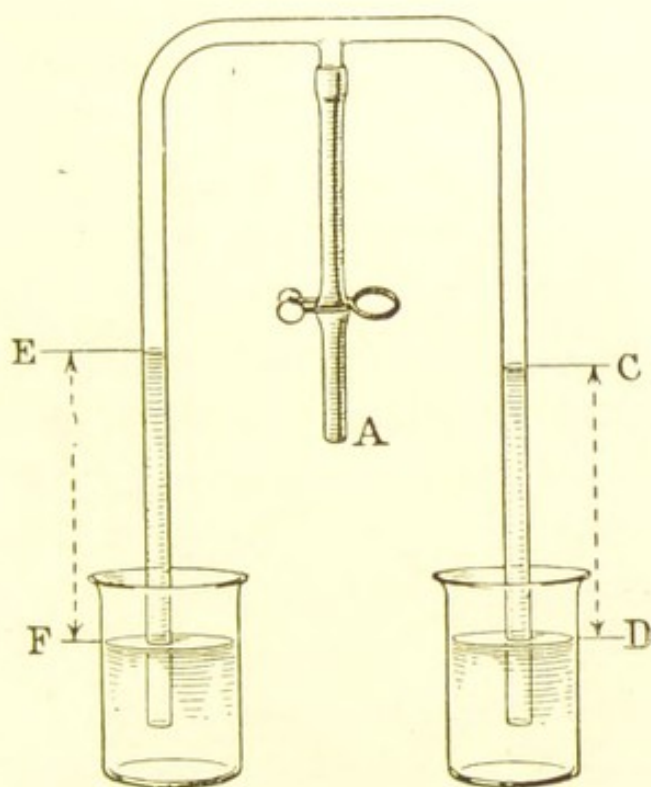
Fig. 14.—Hare's apparatus.

wiped and weighed. The specific gravity bottle and the
Sprengel tube are sometimes called **pyknometers.**

In all cases the temperature of the liquid should
be at 15·5° C. when the bottle is filled.

Hare's Apparatus. — The sp. gr. of liquids
can also be conveniently compared by means of
the apparatus shown in Fig. 14. It consists of
two long tubes, the ends of which dip into the two
liquids. At the top these tubes are connected by a

T tube bearing an india-rubber tube and a spring clip.
On sucking gently at A the liquids are drawn up into
the tubes, the clip is then closed, and the heights
of the columns of liquids above the levels of the
liquids in their respective cisterns measured ; these
heights are inversely as their respective specific
gravities. Thus a specimen of dilute alcohol was
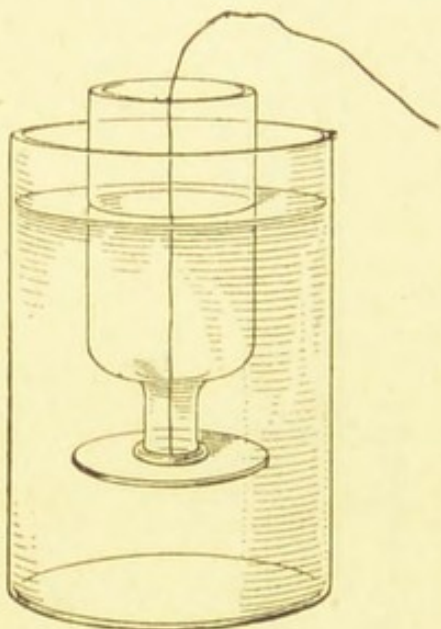
Fig. 15.—Glass plate sup-
    ported by upward
    fluid pressure.
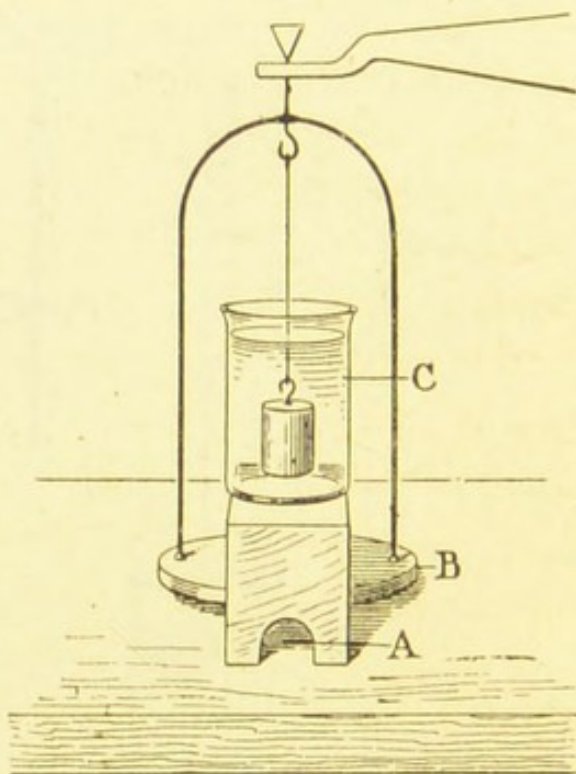
Fig. 16.—Method of weighing a
    substance in water.

compared with distilled water : the alcohol column
from E to F measured 100 millimetres, the water
column from C to D 90 mm. The sp. gr. of alcohol
to water was 0·9 to 1·0.

Specific Gravity of a Solid.—The usual method
of determining the specific gravity of a solid depends
on *the principle of Archimedes*, which states that
when a solid is weighed in a liquid the loss of weight,

as compared to its weight *in vacuo*, is equal to the weight of its own volume of the liquid. This loss of weight is caused by the upward pressure of the fluid. The existence of this upward pressure can be demonstrated by the following experiment. A small ground-glass plate is held by a string against the ground surface of a bell-jar (Fig. 15). The plate and jar are then sunk beneath the water and the string is released, but the glass plate is supported by the upward pressure of the fluid. If water is now poured into the bell-jar, the glass plate sinks as soon as the levels of the water inside and outside are equal.

The truth of the principle of Archimedes can be demonstrated thus :—A solid cylindrical piece of brass is fitted accurately into a metal bucket, so that the bucket when filled contains a volume of water exactly equal to that of the brass. The brass is placed in the left pan of a balance, and the bucket filled with water in the right pan. Shot are then added till equilibrium is obtained, a fine silk thread is attached to the brass, which is suspended from the left hook of the balance and immersed in dis- tilled water. The right-hand pan of the balance is now much too heavy, but if the water in the bucket be thrown away and the dry empty bucket be replaced, equilibrium will be restored, proving that the loss of weight of the brass when immersed in water is equal to the weight of its own volume of water.

The method by which the weighing in water

is effected is shown in Fig. 16. A little wooden platform A is arranged so that its legs straddle over the balance pan B without touching it; on this platform rests the beaker of water C, and in this, suspended by a fine silk thread from the hook on the balance, is the piece of brass.

Determination of the Specific Gravity of a Solid which is Heavier than Water.—A piece of brass, *e.g.*, weighs in air 200 grams; weighed in water, as shown in Fig. 16, it weighs 176·2 grams, its loss in weight being $200 - 176·2 = 23·8$ grams, and this is the weight of a quantity of water equal in volume to the brass, which weighs 200 grams. So the specific gravities of brass and water are as 200 : 23·8. If the sp. gr. of water be 1, that of brass is $\dfrac{200}{23·8} = 8·4$.

If the solid *is soluble in water*, some liquid in which the solid is not soluble is substituted for the water, and the experiment is conducted as before. The number for the sp. gr. so obtained is then multiplied by the sp. gr. of the fluid used—*e.g.*, a piece of sugar was weighed in air and in turpentine, and its sp. gr., *taking turpentine* = 1, was 1·83. Now the sp. gr. of turpentine is 0·87, and $1·83 \times 0·87 = 1·6$, the sp. gr. of sugar (water = 1).

Estimation of the Specific Gravity of a Solid which is Lighter than Water.—In such cases a piece of lead or some other heavy metal is firmly attached to the substance (*e.g.*, wax or cork) so as to act as a sinker. The various steps are as follows :—

1. Weight of wax + sinker in air   = 15 grams.

    ,,   ,,   +   ,,   water = 3·98 ,,

           Loss A .   .   .   11·02

2. Weight of sinker in air   .   = 5 grams.

    ,,   ,,   water.   = 4·4 ,,

           Loss B .   .   .   0·6

3. Weight of wax in air   .   = 10 grams.

Then sp. gr. of wax $= \dfrac{\text{weight of wax}}{\text{Loss A} - \text{Loss B}} =$

$\dfrac{10}{11·02 - 0·6} = ·96.$

If a solid is in fragments, as shot, sand, filings, etc. :—

1. Weigh the shot in air.

2. Insert shot in a sp. gr. bottle, fill up with water, weigh, deduct the weight of the empty bottle.

3. Weigh the sp. gr. bottle full of water and deduct the weight of the empty bottle.

Then $(1 + 3) - 2 =$ weight of water displaced by the shot, and sp. gr. $= \dfrac{1}{(1 + 3) - 2}.$

A second method consists in weighing 50 grams of shot, introducing them into a burette containing water, and observing the rise in the level of the water. This gives the volume of the water in cubic centimetres, and roughly 1 c.c. of water weighs 1 gram. Thus 50 grams of lead shot caused the level of the water in a burette to rise 4·5 c.c.

       Sp. gr. of lead $= \dfrac{50}{4·5} = 11·1.$

The **specific gravity of a gas** is determined on the same principle as the sp. gr. of a liquid, but in the first place the gas must be enclosed ; and secondly, the volume of a gas varies so rapidly with alterations in temperature and pressure that special precautions must be taken ; lastly, a gas is so light, and displaces so much air, that there is a sensible difference between its weight in air and its weight *in vacuo*—
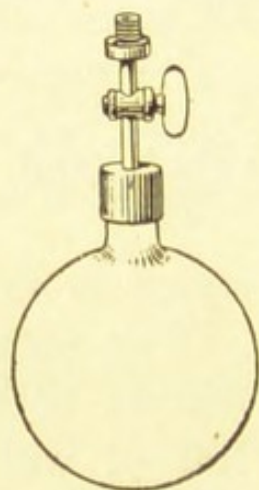
Fig. 17.—Flask for taking sp. gr. of gases.
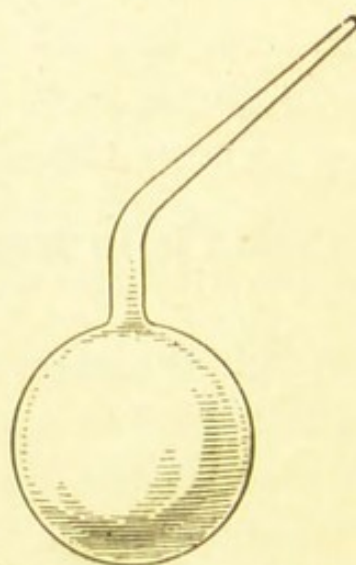
Fig. 18.—Dumas' flask for vapour density.

a difference which, in the case of ordinary solids and liquids, is so small that it can be neglected.

The gas is contained in a small glass balloon or spherical flask (Fig. 17), furnished with a well-made brass stopcock to which a small hook can be attached. The air is sucked out from the flask by an air-pump, the stopcock closed, and the flask connected with a reservoir of the pure gas, whose sp. gr. is to be determined. On opening the stopcock the gas rushes in and fills the flask, and the process of

exhaustion and filling is repeated so as to ensure the removal of all air. The flask, still in connection with the reservoir of gas, is now immersed in a beaker of water of known temperature for two or three minutes, the stopcock is then closed, and the barometer at once read. We have thus succeeded in enclosing a known volume of the gas at a known temperature and pressure. The flask is dried and suspended from one end of the balance, an exactly similar flask without a stopcock is suspended as a counterpoise from the other end, and so the error due to the air displaced is obviated. The weight of the gas is then found as described under the sp. gr. of liquids, and the sp. gr. at 0° C. and 760 mm. calculated (p. 50 and p. 73).

The **specific gravity of a vapour** can be ascertained either (*a*) by finding the weight of a known volume of the vapour at a known temperature and pressure, or (*b*) by finding the volume occupied by a known weight of the substance when converted into gas or vapour. As an example of " *a* " we may cite Dumas' method. In this a glass bulb (containing about 200 c.c.), furnished with a long drawn-out neck (Fig. 18), is partially filled with the substance the specific gravity of whose vapour is to be determined. The bulb is then plunged into a heated liquid, so that the substance boils violently, and its vapour drives out all the air from the bulb. When this has been effected and the bulb is full of the vapour, the end of the drawn-out neck is fused up by a blowpipe, the temperature of the heated liquid

and the barometer being simultaneously noted. The bulb is then withdrawn, cleaned, and weighed. The weight of the empty bulb is deducted, and thus we get the weight of a known volume of the vapour at a known temperature and pressure: from this, after certain corrections, we can calculate the specific gravity of the vapour at 0° and 760 mm.

The method which is, however, usually employed belongs to the second class, "*b.*" It is known as Victor Meyer's method. A tube about two feet long is expanded at its lower end into a bulb A (Fig. 19); it is closed at its upper end with an india-rubber cork, and has a bent delivery tube B inserted a short distance below the cork; the delivery tube ends in a trough D filled with water. The bulbed tube A is surrounded by a second and larger tube which contains water, anilin, or other liquid of suitable boiling-point. This liquid is caused to boil, and its vapour, heating the air in A, causes it to expand and bubbles escape by the delivery tube into the air. As

Fig. 19. — Victor Meyer vapour-density apparatus.

soon as bubbles cease to escape, the cork is re-
moved and a weighed quantity of the substance
contained in a small bulb is dropped into A, and
the cork immediately replaced. The substance is
at once converted into vapour, which displaces some
of the air, and this displaced air is collected in the
graduated tube C, which has been placed over the
end of the delivery tube. The liquid in the outer
tube should have a boiling-point 20° to 30° higher
than that of the substance; about 0·1 gram of the
substance should be taken.

The volume of the gas collected is corrected for
temperature, pressure, etc., to 0° and 760 mm. The
weight of this volume of hydrogen is then calculated
and divided into the weight of substance taken. As
an example: ·073 gram of ether displaced 25·3
c.c. of air, measured at 21·5° C., and pressure 718·6
mm., correcting for temperature (p. 73).

$$25·3 \times \frac{273}{273 + 21·5} = 23·45 \text{ c.c.,}$$

the pressure was 718·6 − 19·1 (the vapour tension
of water at 21·5) = 699·5 mm.

$$23·45 \times \frac{699·5}{760} = 21·5 \text{ c.c.,}$$

the volume of gas displaced when reduced to 0° C.
and 760 mm.

Now this volume of hydrogen weighs

$$\frac{21·5 \quad ·0896}{1,000} = ·00192,$$

and the sp. gr. of ether vapour equals

$$\frac{·073}{·00192} = 37·9.$$

Nicholson's Hydrometer. — By means of this instrument a body—*e.g.*, a penny—can be weighed in air or in water without a balance. It consists (Fig. 20) of a hollow brass cylinder A with a pan
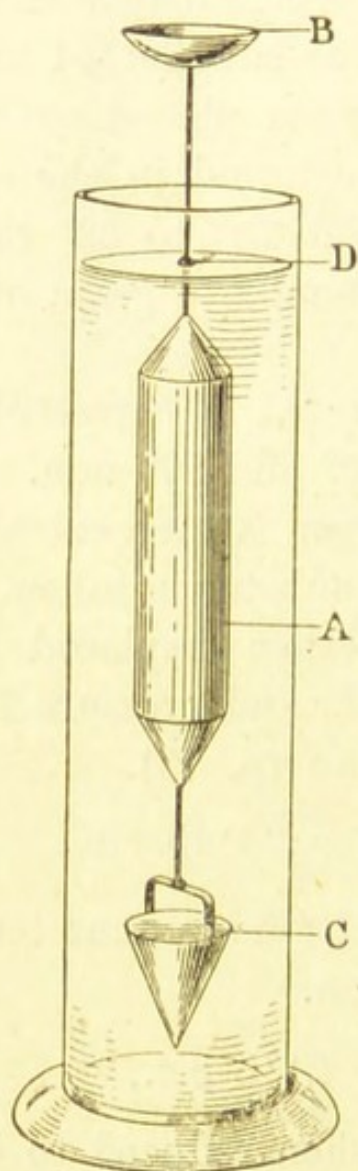
Fig. 20.—Nicholson's
hydrometer.
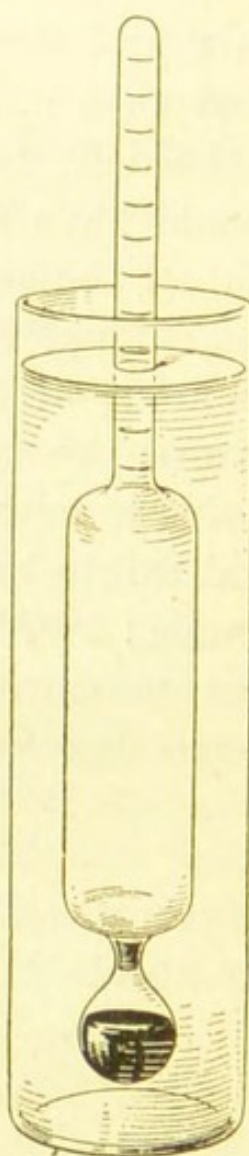
Fig. 21.—Common
hydrometer.

above (B) and below (C). The upper pan B is connected with the cylinder by a stiff wire, which has a mark (a ring of platinum wire) at D. The instrument is immersed in water, and weights are placed

in the upper pan until the mark D is level with the surface of the water—say 35·1 grams are required ; a penny is placed in the pan, and weights are again added as before (25·65 grams). So the weight of the penny in air is 35·1 − 25·65 = 9·45 grams. The penny is then placed in the pan c under water, and weights are added till the mark is again level with the surface of the water ; this requires 26·70 grams. So the penny in water weighs 35·1 − 26·7 = 8·4 grams, and its loss when weighed in water is 9·45 − 8·4 and its sp. gr. $= \dfrac{9 \cdot 45}{1 \cdot 05} = 9.$

The common hydrometer consists of a hollow glass or brass vessel weighted at the bottom and furnished at the top with a long graduated stem (Fig. 21), the weight in the lower bulb (mercury or shot) being so adjusted that the instrument floats at the required level. The reading on the scale at the surface of the liquid gives the sp. gr. It is usual to have several of these hydrometers ; thus, one would read from 1·000 to 1·050, another from ·950 to 1·000, and so on ; by this means a stem of inconvenient length is avoided. Hydrometers are called Urinometers, Lactometers, Alcoholometers, etc., according to the liquid for which they are specially suited. The graduation of a hydrometer should be verified by the sp. gr. bottle and the balance, if any important conclusions depend on the readings. The temperature of the liquid should always be 15·5° C. This is particularly important in the case of urine.

The *pressure of a fluid on a surface immersed in that fluid* is equal to the weight of a column of fluid whose area is that of the surface immersed, and whose height is the vertical distance between the surface of the fluid and the centre of gravity of the immersed substance.

CHAPTER IV.

Atmospheric Pressure.—The atmospheric pressure at any given place is due to the *weight* of the atmosphere resting on that particular portion of the earth's surface. The barometer enables us to measure this pressure.

BAROMETERS.

The simplest form of **barometer** (Fig. 22) consists of a glass tube closed at one end, filled with mercury, and inverted in a cistern of mercury. The tube must be at least 32 inches long. It need not be absolutely uniform in its diameter, but it must be vertical. In such a

Fig. 22.—Barometer tube and cistern.

barometer the mercury will stand, at the sea level, about 30 inches above the mercury in the cistern. The space above the mercury is practically a vacuum, as it contains nothing but a small quantity

D

of mercury vapour — it is termed the *Torricellian vacuum.* The reason why the mercury usually stands about 30 inches at the sea level is that a vertical column of mercury of this height balances the weight of the atmosphere pressing downwards on the surface of the mercury in the cistern.

It will be instructive here to consider **the way in which pressure is transmitted in a fluid** (liquid
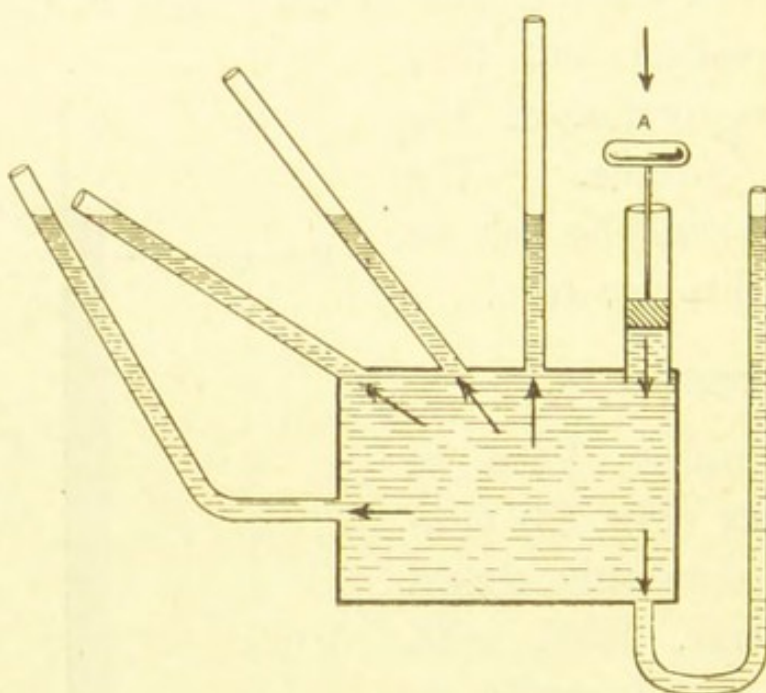
Fig. 23.—Transmission of pressure by fluids in all directions.

or gas). If we take a flat block of wood resting on a table and press it vertically downwards, it will have no tendency to move sideways ; a solid only transmits pressure in the direction in which this is applied. If, however, we take a vessel filled with water, having tubes fastened into it bent in various directions, and apply vertical down-ward pressure by means of the piston A (Fig. 23), the liquid will rise in *all* the tubes, irrespective

of their direction, showing that a fluid transmits pressure in *all* directions. So, in the barometer, the vertical downward pressure of the atmosphere on the surface of mercury in the cistern is transmitted through the fluid, and presses the mercury in the barometer tube vertically upwards until the column of mercury balances the atmospheric pressure. If the atmospheric pressure decreases, the mercury sinks in the tube ; if it increases, the mercury rises.

The three principal causes of the **variations in atmospheric pressure** are—changes in temperature, changes in the amount of aqueous vapour, and mechanical movement of the atmosphere upwards or downwards. If the temperature rises, the air expands, and the weight of a given column is less. If aqueous vapour displaces dry air, the pressure is also diminished, since aqueous vapour has a sp. gr. of $\dfrac{18}{2} = 9$, as compared with air $14 \cdot 4$ ($H = 1$). When the circulation of the air is cyclonic, there is an *upward* suck in the centre of the cyclone, which diminishes the pressure, whereas in an anticyclone there is a *downward* movement of the air in the centre and the pressure in increased. In this part of the globe, during the winter the high barometer is over the cold plains of Russia ; but in the summer the high barometer will be found over the Atlantic, which is cool as compared with the heated continent of Europe. Roughly speaking, in this country change of temperature may produce

a variation of the barometer of half an inch, of moisture half an inch, and mechanical movement $1\frac{1}{2}$ inch.

In the weather maps published by the *Times* and other daily newspapers lines of equal barometric readings are marked : these are termed *isobaric* lines. In a cyclone (Fig. 24) the *lowest* barometer is in the centre, and the winds circulate round the centre in a direction opposite to that in which the

Cyclone.   Anticyclone.
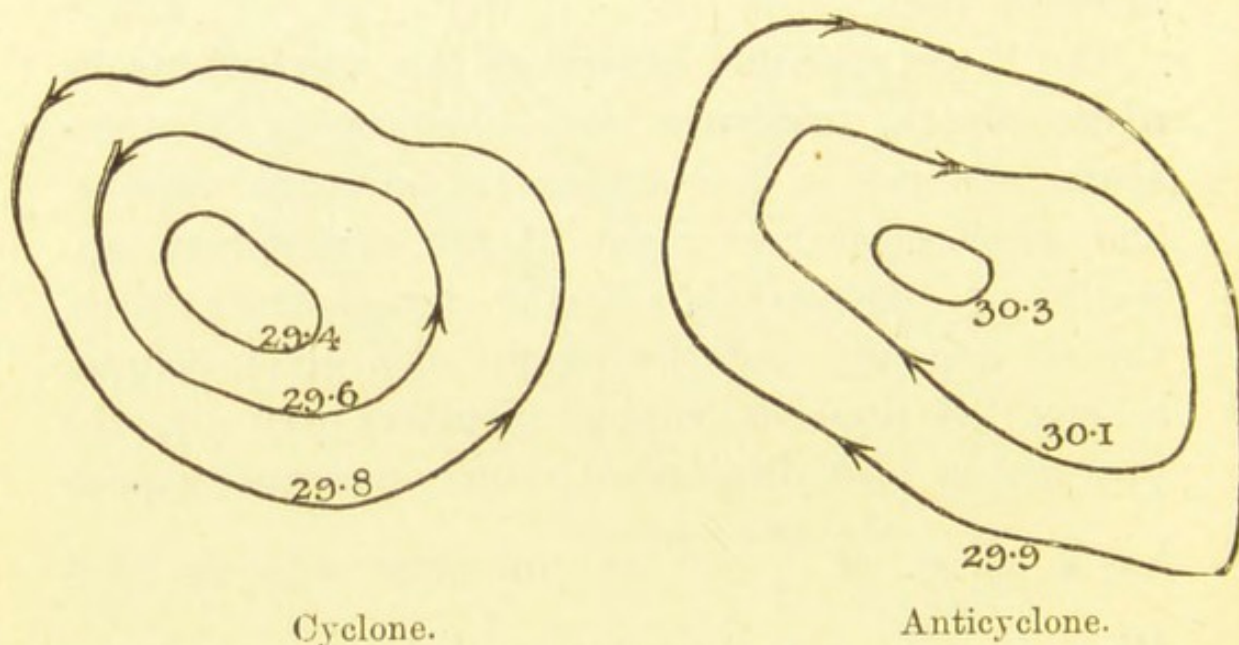
Fig. 24.—Barometric pressure and direction of wind.

hands of a clock revolve. In an anticyclone the *highest* barometer is in the centre, and the winds circulate in the same direction as that taken by the hands of a clock. In the southern hemisphere the direction of the wind in a cyclone and in an anticyclone is reversed.

As the height of the barometric column depends on the weight of the atmosphere, it is obvious that, as we ascend a mountain and leave more and more

of the air beneath us, the barometer will go down; in fact, the mercury column falls 1 in. for every rise of 933 ft. So we can determine the height of a mountain by noting the difference between the barometer readings at its base and at its summit.

Corrections to be applied in reading an ordinary Barometer. (1) *Cistern Error.*—This arises owing to the brass scale of inches or millimetres being fixed, while the level of the mercury in the cistern varies. If the atmospheric pressure diminishes, the mercury falls in the barometer tube, runs out into the cistern, and raises its level. Now, the distance we wish to measure is the vertical height between the level of the mercury in the cistern and the level of the mercury in the tube — the distance A B (Fig. 22). If the mercury falls to C, the mercury in the cistern rises to D, and we want to measure the distance C D ; but if the scale is fixed, we really measure C B, and the result is too great by the length D B.

One way of avoiding this error is to make the scale of inches untrue, so as to allow for the alteration in the cistern level; but the more general plan is to have the bottom of the cistern made of leather so as to be movable, a device we owe to Fortin. In Fig. 25 will be found a diagram giving the construction of the cistern. A is the barometer tube, B the scale which ends in a white ivory point P, C C the upper part of the cistern, which is made of glass ; into this fits a boxwood tube D D, to the lower end of which is wired on a leather bag E E. The whole of the

cistern and the bag is filled with mercury. Before
reading the barometer the screw F is turned until
the surface of the mercury touches the point P, which
is the zero of the scale. The reading then gives the
correct height of the barometer above the cistern
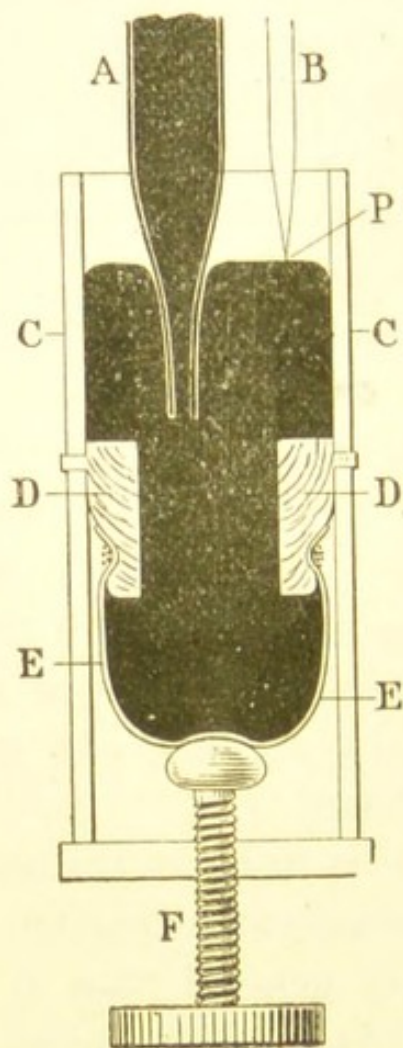
Fig. 25.—Cistern of Fortin's
barometer.
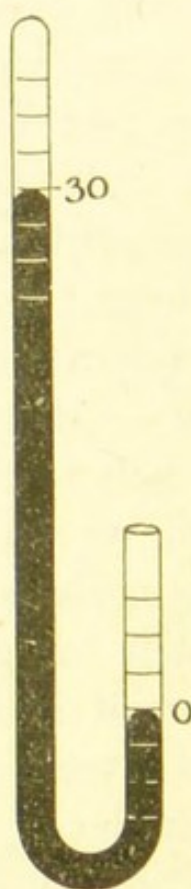
Fig. 26.—Siphon barometer.

The vernier used with this instrument has already
been described (Fig. 3*a*).

(2) *Temperature Error.*—This is due to the fact
that brass (of which the scale is usually made) and
mercury expand at different rates when heated.

The error is corrected by means of tables which have been calculated for the purpose.

(3) *Capillarity Error.*—Mercury is repelled by glass, so that in a narrow tube it stands lower than in a wide one. This also can be corrected by tables.

(4) *Error Due to Height above Sea Level.*—As a height of 933 ft. causes a difference of 1 in. in the height of the barometer, it is obvious that the height of the observing station must be known. This can be ascertained by consulting the ordnance maps of the district or by comparing the height with that of some known station by means of some form of portable barometer.

Barometer readings are usually reduced to what they would be at 0° C. and at the sea level.

Siphon Barometer.—In this form the open end of the barometer tube, which should be of uniform bore, is turned up to form a cistern (Fig. 26). It has two scales, one on the turned-up end and one at the level of the barometric column, and thus the cistern error is obviated. Suppose the atmospheric pressure is 30 in., and that the surface of the mercury in the turned-up end is then at zero. If the mercury falls $\frac{1}{2}$ in. in the barometer tube, it will rise $\frac{1}{2}$ in. in the open end, so that the real atmospheric pressure is $29\cdot5 - 0\cdot5 = 29$ in. It will be noticed that a diminution of atmospheric pressure of *one* inch is only indicated by a movement of *half* an inch in the mercury column.

The **Wheel Barometer** is a siphon barometer, and the movements of the mercury are, more or less,

indicated by the oscillations of a counterpoised glass float A, which, as it rises and sinks with the mercury, turns the index on the face of the barometer (Fig. 27).

A barometer tube can be tested as to its freedom from air by gently inclining it. If there is no air the mercury runs up with a metallic click and fills
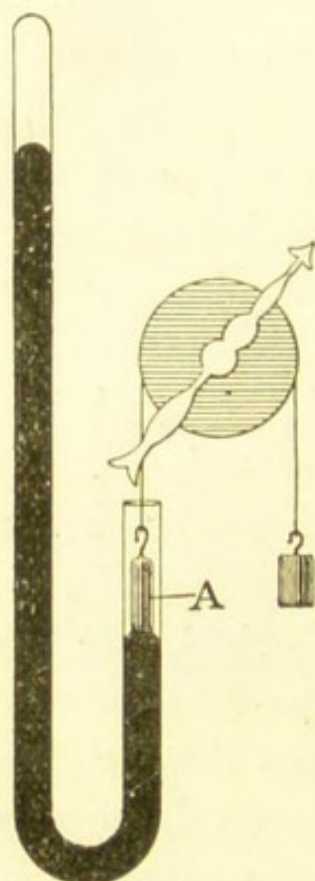
Fig. 27.—Construction of a
wheel barometer.

30 inches
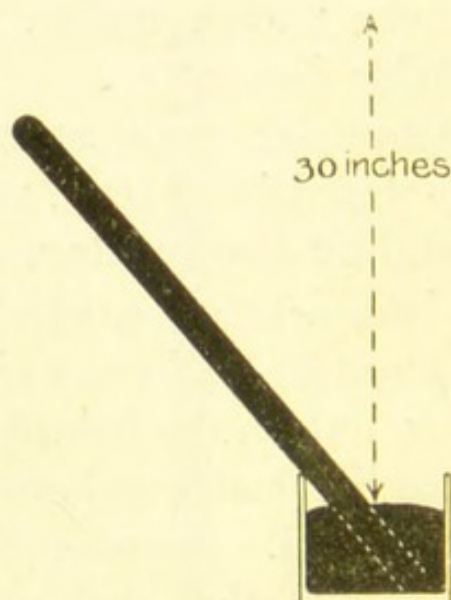
Fig. 28.—Testing a
barometer.

the tube ; if there is any air the bubble at once becomes evident (see Fig. 28).

Glycerin Barometer.—Other liquids have been used to fill barometer tubes instead of mercury. There is a glycerin barometer in the *Times* office, and its readings are published. Another is to be found at the Geological Museum in Jermyn Street.

The relative heights of the columns of glycerin and mercury are inversely as their sp. gr. The sp. gr. of mercury = 13·6, of glycerin 1·27, so that a column of mercury 30 in. = a column of glycerin $\dfrac{30 \times 13 \cdot 6}{1 \cdot 27} = 321$ in., or 26 ft. 9 in.

The variations in the glycerin barometer are about eleven times as great as when mercury is used, but no particular advantage seems to be gained by this increased movement.

The density of the atmosphere diminishes in geometrical, as the altitude increases in arithmetical,
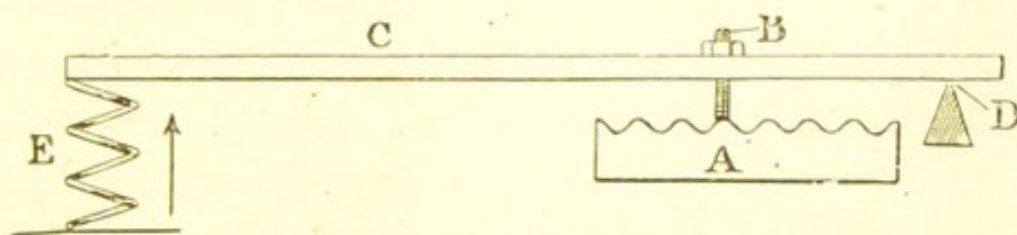
Fig. 29.—Construction of aneroid barometer.

progression. Thus at 18,106 ft. the air has doubled its volume; at twice that height (36,200 ft.) the volume is quadrupled.

The **Aneroid Barometer,** so called because it has no liquid (*a*, not; *νηρός*, a liquid), consists of a flat metallic circular box (A, Fig. 29), with a corrugated lid thinner than the bottom. This box is partly exhausted of air. When the atmospheric pressure increases, the box lid is forced in, and when the pressure diminishes, the elasticity of the air inside forces the top out. The rest of the instrument consists of a mechanism for rendering this minute movement of the top of the box visible. A stud of brass

B is fixed on the lid and bolted to a strong lever C near its fulcrum D ; the other end of the lever is pressed upwards by a spiral spring E, which tends to lift the top of the box. The movement of the top is thus magnified, and, by means of a series of bell crank levers, etc., turned into the rotary motion of the hand on the dial.
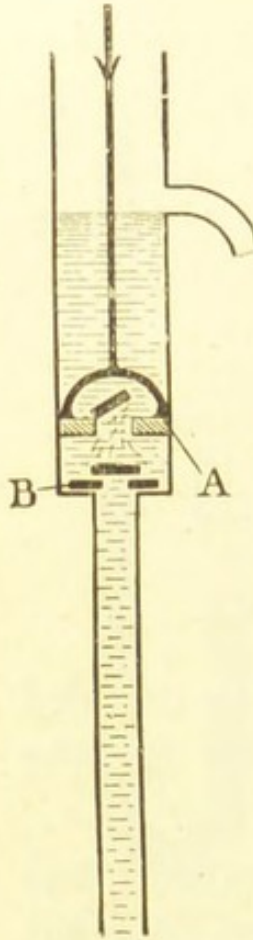
It must be remembered that the graduations on the dial of an aneroid are made by comparing its indications with those of a mercury barometer, and as the mechanism is somewhat delicate something may shift and the instrument be inaccurate, so that if the reading of an aneroid barometer is of importance, as in fixing the height of a mountain, it should always be checked by comparison with a standard mercury barometer.

Fig. 30.—Lift pump.

The terms " stormy," " set fair," etc., engraved on the dials of barometers are of but little significance, except to indicate that if the barometer falls the weather tends to become wet, warm, and windy ; if it rises it is likely to be fine and dry. In barometers for use at about the sea level " change " is usually placed at 29·5 in., and " fair " at 30·2 in.

ORDINARY PUMPS.

The action of the ordinary pumps depends on the atmospheric pressure.

The Lift Pump.—This consists of a barrel (Fig. 30) in which works a piston A having a valve opening upwards. To the bottom of the barrel is connected the pipe passing down into the well. At the top of this pipe is a second valve B, also opening upwards. The pump has usually to be " primed " by pouring in water until the barrel is full. When the piston descends the valve A opens, the water passes through and is at the end of the stroke above the piston; at the up stroke the valve A closes, the atmospheric pressure, acting on the surface of the water in the well, forces the water through the valve B, and fills the barrel, while the water which was above the piston is lifted up and runs out at the spout. It is obvious that the valve B must not be much more than 30 ft. above the level of the water in the well. If it were over 34 ft. the pump would be converted into a water barometer, and the atmospheric pressure would not be able to fill the upper part with water. The height to which water can be raised by the lift pump is limited, because as the distance of the spout above

Fig. 31.—Force pump.

the piston increases, the weight of water on the piston during the lift becomes so great that the pump is unworkable.

The Force Pump.—In this pump (Fig. 31) the piston is solid, and the water is forced up a side pipe c, which has at its lower end a valve A opening outwards. The pipe to the well has at its upper end a valve B opening upwards. When the piston descends
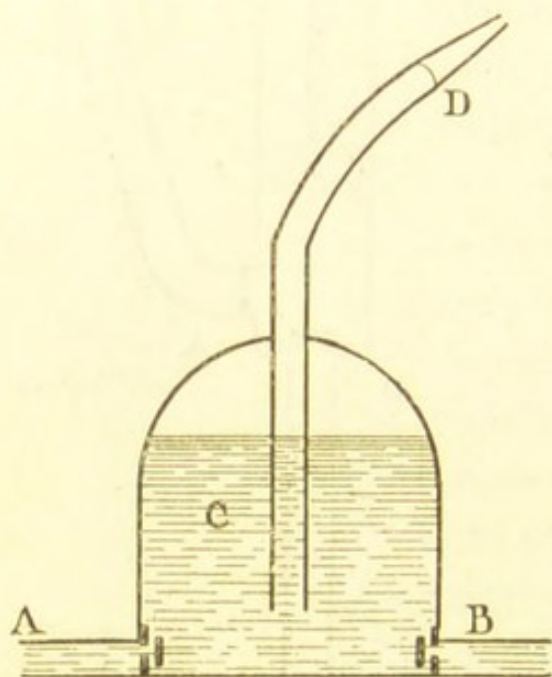
Fig. 32.—Air chamber for continuous flow.
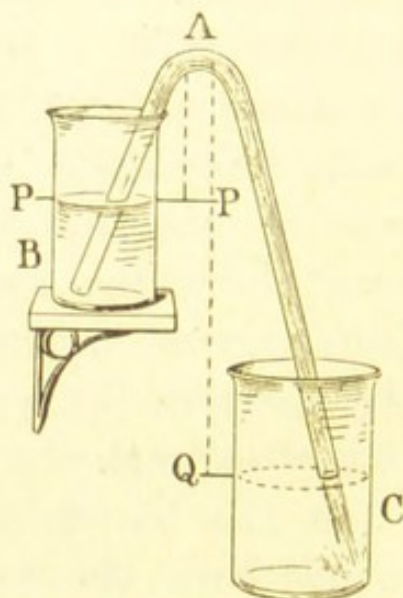
Fig. 33.—Siphon.

the water is forced through the valve A and up the pipe c. During the up stroke the barrel is filled with water by the atmospheric pressure, as in the lift pump. The valve B must not be much over 30 ft. above the well, but the pipe c can be of any reasonable height. In this pump the flow of water is discontinuous. When a continuous flow is required, as in a fire engine, an air chamber is introduced (Fig. 32). Usually two force pumps deliver water through the

tubes A and B, each furnished with a valve opening inwards. The strong chamber C is only partly filled with water, and each stroke of the pumps compresses the air in the upper part of C. This compressed air forces a fairly continuous stream of water up the pipe D.

The Siphon is another device which depends on the atmospheric pressure. It consists of a bent tube of glass, metal, etc. (Fig. 33), one leg of the bend being longer than the other. It is used for transferring fluid from one vessel to another at a lower level. Its action may be explained as follows : The siphon is filled with the fluid and the short leg immersed in the vessel to be emptied. Now consider a particle at the top of the bend at A ; it is pulled towards B by a column of liquid whose vertical height is A P, and towards C by a longer column A Q ; so the particle is pulled towards C, and the atmospheric pressure forces the fluid up the short limb until the vessel is emptied. If the liquid is water, A must be less than 34 ft. in vertical height above the level in B.
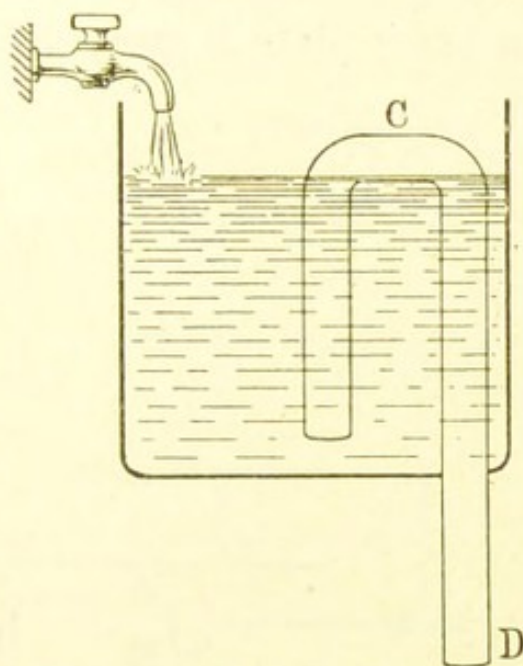
Fig. 34.—Automatic flushing cistern.

The siphon is very useful for automatic flushing. A small stream of water flows into a cistern (Fig. 34), and the water rises until it fills. the top bend of the

siphon at C. The siphon then acts, and a powerful rush of water issues from D until the cistern is emptied, when the process is repeated.

AIR PUMPS.

The ordinary air pump acts exactly like a lift pump, but the valves are made of oil silk. Instead of lifting water out of a well, it sucks air out of a glass bell-jar (Fig. 35), called a receiver A, which rests on a brass plate B ground flat and smeared with grease.
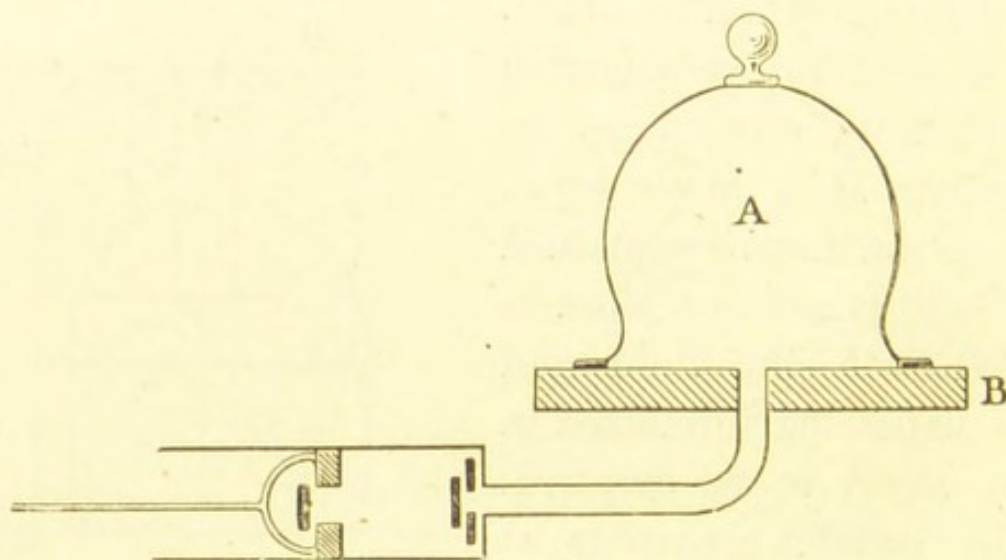
Fig. 35.—Common air pump.

The **Tate Air Pump** (Fig. 36) is a superior form of pump. The barrel is about twice as long as in the common pump, and there are two solid pistons A and B firmly connected together by the piston rod C. At each end of the barrel is a valve opening outwards, D and E. If the pistons be pulled outwards, the air between B and E is forced out through the valve E and escapes. As A moves with B the valve D shuts, and the space between D and A is a vacuum, until the

piston A passes the hole F leading to the receiver, when air rushes in from the bell-jar, to be forced out at the valve D when the pistons are pushed inwards. A similar action takes place with piston B and the space B E.

In the pumps described above the valves are opened by the compressed air, and when the air is much rarefied it has not elastic force enough to open the valve, and the pump ceases to act. As a consequence
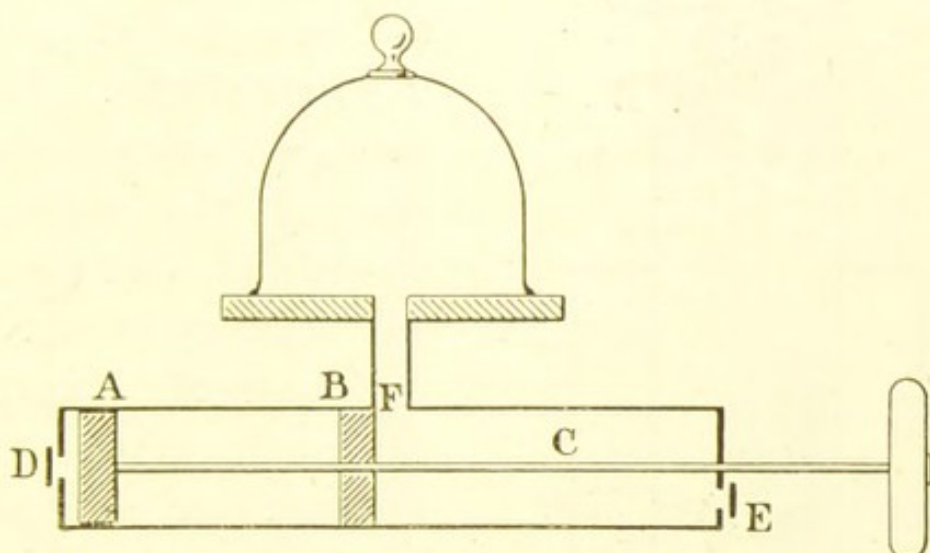
Fig. 36.—Tate air pump.

such pumps cannot reduce the air pressure below 1 mm. or 2 mm.—*i.e.*, if they are connected with a vertical glass tube, the lower end of which dips into mercury, they cannot raise the mercury to more than 758 or 759 mm.

A much better vacuum can be obtained by using a valve worked mechanically, as in the **Fleuss pump.** In this pump (Fig. 37) the piston has a boss A, which lifts the valve B mechanically in the up stroke. The valve is replaced by the spiral spring C. Both the

valve and the piston have a layer of oil o o. In the up stroke, as soon as the piston passes the aperture D, the air above the piston is forced out by the valve B, which is lifted by the boss A. At the down stroke the valve B is closed by the spring C; a vacuum is formed, and as soon as the piston is below the aperture D air rushes in from the receiver, which is connected with E through the aperture D, to be ejected at the next up stroke. The oil serves to perfect the fitting of the valve and the piston, and prevents any leakage of air.

Sprengel Pump. — A much more perfect vacuum can be obtained by this pump (Fig. 38). Mercury falls from a funnel A through a piece of thick - walled india-rubber tube B, which

Fig. 37.—Fleuss air pump (*after Lehfeldt*).

can be compressed with a screw pinch-cock C, down a glass U tube D, and falls over E into a glass tube F, which must be 6 ft. to 7 ft. long, and which has a T tube G in the upper end. The bore of the glass tube must be small, a little over 1 mm. The screw pinch-cock is so adjusted that the mercury as it falls into F breaks up into little

threads, which act as pistons as they fall and suck in air from the side tube G.   If an upright glass tube,
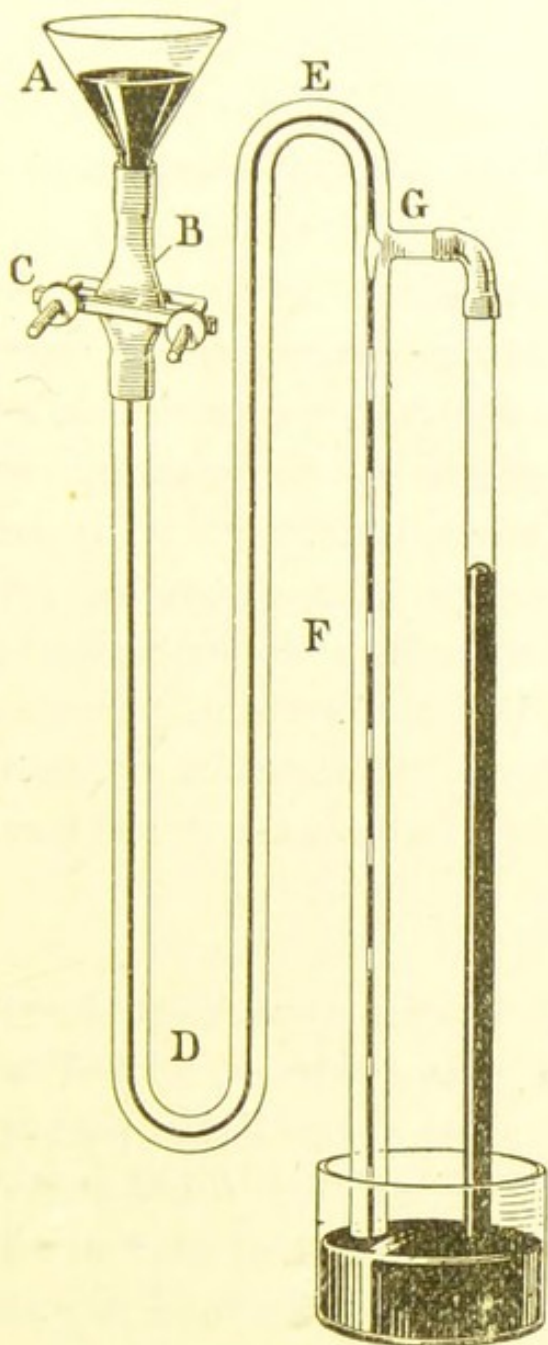
Fig. 38.—Sprengel pump.
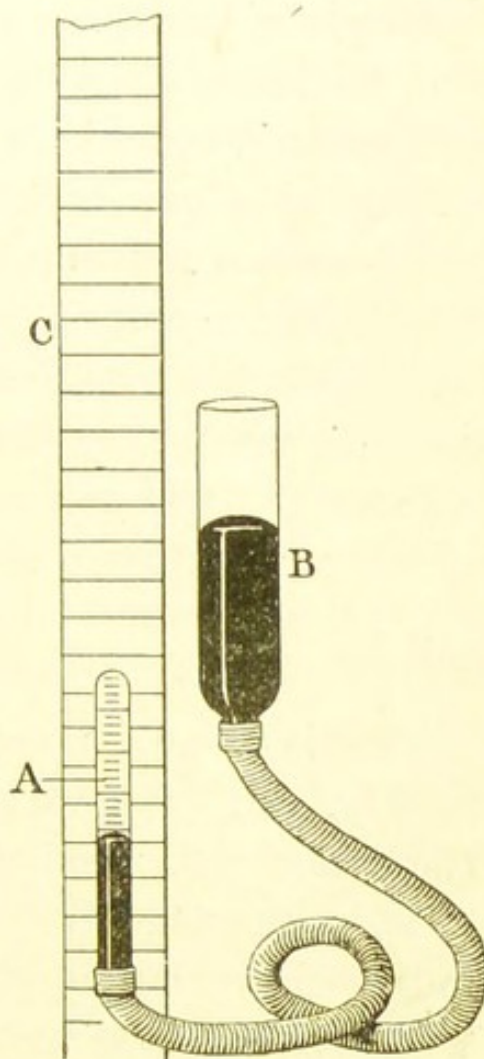
Fig. 39. — Apparatus for verifying Boyle and Mariotte's law.

the lower end of which dips into mercury, be attached to G, the mercury will rise as the air is removed, until it stands at 760 mm.   When the vacuum is

E

perfect the pellets of mercury fall with a metallic click owing to the complete absence of air.

It is to the Sprengel pump that we owe the discovery of the phenomena in high vacua investigated by Sir William Crookes, the Röntgen tube, etc., and it is largely used for exhausting the bulbs of incandescent electric lamps.

Boyle's Law, sometimes called the law of Boyle and Mariotte, gives the relation between the volume of a gas and the pressure to which it is exposed. *The volume of a gas varies inversely as the pressure*, or the pressure × volume = a constant. Thus, if we double the pressure, the volume of a gas is halved, etc. This law enables us to reduce the volumes of gases to what they would be at 760 mm. Thus a volume of hydrogen measures 240 c.c. at a pressure of 620 millimetres of mercury ; its volume at 760 mm. will be $\dfrac{240 \times 620}{760} = 195 \cdot 7$ c.c.

This law can be verified by the apparatus shown in Fig. 39. A graduated glass tube A, closed at the upper end, contains the gas ; the lower part of A is connected by a long length of thick-walled india-rubber tubing with the reservoir of mercury B. The latter can be moved up and down, and a scale C enables the height of the mercury level in B above that in A (which is fixed to the scale C) to be read off. The mercury is levelled (by moving B) in the tubes A and B, and the volume of gas in A read off (say it is 40 c.c.), the gas being then subject only to the atmospheric pressure (760 mm.). The reservoir B

is then raised till its level is 200 mm. above the level in A. The gas is now exposed to a pressure of $760 + 200 = 960$ mm., and its volume will be found to be $\dfrac{40 \times 760}{960} = 31 \cdot 6$ c.c.

Cohesion of Liquids and Surface Tension.— If a drop of bisulphide of carbon, coloured pink with a trace of iodine, be suspended in a mixture of sulphuric acid and water of the same specific gravity, as the influence of gravity is removed, the cohesion of the liquid particles will cause the drop to take the form of a sphere which floats in the liquid ; the surface tension acts as a stretched elastic skin enclosing the sphere. If a clean metallic hoop or ring be dipped in a solution of soap and withdrawn, a film of the liquid remains stretched across the ring. If a thread moistened with soap solution be placed on this film it will form a loop of any desired shape as long as the film is intact, but if the film be broken it immediately springs into a circle. This is due to the surface tension acting on one side of the loop only, and thus dragging it out into a circle. If a soap bubble be blown on a tube and the mouth be withdrawn, the bubble will be seen to contract and become smaller owing to the action of the surface tension. These simple experiments demonstrate the existence of surface tension.

If a clean glass tube be drawn out into a *capillary tube* (Fig. 40), and one end of the capillary tube be immersed in some ink, the liquid will be seen to rush up the capillary, and will remain permanently above the level of the main bulk of the fluid.

The height to which the fluid will rise depends (1) on the nature of the tube, (2) on the nature of the fluid, (3) on the medium in which the experiment is made, (4) on the size of the tube, varying inversely as the diameter. If the capillary be dipped in mercury the mercury will be depressed. Similarly, if a glass tube be smeared with vaseline and dipped into water, the level of the water will be depressed in the greasy tube.

Fig. 40.—Capillary tube.   Fig. 41.—Surface tension.
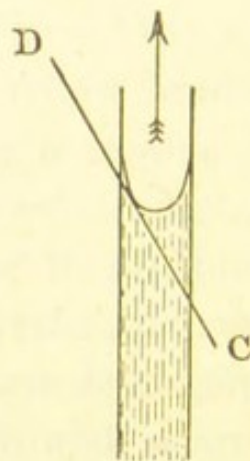
The cause of these changes in level is surface tension (Fig. 41).

The surface tension on the inside of a tube gives rise to a force directed along the tangent to the surface of the fluid at C D. The resolved portion of this force, acting parallel to the axis of the tube, supports the column of liquid.

If the radius of a capillary tube and the capillary elevation be known, the value of the surface tension can be calculated.

Capillarity produces a slight error in the reading

of the level of the mercury in the barometer, which becomes greater as the tube becomes narrower. Capillary tubes afford a most convenient method of collecting small samples of pathological fluids, vaccine, etc.

Part II.

HEAT.

CHAPTER I.

THERMOMETERS AND OTHER INSTRUMENTS FOR MEASURING TEMPERATURE.

HEAT has been defined as a *mode of motion*—in other words, the molecules of bodies when heated are thrown into a state of invisible vibration which reveals itself to our senses as heat.

We must distinguish between the temperature —*i.e.*, the *degree* of heat—and the *amount* of heat or heating power of a substance. Thus a red-hot cannon ball has obviously far greater heating power than a red-hot needle, though both consist of iron and are at the same temperature, so that the heating power of a body depends upon its weight as well as its temperature.

Two bodies A and B are said to be at the same temperature if, when they are in contact, the flow of heat from A to B is equal to that from B to A. If the flow of heat from A to B is greater than that in the opposite direction, A is said to have a higher temperature than B.

The effect of heat on a substance is usually to

make it expand and become larger (exceptions are met with in water at 0° C. and in india-rubber, both of these substances contracting when heated). Thus, if we take a brass ball which slips easily through a ring when cold, and heat it for a few minutes, it will expand so much that it will rest on the ring (Fig. 42).

In a thermometer, when heated, the mercury expands and rises in the tube. It is the same with
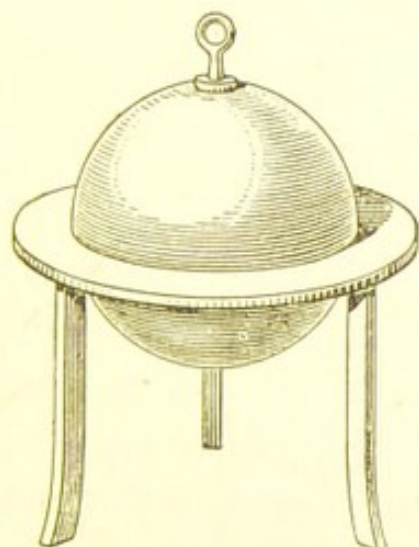
Fig. 42.—Gravesande's ball and ring.
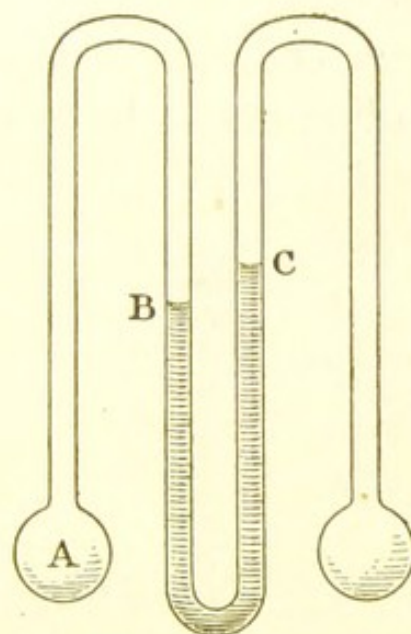
Fig. 43.—Leslie's differential air thermometer.

gases, as can be seen in Leslie's differential air thermometer (Fig. 43). If we warm bulb A with the hand, the expansion of the air is at once indicated by the downward movement of the liquid in B, and the upward movement in C.

The **Thermometer** is not an instrument for measuring the *amount* of heat in a substance, but is used for comparing the relative temperatures of various substances.

A glass tube with a small bore is taken and calibrated to see if the bore is uniform. This is done by introducing a short column of mercury (Fig. 44), and accurately measuring its length in various parts of the tube.
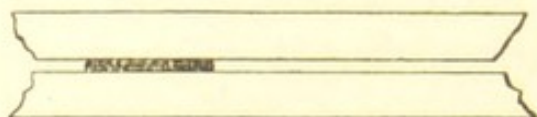
Fig. 44.—Calibration.

If the tube be uniform in its bore, the mercury will be of the same length in all parts. A tube with uniform bore having been selected, a bulb is blown at one end and a piece of wider tube attached at the other so as to form a funnel.

Fig. 45.—Filling thermometer bulb.
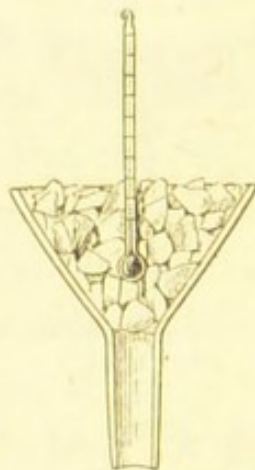
Fig. 46.—Verifying zero of thermometer.

The liquids used for filling thermometers are usually mercury or coloured alcohol. Mercury is peculiarly suitable for the purpose, because (1) it is easy to obtain it pure by distillation ; (2) its expansion is almost uniform ; (3) it remains liquid

through a wide range of temperature, freezing at $-38 \cdot 8°$ C., and boiling at 350° C.

The liquid is poured into the funnel and the bulb gently heated, the air expands and escapes through the mercury in the funnel. The bulb is then allowed to cool, and as the air contracts some of the mercury is sucked back into the bulb (Fig. 45). The bulb is again heated till the fluid boils, when its vapour chases out all the air, and on allowing the bulb to cool it rapidly fills with mercury as the vapour condenses.

The tube having been filled, the thermometer is heated slightly above the highest temperature it is to indicate, and the end of the tube near the funnel drawn off and sealed by the blowpipe. The thermometer is then laid aside for some months to allow the bulb, which contracts slightly when freshly blown, to assume a position of equilibrium, when it is ready for graduation.

Graduation of a Thermometer.—The two fixed points on the thermometric scale are the *melting point* of ice and the *boiling point* of water, when *the barometer stands at* 760 *mm. or* 30 *inches*. The thermometer is accordingly plunged into melting ice (Fig. 46), and when it has reached its lowest point, this is marked as the freezing point. It is then placed in an instrument called a " hypsometer," as seen in Fig. 47. The tube in which the thermometer bulb is placed is surrounded by steam, which escapes at A ; the mercury just appears above the cork when the liquid boils, the bulb of the thermometer

being surrounded by the vapour of the boiling water. If the barometer does not stand at 760 mm. a correction must be made before the boiling point is marked on the thermometer.

There are three scales in use at the present time : (1) the Fahrenheit, in use in the British Isles, in
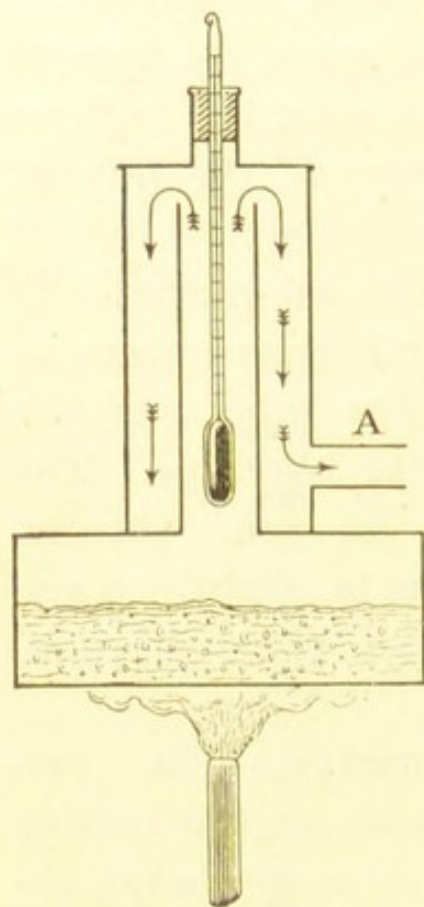
Fig. 47.—Hypsometer, for determining boiling point.
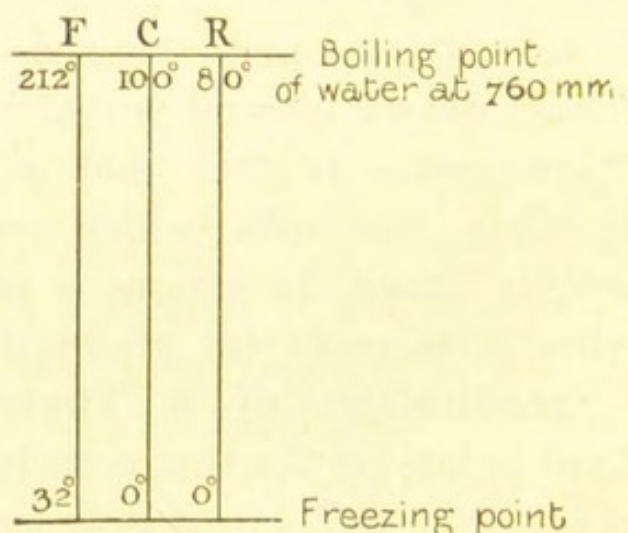
Fig. 47*a*.—Relation between the thermometrical scales.

Canada, the United States, etc. ; (2) the Centigrade, or Celsius, in use in France, Germany, etc. ; and (3) the Réaumur, in use in Italy, Russia, etc. The relation between the scales can be seen at a glance in the diagram (Fig. 47*a*).

The freezing point of water is marked 32° in the Fahrenheit scale and 0° in the Centigrade and

Réaumur. Water boils at 212° F., 100° C., and 80° R. So that 180° F = 100° C. = 80° R.

To convert one scale into another, the scheme set out in Fig. 48 will be found useful. Thus to convert 40° C. into Fahrenheit, $40 \times \frac{9}{5} = 72 + 32 = 104$ Centigrade ; to convert 82° F. into Réaumur subtract $32 = 50 \times \frac{4}{9} = 22°·2$ R. In cheap, common thermometers the scales are made first and the thermometer tubes and bulbs are blown
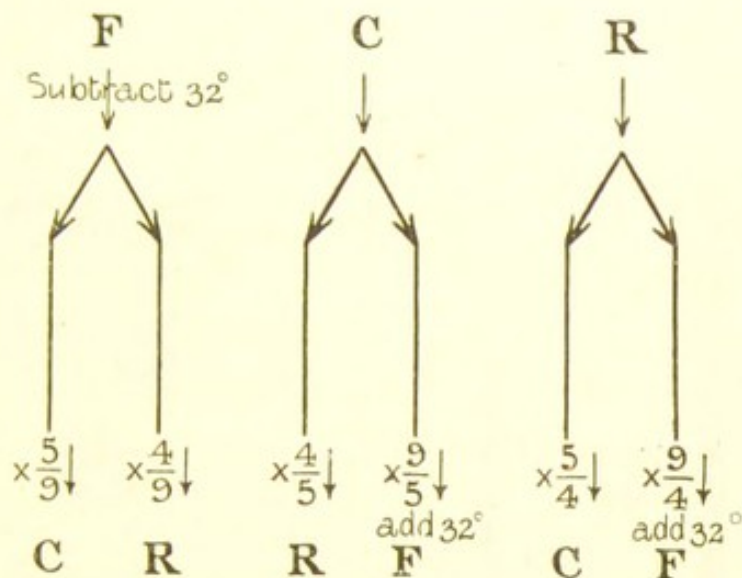
Fig. 48.—Conversion of thermometrical scales.

to fit the scale. High-class clinical thermometers in this country have usually the " Kew certificate "— that is, they have been verified at the Physical Laboratory.

The *delicacy* of a thermometer is the smallest fraction of a degree it will show, and depends on the relative sizes of the bulb and the bore. The larger the bulb and the smaller the bore the more delicate is the thermometer.

The *sensitiveness* of a thermometer—that is, the

rapidity with which it will take up a temperature
—depends on the size of the bulb. The smaller
the bulb the more sensitive the thermometer.

Registering Thermometers are thermometers
which show the highest or lowest temperature to
which they have been exposed.

Six's Thermometer is an alcohol thermometer
(Fig. 49). The bulb is at A, the alcohol column of the
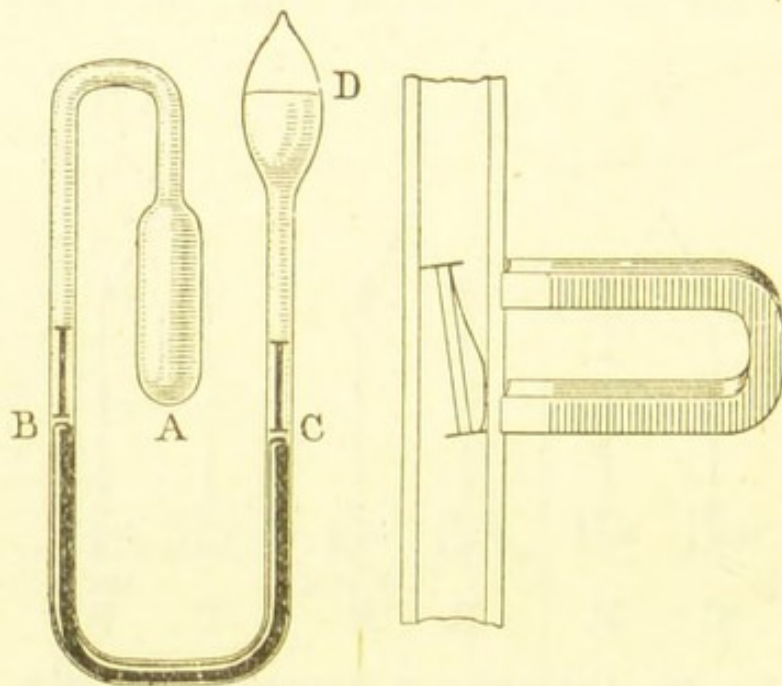
Fig. 49.—Six's thermometer, showing use of magnet for setting it.

thermometer ends at B; the tube is filled with
mercury up to C, and the rest with alcohol, which
only half fills the bulb D. The maximum and
minimum temperatures are registered by two little
indices of iron wire at B and C, which are kept in
position by a very delicate spring. When the
temperature goes up, the mercury rises at C and
pushes up the index until the maximum temperature
is attained, when the mercury falls, the index,

however, remaining fixed up. As the temperature sinks the mercury forces up the iron index at B , so that the lower end of the index B gives the minimum and the lower end of C the maximum temperature. The indices are set by means of a small horseshoe magnet, whose hollowed-out ends are moved along the glass tube, and bring the indices again into contact with the mercury.

Rutherford's Maximum and Minimum.—The maximum thermometer is filled with mercury, and the maximum temperature is registered by a little index of iron wire, which is pushed along by the mercury A (Fig. 50) as it expands, and so marks the maximum temperature.
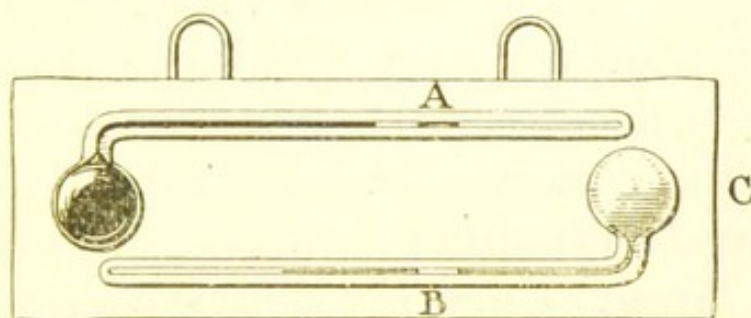
Fig. 50.—Rutherford's maximum and minimum.

The minimum thermometer is filled with alcohol, and the index is a piece of glass (B), which allows the alcohol to pass it as the temperature rises; but when in cooling the surface of the liquid reaches the index, the surface tension pulls the index back with it, and so the minimum temperature is registered. In order to set the instrument the end C is raised, when the indices fall to the surfaces of the liquids. When in use the instrument should be horizontal.

Negretti and Zambra's Maximum.—In this instrument (Fig. 51) the bore is narrowed close to the bulb. As there is repulsion between mercury and glass, the mercury will only pass through this narrow glass tube, A, when forced to do so. As the temperature rises the expansion of the mercury in the bulb forces the liquid through the narrow tube; but when the
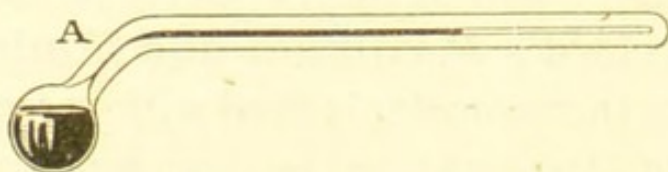
Fig. 51.—Negretti and Zambra's maximum.

temperature falls the column breaks at A, one portion retreats into the bulb, and the other registers the maximum temperature. The thermometer is set by shaking it, or by jarring it on the hand.

This form is much used for clinical thermometers.

Philipps' Maximum.—In this instrument (Fig. 51a) the thread of mercury is broken by a bubble of
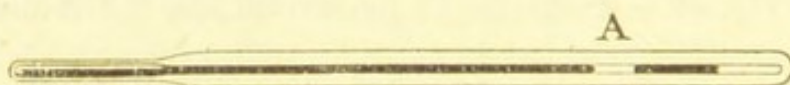
Fig. 51a.—Philipps' maximum.

air A. When the temperature rises, this bubble forces the index column of mercury along the tube, but when the temperature falls, the index column is left indicating the maximum temperature. It is set in the same way as Negretti and Zambra's.

For temperatures below —38° C. alcohol can be used down to —130° C., when it freezes.

Air Thermometer.—This instrument can be used for a very wide range of temperature. A bulb of porcelain or platinum is inserted in the furnace and connected with a bent glass tube outside, which contains mercury (Fig. 52). The thermometer is graduated by plunging the bulb into melting ice and steam (at 760 mm.), noting the expansion, and then, if the tube is uniform, marking the rest of the scale. A correction is made for the increase of pressure produced by the rising column of mercury.

Temperatures beyond the range of the ordinary mercury thermometer can be determined by filling the space above the mercury with hydrogen under pressure, when the boiling

Fig. 52.—Air thermometer.

point of mercury is raised, and the thermometer, which must be made of hard glass, can be used up to 550° C.

Temperatures, both high and low, can also be determined **by electrical means** : (1) by the variation of the resistance of a platinum wire, the
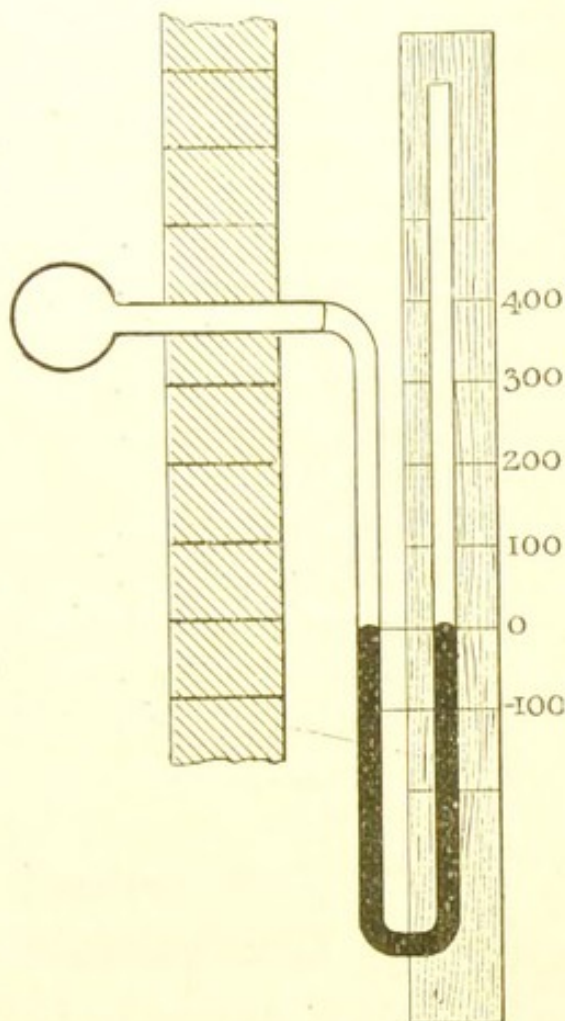
resistance increasing at a known rate as the temperature rises (p. 160); (2) by measuring the current developed on heating a junction of two dissimilar metals, such as platinum and iridium, with the aid of a galvanometer (p. 190).

VARIOUS TEMPERATURES (C.).

Absolute zero (so-called) . .	—273°
Hydrogen solidifies . . .	—257°
Hydrogen liquefies . . .	—238°
Oxygen liquefies	—180°
Alcohol freezes	—130°
Greatest natural cold (Nares) . .	—57·7°
Mercury freezes	—38·8°
Mercury boils	350°
Red heat just visible . . .	526°
Silver melts	1000°
Cast iron melts	1530°
Highest temperature of a wind furnace	1805°
Platinum melts	2000°
Electric furnace	3500°

CHAPTER II.

EXPANSION OF SOLIDS, LIQUIDS, AND GASES BY HEAT.

Expansion of Solids.—Every solid has its own rate of expansion. This can be shown by taking two rods, one of iron and one of brass, and magnifying their motion by levers or some other suitable mechanical device. One simple method is seen in Fig. 53. The rod is placed in a bath, one end resting against one end of the bath and the other pressing against a lever L. A small mirror M is cemented on the axis at C; a beam of light A B is reflected from the mirror M and received on a scale. When the bar expands, the beam of
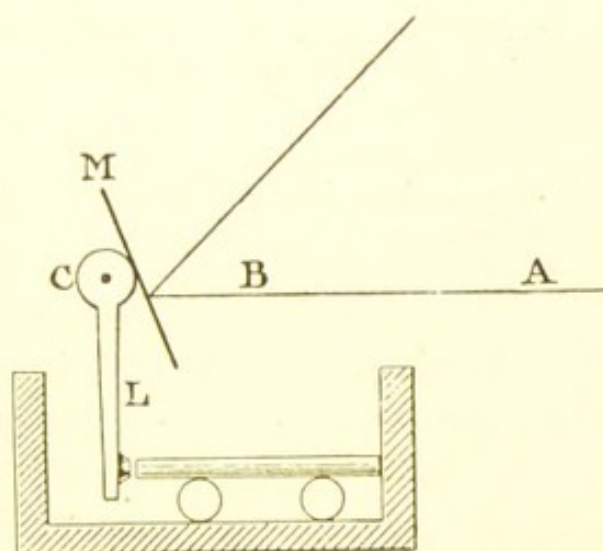
Fig. 53.—Expansion of a rod of metal.

light moves on the scale. The bath can be filled with water at various temperatures.

The exact increase in length of a bar of metal for a given rise in temperature can be determined by the spherometer (Fig. 5). A bar of brass one metre in length rests on a solid foundation F (Fig. 54), and is surrounded by a glass tube A, through which

F

water at any temperature can be passed by the tubes B C. On the top of the framework rests a

Fig. 54.—Determination of increase of length of brass rod.

piece of plate glass D D, through which a hole is bored large enough to receive the end of the rod of brass E. Water is run through, say, at 10° C., and the level of the end of the brass rod, relative to the plate glass, is determined by the sphero-meter. The temperature of the water is raised to 50°, and the in-crease in length found by a second reading of the spherometer.

The amounts of expansion of various substances are given in what are termed *coefficients of linear expansion.*

Thus the coefficient for iron is . ·000012
    ,,   ,,   brass is . ·000019
    ,,   ,,   zinc is . ·000030
    ,,   ,,   slate is . ·000014
    ,,   ,,   glass is . ·000009
    ,,   ,,   platinum is . ·000009
    ,,   ,,   pine wood is ·0000005

It will be noticed that glass and platinum expand at the same rate, so that when a platinum wire is fused into a glass globe the joint remains sound when cold.

Suppose we wish to calculate the increase in length of 50 miles of *iron rails* for a rise in temperature of 20° C. : 1 mile becomes 1·000012 mile if its

temperature be raised 1° C., so 50 miles would become 50 + (50 × ·000012) if raised 1°, and if raised 20° would measure 50 + (50 × 20 × ·000012) = 50·012 miles.

If we consider the increase in size of a *sheet* of metal, taking the coefficient of linear expansion to be a, and supposing the sheet to be 1 ft. square, each side will increase (for 1°) to $1 + a$, and therefore the new area will be $(1 + a)^2 = 1 + 2a + a^2$. Now a^2 is so small that it is neglected, and the new area is therefore written $1 + 2a$.

The *square expansion* is therefore reckoned as twice the linear expansion. Thus a square plate of iron 3 inches in the side raised 10° C. would become $9 + (9 × ·000012 × 2 × 10) = 9·00216$ sq. inches.

In a similar way the *cubic expansion* is taken as three times the linear expansion.

The expansion of metals has to be taken into account in many directions. Thus the wooden patterns for brass castings have to be made larger than the brass articles are intended to be, the iron tyres of wheels are made smaller than the wooden wheel, so that when made red hot they can just slip over, and as they cool contract and bind the wheel firmly together. The rails on the line are laid so as to leave a small gap between the rails to allow room for expansion. In a long iron bridge like the Forth bridge the difference in length in summer and in winter may amount to a foot, and the ends of the girders are mounted on rollers to allow this movement to take place.

The force with which this contraction or expansion takes place is enormous, as can be shown by the apparatus in Fig. 55. An iron bar is heated, and while it is hot a rod of cast iron, about $\frac{1}{4}$ inch in diameter, is passed through the hole A, and screwed up tightly by the nut C against the jaws B B. As the bar cools it contracts and breaks the rod.

Two other interesting applications must be mentioned—the *compensating pendulum* and the *compensating balance wheel*.
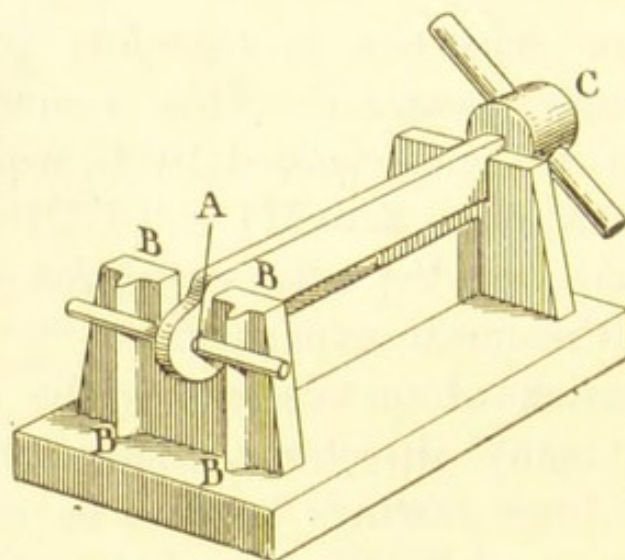
Fig. 55.—Apparatus to show the force of contraction when cooling.

Compensating pendulum.—The object of this contrivance is to keep the distance from the point of suspension to the centre of gravity of the heavy bob unchanged, however the temperature may vary. A simple pendulum in summer lengthens, and so the clock loses; the reverse is the case in winter. The bars A A A in Fig. 56 are of iron and the bars B B of zinc. As the temperature rises the iron bars A A A expand and the bob tends to drop;

but as the zinc bars B B expand more than the iron they tend to raise the bob, and if the relative lengths be inversely as their coefficients of linear expansion (zinc : iron : : 12 : 30), the distance between the point of suspension P and Q will remain unaltered. This contrivance is sometimes called the *gridiron* pendulum, from its obvious resemblance to that domestic implement.

If two flat pieces of brass and iron respectively be riveted together at the ordinary temperature, and the compound bar be heated, as the brass expands more than the iron, the bar will become curved, the brass forming the outer and longer curve (Fig. 57). This

Fig. 56.—Gridiron pendulum, zinc and iron.

fact is utilised in the construction of *the compensating balance wheel.* It has a compound rim of brass and iron, the brass being on the outside (Fig. 58). The rim is

Fig. 57.—Compound bar of brass and iron bending when heated.

divided in three places, A A A ; on the free ends little weights are attached. As the temperature rises the spokes increase in length, and the rim is at a greater

distance from the centre, tending to make the watch lose; but this tendency is compensated, if the
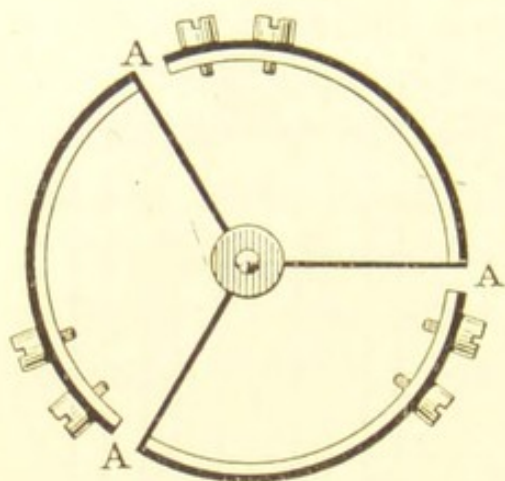
Fig. 58.—Compensating balance wheel.

weights are properly adjusted, by the rim curving inwards and bringing the weights at A A A nearer the centre.

Expansion of Liquids. —We have only to consider the *cubical* expansion of liquids; it is usually much greater than that of solids. Mercury = ·00018.

Each liquid has its own rate of expansion. The rate of expansion is usually determined by weighing a specific gravity bottle filled with the liquid at different temperatures. Or a *weight thermometer* can be used (Fig. 58*a*). This consists of an elongated bulb with drawn-out neck, which is bent down so as to dip into a small vessel of the liquid. The empty bulb is first weighed = 20 grams; it is then filled with mercury (or any
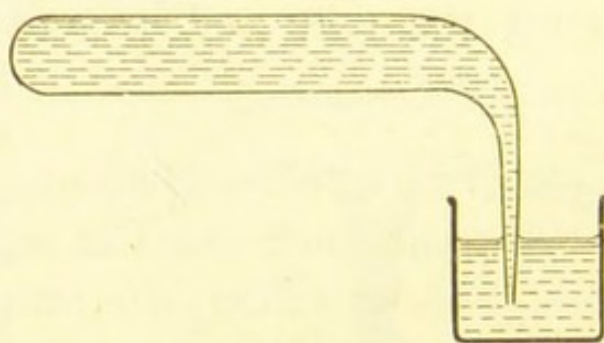
Fig. 58*a*.—Weight thermometer.

other liquid) at 0°, re-weighing = 48 grams. It is then heated to 100°, and weighs 47·55 grams, so that at 0° the bulb contains 28 grams and at 100° 27·55 grams ∴ 1 gram of mercury at 100° measures

$$\frac{28}{27 \cdot 55} = 1 \cdot 016 \text{ times its volume at } 0°. \text{ The ap-}$$

parent expansion for 100° is therefore ·016, and for 1°

$$\frac{·016}{100} = ·00016.$$

As the mercury is contained in a glass bulb, which also expands when heated, the *apparent expansion* as determined above only shows ·the *difference* between the expansion of the mercury and the expansion of the glass, and this is obviously less than the *absolute* expansion.

That the glass bulb does expand can be readily shown by plunging a thermometer, with a large bulb, suddenly into hot water,
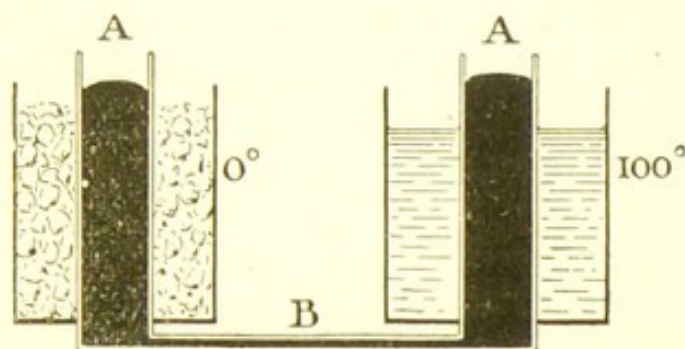
Fig. 59.—Apparatus for the absolute expansion of mercury.

when the mercury will be seen to drop for a moment and then rapidly rise in the stem. The absolute expansion of mercury can be determined (Fig. 59) by connecting two vertical glass tubes, A A, filled with mercury, by a long narrow tube B. One of the vertical tubes is surrounded with ice, the other with hot water. The difference in their levels is read off. Their specific gravities will be inversely as their heights, so the volumes will be proportional to the lengths of the columns, and the ratio of the difference of height to the height in the tube surrounded

by ice will give the total absolute expansion between 0° C. and the temperature of the hot water. Thus, supposing the height in the tube at 0° is 1000 mm., and that in the tube at 100° is 1018 mm., the absolute expansion for 100° is $\dfrac{18}{1000} = $ ·018, or for 1° C. ·00018.

The expansion of water is anomalous : thus 1000 c.c. of water at 0° when heated *contracts* to 999·88 c.c. at 4°. At 8° the volume is again 1000, at 16° 1·00085, and the expansion continues as the temperature rises. Water therefore is not, like most liquids, heaviest at its freezing point, but at 4° C. above it.

This apparently insignificant physical fact has a far-reaching effect on natural phenomena. If water continued to become heavier until it froze, ice would begin to form at the *bottom* of lakes, rivers, etc. They would be frozen solid during a severe winter, and would probably not completely melt during the summer. But as water when cooled below 4° expands, the colder and lighter water rises to the top and ice forms on the top, while the heavy layer of water at 4° rests on the bottom.

This can be shown by Hope's experiment. A tall cylinder (Fig. 60) has two thermometers fitted in its side, one at the top and one at the bottom ; the middle is cooled by a gallery containing ice and salt. The thermometer beneath will be found to sink to 4° C. and no lower, while the thermometer at the top falls till ice begins to form.

When water freezes it expands $\frac{9}{100}$ of its volume, so that ice is lighter than water, its sp. gr. being ·9175. This expansion takes place with enormous force, bursting iron bottles, water-pipes, disintegrating rocks, etc.

Expansion of Gases.—All gases expand at the same rate, $\frac{1}{273}$ of their volume for 1° C. This holds good except when the gas approaches its liquefying point, its contraction then becoming irregular. As a gas contracts $\frac{1}{273}$ of its volume for a fall of 1° C., if it continues to do so as the temperature falls, it will occupy no volume at all at — 273° C., because it will have contracted $\frac{273}{273}$ of its volume.

This temperature,—273° C., is sometimes called the *absolute zero*, and temperatures reckoned from this point are known as *absolute* temperatures. The absolute temperatures are obtained by adding 273 to the ordinary temperature Centigrade. Thus 100° is 373° absolute, 0° is 273° absolute, etc.

Fig. 60.—Hope's experiment.

Charles and Gay Lussac's Law.—"The volume of a gas varies directly as the absolute temperature." *E.g.*, a volume of hydrogen measures 250 c.c. at 20° C.; find its volume at 0°.

20° C. = 293° absolute,   0° = 273° absolute

$$\therefore \text{ vol. at } 0° = \frac{250 \times 273}{293}.$$
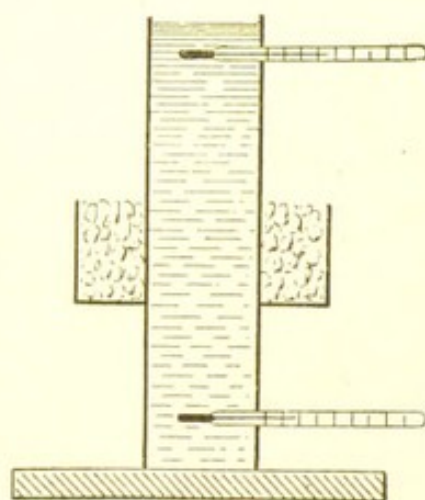
If v = volume at temperature (absolute) T, then

$$v' = \frac{v \times T'}{T}. \quad (v' = \text{volume at new temperature } T'.)$$

On the expansion of air depends the ventilation of rooms, collieries, etc. The hot air rises and escapes by any opening at the top of the room, the cold, fresh air flowing in along the floor. It is advantageous to remember this fact when a rescue is
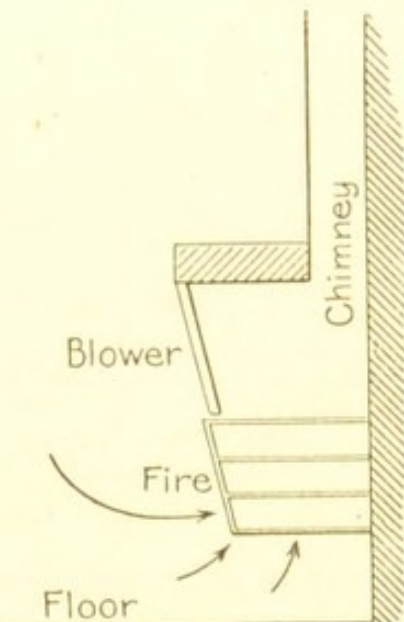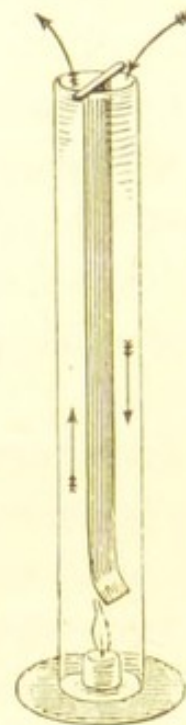
Fig. 61.—A "blower."   Fig. 62.—Effect of partition.

being attempted from a burning building : a cold, fresh current of air fairly free from smoke can usually be found by crawling along the floor, whilst on standing up the air will be found quite irrespirable.

To the expansion of air is due the draught in a chimney. The draught can be increased by shutting out all the cold air, which is usually sucked in between the mantelpiece and the fire-bars, by a thin

sheet of metal. Such a contrivance is called a
" blower " (Fig. 61). It forces all the air to pass
through the fire, thus quickening combustion ; at
the same time it ensures that all the air passing into
the chimney is well heated. A greater difference
between the specific gravity of the gases in the
chimney and the air outside is thus set up, and the
draught thereby greatly increased.

Sometimes it is of great use to divide the incoming
and the outgoing currents by a partition. Thus, a
night-light at the bottom of a tall, narrow glass jar
soon flickers and goes out, but if a loose partition
be inserted the flame burns brightly, and the two
currents of air, one ascending and the other descend-
ing, instead of fighting and interfering with each other,
pass on opposite sides of the partition—one up, the
other down (Fig. 62).

CHAPTER III.

TRANSMISSION OF HEAT.

HEAT can be transmitted in three ways—*conduction, convection,* and *radiation.*

Conduction is the method by which heat is transmitted in solids. The molecules are set in vibration, and the vibration is transmitted from one particle to the next *without any perceptible movement of the particles.*
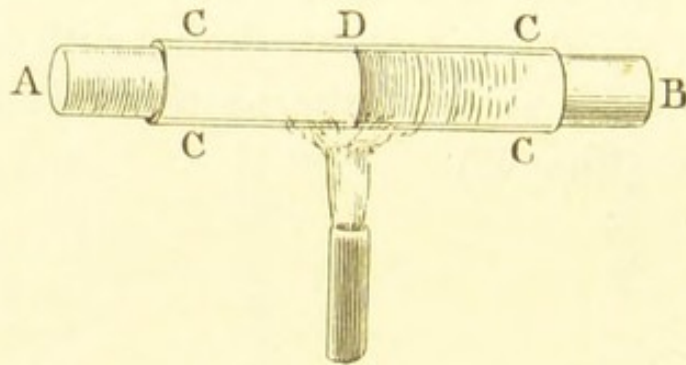
Fig. 63.—Conduction of brass and wood.

The metals are by far the best conductors of heat. Next come marble and various stones, whilst wood, wool, furs, cotton, etc., are such bad conductors that they are usually termed non-conductors.

The best conductors among the *metals* are silver and copper, whilst platinum and German silver are among the worst. Taking the conductivity of silver as 100, copper would be estimated at 74, platinum 8, German silver 6.

Fig. 63 shows an experiment illustrating the fact that *brass* is a much better conductor than wood. A cylinder, half brass, half wood, has a sheet of thin paper tightly gummed round it. On the joint between the brass and wood in a Bunsen flame being heated, the paper over the wood chars, but the brass conducts away the heat so rapidly that the paper is not scorched.

The conducting power of *copper* is well shown by placing a piece of fine copper gauze about an inch
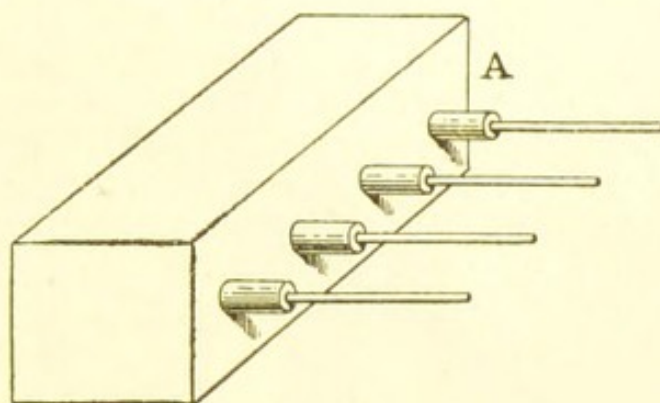
Fig. 64.—Ingenhausz trough.

above a Bunsen burner. When the gas is turned on and a light applied *above* the gauze, the gas will burn above, but remain unlighted below, the gauze, the copper conducting the heat away so rapidly that the flame is put out and cannot pass through.

The miner's safety lamp depends on the same principle. The flame of the lamp is surrounded by fine copper gauze. If the lamp be placed in an atmosphere containing " fire damp," the marsh gas may burn inside the lamp, but the flame is so cooled down by the copper gauze that it is extinguished as

it passes through the gauze, and cannot light the fire damp in the mine.

Non-conductors of heat—wool, furs, flannel, feathers, etc.—have been chosen instinctively for clothing. Ice is surrounded with non-conductors to prevent it from absorbing heat during the summer time.

The relative conductivity of substances for heat can be shown by means of the *Ingenhausz trough* (Fig. 64), in which rods of various substances coated
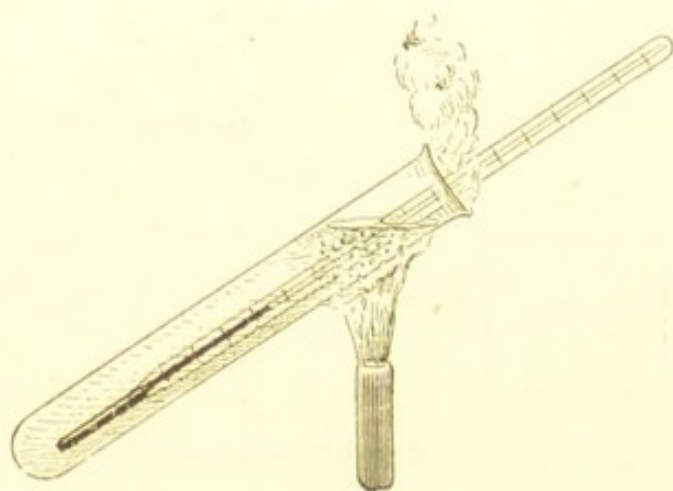
Fig. 65.—Non-conductivity of water.

with wax are fixed by corks in the side A, having their ends projecting into the trough. Hot water is poured into the trough, and the relative conductivity is shown by the lengths of wax which are melted.

Liquids, except mercury, are *bad conductors* of heat. Thus water in the upper part of a test tube can be boiled without any rise being produced in a thermometer whose bulb is at the bottom of the liquid (Fig. 65).

The relative conductivity of liquids can be investigated by floating a tin of hot water on the surface and placing a thermometer at a definite distance below (Fig. 66).

Convection is the name given to the process by which liquids and gases are usually heated. It can be demonstrated by placing a few crystals of magenta
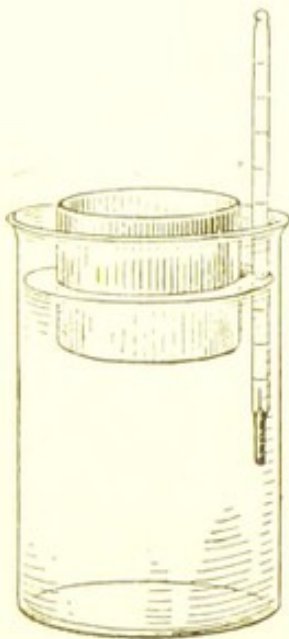
Fig. 66.—Relative conductivity of liquids.
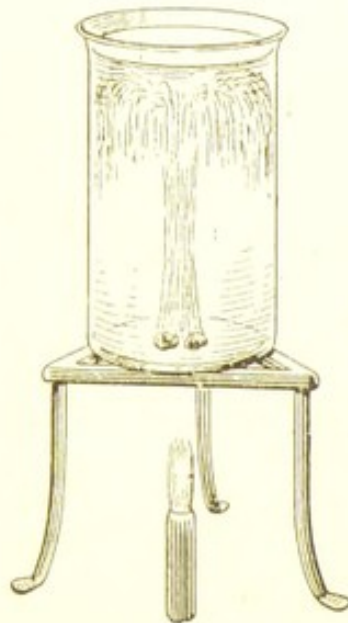
Fig. 67.—Convection currents.
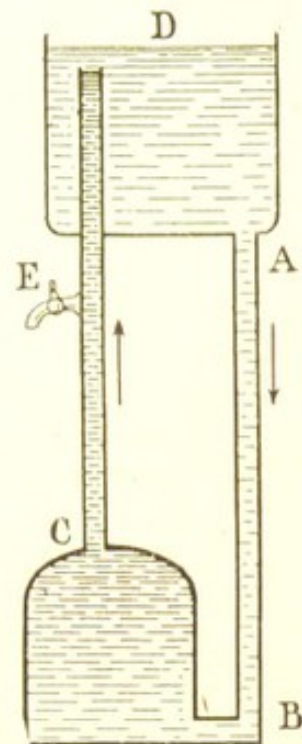
Fig. 68.—Hot-water system.

at the bottom of a large beaker of water and heating with a small flame (Fig. 67). As soon as the heat penetrates the glass the particles of water expand and rise to the surface. As they are coloured, their motion can be seen, so that in convection there is *a visible movement of the particles.*

It is in this way that the circulation in the ordinary domestic hot-water supply is carried on. There is a

closed boiler in the lower part of the house (Fig. 68), and a cistern at the top. One pipe A passes from the bottom of the cistern and ends close to the bottom of the boiler at B, and a second tube passes from the top of the boiler c and ends near the surface of the water in the cistern at D. The whole system is filled with water and the boiler heated,
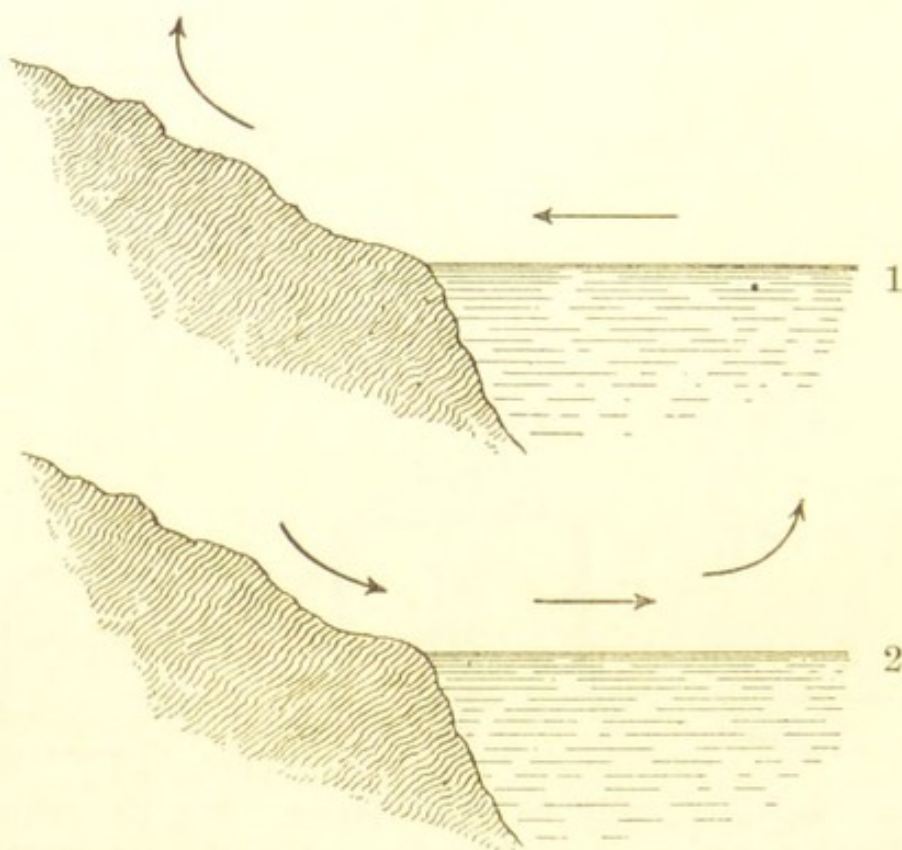
Fig. 69.—Land and sea breeze circulation (1) by day, (2) by night.

when a current of hot water passes up c D and a return current of cold water flows through A B. If a tap be inserted at E hot water can be drawn off, and if a coil of pipes be inserted in c D it will be filled with hot water, and can be used for warming a room.

To the convection established by hot-air currents we owe the "land and sea" breeze and the trade winds.

Land and Sea Breeze.—In the tropics, where the atmosphere is clear, there is a great difference between the day and the night temperature of the land; whereas the temperature of the ocean remains fairly constant. In the day when the sun is shining the land gets intensely heated, and a current of hot air ascends from the heated land, and a cooler current flows in from the sea. After the sun sets, the land cools rapidly by radiation into space, while the temperature of the ocean remains almost unaltered;
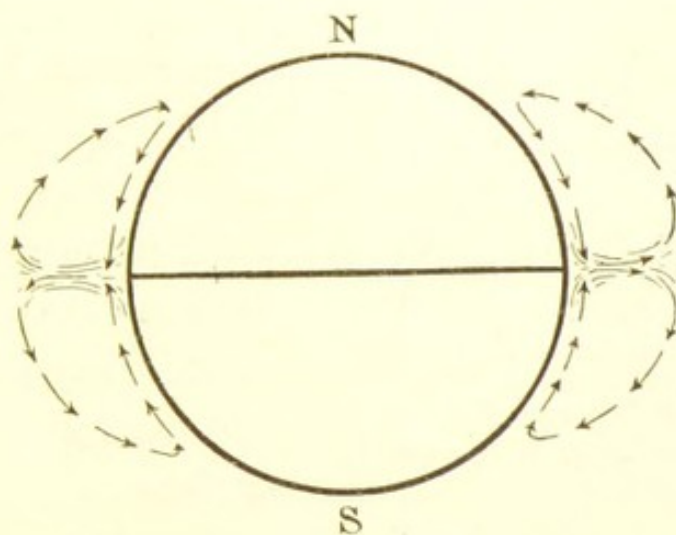
Fig. 70.—Origin of trade winds.

and so we have a current of warm air ascending from the ocean and a deliciously cool current coming off the land (Fig. 69).

Trade Winds.—The sun warms the earth most powerfully at the equator, and the hot air, rising up, flows off towards the poles, while a return current of air flows in the reverse direction along the surface of the earth.

If the earth did not revolve on its axis the upper current in the northern hemisphere would set towards

G

the north, and the return current to the south
(Fig. 70) ; but as the earth rotates from west to
east, the particles of air (which move with the earth)
travel in this direction most rapidly at the equator,
and their velocity diminishes as we approach the
poles. A particle of air starting from the equator
towards the North Pole gains on the particles under-
neath, and so the upper current flows to the north-
east (Fig. 71), and for a similar reason the return
current flows to the south-west. Occasionally a
volcanic eruption at Teneriffe shoots up a cloud of
ashes with such energy that it reaches the
upper trade wind and demonstrates its exist-
ence as it moves along in a direction opposed
to the wind at the earth's surface.
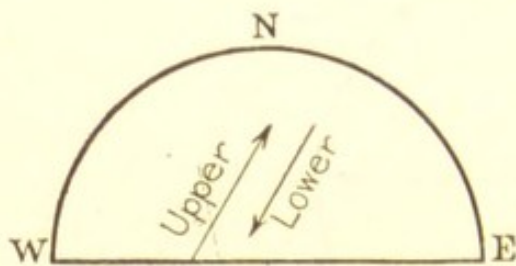
Fig. 71.—Deflection of trade
winds from rotation of the earth.

The return " trades " in the northern hemisphere
flow from north-east to south-west in a zone north
of the equator—*e.g.*, from North-west Africa to the
northern coast of South America.

Radiation.—This is the third great method by
which heat is transmitted. It is so named because
a heated body throws off heat *in all directions*. The
sun warms the earth by radiation. We are warmed,
when we stand in front of a fire, by radiation. The
heat waves or vibrations are transmitted through
a vacuum by the mysterious ether which pervades
all things.

Some substances absorb radiant heat much better than others. Thus, the sun's heat passes through the atmosphere without perceptibly warming it; but when it falls on the earth the heat is absorbed and the hot surface warms the air. The top of a mountain is much colder than the ground at its foot, because, although the mountain is a little nearer the sun, it is constantly dissipating its heat by radiation into space; whereas the plain is receiving the heat radiated from the higher ground which surrounds it on every side.

A dull, black surface is the best absorber of heat rays, and a polished metal surface the worst. On the other hand, the polished metal surface reflects heat better than a dull, black surface.

It is obvious that the heat which falls on a surface will be partly absorbed, raising the temperature of the body, and partly reflected. If the absorption is great the portion reflected will be small, and *vice versa.*

A surface which absorbs heat well will form a good radiator.

These facts can be demonstrated by a *Leslie's cube* (Fig. 72)—a tin box filled with hot water. One side is polished, one painted, one varnished, and the fourth smoked a dead black. The sides *must* be all at the same temperature, but it will be found that they radiate very different amounts of heat, the smoked surface being by far the best radiator. The superior absorption by a smoked surface can be shown (Fig. 73) by exposing two tin plates, one

polished and one smoked, to the radiation from a red-hot iron ball. The smoked surface rapidly rises in temperature and lights a piece of phosphorus placed behind it.

If it is wished to boil a saucepan placed in front of a fire, its surface should be blackened. On the other hand, to boil a kettle on a hot plate, the bottom of the kettle should be bright and free from soot, because the latter, being a non-conductor, prevents the heat from passing from the plate to the kettle.
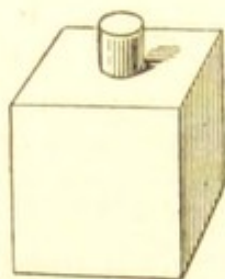
Fig. 72.—Leslie's cube.   Fig. 73.—Absorption by black and by polished plate.   Fig. 74.—Dewar's vacuum vessel.
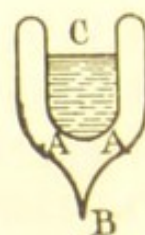
Hot-water pipes should be dead black, teapots should be brightly polished, as in the former the object is to promote radiation, in the latter to prevent it.

A red-hot iron ball placed on a metal stand illustrates the three methods by which heat is conveyed. Thus, it loses heat by *conduction* along the metal stand, by *convection* from the currents of cold air which are constantly carrying off heat as they get warmed and rise, and by *radiation* as it throws off heat through the air on all sides.

Sir James Dewar found, when working with liquid air, that most of the loss by evaporation of this intensely cold (−180° C.) liquid was due to the heating by convection currents of the air, which warmed up the outside of the flask and then sinking gave place to other particles. He therefore invented his *vacuum vessel* or cup (Fig. 74), so well known to all workers at low temperatures. In this, convection is completely stopped by placing the outside wall of the vessel containing the liquid air c in a vacuum, in which, as no particles of air are present, no convection can take place. The space A A is exhausted by a pump and sealed off at B.

Some substances are transparent to heat rays, as ordinary glass is to light. Such substances are said to be *diathermanous.* Colourless rock salt is the most diathermanous substance known. It· allows heat from the sun, from a lamp, from boiling water to pass equally well.

Glass allows the heat vibrations which are rapid enough to affect the retina (and so are called *luminous heat rays*) to pass, but completely blocks those which are non-luminous. Thus a glass screen, in front of a blazing fire, allows the luminous heat rays to pass, but the non-luminous heat rays, given off by the bars, etc., which constitute by far the largest proportion of the heat, are absorbed by the glass, which accordingly becomes very hot.

Substances may be quite opaque to light and yet be diathermanous—*e.g.*, vulcanite, a strong solution of iodine in carbon disulphide, etc.

The following table shows the proportion of heat rays which pass through various substances from different sources of heat, the total number of heat rays emitted in each case being taken as 100:—

PLATES 0·1 IN. THICK OF	SOURCE OF HEAT.			
	Oil Lamp.	*White-hot Platinum.*	*Copper at* 400°	*Copper at* 100°
Rock Salt .	92·3	92·3	92·3	92·3
Glass . .	39	24	6	0
Quartz . .	38	28	6	3
Alum . .	9	2	0	0
Ice . . .	6	5	0	0

Aqueous vapour absorbs a considerable amount of heat. In damp climates the radiation at night is largely stopped by the aqueous vapour.

In dry climates—South Africa, Australia, etc.—the absence of aqueous vapour leads to a rapid cooling by radiation, so that even after the hottest day the temperature soon falls to the freezing-point. This is turned to account in India, where ice is made by exposing pans of water, in shallow pits lined with rice straw, to the rapid radiation into space which takes place owing to the absence of aqueous vapour.

The excessive heat in a conservatory, with a glass roof, when the sun is shining, is explained by the property that glass has of allowing the luminous heat rays of the sun to pass in, while it stops the non-luminous heat rays from the interior walls, shelves, etc., from passing out.

CHAPTER IV.

FUSION—MELTING POINT—LATENT HEAT—FREEZING
MIXTURES — VAPOURS — VAPOUR PRESSURE —
BOILING POINT—DISTILLATION.

Fusion.—When a substance is heated it expands, its
molecules get further apart, and the force of cohesion
is diminished until the solid becomes a liquid.   If we
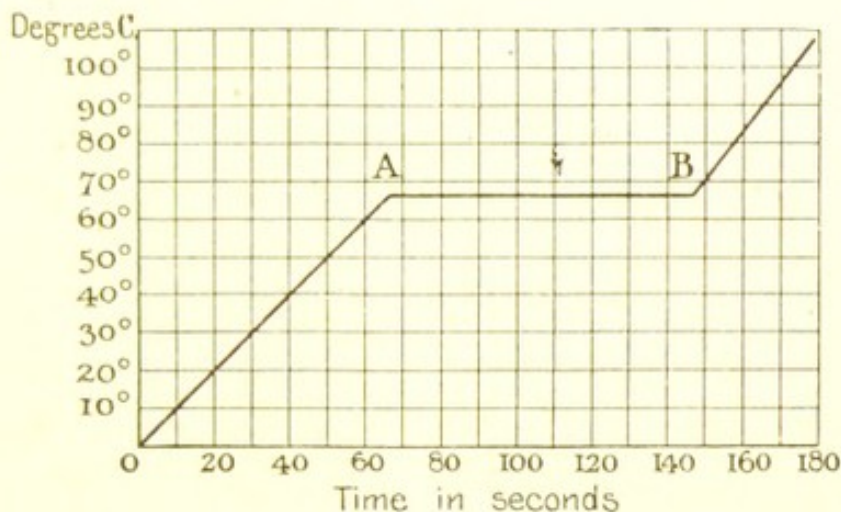
Fig. 75.—Graphic representation of rise of temperature on heating
a solid, showing the stationary position of the thermometer
during the melting, A—B.

note the temperature of a melting substance, we
shall find that the thermometer rises until the solid
begins to melt, and then the temperature remains
unaltered until all the solid has melted (Fig. 75).
During the time the thermometer remains stationary,
heat is being poured into the substance, and this
heat is apparently lost, as there is no rise in tempera-
ture. It was therefore termed **latent heat.**   But it

is really used up in performing molecular work, and
in so arranging the molecules that they take up the
heat vibrations. If two exactly similar vessels be
taken, one containing 1 lb. of *ice* at 0°, and the other
1 lb. of water at 0°, and if these vessels be heated
with exactly similar burners starting at the same
moment, the temperature of the water will begin to　·
rise at once, but that of the ice will remain at 0° till
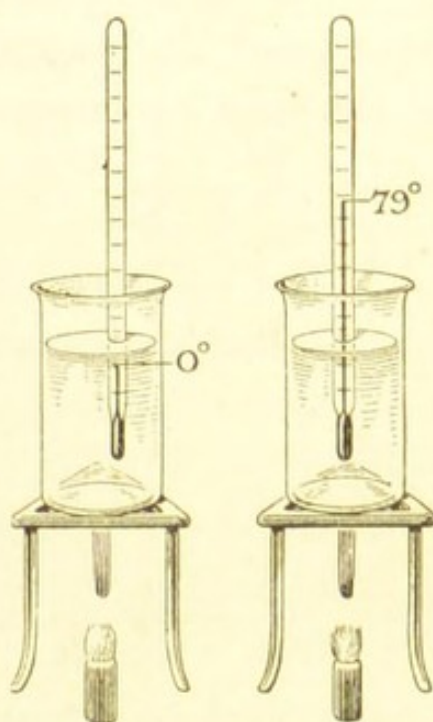
Fig. 76.—Latent heat of water.

all the ice has melted. By this time the thermometer
in the water will be at 79° (Fig. 76). In other words,
as much heat is required to convert 1 lb. of ice at 0°
into 1 lb. of water at 0° as would raise 1 lb. of water
from 0° to 79° C. The latent heat of water is said
to be 79°. If 1 lb. of water at 100° be mixed with
1 lb. of ice at 0°, we shall have 2 lbs. of water at
10·5°, because the 1 lb. of water at 100° will be

reduced to 21° in melting the ice, and 1 lb. of water
at 21°, mixed with 1 lb. of water at 0°, gives 2 lbs. at
10·5°.

The **melting point** of many substances can be de-
termined by placing a few fragments of the substance
in a small tube, which is fixed to the bulb of a ther-
mometer by an india-rubber ring (Fig. 77), and then
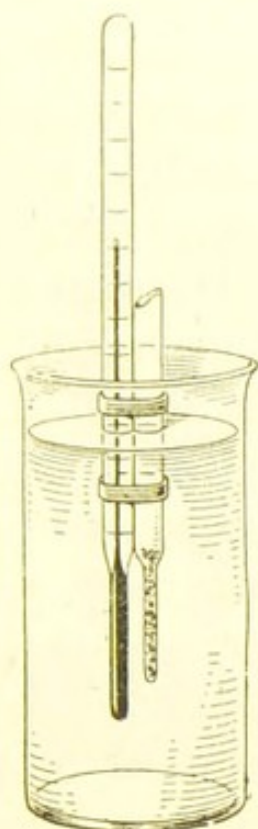
Fig. 77.—Determination of
melting point.
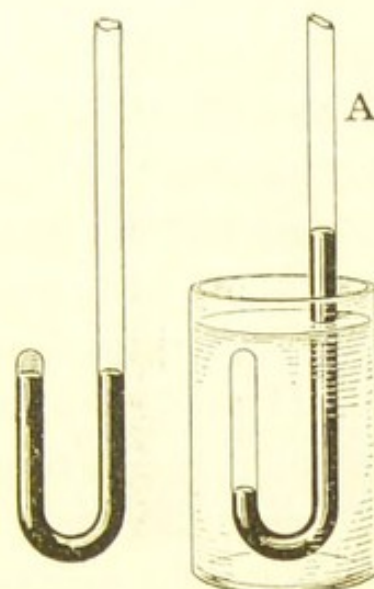
Fig. 78.—Vapour tension of
ether.

immersing the thermometer in a vessel of water, the
temperature of which is *slowly* raised till the sub-
stance melts.   Anilin, strong sulphuric acid, etc., may
replace the water if a higher temperature is required.

Some substances pass through an intermediate
pasty state before they become liquid.   This pasty
state enables us to unite two pieces of wrought-iron

or platinum by welding, also to work glass into a great variety of useful articles.

Mixtures often melt at a lower temperature than their constituents. A notable example of this is Wood's fusible metal, which, consisting of 4 parts by weight of bismuth (melting at 264° C.), 2 parts of lead (m.p., 335°), 1 of tin (m.p., 228°), 1 of cadmium (m.p., 228°), melts at 60·5° C.

When a liquid solidifies, as when water freezes, all the latent heat is set free, and when the solid liquefies this heat is abstracted from surrounding substances.

Freezing Mixtures —The action of many freezing mixtures depends on the heat abstracted during the sudden and enforced liquefaction of a solid. Thus 2 parts of crushed ice or snow, mixed with 1 part of salt, form a liquid brine, having a temperature of about −18° C. Brine does not freeze at 0°, and so, as soon as the ice and salt come into contact, the ice melts to form the solution of salt, and the sudden abstraction of heat required to melt the ice causes the fall in temperature. In some cases, instead of ice we use a solid salt containing a large quantity of so-called *water of crystallization*, as Glauber's Salt ($Na_2 SO_4 + 10 H_2O$); the so-called water is solid, just as ice is solid. When this salt is mixed with hydrochloric acid the chemical action forms a solution of salt, and the ten molecules of solid water rapidly liquefy, causing a great fall in temperature. The sudden solution of a large quantity of a very soluble salt, as sal-ammoniac (NH_4Cl), in water also brings about a great fall in temperature.

Vapour.—The term " vapour " is applied to the gas of a substance which is usually a liquid or a solid ; thus we speak of alcohol vapour, ether vapour, water vapour, arsenic vapour, etc. Vapours are elastic, and exert a **pressure** on substances around them.

Thus if we introduce a small drop of ether at the closed end of a U tube containing mercury (Fig. 78) and plunge it into a vessel of hot water, the ether is
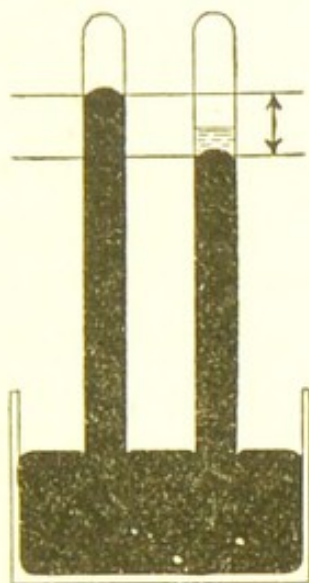
Fig. 79.—Depression of barometer by vapour.
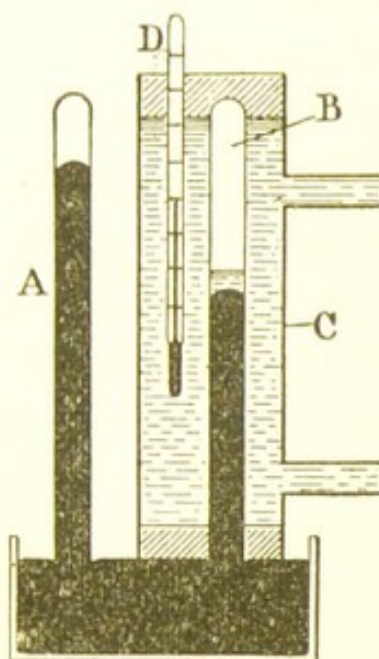
Fig. 80.—Apparatus for estimating tension of vapour.

converted into vapour which proves its elasticity by supporting a heavy column of mercury in the open leg A. Another striking experiment is to place a small quantity of water in a tin canister, the mouth of which can be closed by a cork. The water is boiled vigorously for some minutes to allow the steam to chase out all the air. The outside of the tin is subject to the atmospheric pressure, but it does not collapse,

because this is balanced by the elasticity of the steam inside. If we now cork up the canister, at the same time removing the flame, and abolish the steam pressure by pouring on cold water, the enormous atmospheric pressure of 15 lbs. on the square inch acts, the canister is at once crushed in, and falls as a shapeless mass.

The vapour pressure of a liquid can be measured by the fall which it produces in the mercury column, when passed up into a barometric vacuum (Fig. 79). If, *e.g.*, some alcohol, ether, or water be introduced into a barometer, the level of the mercury instantly falls, and the amount of the depression enables us to measure the vapour pressure in fractions of an inch, or of a millimetre of mercury. As the temperature rises the vapour pressure increases until the vapour pressure, by itself, supports the atmospheric pressure, and the mercury stands at the same level in the barometer tube and in the cistern. The temperature at which this takes place is the **boiling point** of the fluid.

In all determinations there should be some liquid visible on the surface of the mercury ; in other words, the space above the mercury should be *saturated* with the vapour. If a very small quantity of liquid is passed up into the barometer it will be completely converted into vapour, the space will be *unsaturated,* and the full vapour pressure will not be developed. The vapour pressure depends on the nature of the liquid and the temperature, but is independent of the pressure.

The vapour pressure of a liquid at various temperatures can be ascertained by the apparatus shown in Fig. 80. A is an ordinary barometer, B is the barometer tube containing the liquid. This is surrounded by a second tube C, through which water at different temperatures can be passed ; the temperature is given by the thermometer D. The *difference* between the heights of the mercury in A and in B above the cistern level gives the depression produced by the vapour.

VAPOUR TENSION OR PRESSURE.

TEMP. IN °C.	WATER. Mm. of Mercury.	ALCOHOL. Mm. of Mercury.
0	4·6	12·2
10	9·1	23·8
20	17·4	44·0
40	54·9	133·7
60	148·9	350·0
80	355·0	812·0
100	760·0	1692·0
200	11689·0	22182·0

It has just been stated that the temperature at which the vapour pressure of a fluid is equal to the atmospheric pressure is called the boiling point of the fluid. It follows that at the top of a mountain 15,000 ft. high, where the atmospheric pressure would be about 354 mm., water would boil a little below 80° C. This becomes serious when an army is sent on a mountaineering expedition, as the water

cannot be made hot enough, in open vessels, to cook properly, and the troops suffer from indigestion. The fall in the boiling point of water in an open dish has been used to determine the height of a mountain, 1° C. indicating an ascent of 1,080 ft., or 1° F. = 600 ft. ; but, according to Whymper, this method does not give such accurate results as the barometer.

The fall in the boiling point can easily be demonstrated by placing some hot water under the air pump ; as the pump is worked and the pressure diminished the water boils vigorously.

Fig. 81.—Water boiling under reduced pressure.

Fig. 82.—Ether boiling with the warmth of the hand.

The same fact can be shown without an air pump, as follows :—A strong, round-bottomed flask is half filled with water and boiled for some time so as to chase out all the air ; it is then corked and inverted, when it can be made to boil (Fig. 81) by pouring on it cold water, which condenses the steam and forms a vacuum.

Ether, if sealed up in a glass tube free from air, boils when warmed by the hand, owing to the

diminished pressure (Fig. 82 ; the bulb A is held in the hand). A practical application is found in the vacuum pans used for the evaporation of sugar syrup ; by covering the pans and reducing the pressure inside, the boiling point of the syrup is reduced from 110° to 65·5°.
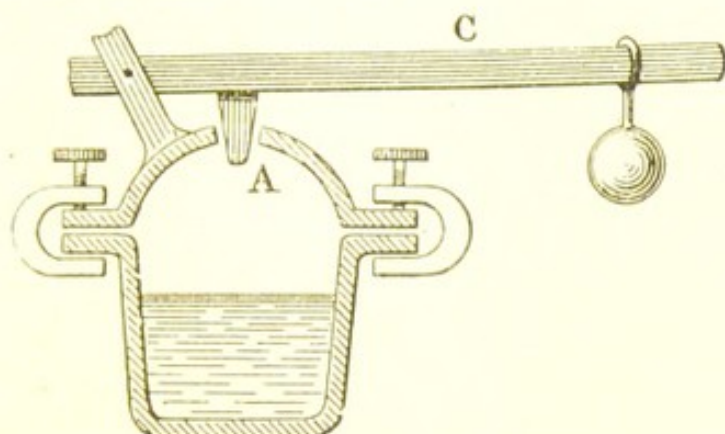
Fig. 83.—Papin's digester.

On the other hand, by increasing the pressure we can raise the boiling point, thus :—

Pressure in atmospheres.	Boiling Point of water.
1½	112·2
2	120·6
4	144
8	171
10	180·3
20	213
28	231

This increase in pressure is effected in the domestic contrivance termed *Papin's digester* (Fig. 83). An iron saucepan has a turned iron flange on which rests a lid with a similar flange, and the two are clamped so as to make an air-tight joint, the lid is perforated with a conical hole A in which fits

a valve ; this is kept in its place by the weighted lever c. Before the water can boil, the vapour has to lift this valve, in addition to the atmospheric pressure ; the boiling point is therefore raised and the solvent power of the water increased. In this way bones, calves' feet, etc., are quickly converted into gelatin, and the apparatus forms a ready means of making "stock" for soups, sauces, etc.

The boiling point also depends, to a small extent, on the *nature* of the vessel containing the liquid.
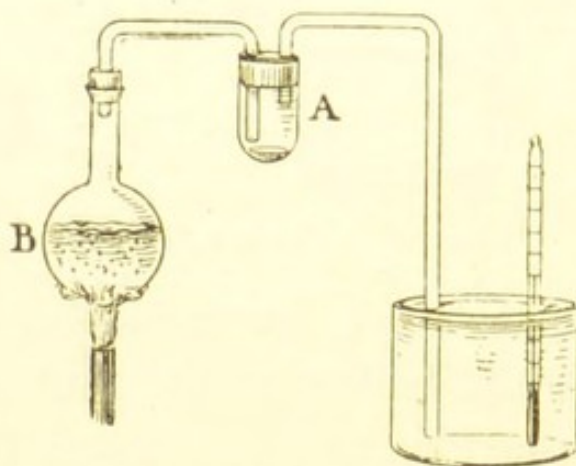
Fig. 84.—Latent heat of steam.

If its inner surface be smooth and clean the liquid may be heated slightly above its boiling point. Then, if the vessel be shaken or the liquid stirred, a sudden rush of vapour ensues, and the temperature sinks to its normal boiling point. This is the cause of the phenomenon of "bumping."

The boiling point of water can also be raised by dissolving in it various substances, as common salt, calcium chloride, etc.

If water be heated under ordinary conditions it begins to boil at 100° C. (212° F.), and remains

at that temperature until it has all boiled away. The heat that is being poured into it is used up in converting the liquid *water* at 100° into *steam* at 100°; it is termed the latent heat of steam, and is 537·2°. That is to say, to convert 1 gram of water at 100° into steam at 100°, an amount of heat is required which would raise 537·2 grams of water 1° C.
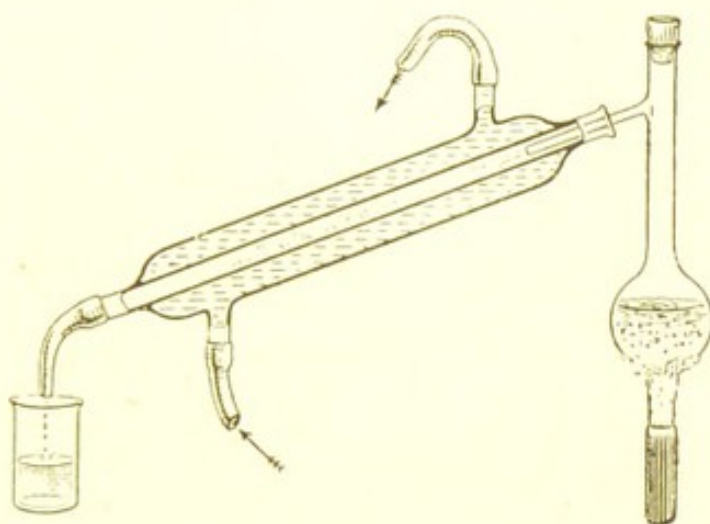
Fig. 85.—Distillation with Liebig's condenser.

This can be estimated by passing a known weight of steam into a calorimeter containing a known weight of water at a known temperature, and observing the rise in temperature produced, a short tube A (Fig. 84) fitted up like a wash-bottle, being interposed as a trap to catch any water spirted over. The loss of weight in the flasks A and B gives the weight of the steam.

Latent heat may be defined as **heat which produces a change in the physical state of a body without altering its temperature.**

H

Distillation.—This depends upon the fact that
when two vessels A and B, connected together,
are at different temperatures and contain liquid,
the latter rises in vapour from the one having the
higher vapour pressure A, while the vapour in
B, which is at the lower temperature, condenses,
the tendency being to bring the whole system down
to the lower vapour pressure. So vapour rises con-
tinuously from A, and is condensed in B as long
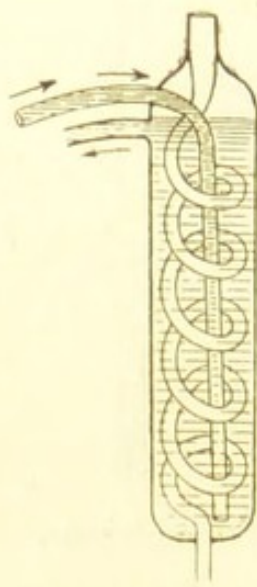
Fig. 86.—Spiral condenser.
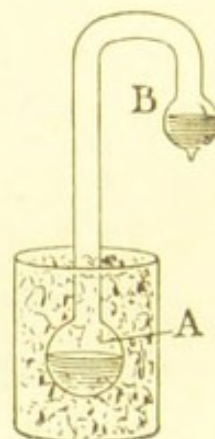
Fig. 87.—Cryophorus.

as the difference in temperature is maintained. In
practice the usual plan is to heat A and cool B.

One form of " still " or " condenser " largely used
is the *Liebig condenser* (Fig. 85); another form has
the condenser tube, whether metal or glass, twisted
in a spiral called the " worm " (Fig. 86).

We can also distil by artificially cooling vessel
B and forcing the liquid in A to distil over at the
expense of its own heat. This is the principle of

the *cryophorus* (Fig. 87).   In this instrument we have two bulbs, A and B, connected by a tube containing water and water vapour.   The air has been

boiled out and the apparatus sealed by the blow-pipe at B. The water is transferred to the bulb B and the lower bulb A immersed in a mixture of ice and salt, the water vapour in A is condensed rapidly, vapour rises from B, the water in B cools, and eventually freezes
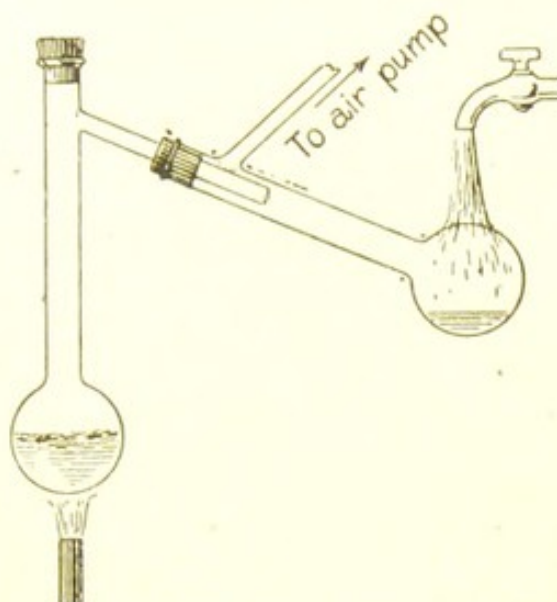
Fig. 88.—Distillation at reduced pressure.

owing to the loss of heat from the enforced distillation. Some organic liquids decompose when distilled

Fig. 89.—Freezing with ammonia.

under the atmospheric pressure, so that it is advisable to distil them under diminished pressure, and thus lower the boiling point. An apparatus for effecting this,

made out of two distilling flasks, is shown in Fig. 88.

Cooling by rapid evaporation is often used on the large scale for producing cold; one form of

apparatus is shown in Fig. 89. A and B are two iron vessels ; in B is placed a solution of ammonia saturated at 0° C. This is gently heated, and the ammonia gas is driven off and condenses as a liquid in the interspace of the double-walled vessel A, which is kept in cold water. When sufficient ammonia has distilled over, the substance to be frozen is placed in C, A is taken out of the water and surrounded with some non-conducting substance, while B is plunged into cold water, the ammonia is rapidly re-absorbed by the cold water in B, and this enforces a rapid evaporation of the liquid in A, with a corresponding abstraction of heat from C.

CHAPTER V.

HYGROMETRY.

Dew=point.—The atmosphere, under ordinary conditions, always contains water in the form of invisible vapour, which may become visible as mist or fog, or may be deposited on cold surfaces in the form of dew. The explanation of the formation of dew we owe to Dr. Wells. When the sun sets the temperature of the surface of the earth rapidly falls, heat being radiated into space. At last the portion of the atmosphere close to the earth becomes so cold that it is unable to retain all its moisture in the form of vapour; some of it therefore condenses as visible drops on the cold surface. If the sky is clouded, free radiation into space is much hindered, and no dew is formed. If there is much wind, but little dew is deposited, because as fast as one portion of air is cooled it is carried away by the wind, and its place taken by uncooled air. The largest formation of dew is always observed on calm, clear, cold nights. Obviously the best radiators cool the quickest; the minimum temperature is found on the grass. On a frosty morning the wooden sleepers on a railway line will be covered with hoar frost, whilst the polished " metals " remain free. **The temperature at which the first deposition of dew is observed is called the dew=point.**

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The drying power of the air depends upon its relative humidity—*i.e.*, the amount of aqueous vapour it actually contains, compared with the amount it *could* take up if it were saturated.

$$\text{Relative humidity} = \frac{\text{V.P. at dew-point}}{\text{V.P. at the tempera-ture of the air}} \times 100.$$

E.g., Air temperature $= 55°$ F., dew-point $46\cdot5°$.

Vapour pressure at $55° = \cdot433$ inch, at $46\cdot5 \ \cdot317$ in.

$$\text{Relative humidity} = \frac{\cdot317}{\cdot433} \times 100 = 73 \text{ per cent.}$$
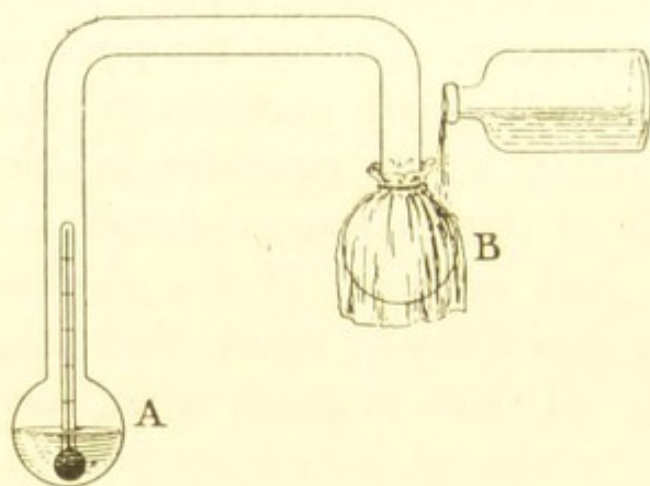
Fig. 90.—Daniell's hygrometer.

Hygrometry. —The dew-point is determined by h y g r o m e t e r s. *Daniell's hygrometer* (Fig. 90) consists of two glass bulbs connected by a large bent tube. The longer leg of this tube has a small thermometer A inside, and the bulb on the short leg is covered with muslin. The bulbs contain ether, which was boiled for some time before the apparatus was sealed, so that there is no air, only ether and ether vapour. The ether is run into bulb A, so as to surround the thermometer, while the bulb B is cooled by pouring ether on the muslin outside; the vapour in B condenses,

fresh vapour from A distils over, the thermometer falls, and at last dew is deposited on A, the thermometer is read off, the cooling discontinued, and the temperature again read when the dew has just disappeared. The mean of these temperatures is the dew-point. The bulb A is usually gilt to render the dew more visible.

Dines' hygrometer.—In this apparatus (Fig. 91) iced water is run into a little metal box, in the top of which is inserted a thin plate of black glass A; underneath this is a delicate thermometer B. The
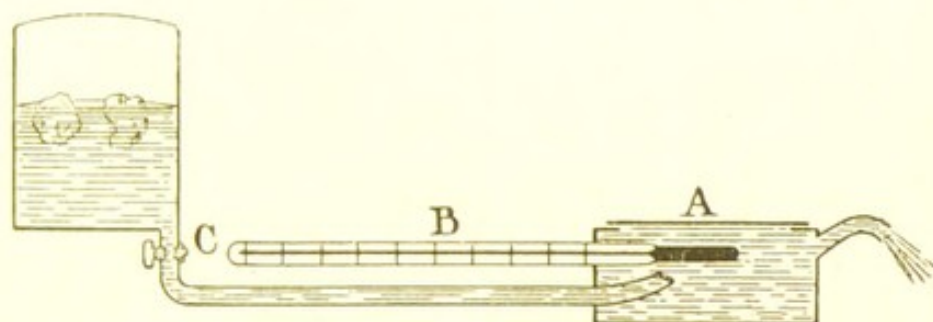
Fig. 91.—Dines' hygrometer.

cold water is turned on by the tap C, and the temperature at which the black glass gets dim noted, as with the previous instrument.

Regnault's hygrometer.—Some ether is placed in a thin glass tube (Fig. 92) furnished with a cork and two tubes—one long, one short—and a thermometer. Air is sucked through the ether, the temperature falls, and the readings are taken as before. The lower part of the glass tube is gilt.

Wet and dry bulb.—This hygrometer consists of two thermometers (Fig. 93) exactly alike, except that the bulb of one is kept constantly moist by

being surrounded with a piece of muslin, round which is twisted some lamp wick immersed in a small vessel of rain or distilled water. If the air is saturated, the two thermometers read alike, but in dry air the water on the wet bulb evaporates rapidly, and the thermometer has a lower reading than the dry bulb, so that the drier the air the greater is the difference between the thermometers.
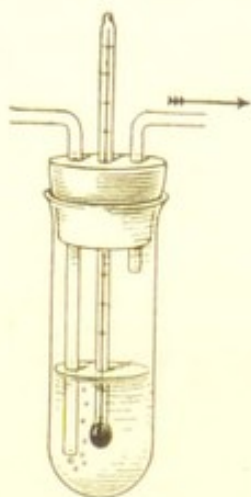
Fig. 92.—Regnault's hygrometer.
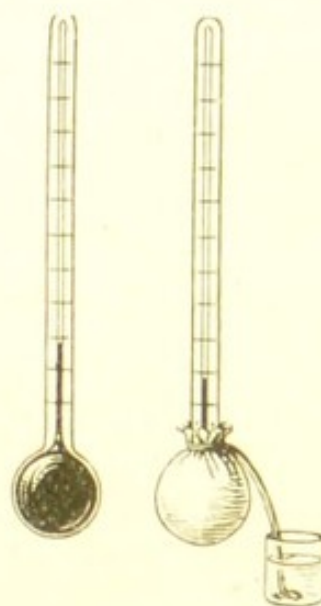
Fig. 93.—Wet and dry bulb.

Glaisher compared these differences with the readings of a Daniell's hygrometer taken under similar conditions, and has given a set of factors (see Appendix) which, when multiplied by the difference between the thermometers, yields a number that, subtracted from the dry bulb reading, gives the dew-point— *e.g.*, dry bulb 50° F.

wet bulb 45°

$$5° \times 2 \cdot 06 \text{ (factor for } 50° \text{ F.)} = 10 \cdot 3.$$
$$50 - 10 \cdot 3 = 39 \cdot 7 \text{ dew-point.}$$

The dew-point can also be determined with this instrument by first finding the pressure of aqueous vapour f'' at the temperature of the dew-point by Apjohn's formula.

$$\text{Thus } f'' = f' - \frac{t - t'}{87},$$

where f' = V.P. at the temperature of the wet bulb in inches of mercury, t = temperature Fahrenheit of the dry bulb, t' of the wet bulb (below the freezing
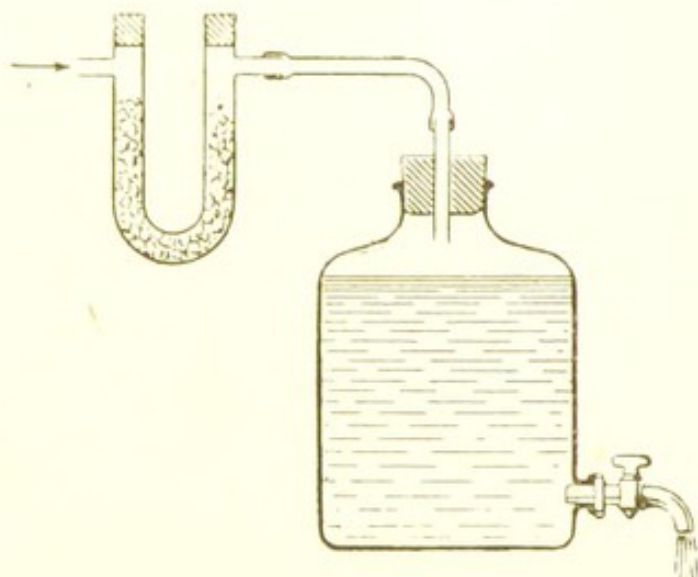
Fig. 94.—Direct determination of weight of water in air.

point the number 96 is taken as the denominator instead of 87). Having found the pressure of aqueous vapour at the dew-point, by consulting tables (see Appendix), the dew-point itself is ascertained.

Thus, taking the numbers given above—

$$f'' = \cdot299 - \frac{50 - 45}{87} = \cdot299 - \cdot057 = \cdot242'',$$

which is the vapour pressure at the dew-point, and from tables this is the V.P. at $39 \cdot 5°$ F.

The amount, by weight, of aqueous vapour in a given amount of air can be ascertained by drawing the air slowly through a weighed U tube containing strong sulphuric acid, when the increase in weight of the U tube gives the weight required (Fig. 94). As air is obviously saturated at the dew-point, we can calculate the weight of water in a given volume of air in grams by the following formula :—

$$\cdot 804 \ V \ \times \frac{273}{273 \ + \ t^\circ} \ \times \frac{f}{760},$$

where V = volume of air in litres, t = temperature Centigrade of the dew-point, f = vapour pressure at t° in mm. of mercury. $\cdot 804$ is the theoretical weight in grams of a litre of aqueous vapour at 0° C. and 760 mm.

CHAPTER VI.

SPECIFIC HEAT.

WE have seen that the heating power of a sub-
stance depends not only on its temperature, but also
on its weight. But there is a third factor to
be taken into account—the energy employed in
molecular work in enabling the molecules to take
up the heat vibration.

This will be more easily under-
stood by giving some examples.
Two balls, one of iron and one
of bismuth of equal weight (Fig.
95), are heated in boiling water
for some time, and then laid
on a cake of wax. Although
these substances are of equal
weight and at the same tem-

Fig. 95. — Greater
heating power of
iron compared
with bismuth.

perature, it will be seen that they have very different
heating power ; the iron obviously melts much more
wax than the bismuth. The specific heat of iron
is much greater than that of bismuth.

Again, if equal weights of water and iron, heated
to 100°, be cooled in equal weights of cold water,
the heating effect of the water is much greater than
that of the equal weight of iron. The difference is
quite perceptible to the hand, and can be demon-
strated (Fig. 96) by immersing the bulbs of a

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differential air thermometer in the two beakers. Again, we say the specific heat of water is much greater than that of iron.

Specific heat may be defined as **the ratio of the amount of heat required to raise 1 lb. of the substance 1° C. to the amount of heat required to raise the same weight of water 1° C.**

Or it may be put in a shorter form : the specific heat of a substance is the **number of thermal units required to raise a unit weight of the substance 1° C.**

Water has the highest specific heat of any simple liquid, and its sp. h. is taken as 1.

SPECIFIC HEATS OF VARIOUS SUBSTANCES.

Hydrogen	.	3·409	Steam . . 0·48
Water, mixed			Glass . . 0·187
with 20 per			Iron . . 0·113
cent. alcohol	1·045		Copper . . 0·095
Water .	.	1·000	Zinc . . 0·095
Alcohol .	.	0·615	Bismuth . 0·031
Glycerin	.	0·612	Lead . . 0·031
Ice	.	0·5	

It has been shown that the specific heat of a solid element × its atomic weight is equal to a constant, about 6·4—

e.g., Iron $\cdot113 \times 56 = 6\cdot34$, bismuth $208\cdot5 \times \cdot031$
$$= 6\cdot45.$$

So that the specific heat of any of the metals can be found by dividing 6·4 by the atomic weight, or the approximate atomic weight by dividing 6·4 by its specific heat.

DETERMINATION OF THE SPECIFIC HEAT OF A SOLID.

1. Method of Lavoisier and Laplace.—A small thin copper box A (Fig. 97) is surrounded by a second vessel B containing ice which drains into a weighed beaker C; outside B is a third vessel D also containing melting ice, so as to protect B from any heat from the outside. A weighed mass of the solid is heated up to a known temperature in a steam oven and then dropped into the box A and the lids are
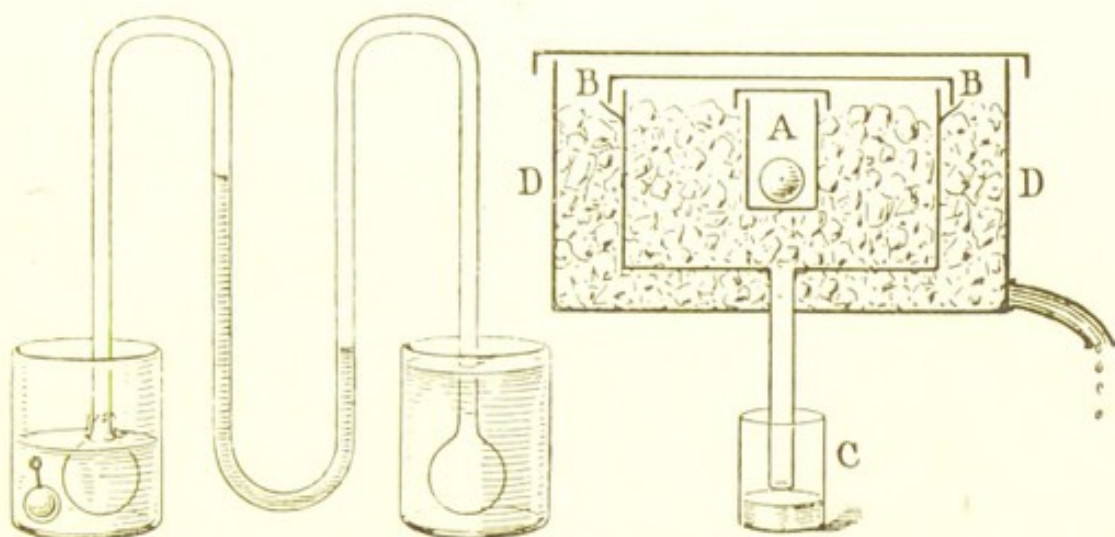
Fig. 96.—Specific heats of iron and water.

Fig. 97.—Lavoisier and Laplace calorimeter.

put on; the beaker C has been previously dried and weighed. The heat rapidly melts the ice, the resulting water collects in C, and is weighed.

Black previously used a rougher and less accurate method by boring a hole in a block of ice, inserting the heated substance, and mopping up, with a weighed dry rag, the water produced. The greater the specific heat, the more ice will be melted. The exact method of calculating the specific heat will be given further on p. 111.

2. **Regnault's Method.** — This gives the most accurate results. The apparatus (Fig. 98) consists of two parts, the heating arrangement and the calorimeter. The heating arrangement consists of a tube of thin metal A, which is heated by steam. In this tube the substance B is suspended with a thermometer; the substance is preferably made in the
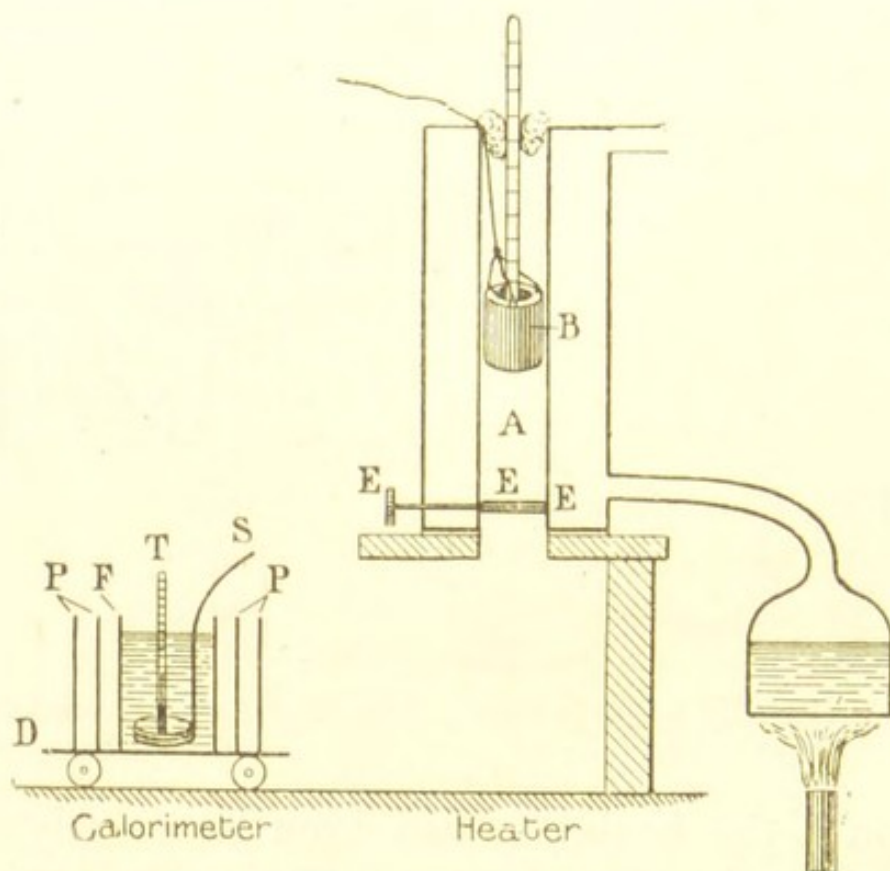
Fig. 98.—Regnault's specific heat apparatus.

form of a thick ring, inside which the thermometer is placed. The heating is continued until the thermometer remains constant for about twenty minutes. In the meantime the little carriage D on which the calorimeter is placed with its stirrer s, a delicate thermometer T, and a weighed quantity of water, is wheeled away, so as not to be affected by the heat

from the steam, and its temperature carefully read off. As soon as the temperature of the heated weight is steady, the calorimeter F is run under the tube A, a sliding door E, which closes the lower end of A, is opened and the heated substance lowered into the calorimeter, which is at once removed, constantly stirred, and the rise in temperature carefully noted. The calorimeter is surrounded with several polished screens P P, and with non-conducting material to prevent, as far as possible, its temperature from being affected by surrounding objects.

In this and all similar transfers of heat we have— the weight of the substance heated × its fall in temperature × its sp. heat = the weight of water in the calorimeter × its rise × its sp. heat.

As the sp. heat of water = 1, this can be neglected, and we have roughly—

$$\text{Sp. heat} = \frac{\text{Weight of water} \times \text{its rise}}{\text{Weight of substance} \times \text{its fall}}.$$

It is obvious that the heated substance warms the calorimeter, the stirrer, and the thermometer, as well as the water, so a correction, on this account, must be introduced, called the " water value " of the calorimeter, etc. This is ascertained by weighing these various items and multiplying the weights by their respective specific heats. Thus, if the copper calorimeter weighs 100 grams, 100 × ·095 = 9·5 grams. This water value must be added to the weight of water.

To take an example : a mass of copper weighing

500 grams is heated to 100° and plunged into a calorimeter containing 1,000 grams of water at 12°, the resulting temperature is 15·7°. Water value of calorimeter = 4·5 grams.

$$\text{Sp. heat of copper} = \frac{1004\cdot5 \times 3\cdot7}{500 \times 84\cdot3} = \cdot088.$$

Another example, with the Lavoisier and Laplace calorimeter :—500 grams of copper at 100° melted 57 grams of ice (now 1 gram of ice melted = 79 grams of water raised 1° C.—see p. 88), and we have, neglecting the water value of the calorimeter,

$$\text{sp. heat} = \frac{57 \times 79}{500 \times 100} = \cdot09.$$

Several other small corrections have to be made to allow for the loss of heat by radiation, etc., during the experiment, in order to obtain rigidly accurate results.

3. **Bunsen's Method.**—By this method the specific heat is determined by measuring the amount of ice melted by the heated body, from the *contraction* which takes place when ice is melted. The instrument (Fig. 99) consists of a long glass bulb A, attached to a graduated capillary tube B; a small test tube C is fused into the bulb A. The bulb is filled with water, which has been previously boiled, to free it from air, and the capillary tube with mercury.

Fig. 99.—Bunsen's calorimeter.

Some ether is poured into c, and by passing a
rapid current of air through the ether, a thin layer
of ice is formed round c in the water in A. The
ether is now emptied out, some water placed in c,
and the whole allowed to stand till it has attained
the temperature of 0° C., which is indicated by the
column of mercury in the capillary remaining
stationary. The heated body is then introduced
into c, when some of the ice is melted, and from
the contraction of the mercury in the capillary
tube the amount can be calculated.

I

CHAPTER VII.

HEAT AND WORK—LIQUEFACTION OF GASES.

Mechanical Equivalent of Heat. — In 1798 Count Rumford boiled 20 lb. of water, in about $2\frac{1}{2}$ hours, by the friction of a solid plunger pressing on the bottom of an iron cylinder, the plunger being turned by horses. It is also well known that savages obtain fire by the friction of a piece of hard wood on soft wood. In these cases energy is converted into heat.

We have another example in the sparks formed when the brake is applied to a rapidly moving train ; so much energy is converted into heat that the flakes of iron on the tyre become ignited.

If we compress a gas, heat is evolved, because energy is liberated, owing to the molecules being squeezed closer together, and therefore not requiring so much energy to keep themselves apart. If a gas is already compressed and we allow it to expand suddenly, the gas is cooled, owing to energy being absorbed in keeping the molecules further apart. In the same way, when a soda-water bottle is opened in the winter, the sudden absorption of heat owing to the expansion of the gas sometimes causes the water to freeze.

In 1845 Joule determined by the friction of a paddle-wheel in water the amount of energy

required to produce a certain quantity of heat. After
many experiments it was concluded that a weight
of 778 lb. falling 1 ft. would produce enough energy
—if converted into heat—to raise 1 lb. of water
1° F., or 1,400 lb. falling 1 ft. would raise 1 lb. of
water 1° C. The principle of Joule's experiments
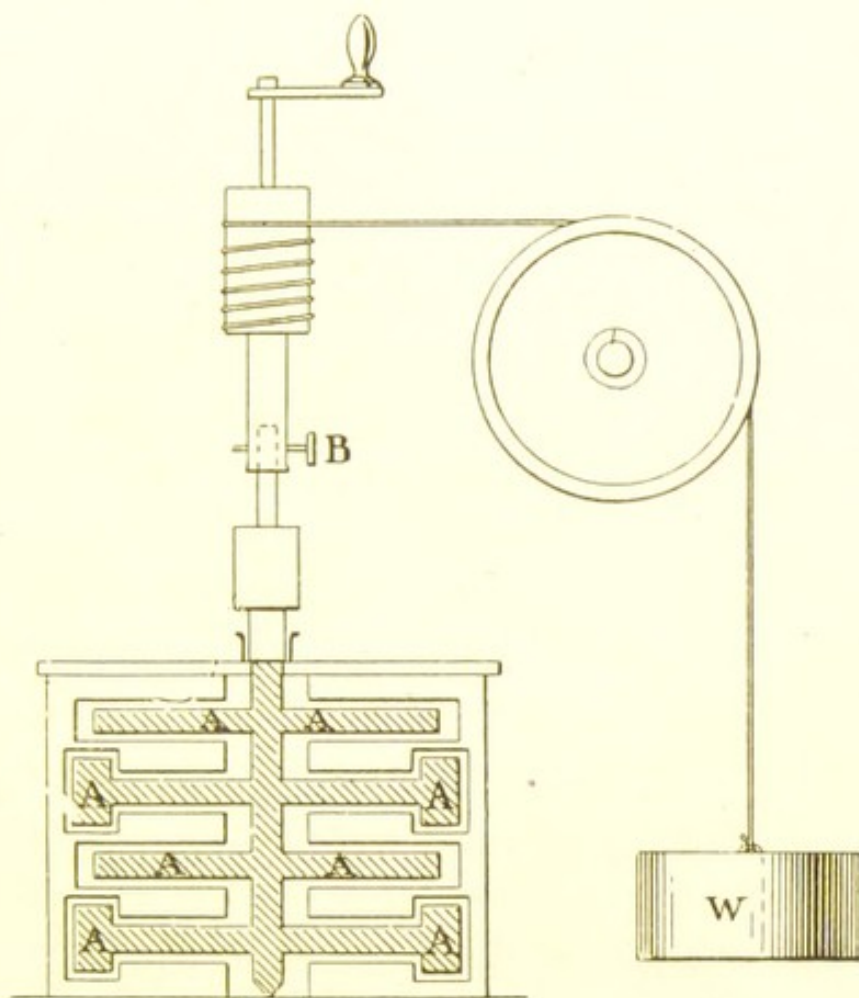
Fig. 100.—Joule's apparatus.

is illustrated diagrammatically in Fig. 100; the
paddles A A are caused to rotate by the falling
weight w, which is lifted by turning the handle at
the top after taking out the pin B, and is allowed to
fall many times. The rise in temperature in the

water of the calorimeter is given by a delicate ther-
mometer.

This determination of the mechanical or dynamical
equivalent of heat, besides being of great theoretical
interest, has been of immense practical value, as by
means of it we can compare the actual amount of
work performed by a steam engine with the energy
produced in the boiler by the burning of the coals.
The comparison is not satisfactory, even in the
best steam engines, only about 20 per cent. of the
energy evolved being converted
into horse-power. The efficiency
of the gas engine is greater, being
about 35 per cent.

The mechanical equivalent of
heat can also be calculated from
the difference in the heat required
to raise the temperature of a given
volume of air (1) when its volume
is kept constant, and (2) when it
is allowed to expand. In the latter
case it has to lift the air above it as it expands, and
so, more work being done, more heat is required.
If the amount of heat required in the first case be
taken as 1, that required in the second will be 1·42.
Take (Fig. 101) a vessel with a base 1 square foot in
area ; let P mark the surface of 1 cubic foot of air
at 0°. If we heat it to 273° C. it doubles its volume
to P'. In expanding it lifts 15 lb. × 144 square
inches = 2,160 lb. 1 ft. Now the specific heat of
air at constant pressure—that is, when it is allowed

Fig. 101. — Calcu-
lation of the
mechanical equi-
valent of heat.

to expand—is 0·24. The weight of a cubic foot of air is 1·29 oz., and 1·29 oz. of air raised 273° C. = 1·29 × ·24 = ·31 oz. of water raised 273°, or 84·63 oz. raised 1°.

If the air is not allowed to expand, but the volume is kept constant, the heat required to raise its temperature will be less, in the ratio of 1 : 1·42, and will

be $84 \cdot 63 \times \dfrac{1}{1 \cdot 42} = 59 \cdot 6$, and the difference, $84 \cdot 6$

— 59·6 = 25 oz. or 1·56 lb. of water raised 1° C., is the measure of the heat expended in lifting 2,160 lb. 1 ft.

∴ energy required to raise 1 lb. 1° C. =

$\dfrac{2160}{1 \cdot 56} = 1{,}384$ lb. falling 1 ft.

By the experimental work of Rowland and others the mechanical or dynamical equivalent of heat or joule is fixed at 1,400 lb. falling 1 ft. as the energy which will raise 1 lb. of water 1° C.

If we convert this into the metric system we have

$$\dfrac{1400 \times \cdot 453 \text{ kilo.} \times 30 \cdot 5 \text{ cm.}}{453 \text{ grams}}$$

$= \dfrac{1400 \times 30 \cdot 5}{1000} = 42 \cdot 7$ kilograms falling 1 centimetre raise 1 gram of water 1° C.

This equals 4·2 joules = 42 million ergs (4·2 × 10⁷), and gives the energy required to raise 1 gram of water 1° C.

The heat required to raise 1 gram of water 1° C. is termed a *calorie*.

Heat of Combustion.—The heat of combustion of a substance is the quantity of heat units expressed in calories which is given out during the combustion of a given weight of that substance. In the case of the chemical elements the *atomic weight* of the substance in grams is taken. Thus :

$$C + O_2 = CO_2 + 97,000 \text{ calories}$$

means that when twelve grams of carbon are burnt to form carbon dioxide an amount of heat is evolved which would raise 97,000 grams of water 1° C. If carbon is burnt to carbonic oxide the heat evolved is much less :

$$C + O = CO + 26,300 \text{ calories}.$$

Again, $H_2 + O = H_2O + 68,000$ calories indicates that two grams of hydrogen when burnt to water liberate enough heat to raise 68,000 grams of water 1° C.

With bodies of complicated composition, as starch, fat, proteids, coal, etc., the heat evolved by *one gram* is usually given.

Thus 1 gram of proteid evolves 5,000 calories.

| 1 | ,, | fat | ,, | 9,100 | ,, |
| 1 | ,, | starch | ,, | 4,000 | ,, |

From these data we can calculate the amount of energy in the form of heat that a particular diet, if completely burnt, should evolve. Thus :

A daily diet of 140 grams of proteid = 700,000 calories.

| ,, | ,, | 105 | ,, | fat | = 955,500 | ,, |
| ,, | ,, | 420 | ,, | carbo- | | |

hydrates, starch, etc.   = 1,680,000   ,,

Total . . 3,335,500   ,,

Only about four-fifths of this total is liberated as heat, the rest is used up in the work of the body, since it has been found that when a man is placed in a calorimeter and the heat he evolves determined directly, it amounts to about 2,500,000 calories per diem.

The heat liberated in the burning of a sample of coal can be estimated as follows. The coal is finely powdered, and two grams of the powder is mixed with sufficient oxidising material, such as potassium nitrate, to furnish oxygen to burn it completely, and the mixture pressed into a stout copper cylinder. In the mouth of this cylinder is inserted a piece of cotton wick previously soaked in potassium nitrate, so as to act as a slow match. A calorimeter, containing a sufficient quantity of water, about two litres, is prepared. When all is ready, the slow match is lighted and a little copper diving bell fixed over the copper cylinder containing the mixture of coal and potassium nitrate, and the whole is quickly sunk in the water of the calorimeter. As soon as the spark in the slow match reaches the mixture the latter deflagrates, the coal burning violently ; when the combustion is finished, the water is mixed, and its rise in temperature noted with a delicate thermometer ; the number of calories evolved can then be calculated after the necessary corrections have been made.

In a similar way the heat evolved during the combustion of starch, sugar, and other substances can be estimated. If the combustible substance is a gas, it is burnt at a jet (oxygen being supplied) in a copper

calorimeter under water; the jet is lighted by a platinum wire made white hot by passing a current of electricity through it.

If we know the heat of combustion of a chemical compound and the heats of combustion of its constituent elements, we can calculate what is termed its *heat of formation*—*i.e.*, the energy which is evolved (or absorbed) when it was formed.

Thus Marsh Gas, Methane, CH_4:

Heat of combustion of 12 grams of carbon = 97,000

,,   ,,   4   ,,   hydgn. = 136,720

_____

233,720

Heat of combustion of a molecular weight of CH_4 = 211,930, and $233,720 - 211,930 = 21,790$, Heat of Formation.

In other words, 21,790 calories were evolved when 12 grams of carbon combined with 4 grams of hydrogen to form 16 grams of marsh gas.

Liquefaction of Gases.—Andrews first proved that the temperature of a gas must be brought below a certain temperature, called its *critical point*, before pressure will liquefy it. Above this critical temperature no amount of pressure will transform it into a liquid. He enclosed some carbon dioxide in a thick-walled glass tube A (Fig. 102) closed at its upper end, but connected below with a reservoir of mercury to which great pressure could be applied. At a temperature of 13·1° C., a pressure of 48 atmospheres caused some carbon dioxide to liquefy; when the temperature was

21° the pressure had to be raised to 60 atmospheres before any liquid was formed ; but when the temperature rose to 31·9° the line of demarcation between the liquid and the gas became hazy, the liquid disappeared, and by no amount of pressure could it be made to reappear, until the temperature fell below 31·9°, the critical point.

Those gases whose critical points are low—oxygen 119, nitrogen 146, hydrogen 223—for a long time resisted all attempts to liquefy them, since no known means of attaining such low temperatures existed. Finally Pictet and Cailletet liquefied oxygen about the same time (1877). Pictet succeeded by a methodical lowering of temperatures. He first liquefied sulphur dioxide, and then utilised the cold produced by the rapid evaporation of the liquid to liquefy large quantities of carbon dioxide ; rapidly evaporating this, in its turn, he reached

Fig. 102. — Andrews' experiment to show critical point of a gas.

the critical point, and with the aid of great pressure liquefied oxygen. Cailletet compressed oxygen to an enormous extent, and then, by opening a stopcock and allowing the gas to expand suddenly, a sufficient degree of cold was produced to form a mist of liquid oxygen.
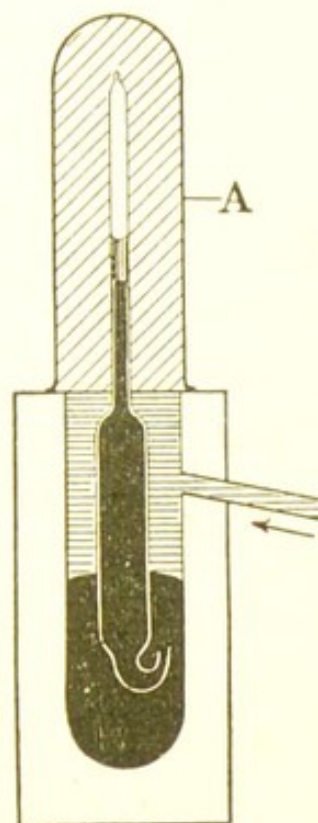
Since that time liquid air has become a commercial article, and can be purchased by the litre. This result we owe chiefly to Dewar and Linde. The air is subjected to a pressure of 200 atmospheres, and allowed to escape through a fine orifice. As the air expands heat is absorbed, but it is nearly all regenerated by the friction, and if air were a perfect gas no cooling would result, but air not being a perfect gas, the heat *lost* by the expansion is somewhat greater than that produced, and so the temperature falls, the gas is cooled and is used to cool the air coming to the fine aperture. This in its turn is cooled to a lower temperature, so a sort of cumulative cooling is set up, and the liquid air begins to drop from the orifice at —180° C. The only gas which has not yet been liquefied is helium.

Part III.

ELECTRICITY.

CHAPTER I.

ELECTRIFICATION BY FRICTION AND INDUCTION — CONDUCTORS — INSULATORS — ELECTROPHORUS —WIMSHURST MACHINE—CONDENSER—LEYDEN JAR.

Electricity developed by Friction.—The name is derived from the Greek ἠλεκτρον—*amber*. If a piece of amber be rubbed, it acquires the property of attracting light objects, such as feathers, small pieces of paper, etc. This phenomenon was observed in classical times, but Dr. Gilbert, in the sixteenth century, found that not only amber, but all substances, when rubbed with a suitable rubber under suitable conditions, acquired this property.

If we rub a stick of sealing wax or vulcanite with dry flannel, and then bring it near a pith ball suspended by a silk string (Fig. 103), the pith ball is at first attracted, and then, after contact, violently repelled. The same phenomenon occurs if we rub a dry glass rod with dry silk. If we bring the rubbed glass rod near a pith ball which has touched the rubbed sealing wax, we shall find that, although the

123

pith ball is repelled by the sealing wax, it is strongly
attracted by the rubbed glass.

These phenomena are usually explained as fol-
lows :—The friction of the flannel on the sealing wax
disturbs the normal electrical condition of both.
Negative or resinous electricity is said to be developed
on the sealing wax, and positive on the flannel. In
a similiar way *positive* or vitreous electricity is said to
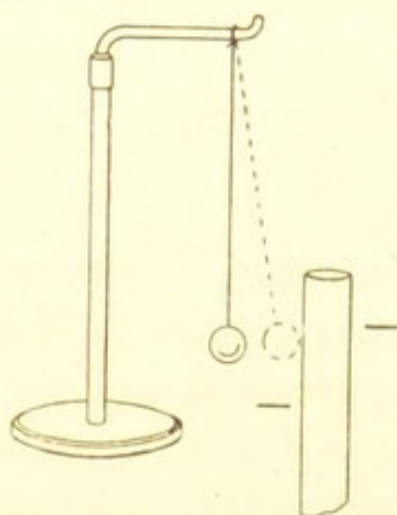be developed on the glass rod and negative on the silk.

Fig. 103.—Attraction of   Fig. 104.—Induction.
pith ball by rubbed
sealing-wax.
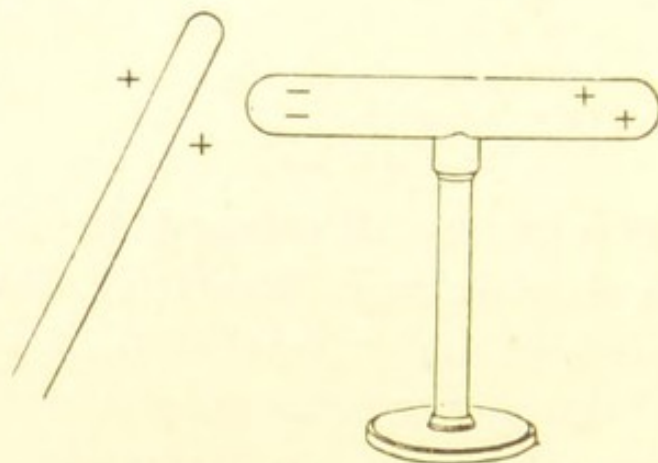
Now, it has been observed that electricities of
the same name repel, but that those of unlike names
attract, each other ; thus, positive repels positive
and attracts negative, and negative repels negative,
but attracts positive. If a rubbed glass rod be
brought near a metal cylinder, mounted on a vul-
canite or dry glass rod, the electrical state of the
cylinder is upset, some of its negative electricity is
attracted to the end nearest the glass rod, and a
corresponding quantity of positive electricity will

be repelled (Fig. 104). This process is called **induc-
tion.** If the rod touch the cylinder the negative
on the cylinder will neutralise some of the positive
on the glass, and the cylinder will remain charged
with positive electricity. An explanation of the
sealing wax (Fig. 103) first attracting and then
repelling the pith ball is now possible : the ball was
first attracted by induction, and then, when charged
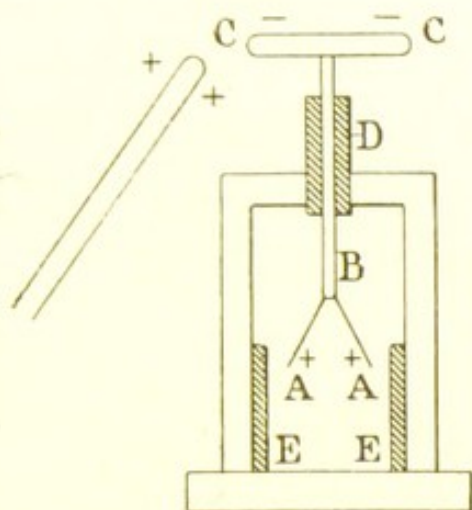with negative electricity, repelled.

Fig. 105.—Gold-leaf
electroscope.
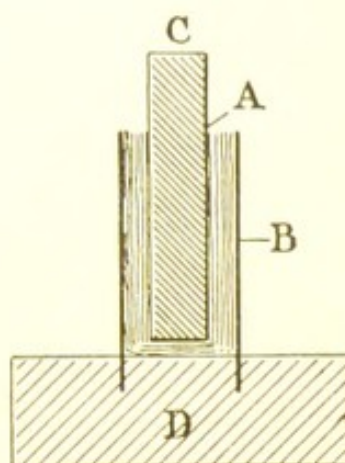
Fig. 106.—Charge on rubber.

The *gold-leaf electroscope* (Fig. 105) is a very useful
instrument for detecting charges of electricity
developed by friction. It consists of a square box
with glass sides or a round glass bell-jar, in which
slips of gold leaf are attached A A to a brass rod B,
which passes through a thick vulcanite collar D, and
ends in a circular brass plate C. When an electrified
body is brought near plate C the gold leaves diverge,
being charged with electricity of the same name.
Two strips of tinfoil are cemented on the inside of

the case E E, so that the leaves can discharge them-
selves to earth if the charge is too strong. The
leaves can be charged with electricity of the same
name as the electrified body by contact, or with that
of the opposite name by induction. Thus, if we
bring a rubbed glass rod into contact with the plate
c (Fig. 105), the leaves diverge with positive elec-
tricity, but if the rubbed glass rod be brought very
near without touching, as in the same figure, and the
plate be touched with the finger, the positive elec-
tricity will escape to the earth, and the divergence
ceases. But on the withdrawal of the glass rod
the leaves again diverge with the negative electricity,
which had previously been held captive by the induc-
tive effect of the glass rod.

Conduction.—If a brass tube, *held in the hand*, be
rubbed with flannel, no charge will be developed on
the brass. This is due to the fact that metals *conduct*
electricity, which passes through them to the earth.
If the brass tube be mounted on a vulcanite rod, then,
on rubbing, a charge will be found on the brass. Vul-
canite is a non-conductor, and so isolates the brass,
and the charge remains. A very convenient method
of proving that a charge is developed on metals by
friction is to strike the brass plate of the gold-leaf
electroscope with a feather brush. Water is also
a conductor, so that if a glass rod be damp it cannot
be charged. For this reason great care must be
taken in these experiments to have everything
thoroughly dried.

Bad conductors are often called *insulators*.

SUBSTANCES ARRANGED IN THEIR ORDER OF CON-
DUCTIVITY.

Conductors.	*Non-Conductors.*
Metals.	India-rubber.
Carbon.	Silk.
Acids.	Glass.
Water.	Shellac.
Ice.	Ebonite.
Marble.	Paraffin Wax.

To prove that a charge is developed on the rubber,
a convenient plan is to mount a short cylinder of
flannel A (Fig. 106) inside a *metal* tube B, bedded on
a block of paraffin wax D. If a vulcanite rod C be
twisted quickly inside the flannel bag, the tin tube
in contact with the flannel will be found charged
with positive electricity.

The sign of the electricity depends on the nature
of the rubber, as well as on the substance rubbed.
Glass rubbed with flannel becomes negative, but on
friction with silk it is positive.

The following is a list of substances arranged in
order so that each substance becomes positive when
rubbed with any substance which comes after it,
the latter at the same time becoming negative.

+	
Catskin.	Metals.
Flannel.	India-rubber.
Glass.	Sealing wax.
Silk.	Sulphur.
Dry hand.	Guncotton.
Wood.	—

. The charge resides on the *outside* of a body. This can be shown by Faraday's butterfly net, the apex of which is attached to two long silk threads. It is mounted on an insulating stand and charged. If a small charge be taken off with a proof plane, a small piece of sheet metal on a vulcanite handle (Fig. 107), it will be seen that the charge is on the outside of the net. If the net be inverted by pulling the silk thread, the charge will again be found on the outside.
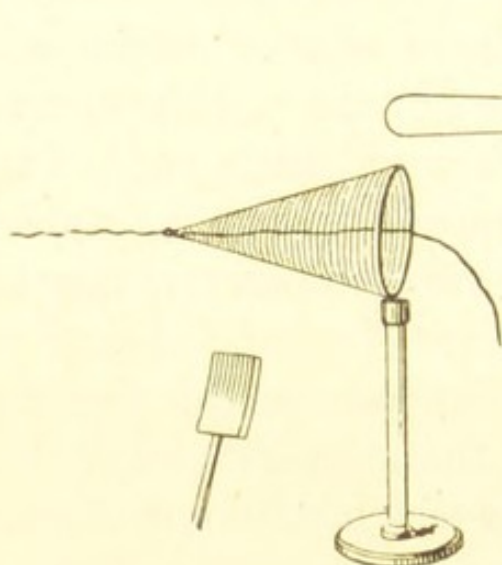

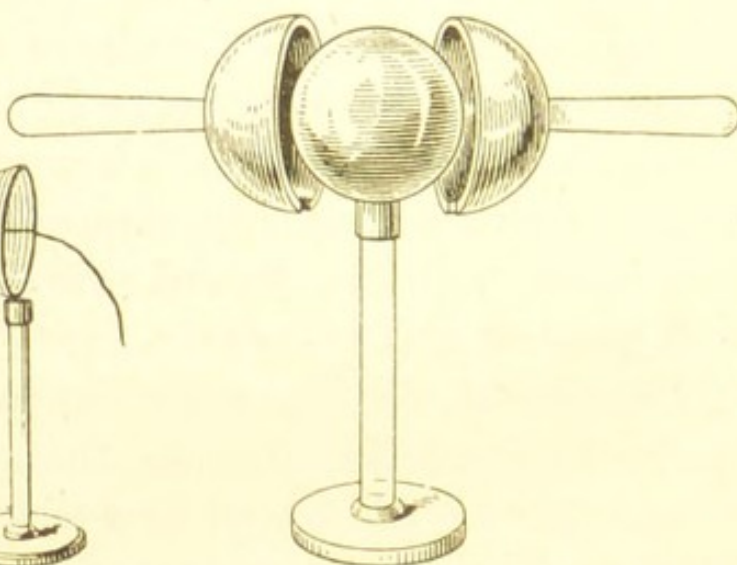Fig. 107.—Proof plane and Faraday's butterfly net.

Fig. 108.—Charge always outside.

The same fact can be shown by charging an insulated brass sphere, and then surrounding it with two brass cups with glass handles. On the cups being removed by their glass handles, they will be found to have the charge, none being left on the sphere (Fig. 108).

For a similar reason the charge tends to accumulate in greater density *round sharp edges and points,*

whereas in a sphere the density of the charge is uniform (Fig. 109). In fact, if a body has any sharp points, the electricity escapes from it so readily that it is impossible to charge it to any great extent. Lightning conductors therefore always terminate in sharp points, so that when a positively charged thunder-cloud tends to charge the building by induction, the negative electricity escapes from the pointed end so readily that it prevents a charge of any great density accumulating on the top of the building.
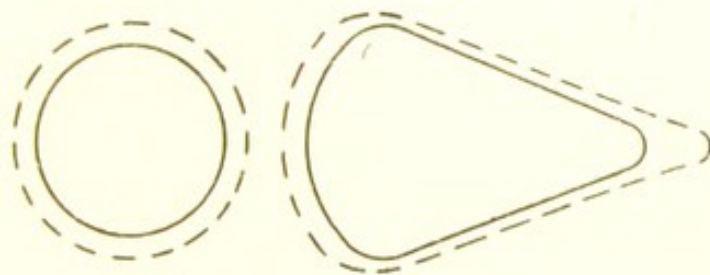

Fig. 109.—Distribution of charge.

Radium salts have a marvellous effect in discharging electrified bodies. If a gold-leaf electroscope be charged, and a small fragment of radium bromide be brought anywhere near it, the gold leaves collapse.

It will be noticed that in all the above experiments the earth is considered to have no charge, and it is of such an infinite size, as compared with our apparatus, that if an electrified body is connected by a conducting substance with the earth, it is instantly and completely discharged.

Electrophorus.—This instrument (Fig. 110) consists of a flat circular plate, the " sole," of vulcanite or shellac, coated on the under side with

J

tinfoil. On this rests a somewhat smaller plate of brass furnished with a vulcanite handle. On the sole being flapped with catskin, negative electricity is developed. The brass plate is now placed on the vulcanite, and induction ensues. On the brass plate bein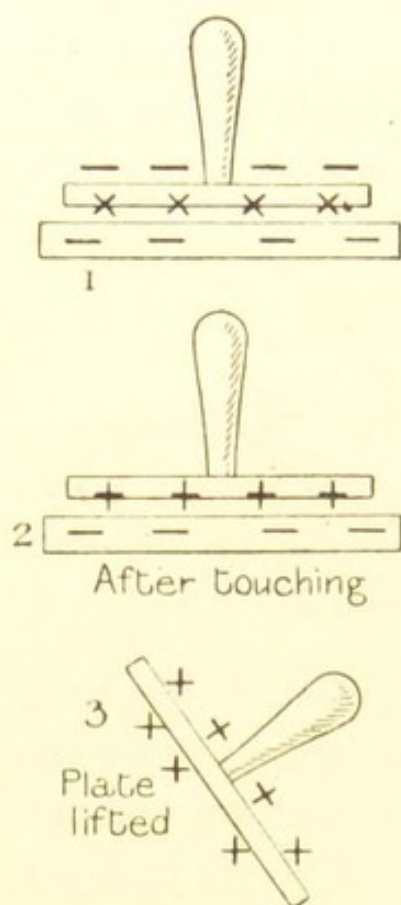g touched the repelled negative electricity escapes (2), and on the brass plate being lifted by the insulating handle (3) it is found to be charged sufficiently with positive electricity to give a small spark to the knuckle, or it may be used to light a gas burner. As the plate touches the sole in relatively few points, the charge on the sole remains almost undiminished, and the plate can be recharged many times by repeating the above process.

One of the best machines for producing electricity by friction and induction is the

Wimshurst machine (Fig. 111). It consists of two thin circular plates of vulcanite, mounted so as to rotate in opposite directions. On the surface of the plates are cemented, at regular intervals, tongues of tinfoil B B, which, as they rotate, touch the brass brushes A A. C C are two **U**-shaped rods of metal, the sides of which towards the plate terminate

Fig. 110.—Electrophorus.

in a sharp edge or in points. The brushes A A are
connected by a brass rod D. The second vulcanite
plate is fitted up in a similar way.

The action can be explained with the help of the
next diagram (Fig. 111*a*), copied from Silvanus
Thompson's "Magnetism and Electricity." For
the sake of simplicity the discs are shown as cylinders
revolving in opposite directions. A small charge of
negative electricity is developed by the friction of
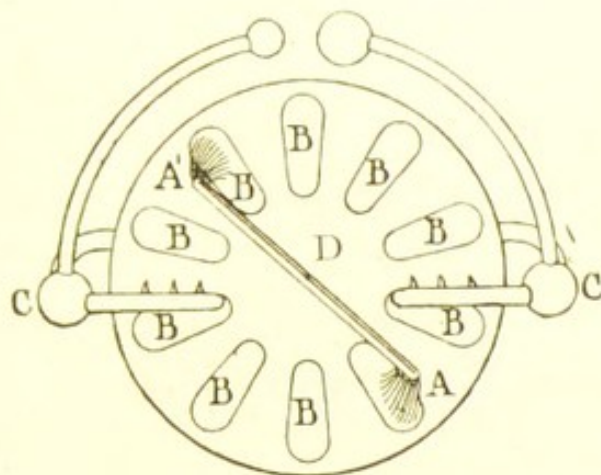the brushes on one of the tongues of tinfoil A ; this

Fig. 111.—One plate of Wimshurst machine.

acts by induction on the tinfoil B opposite, on the
other vulcanite plate. As B rotates to the left it
touches brush C, and the negative electricity, re-
pelled by induction, passes over and charges D with
negative. B, remaining positive, rotates until it
comes opposite the U-shaped piece X, when, acting by
induction, it draws off negative electricity from X,
and itself becomes neutral. Passing on, it becomes
subject to induction from E, and when it touches
the brush D positive electricity passes over by the

brush D through the cross-wire to C. If we trace the progress of a tinfoil tongue on the other disc, say A, which is negative when it arrives at the **U**-shaped piece connected with Y, it draws off + from Y, and becomes neutral. At F it is exposed to induction, and when it touches the brush G the negative electricity is repelled over to H, and so on.
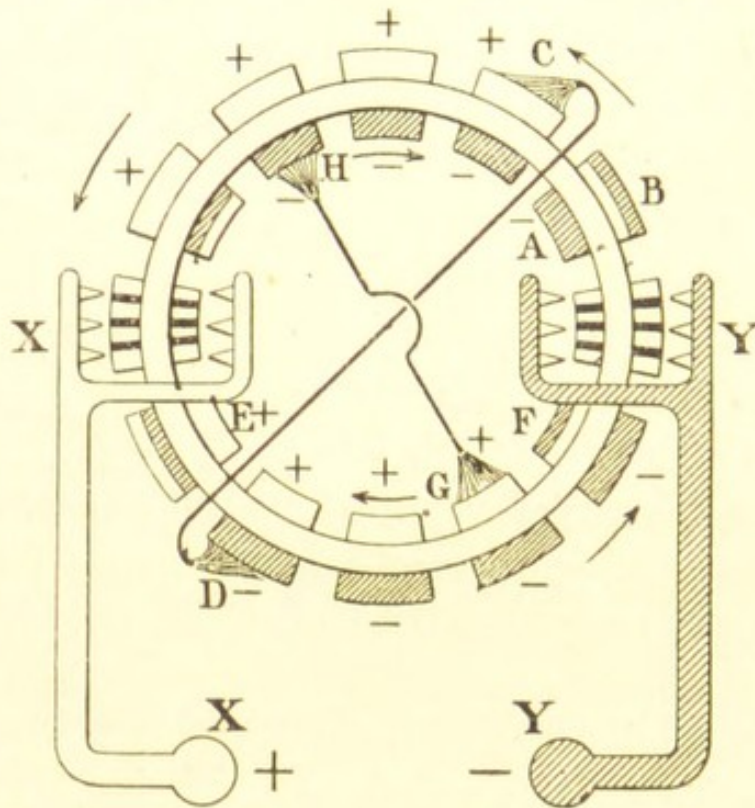

Fig. 111*a*.—Wimshurst machine (*after Silvanus Thompson*).

It will be noticed that the tongues of tinfoil on the upper half of the outer cylinder are constantly positive, and those on the inner cylinder negative, the reverse being the case in the lower half. The result is that X is constantly being drained of negative electricity, and Y of positive, so that a charge of positive accumulates on X and negative on Y until a spark crosses.

Thunderstorms.—The cause of the electricity in the air is not known. It may be due to the friction of air, or when aqueous vapour condenses to water some of the energy may take the form of electricity. The clouds are usually positive, but in wet weather may be negative. The electrical state of the air is ascertained by allowing water to drop from a carefully insulated can. If the air is negative it draws positive from the drops of water and the can until the can is at nearly the same potential as the air.

Franklin first demonstrated, in 1750, that lightning was due to an electrical discharge, by flying a kite during a thunderstorm. At first he could get no sparks, the dry silk thread which held the kite being a non-conductor, but when the rain fell and the string became wet plenty of sparks could be obtained by presenting his knuckle. In 1753 Richmann was killed while making a similar experiment at St. Petersburg.

The lightning may pass between clouds charged with opposite kinds of electricity, or between a charged cloud and the earth by induction.

Lightning Conductors.—It is usual to protect buildings by lightning conductors. These, as we have seen (p. 129) should end in points. The effect of points in preventing the charging of a surface is well shown by the following experiment :—A head of hair on a doll's head is connected with a machine and electrified, when it will be seen that the hairs all repel each other and stand out like a brush. If a knuckle is presented to them they are all attracted,

but if the point of a needle be held to them they are all, as it were, blown away. The electricity of the opposite name escapes so readily that the hairs are surcharged with electricity of the same name, and so are repelled.

Lightning conductors should therefore end in points, preferably gilded, and should be connected by stout iron or copper rods with the earth. If the earth is not damp where the rod enters the soil, the end of the conductor should be buried in a pit tightly
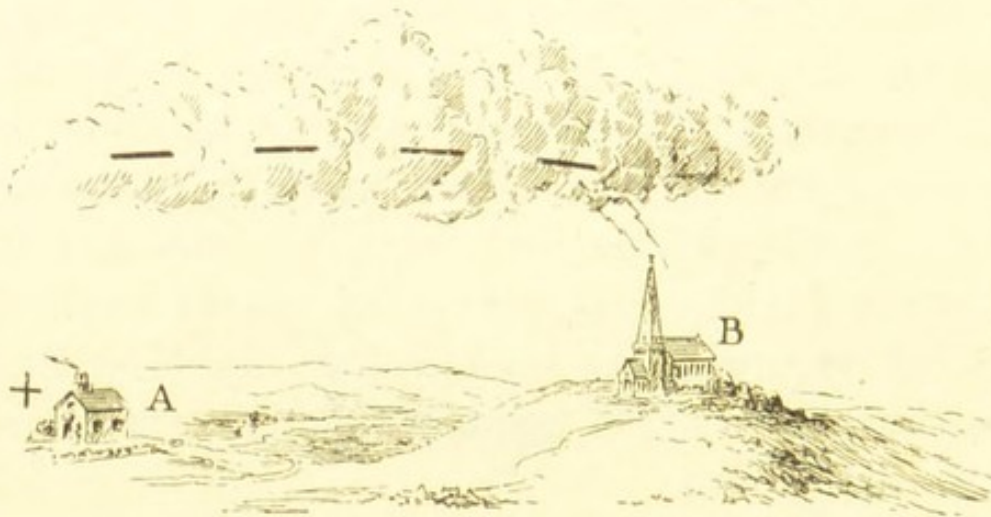

Fig. 112.—Return lightning shock.

packed with coke. All masses of metal, lead roofs, pipes, etc., should be connected metallically with the conductor so as to neutralise induction.

The **return shock** is a curious phenomenon by which people have been killed by electricity when no thunderstorm has taken place in the immediate vicinity. A cloud charged with (say) negative electricity extends for some distance, and subjects the building A (Fig. 112) to induction, but the distance is too great for a flash to strike across. A

thunderstorm is raging at B, and the cloud is discharged by striking to earth there, and the restoration of A to its normal electrical state may be so sudden and violent as to produce fatal results.

The Condenser.—By means of the condenser we can store up on a surface very much more electricity than it would otherwise contain. A simple simile may illustrate this. If we take a level slab of slate, 1 sq. yd. in area, the quantity of water which we
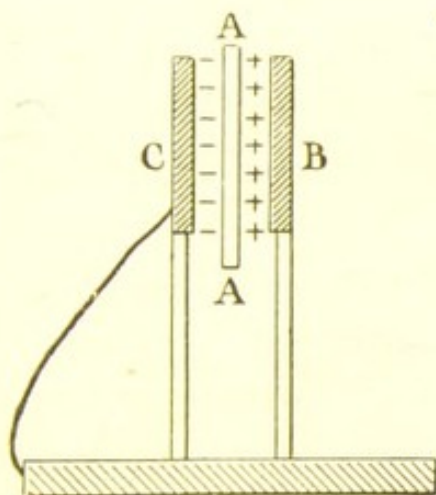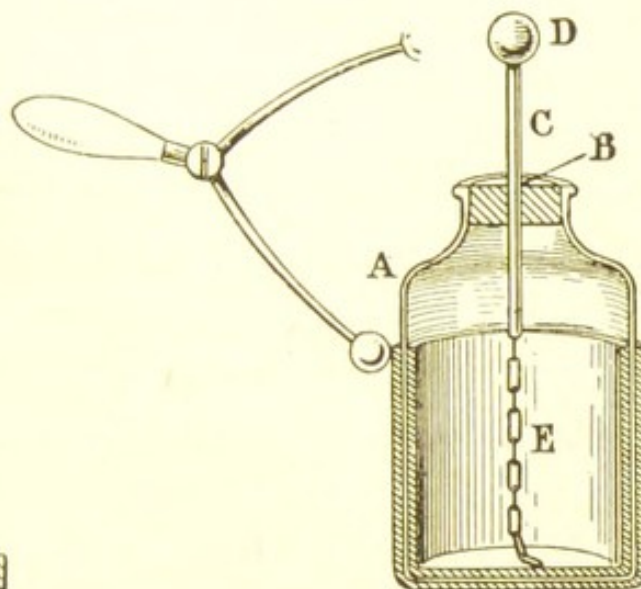

Fig. 113.—Condenser.

Fig. 114.—Leyden jar.

could store up on it would be small; but if we surround the slate with water-tight walls, so as to make it the bottom of a deep cistern, it is evident that although we have not increased the superficial area, we have enormously increased the storage capacity.

If we mount a circular brass plate on a glass stand, and present to it a charged electrophorus plate, a spark will pass. If we repeat this two or three times we shall find that no spark will pass, indicating that

the plate is fully charged. If against this plate we place a thin, slightly larger sheet of glass A (Fig. 113), and on the other side a second brass plate connected with the earth by a wire, we shall find that the capacity of the brass plate is enormously increased, and that many more sparks will pass. The explanation is that the electrophorus plate is charged with positive electricity, and charges B with positive ; this acts by induction through the glass plate, and draws up an almost equal quantity of negative electricity from the earth, and is neutralised thereby, so that B has practically no *free* charge, and can receive another quantity from the electrophorus, and this in its turn is neutralised by the process of induction. So the action goes on until we have comparatively enormous charges of + and − on the plates B and C, attracting each other powerfully, but prevented from combining by the intervention of a *dielectric*, the plate of glass.

The Leyden Jar.—The action of this form of condenser was discovered by accident by a philosopher of the eighteenth century, who, wishing to electrify water, took a bottle of water, and, holding it in his hand, placed a chain in it from the prime conductor of an electrical machine. After working the machine for some time, as apparently nothing had happened, he proceeded to lift out the chain, when he received a severe shock. The water represented plate B, the hand of the operator plate C, in Fig. 113.

The Leyden jar (Fig. 114) consists of a glass bottle or jar A lined internally and externally with tinfoil,

the upper two inches of the glass being free from tinfoil and carefully lacquered with shellac varnish. A circular piece of varnished wood rests on the top of the jar B, and from the centre of it passes a brass rod C, ending in a knob D.   Internally, C is connected with the inside coating of tinfoil by a chain E.   The outside coating rests on the table, so that it is connected with the earth.   The knob D is connected with an electrical machine and charged with (say) negative electricity ; this acts by induction on the outer coating, attracting positive electricity from the earth, etc., as described above (p. 136), and so powerful charges accumulate on the outside and inside coatings, and on their being connected by a discharger with a glass handle a bright flash passes. If the discharger be presented a second time a much smaller spark will pass.

It is obvious that the jar cannot be charged if placed on a glass support, as no positive could come from the earth, and the process of induction would be stopped. The charges are really on the two surfaces of the glass, as can be shown by having the two metal coatings moveable and made of tinplate instead of tinfoil.   The brass rod C is surrounded by a glass tube, so that it can be lifted, and with it the internal coating, which is soldered to it, without getting a shock. The jar having been charged as usual, the inside coating is lifted out by the glass tube, then the glass jar is removed from the outside tin can, and the two coatings are made to touch each other so as to discharge any free electricity.   On

the jar, etc., being replaced, and the two coatings brought into contact by a discharger, a flash will pass.

Leyden jars can be coupled together to form batteries, either by placing them in a box and coupling all the inner coatings together by brass rods, or by placing each of them on an insulated support and connecting the inner coating of one with the outer coating of the next, the outer coating of the last jar being "earthed." This latter method is called coupling in "cascade."

Fig. 115.—Slow discharge of Leyden jar.

A Leyden jar can be discharged slowly (Fig. 115) by a ball A suspended by a silk thread oscillating between the knob and some object, as a bell, connected with earth.
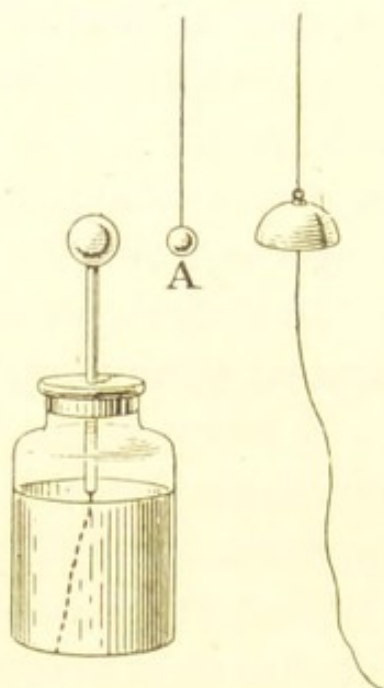
The duration of the spark of a Leyden jar is about $\frac{1}{24000}$th of a second, of a flash of lightning about $\frac{1}{10000}$th. It may be noted that death by lightning is instantaneous, so that a person never sees the flash which kills him. He is dead before the brain has time to translate the image on the retina into vision.

The velocity of the discharge of a jar through copper wire has been given as 288,000 miles a second.

The Atlantic cable and all submarine cables act as Leyden jars. The copper wire represents the inside coating, the gutta-percha and other insulating material the glass jar, and the ocean the outer coating; so that it takes a sensible interval of time— one second or so—to charge a long cable before any electrical disturbance is noted at the other end.

CHAPTER II.

ELECTRICITY DEVELOPED BY CHEMICAL ACTION —
SIMPLE CELL — POLARISATION — PRIMARY BAT-
TERIES — KEYS — COMMUTATORS—ELECTROLYSIS
—ACCUMULATORS OR SECONDARY BATTERIES.

Galvanic or Voltaic Electricity.—In 1790 Galvani observed that some frog legs which were hung up on an iron balcony with copper hooks, twitched when the legs touched the iron. It was soon found that thi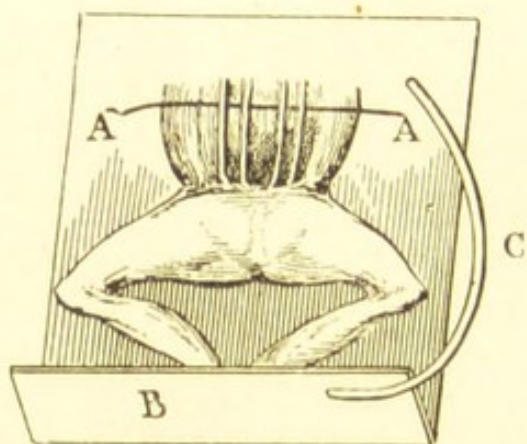s was due to an electrical **current** generated by the contact of the two dissimilar metals, iron and copper, with the tissue juices of the frog.

The experiment can easily be repeated (Fig. 116). A frog is killed, the lower half of its body cut off, and a fine copper wire A inserted under the large nerves which supply the legs. The legs are then flexed and placed on a platform of zinc, the toes being placed against the ledge B, to which a flexible copper wire C has been soldered. On the thin copper wire being touched with the flexible copper wire the legs jump.

Fig. 116.— Galvani's experiment.

Simple Voltaic Cell.—This consists of a plate of zinc and a plate of copper immersed in 10 per cent. sulphuric acid. If such a combination be examined with a delicate electroscope, a small charge of positive electricity will be found on the copper plate, and one of negative electricity on the zinc plate. If these two plates be connected by a copper wire, the zinc begins to dissolve, and bubbles of hydrogen are given off at the *copper* plate, and the process continues as long as any zinc remains. Pure zinc does not dissolve in pure sulphuric acid (when no current is passing). Commercial zinc contains impurities—arsenic, lead, etc.—which cause it to dissolve in sulphuric acid; but if the surface be *amalgamated*—that is, rubbed over with mercury, it behaves like pure zinc. The hydrogen, be it noted, does not come off from the zinc, but is liberated on the copper plate. If these two plates be connected with a copper wire, the positive current flows outside the cell from the copper to the zinc, and a negative current in the reverse direction.

As these two currents are in opposite directions endless confusion would arise if both were mentioned, so we talk only of the positive current and its direction, and neglect the negative current altogether. Thus in a cell consisting of a plate of zinc, and a plate of copper immersed in dilute sulphuric acid, we say that the current flows *from the copper to the zinc outside the battery*, and returns inside the battery, through the sulphuric acid, in the reverse direction. The ends of the battery, whether plates or wires connected with

them, are often called the *poles* of the battery ; or if used for plating, decomposing water, exciting a nerve, etc., they may be called *electrodes.* The positive electrode is called the anode, and the negative the kathode.

All these very important facts may be summed up in the mnemonic word CAPE—*i.e.*, the Copper end of the battery is connected with the Anode. It is the Positive pole, and indicates the place where the current Enters the fluid to be decomposed (Fig. 117).

A galvanic cell, therefore, consists of two substances, one of which is usually zinc and the other may be copper, platinum, carbon, silver, etc., and
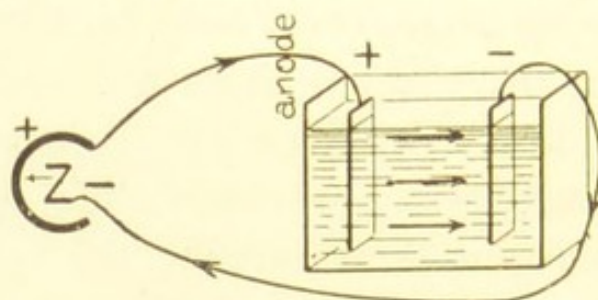
Fig. 117.—Direction of current.

of a fluid which acts more on one substance than on the other. The plates are named the opposite to the poles ; thus, the zinc plate is the positive plate. The action of a cell has been compared to two cisterns of water at different levels, joined by a pipe. When the pipe is open and connection made, the water at the higher level flows down to the other cistern, while the galvanic action of the zinc, copper, and sulphuric acid represents a pump tending to keep up the difference in level (Fig. 118).

If a simple cell, as described above, be coupled up with an electric bell so as to ring it continuously, it will be noticed after a short time that the bell ceases to ring. If the battery be examined it will
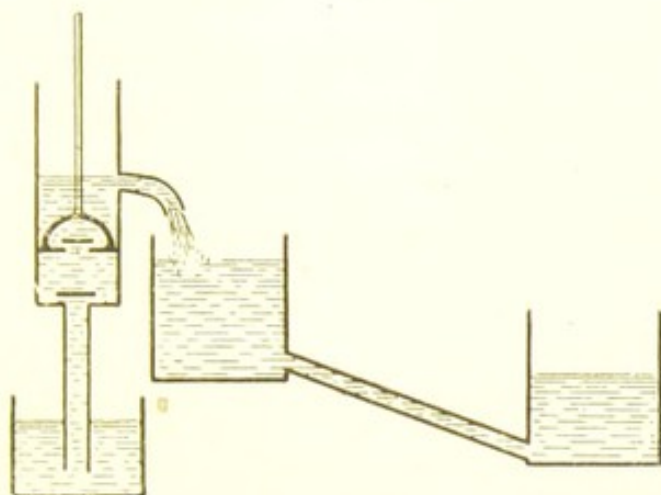

Fig. 118.—Difference of water level compared to potential.

be found that the copper plate is covered with a creamy effervescence of bubbles of hydrogen, being, in fact, on its surface, converted into a hydrogen plate; and if it be carefully taken out and placed in fresh sulphuric acid, it will act like a *zinc* plate to a clean copper plate for a short time (Fig. 119). This phenomenon is called **polarisation**. The strength of the battery is weakened princi- pally because the hydrogen-coated copper plate acts like a zinc plate, but also because the film of gas causes a resistance to the passage of the current.
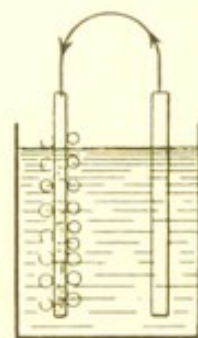

Fig. 119.—Copper plate behaving like zinc.

Many devices for getting rid of this hydrogen which is evolved at the positive pole of the battery

have been invented. The simplest plan is to remove
it mechanically by a stream of bubbles of air from a
blower. Another plan is to roughen the surface and
use a platinum plate coated with spongy platinum,
the rough points facilitating the escape of the hydro-
gen. This device is used in the **Smee battery,**
which consists of a platinum plate stretched in a
wooden frame, on which are clamped two zinc plates,
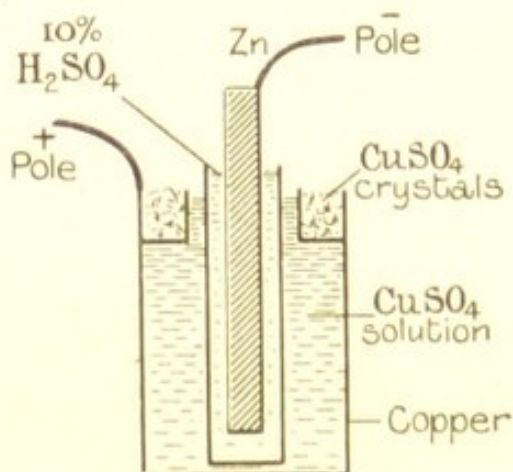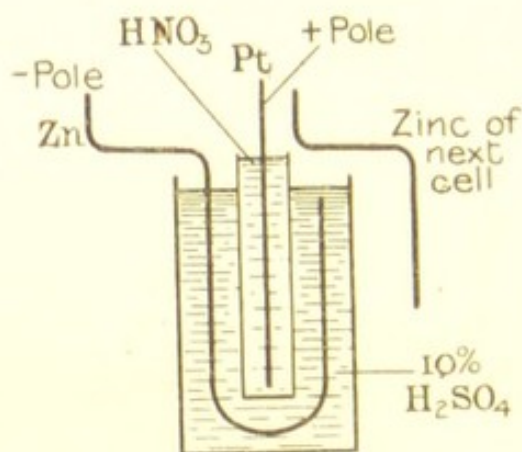the whole being immersed in 10 per cent. sulphuric
acid.
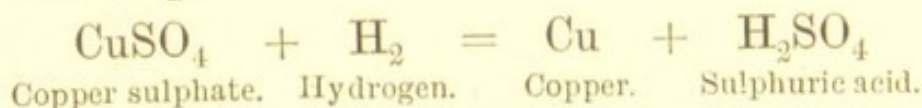

Fig. 120.—Daniell cell.   Fig. 121.—Grove cell.

In the **Daniell cell** the hydrogen which tends to
be evolved at the copper plate acts upon a strong
solution of copper sulphate, forming metallic copper
and free sulphuric acid :

$$CuSO_4 + H_2 = Cu + H_2SO_4$$
Copper sulphate. Hydrogen.   Copper.   Sulphuric acid.

The cell consists of a rod of zinc immersed in 10 per
cent. sulphuric acid, which is contained in a porous
pot. This is surrounded by a copper vessel filled
with a saturated solution of copper sulphate. The

copper vessel forms the positive pole of the battery. The strength of the copper sulphate solution is maintained by some crystals of this salt placed in the perforated gallery (Fig. 120).

In the Grove and in the Bunsen cell the hydrogen is oxidised by strong nitric acid to water.

The **Grove cell** contains a zinc plate bent as seen in Fig. 121, immersed in 10 per cent. sulphuric acid, and enclosing in the bend a porous pot filled with
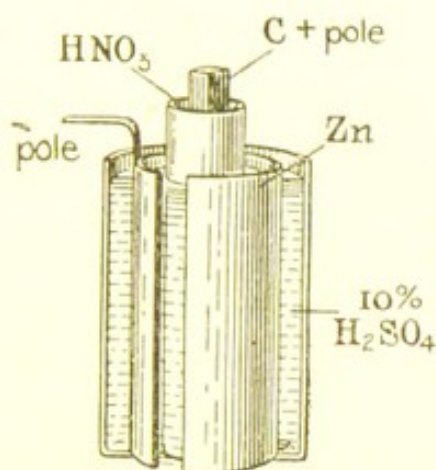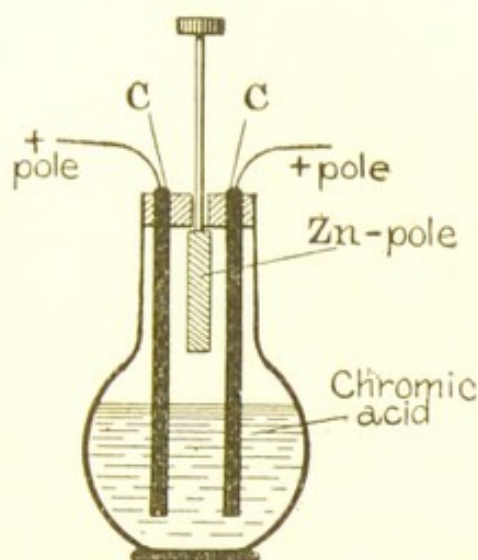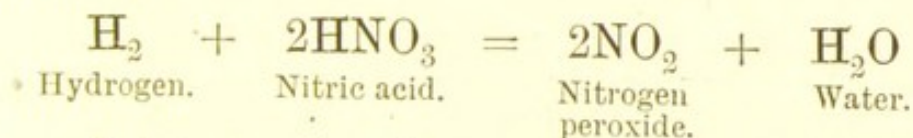

Fig. 122.—Bunsen cell.   Fig. 123.—Bichromate cell.

strong nitric acid, in which is immersed a platinum plate. The hydrogen which tends to come off at the platinum plate is at once oxidised by the strong nitric acid :

$$H_2 \;+\; 2HNO_3 \;=\; 2NO_2 \;+\; H_2O$$

Hydrogen.   Nitric acid.   Nitrogen   Water.
                                   peroxide.

The red fumes of nitrogen peroxide which escape render this cell objectionable unless the cells are placed in a draught cupboard.

The **Bunsen cell** (Fig. 122) has a cylindrical

K

plate of zinc, and the round, porous cell contains a stick of gas carbon immersed in strong nitric acid. In other respects it resembles the Grove cell.

Bichromate Cell.—In this a plate of zinc is immersed in a saturated solution of potassium bichromate containing 10 per cent. sulphuric acid, or a solution of so-called chromic acid can be used. The zinc plate has a carbon plate fixed on either side. The hydrogen is oxidised, the orange colour of the
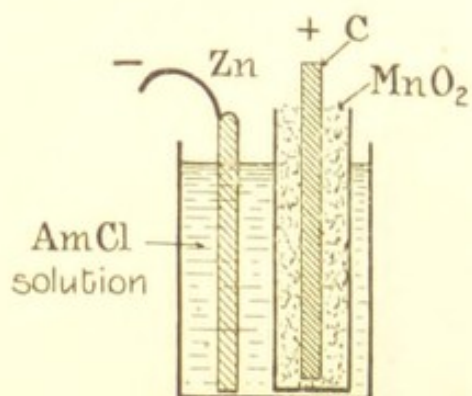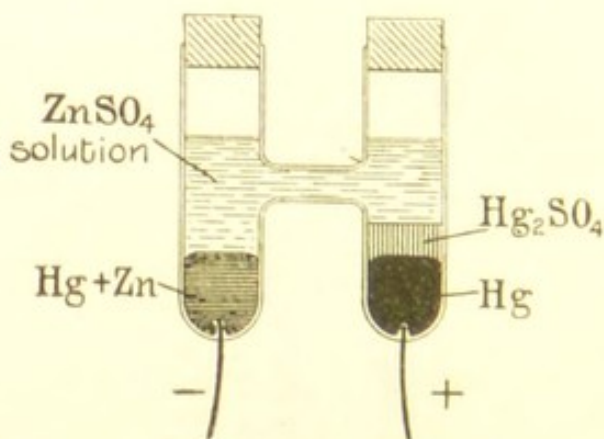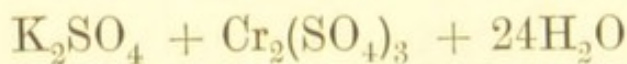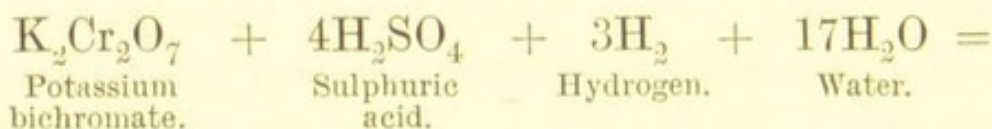

Fig. 124.—Leclanché cell.   Fig. 125.—Latimer-Clark cell.

bichromate changing to the purple green of chrome alum. The reaction is :

$$K_2Cr_2O_7 \quad + \quad 4H_2SO_4 \quad + \quad 3H_2 \quad + \quad 17H_2O =$$

Potassium   Sulphuric   Hydrogen.   Water.
bichromate.   acid.

$$K_2SO_4 + Cr_2(SO_4)_3 + 24H_2O$$

Chrome alum.

In this form of cell (Fig. 123) the zinc must be so arranged that it can be lifted out of the solution, when the battery is not at work, because chromic acid attacks zinc, even if it is amalgamated.

The **Leclanché cell** (Fig. 124) contains an amalgamated zinc rod immersed in a solution of ammonium chloride, and a carbon plate surrounded by a mass of black oxide of manganese. The hydrogen, which tends to be evolved at the carbon plate, reduces the manganese to a lower state of oxidation, being itself converted into water. This oxidation is slow, so that if short-circuited the cell polarises, but recovers if disconnected and allowed to stand :

$$Zn + 2NH_4Cl = ZnCl_2 + 2NH_3 + H_2$$

Zinc.   Ammonium   Zinc   Ammonia. Hydrogen.
         chloride.   chloride.
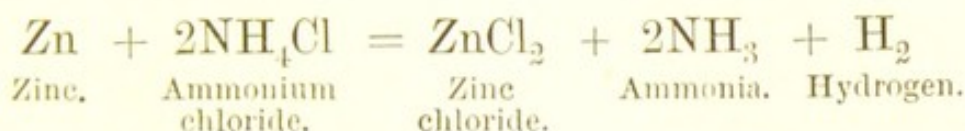
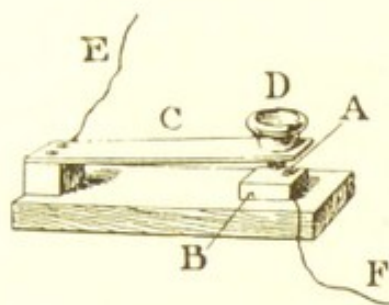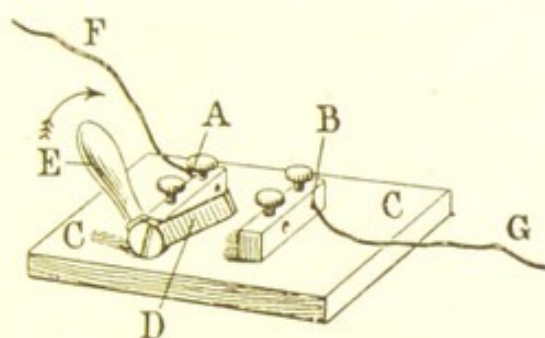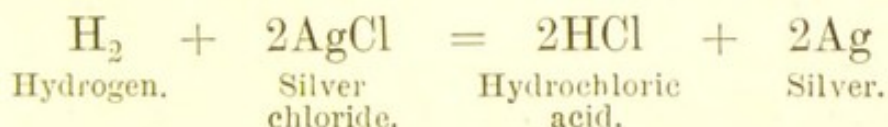The **De La Rue cell** has a rod of zinc immersed

Fig. 126.—Du Bois-Reymond key.   Fig. 127.—Spring key.

in a solution of ammonium chloride and a strip of silver surrounded by a stick of fused silver chloride. The hydrogen reduces the silver chloride :

$$H_2 + 2AgCl = 2HCl + 2Ag$$

Hydrogen.   Silver   Hydrochloric   Silver.
             chloride.   acid.

Dry Cells.—Most of these contain plates of zinc and carbon, the latter surrounded by black oxide of manganese, the exciting fluid being ammonium or zinc chloride, rendered more or less solid by admixture with plaster of Paris, flour, etc.

Latimer=Clark Cell.—This form of battery has been generally adopted as a standard cell for measuring purposes, having an electromotive force of 1·434 volts. It consists (Fig. 125) of a rod of pure zinc or a mass of amalgam of pure zinc and pure mercury for the negative pole, and a mass of pure mercury for the positive. The mercury is covered with a layer of pure mercurous sulphate, and then the cell is filled up with a saturated solution of pure zinc sulphate. Finally the cell is sealed up to avoid evaporation.
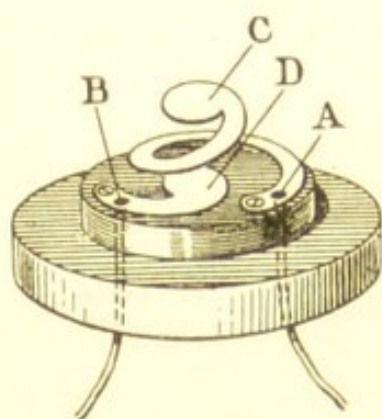

Fig. 128.—Bell push.

Keys.—An electrical key is an instrument for making or breaking a circuit. A form much used in physiological work is the *Du Bois-Reymond key* (Fig. 126). A piece of flat brass D, having a vulcanite handle E, is screwed to a brass block A, which is mounted on a vulcanite block C. On the handle being turned over to the right, D rubs against the end of the brass block B and establishes contact between the wires F and G.

Another form of key is the *spring key* (Fig. 127). A springy strip of brass C ends underneath in a metallic point A. On the disc of vulcanite D being pressed down, A comes into contact with the metallic plate B and establishes connection between the wires E and F. The electric bell push (Fig. 128)

is a spring key. On the ivory button being pushed
down the spiral spring c comes into contact with
the metal D, and the wires A and B are connected.

One other kind of key is seen in Fig. 129—the
" burglar alarm." This is fitted where the hinges
are usually placed. When the door is shut, as in
the figure, the edge of the " stile " of the door

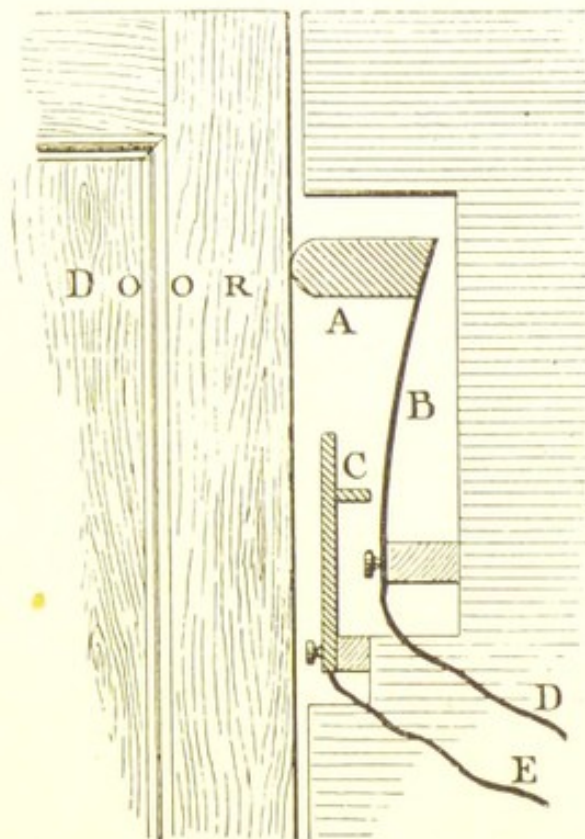Fig. 129.—Burglar alarm key.

forces the vulcanite stud A back into the recess
cut out for it, so that the spring B does not touch
the fixed point c. When the door is opened the
spring B moves to the left and makes contact with
c, thus establishing connection between the wires
D and E.

Commutator or Reverser.—This is an instru-
ment for changing or reversing the direction of a

current in a circuit. Fig. 130 shows one form of the instrument. Six circular holes, 1 to 6, are drilled in a block of vulcanite and filled with mercury; 1 and 6 are connected by a copper wire, also 2 and 5. There are six brass binding screws s, whose ends are screwed quite through the vulcanite, so that they project into the mercury. B is a moveable bridge of copper wire, with a glass handle c, by means of which 3 can be connected with 5, and 4 with 6,
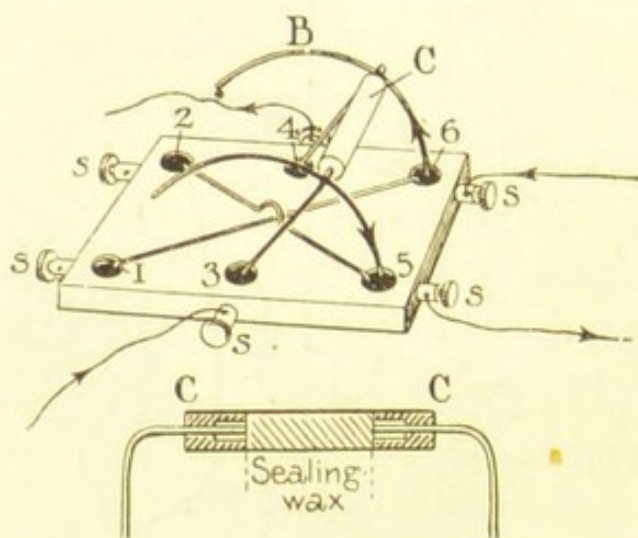

Fig. 130.—Commutator or reverser.

or by turning the bridge over, 3 can be connected with 1 and 4 with 2. Suppose the battery current enters at 3; it passes over the bridge to 5 and passes out into the circuit (as seen by the arrows), returns to 6, and passes out at 4. If the bridge is turned over, so that 3 is connected with 1, the current enters as before at 3, passes over by the cross wire to 6, and thus passes into the circuit in the reverse direction.

Sometimes a key and reverser are combined in

one instrument as in the key on the *Ruhmkorff coil* (Fig. 131). This consists of a circular block of vulcanite v; in it are fixed two brass axles x and y; with x is connected a handle h by which the whole can be turned. Two brass plates a and a′ are fixed, so as to cover only a small portion of the circumference of the vulcanite; two brass screws s and s′ connect these plates respectively with the brass axles x and y. Two brass springs p and q press
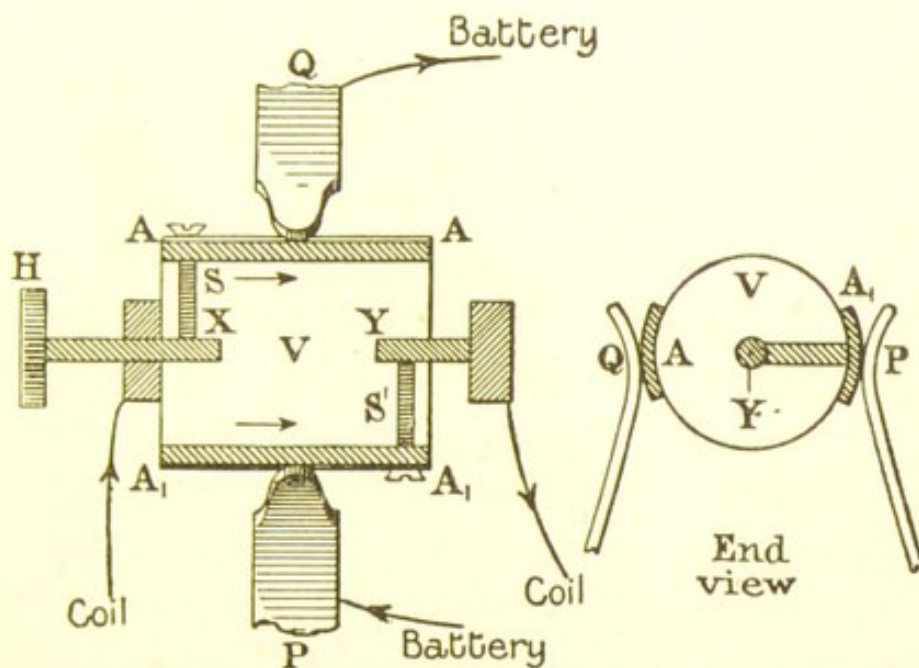

Fig. 131.—Key and reverser combined on Ruhmkorff coil.

against the circumference of the vulcanite; when they touch only vulcanite the *current* is blocked. The battery wires are connected with p and q, the wires of the primary coil with x and y. If the key be turned as in Fig. 131, the current passes in at p through a′ s′ to y. If, however, the vulcanite block be turned half round so that q touches a′, the current passes in by p along a through s to x, and its direction through the primary coil is reversed.

Electrolysis.—When a current passes through a solution of a metallic salt or a fused metallic salt, the salt is decomposed. Thus if a current be sent through some fused sodium chloride, sodium and chlorine will be set free. If the salt is in aqueous solution, the chlorine will be evolved in the free state, but the sodium at once acts on the water, forming a solution of sodium hydroxide, and the hydrogen is set free. The decomposed solution is termed the *electrolyte ;* the process is called *electrolysis.* An electrolyte must be a conductor of electricity, otherwise no decomposition will take place, as with pure water. If, however, a little sulphuric acid be added to the water the current passes, and bubbles of oxygen and hydrogen are evolved.

One group of elements and radicles is liberated at the electrode, by which the current leaves the electrolyte—that is, the negative electrode, the one connected with the zinc end of the battery— and these are called *electropositive* elements and radicles, or sometimes *kations,* as they are liberated at the kathode ; they include hydrogen and the metals. The other class, liberated where the current enters the fluid, are termed *electronegative* or *anions,* and include the non-metals, chlorine, bromine, and the acid radicles SO_4, NO_3, etc.

As illustrating this important fact we may take a solution of copper sulphate and place in it two platinum plates connected with a battery. In a few minutes the platinum plate connected with the zinc end of the battery will be found coated

with red metallic copper. If the direction of the current be reversed the copper will dissolve off the platinum plate, and be deposited on the other, which is now the kathode. Copper, being a kation, is always deposited on the kathode.

To show that anions are liberated at the anode, place a platinum plate connected with the zinc end of the battery, on a piece of flat glass, cover it with some filter paper moistened with potassium iodide and starch solutions. If the anode be brought into contact with the paper, iodine will be liberated, and will declare its presence by turning the starch blue. In this way we can write on the paper by moving the wire.
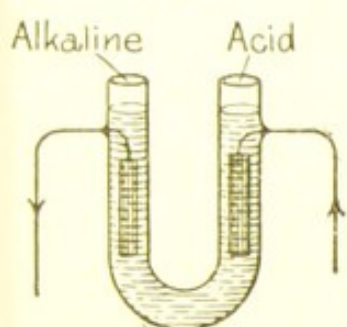

Fig. 132.—Electro-
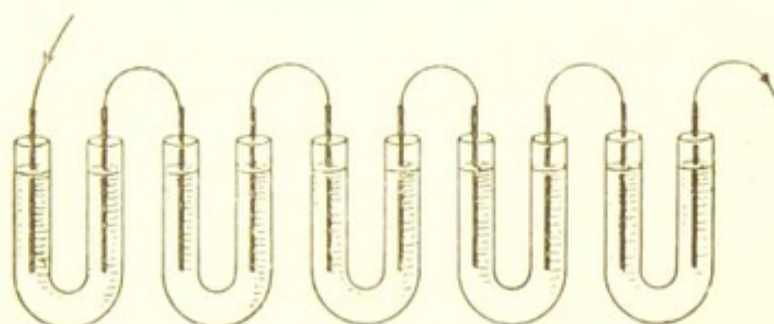   lysis of sodium
    sulphate.

Fig. 133.—Series of U tubes arranged
    for electrolysis.

If a neutral solution of sodium sulphate be electro-lysed in a U tube (Fig. 132), the leg containing the kathode will be found alkaline, the other being acid. The sodium sulphate splits into its kation sodium and its anion SO_4, the sodium decomposes water, forming caustic soda, which renders the water alkaline, and hydrogen, the anion SO_4, decomposes water, forming sulphuric acid and oxygen.

The decomposition of metallic solutions by electro-

lysis finds numerous applications at the present day for electroplating (coating with silver), electrogilding, electrotyping (reproducing objects in copper), nickel plating, etc. All that is necessary is to render the article to be plated thoroughly clean, immerse it in a suitable metallic solution, and make it the kathode by connecting it with the zinc end of a battery, when the metallic coating is deposited upon it. The anode should be a plate of the metal which is being deposited, gold for gilding, silver for electroplating, etc.

Electrolysis is also used in the manufacture of chlorine and caustic soda by the electrolysis of brine and, by the combination of the chlorine and the hydrate, for the preparation of chlorates. Pure copper for electrical purposes, aluminium, sodium, phosphorus, etc., can also be prepared by electrolysis.

Equivalent Weights.—When a current is passed which liberates 1 gram of hydrogen, it will set free 8 grams of oxygen, 108 of silver, $\dfrac{63 \cdot 5}{2} = 31 \cdot 75$ of copper, $\dfrac{197}{3} = 65 \cdot 7$ of gold, 80 of bromine, 35·5 of chlorine. In other words, elements are liberated in proportion to their equivalent weights (equivalent weight $= \dfrac{\text{atomic weight}}{\text{valency}}$). So that if we pass a current through a series of U tubes containing the following solutions—*viz.* (1) acidulated water, (2) copper sulphate, (3) silver cyanide, (4) gold cyanide, (5) salt (Fig. 133)—for every gram of hydrogen set

free there will be liberated 8 grams of oxygen, 31·75 of copper, 49 grams of sulphuric acid, 108 of silver, 26 of cyanogen, 65·7 of gold, 40 of caustic soda, 35·5 of chlorine.

Accumulators, Storage Cells, Secondary Batteries.—One special application of electrolysis is the storing of electrical energy by converting it into chemical energy.

A secondary battery consists of two sheets of lead painted with red lead, Pb_3O_4, or of gratings of lead, with their interstices filled up with a paste of red lead and dilute sulphuric acid, immersed in dilute sulphuric acid. The two plates are connected with the poles of a battery or dynamo, when the lead plates act as electrodes, hydrogen being evolved at the kathode and reducing the red lead on the kathode to a mass of spongy metallic lead, while the oxygen evolved at the anode oxidises the red lead there to peroxide of lead, PbO_2. When all the red lead has thus been converted on the one plate to metallic lead, on the other to peroxide, the hydrogen and oxygen come off in bubbles, indicating that the accumulator is charged. It is then disconnected from the dynamo. If the two lead plates prepared as above be now connected by a wire, a current will flow in the opposite direction, until the spongy lead and the peroxide have both been reconverted into red lead. •

Electrolytic Theory of Solutions.—According to this theory, which is now pretty generally accepted, in dilute solutions of metallic salts—*e.g.*, sodium

chloride—there exist separated atoms of sodium and of chlorine charged respectively with positive and negative electricity. The atom *with its charge of electricity* is termed an *ion*. The student must be careful to distinguish between an *ion* of sodium and an *atom* of sodium. When sodium is separated in *atoms* these form a silvery metallic mass decomposing water, etc. What the sodium *ion* is like is entirely conjectural. It is believed to be physically like a vapour, for solids in dilute solutions obey the same laws as gases—*i.e.*, the laws of Boyle, of Charles, and of Avogadro. We may talk of the *ions* of hydrogen passing from the zinc, through the porous pot, to the copper plate of a Daniell cell, but the *atoms* of hydrogen first appear as bubbles of gas *on* the copper plate.

These ions of sodium and chlorine are supposed to be wandering about in an ordinary dilute solution, first one sodium ion, then another, being attached to one particular chlorine ion. When subjected to electrolysis this irregular mob of ions falls into line, the positively charged ions of sodium moving towards the negative electrode, the kathode, where they give up their positive charge and appear as particles of sodium, decomposing water, etc., while the ions of chlorine move to the anode, yield up their negative charge, and are converted into ordinary yellow chlorine gas.

Neutral substances, such as sugar, alcohol, urea, etc., when dissolved in water, form solutions which do not conduct, and are therefore not electrolysed.

CHAPTER III.

Units.

Resistance.—The unit of resistance is the ohm, and is equal to the resistance of a column of mercury 1 square millimetre in section and 106 centimetres long at 0° C.

Potential.—The unit of electromotive force is the volt, and is roughly the difference in electrical level or potential between the two poles of a Daniell cell. The E.M.F. of a Latimer-Clark cell is 1·434 volts.

Unit of current.—The ampère, the unit of current, is the current which would be produced by a volt through a resistance of 1 ohm, and which, if passed through a solution of silver nitrate, would deposit silver at the rate of ·001118 gram per second or liberate ·00001038 gram of hydrogen.

Potential.—By potential is meant the difference in electrical level. Thus, if two bodies of different potential be connected with a wire, the current flows from the body of higher potential to the body of the lower. In the same way, when we have two

cisterns of water at different levels, if they are con-
nected by a pipe the water flows from the higher
to the lower level. The potential of the earth is
always taken as zero.

Ohm's Law. — The current flowing through a
circuit varies directly as the potential or E.M.F., and
inversely as the resistance—
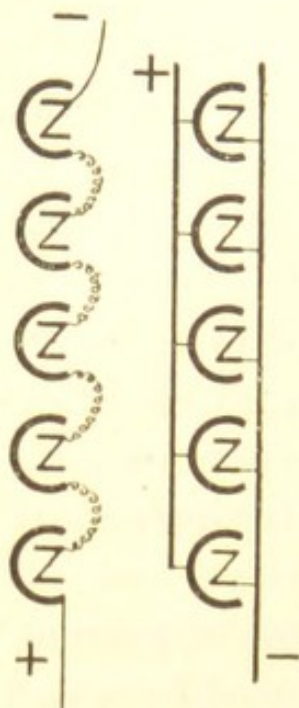
$$C = \frac{E}{R},$$

just as with a water supply the
higher the reservoir and the larger
the pipe the greater is the flow.
It is convenient to split up the
resistance into R, the resistance of
the external circuit, and r, the
internal resistance of the battery
or current producer, so that the
formula becomes—

$$C = \frac{E}{R + .r}.$$

Fig. 134. — Coup-
ling of cell.

**Effect of the Size of the
Plates in a Battery.**—The poten-
tial, or E.M.F., is independent of
the *size* of the battery, and depends only on the
nature of the metals and liquids used, but as the
larger sized plates include a larger prism of fluid, by
which the current can flow across the battery, the
internal resistance is diminished. Since the resistance
varies inversely as the cross section, if you double the
cross section you halve the resistance.

Coupling of Cells in Series and in Parallel

Circuit.—Cells can be coupled up into batteries in two chief ways : (1) In series when the zinc of one cell is coupled to the copper of the next, and (2) in parallel circuit when all the series are joined and all the coppers (Fig. 134).

If we take two cells and couple them in series we double the E.M.F., but at the same time we double the internal resistance, and the same holds with any number of cells. If we couple two cells in parallel circuit, we have practically one cell, with plates double the size. In this case the E.M.F. is unaltered, but the internal resistance is halved.

If the *external* resistance is *large*, say 2,000 ohms, then it is more advantageous to couple in series. If, on the other hand, the *external* resistance is *small*, coupling in parallel circuit is to be preferred. The most satisfactory result is when R = r.

If we have twenty Daniell cells (potential 1 volt, internal resistance of each cell = 10 ohms) at our disposal, which will be the most advantageous, series or parallel circuit—(1) when R = 3,000 ohms, (2) when R = 0·5 ohm ?

(1) When R = 3,000 ohms :—

$$\text{in series } C = \frac{20 \times 1}{20 \times 10 + 3,000} = \frac{20}{3,200} = \cdot006 \text{ ampère,}$$

$$\text{in parallel circuit } \frac{1}{\dfrac{10}{20} + 3,000} = \frac{1}{3,000\cdot5} = \cdot0003 \text{ ampère.}$$

So with a large external resistance it is better to couple the cells in series, as this gives a current twenty times as great as when the cells are in parallel circuit.

(2) When R = 0·5 ohm :—

in series $C = \dfrac{20 \times 1}{20 \times 10 + 0\cdot5} = \dfrac{20}{200\cdot5} = 0\cdot1$ ampère,

in parallel circuit $\dfrac{1}{\dfrac{10}{20} + 0\cdot5} = \dfrac{1}{1} = 1\cdot0$ ampère.

Resistance.—This

(1) depends on the nature of the substance ;

(2) varies inversely as the cross section ;

(3) is proportional to the length ;

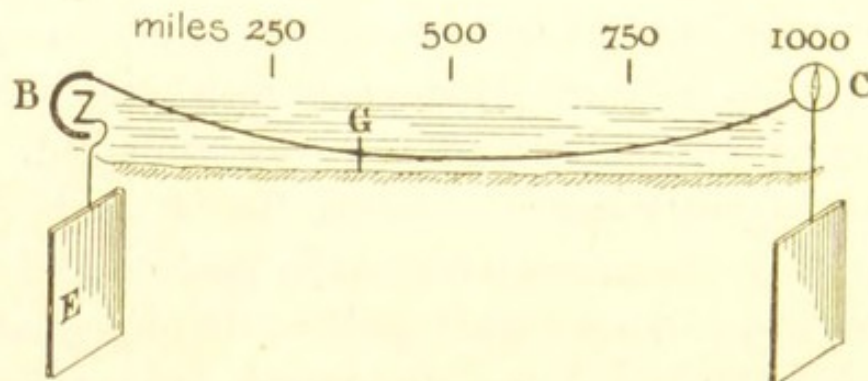(4) varies with the temperature, increasing as this rises.

Fig. 135.—Fault in cable.

Copper and silver are the best conductors ; even traces of impurities reduce the conductivity. Iron is not nearly so good a conductor as copper, but by taking a larger sized iron wire, we increase the cross section, and so compensate for its inferior conductivity. The earth is of such an immense cross-section that it may be looked upon as a perfect conductor. An aluminium wire of the *same size* as a copper wire has only 60 per cent. of its conductivity, but if the size of the aluminium wire be

increased, until it *weighs* the *same* per metre, it is twice as good a conductor as copper.

The utility of determining resistance may be illustrated by the method of locating a fault in a submarine cable (Fig. 135). First let us trace the circuit, starting from the battery at B. The current flows through the cable to the receiving instrument at C, passing by the earth plate back through the earth to the plate E, and so home. Now suppose the cable is 1,000 miles long, and that each mile has a
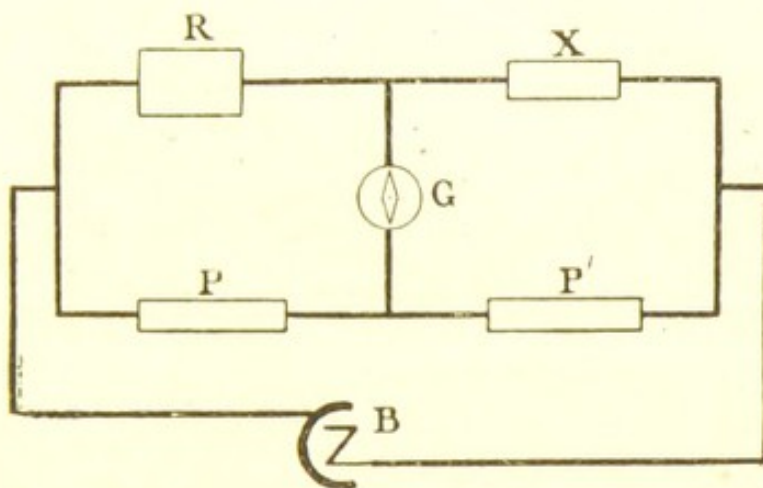

Fig. 136.—Diagram of Wheatstone's bridge.

resistance of 5 ohms. As long as the cable is intact, it interposes a resistance of 5,000 ohms. Suppose it is broken at G, then the broken end is earthed, and the resistance falls to 1,800 ohms. Then the fault is $\dfrac{1,800}{5} = 360$ miles from B.

Wheatstone's Bridge.—The principle of this most useful instrument is illustrated by Fig. 136. R is a resistance which can be varied, X is an unknown resistance to be determined, P and P′ are resistances

L

which can be made of some convenient ratio to each other, as 1 : 1, 1 : 10, 1 : 100. The connections are all made with thick copper wire. A galvanometer G and a battery B are connected as seen in the figure. When the galvanometer indicates that no current is passing, then P : P′ :: R : X. As the ratio P : P′ is known, and R is also known, X can readily be calculated.

In one common form of this bridge, a German silver wire of high resistance *a b* is stretched between two thick copper plates C C (Fig. 137). At R a known
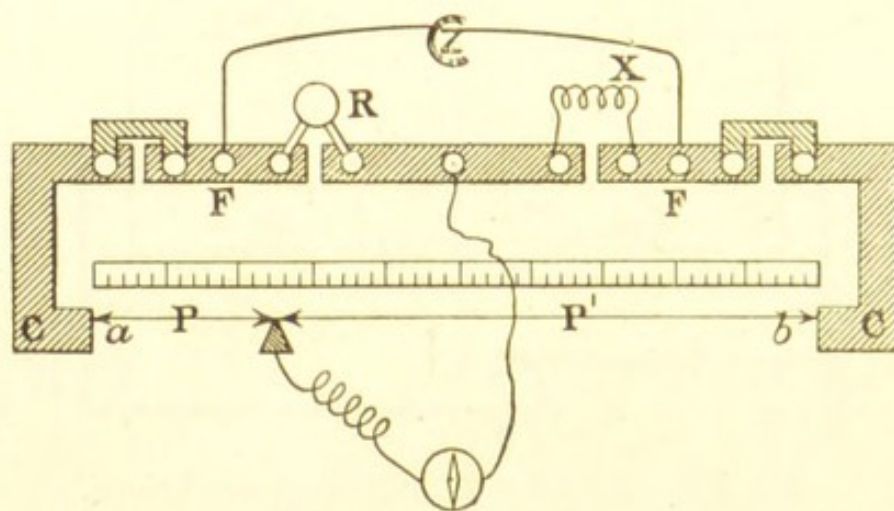
Fig. 137.—Wire form of Wheatstone bridge.

resistance is inserted, and at X the unknown resistance. One wire from the galvanometer can be made to touch the wire *a b* at any spot. The battery is connected as shown at F F. Contact is made between the galvanometer and *a b* until a spot is found at which no deflection of the needle is observed on touching ; then, as before, P : P′ :: R : X. *a b* is furnished with a scale, so that the lengths P and P′ can be read off.

Another very convenient arrangement is the " Post Office box," which is shown in Fig. 138. P and P′ are two sets of resistance coils of 10, 100, and 1,000 ohms each, so that P : P′ may be made 1 : 1, 1 : 10, or 1 : 100. The galvanometer is connected to the key K, and when this key is down the galvanometer is joined up to the end of P. The battery is coupled to the key K′, and when this is down, with B—that is
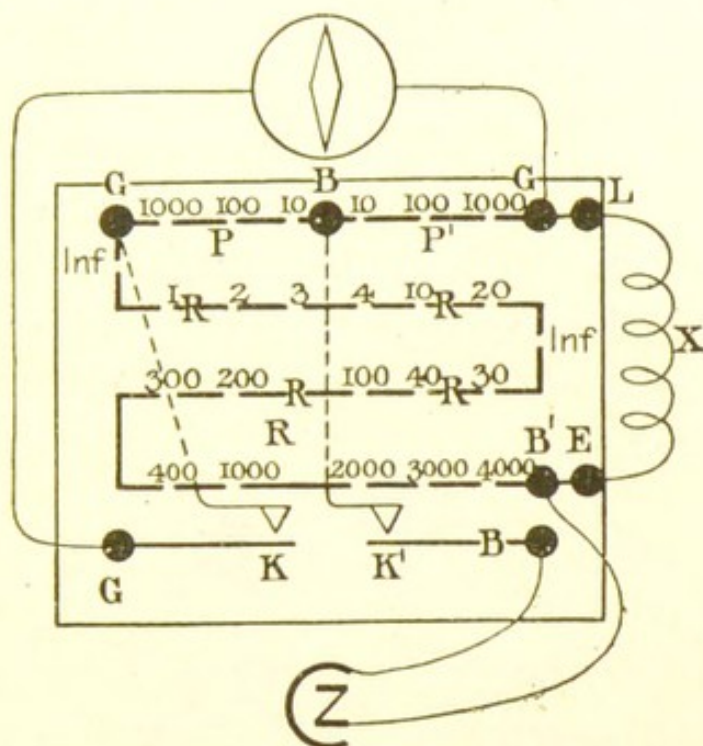

Fig. 138.—"Post Office box."

the brass block connecting P and P′ ; the other end of the battery is attached to B′—that is with E, the further end of the adjustable resistance R ; while the unknown resistance joins B′ with L. In determining X, P and P′ are first adjusted to a suitable ratio by taking out the plugs 10 : 10, 10 : 100, or 10 : 1,000 ; then R is adjusted by taking out plugs till on making contact with the keys K and K′ no deflection of the galvanometer occurs. Then, as above, P : P′ :: R : X.

Rheostat.—This name is given to a resistance which can be varied by winding or unwinding an uncovered German silver wire (Fig. 139) from a vulcanite reel A on to a brass cylinder B, the resistance being determined by the length of wire on the vulcanite.
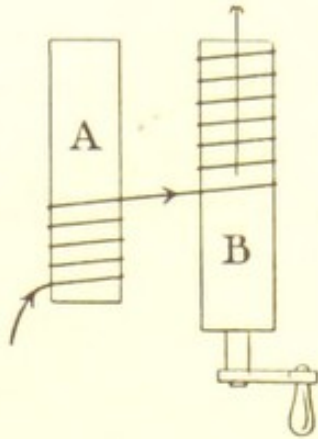
Fig. 139.—Rheostat.

Resistance coils (Fig. 140) consist of two brass blocks A A', which are connected underneath by a fine insulated wire C, which has a resistance of 1, 10, 1,000, etc., ohms, as marked on the instrument. The brass blocks are mounted on vulcanite, and can be connected by
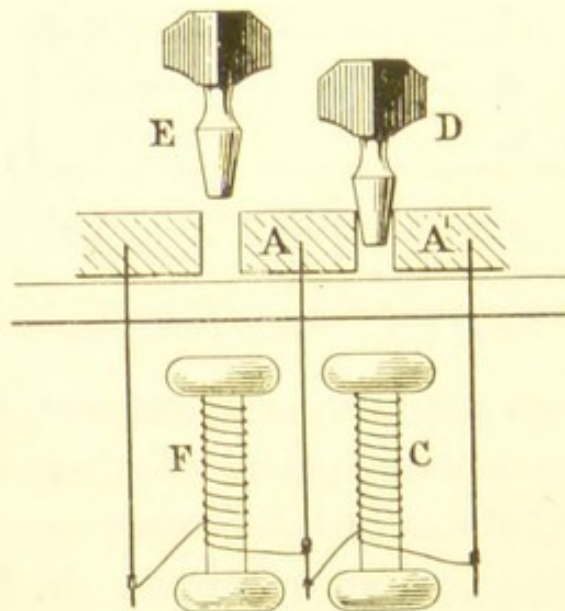
Fig. 140.—Resistance coil.

pushing in a slightly conical brass plug D, and thus cutting out the resistance. When the plug is out (E) the current passes through the resistance F;

when the plug is in (D) the current passes through
the plug.

**Effect on a Magnetic Needle of a Current
passing along a Copper Wire.**—A compass needle
tends to set north and south. If a copper wire con-
veying a current is brought over the needle, the latter
tends to set itself at right angles to the length of the
wire. If the current passes from A to B over the
needle (Fig. 141), the north end of the needle turns
to the left ; if the wire is placed under the needle, the
north end moves to the right. If the direction of
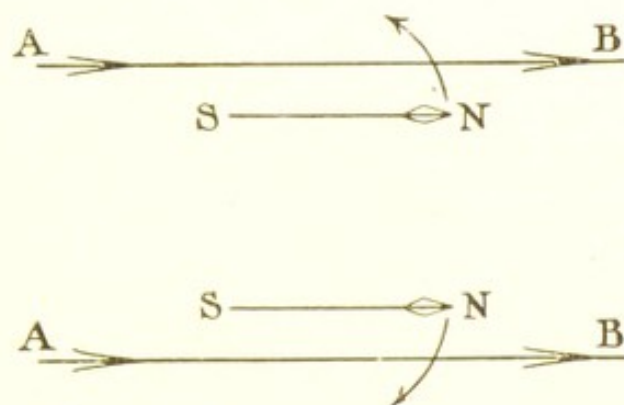
Fig. 141.—Action of current on magnetic needle.

the current be reversed, the movement of the needle
is reversed. The simplest plan of remembering the
direction of these movements is to imagine a little
elf swimming, so that the current passes in at his
heels and out at his head, with *his face* towards the
needle. The north pole will then move to the side on
which his *left* hand is placed. If a wire pass over
a needle and then below, as in Fig. 142, the little elf,
moving with the current along A B, swims on his
breast to face the needle, and the north end is de-
flected to the left. As he turns round the bend

along C D he has to swim on his back to keep his face towards the needle, and his left hand will point in the same direction as before. Thus twice the effect on the needle is produced by the current, and by making many turns of insulated wire round a needle, a small current may be made to produce a considerable deflection. Very small currents can thus be detected.

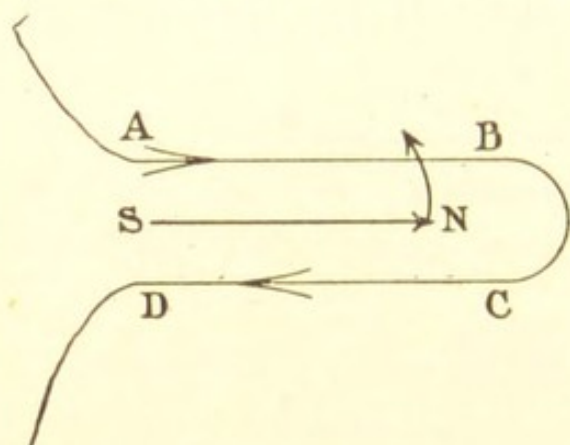**Astatic Needle.**—The effect of a current upon a needle may also be increased by fixing to the needle

Fig. 142.—Effect of wire over and under magnetic needle.
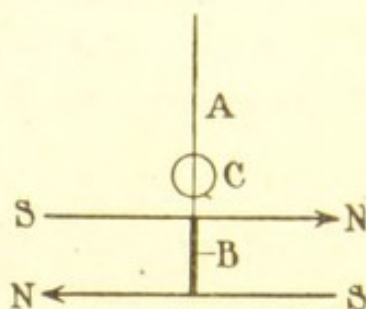
Fig. 143.—Astatic needle.

a second needle of equal strength, but having its poles reversed, so that the north pole of one needle shall be over the south pole of the second, as in Fig. 143. If the two needles were perfectly symmetrical, and exactly balanced as to their magnetism, the combination would set indifferently in any position. As a matter of fact, if the magnets are equally magnetised, the needle sets east and west. By using such an astatic needle, the current has not to overcome the directive force of the earth's magnetism, and we have thus a much more delicate

indicator. The needle is suspended by a silk fibre
A, and the two needles are firmly fixed together by
the rod B. Finally, to render the least movement of
the needle visible, an exceedingly thin silvered glass
mirror C (Fig. 144) is attached to the upper needle ;
a beam of light from a slit at A falls on the mirror
C, and is received, after reflection, on a scale B. Very
small movements of the needle are thus rendered
visible. Fig. 144 shows the mirror C attached to
the astatic needle N N, and the way in which the light
is reflected.
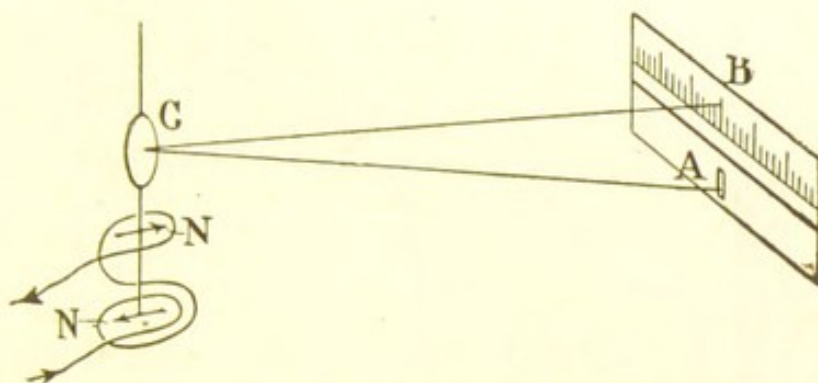
Fig. 144.—Light reflected from mirror on astatic needle.

These reflecting galvanometers are usually fur-
nished with a sliding curved magnet placed over
them on a vertical rod. This avoids the inconveni-
ence of having to place the instrument in the magnetic
meridian, and enables the observer to control the
sensitiveness of the galvanometer.

Tangent Galvanometer.—This consists of a
thick copper wire coiled in a large open ring A (Fig.
145). There may be one, two, or several coils, usually
10 to 15 in. in diameter. The magnetic needle B
must not be more than 1 in. long, and is suspended

exactly in the centre of the ring. A light, long
index of aluminium c c is attached at right angles
to the needle. The position of the index can be read
off on a circular horizontal scale. The coil is set in
the magnetic meridian, the short needle lying in the
plane of the coil.

A current flowing round the hoop of wire twists
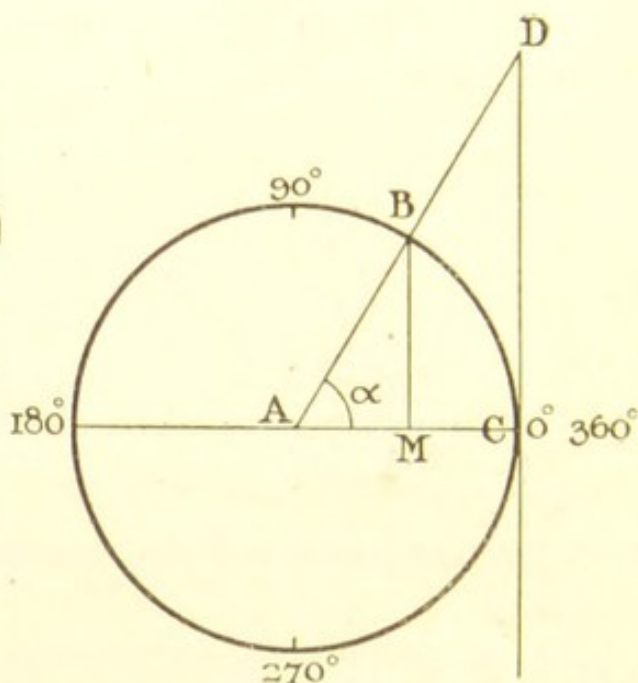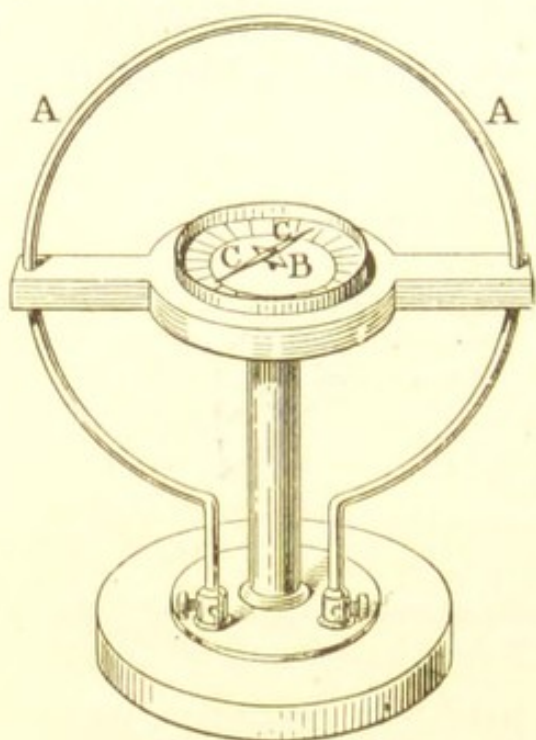the needle through an angle so that the *tangent* of

Fig. 145.—Tangent galvanometer.   Fig. 146.—Tangent of an angle.

the angle of deflection is proportioned to the strength
of the current : *e.g.*, if the angles of deflection of
two currents are 15° and 30°, then tangent 15° = ·268
and tangent 30° = ·577, and the current strengths
are as 1 : 2·1.

(For table of tangents see Appendix.)

If the current produces a deflection equal to the
angle B A C, this can be reckoned by graduating the

circumference into 360°, and measuring the angle in degrees, say 60°; or it can be reckoned as some function of the angle as the *tangent.* If we make a tangent at c and produce A B to meet the tangent at D, then tan. $a = \dfrac{D C}{A C} = \dfrac{B M}{A M}$ (Fig. 146).

There are two units by which currents can be measured. One is the *C.G.S. unit,* or *absolute unit*—i.e., a current which, flowing along a wire 1 cm. long, bent into the arc of a circle of 1 cm. radius, exerts a force of 1 dyne, on a unit magnetic pole placed at the centre (Fig. 147).
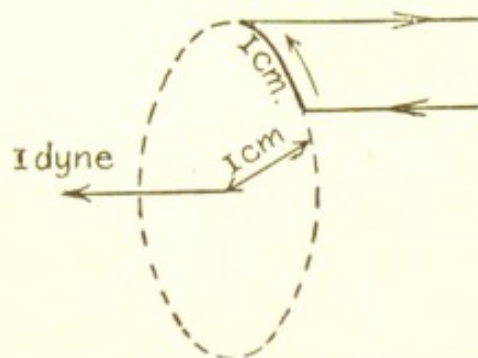
Fig. 147.—C.G.S. current.

The *practical unit* is 1 ampère $= \dfrac{\text{absolute unit}}{10}$.

If the wire is longer than 1 cm. the effect on the needle is proportionally increased.

If the distance from the pole of the magnet is greater than 1 cm. the force diminishes as the square of the distance.

· Find the force in dynes exerted by a current of 80 ampères (8 C.G.S. units), the radius of coil being 20 cm. and having 10 turns.

$$\text{Force in dynes} = \frac{8 \times \left(20 \times 2 \times \dfrac{22}{7}\right) \times 10}{20^2}$$

$$= \frac{8 \times 125 \cdot 7 \times 10}{400} = 25 \cdot 14 \text{ dynes.}$$

The formula for the strength of the current is :

$$C = \frac{Hr^2}{l} \tan. \delta,$$ where H is the horizontal intensity

of the earth's magnetism = ·18.

r = radius of coil in centimetres.

l = length of wire in the coil.

δ = angle of deflection.

What strength of current will be required to produce a deflection of 45°, with coil 10 cm. radius and 12 turns ?

$$C = \frac{\cdot18 \times 10^2}{\left(10 \times 2 \times \frac{22}{7}\right) \times 12} \tan. 45° = \frac{18}{753\cdot6} \times 1$$

= ·023 c.g.s. units or ·23 ampères.

As $\dfrac{Hr^2}{l}$ is always the same for the same instrument at the same locality, it can be calculated once and for all. Calling its value G, the formula becomes :

$$C = G \tan. \delta.$$

CHAPTER IV.

INDUCTION BY CURRENTS—INDUCTION COIL—FARA-
DIZATION—EXTRA CURRENT—RUHMKORFF COIL
— DISCHARGE IN VACUA — MEASUREMENT OF
CURRENT.

Induction by Currents. — We have seen that
when a rubbed glass tube, charged with positive elec-
tricity, is brought near one end of a metallic conductor
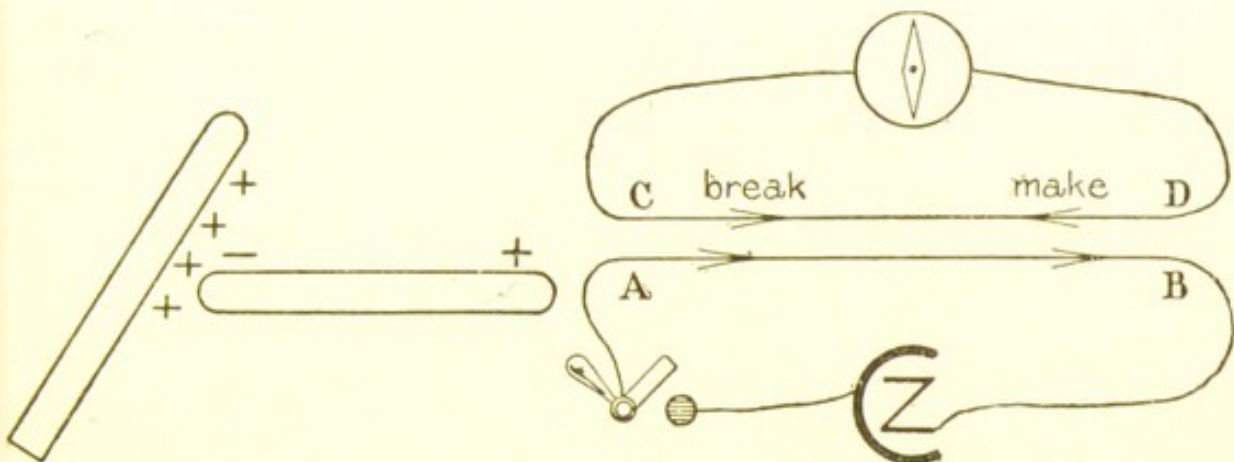the normal electrical state of the conductor is upset,

Fig. 148.—Induction by glass rod.   Fig. 149.—Induction by current.

negative electricity rushes to the end nearest the glass
tube, while the positive electricity (Fig. 148) is repelled,
the process being called *induction*. A somewhat
similar effect is observed with currents. If we take
a copper wire A B, connected with a battery and a key
(Fig. 149), and bring near it a second wire C D, run-
ning parallel to A B, whose ends are connected with a
galvanometer or a capillary electrometer, we shall
see that, at the moment we put down the key, and

the current flows from A to B, we shall have a momentary induced current flashing through the wire D C in a direction *opposite* to that in A B. As long as the current in A B remains constant, nothing further will happen ; but if we lift the key and break the circuit, we shall have another momentary current rushing through C D in the *same* direction as that of the primary current in A B. These currents in C D are called *induced currents*, and their strength can be greatly increased by coiling the insulated wires A B and C D.
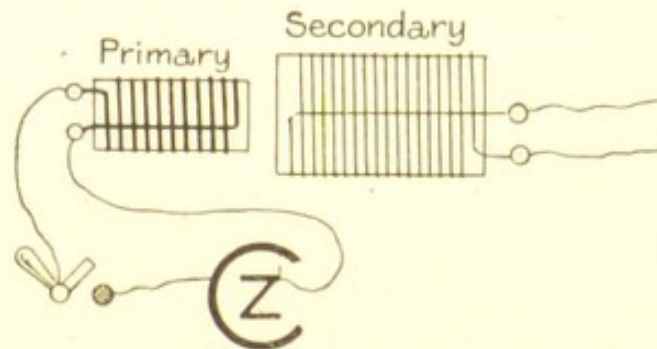
Fig. 150.—Induction coil for single shocks.

This induction of a secondary current, in a closed coil of wire, by the passage of a current through a neighbouring coil, is the principle of the **induction coil.** One form much used in the physiological laboratory is that of Du Bois-Reymond. The *primary coil* is composed (Fig. 150) of comparatively few turns of thick insulated copper wire. A key is inserted in the primary circuit so that the current may be made or broken. The *secondary coil* consists of many turns of thin insulated copper wire, and is so arranged that its distance from the primary coil can be altered. If the ends of the two wires of

the secondary coil be placed on the tongue, a distinct
shock will be felt when the current in the primary
circuit is made, and again when it is broken ; the
break shock being the stronger.

In this arrangement the make and break are made
by hand, but by a simple automatic device a continu-
ous and regular series of makes and breaks is made by
the current itself. This is known as **Faradization.**
The current passes from the battery c (Fig. 151) to
the screw s, thence by the steel spring P to the electro-
magnet M, thence to the primary coil A, and finally
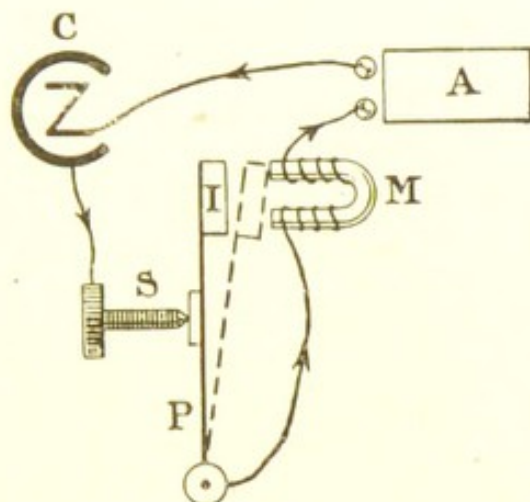
Fig. 151.—Faradization.

home to the battery. When the battery is connected,
the current causes the electro-magnet to attract the
little block of iron I fixed on the spring P. This
breaks the contact between s and P, and the current
ceases. M therefore ceases to attract I, and the
spring re-establishes contact between P and s,
when the cycle of events is repeated. Thus an
automatic series of makes and breaks is set up, and
the rate at which they take place is governed by the

rate of vibration of the spring P. The primary coil is usually filled with soft-iron wires, which increase the inductive effect by becoming magnetised and demagnetised at each make and break. In some coils these iron wires are utilised to attract the vibrating spring, instead of having a special electro-magnet as above. Wires are better than a solid rod, as in the latter local magnetic effects would tend to delay the *sudden* changes in magnetism required to produce the maximum effect.
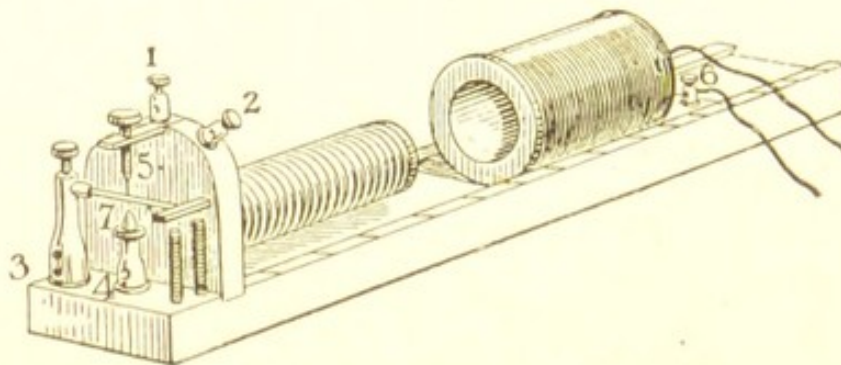

Fig. 152.—Du Bois-Reymond induction coil.

The general appearance of the coil is seen in Fig. 152. For single shocks the wires from the battery are inserted in screws 1 and 2; for the automatic break or Faradization the screws 3 and 4 are used. A modified effect can be obtained by joining 1 and 3 with a thick wire, screwing up screw 7 into contact with the spring and withdrawing 5. The primary circuit is then never broken completely, but only short-circuited when the vibrator touches the screw 7 (*Helmholtz modification*). The secondary coil is moveable, and its distance from the primary can be read off on the scale, the maximum effect being attained when the coils overlap.

Extra Current.—When a wire is wound into a coil and a current sent through, the coils act by induction on each other and produce a momentary current in the coil, which is opposed to the primary current at the " make," and a second current would be generated in the same direction as the primary at " break," if the circuit were not broken when the key was opened.

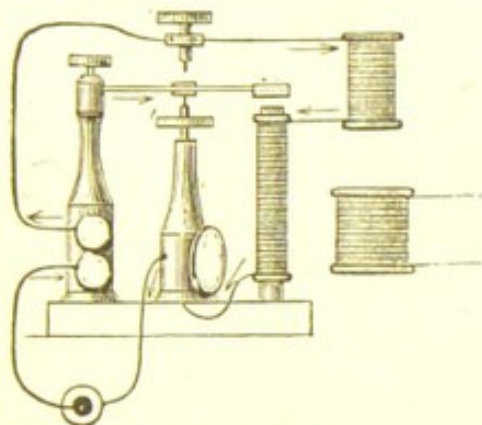This extra current explains the difference between the strengths of the make and break in the Du Bois-

Fig. 152*a*.—Helmholtz
modification.
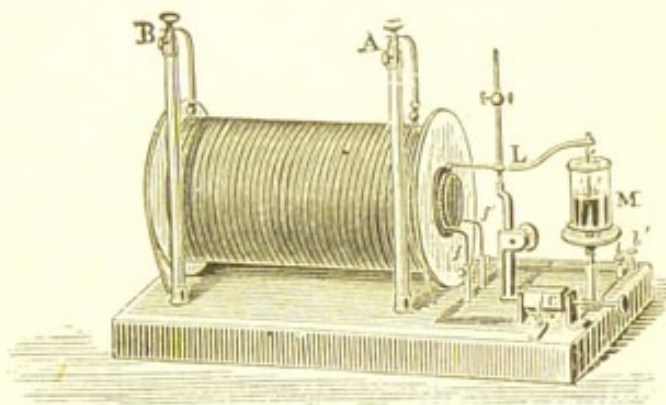
Fig. 153.—Ruhmkorff coil.

Reymond coil. When the current is made in the primary coil, it is opposed by its own self-induced extra current, running in the opposite direction, and so does not attain its full strength at once ; but on breaking the potential falls suddenly from a maximum to zero. Now, the strength of the induced current depends not only on the change in the potential in the primary, but also on the rapidity with which this change is established. If the potential mounts slowly, the secondary current developed is much weaker than when the increase or decrease is instan-

taneous. So at the make, as the current is opposed by its own extra current, the full potential is not immediately attained ; but at the break the potential falls at once to zero, and the break shock in the secondary coil is much stronger.

In the Helmholtz modification (Fig. 152*a*) the extra current at break is not abolished, and being in the same direction as the primary, it tends to tail off the fall of the potential.

In the **Ruhmkorff coil** the secondary coil is not moveable, but is fixed in the position of maximum efficiency. By this means an E.M.F. of 20 volts can be increased to several thousand or more volts, the increase depending roughly on the ratio of the number of turns of wire in the two coils. In a huge coil made for the late Mr. Spottiswoode, the copper wire of the primary coil was 660 yards long, whilst that of the secondary was 280 miles. The diameter of the wire was : in the primary ·096 in., in the secondary ·0001 in. This gave a spark over 40 in. long.

One form of Ruhmkorff coil is shown in Fig. 153. The current from the battery enters at *b'* and passes to the commutator and key (see Fig. 131), thence through the primary coil by the wires *f* and *f'*, thence to the lever centred at L, which forms the automatic breaker and maker of the current. One end dips into the mercury cup M ; the other end has a piece of soft iron attached to it, which is pulled down, when the current passes, by the iron core of the coil ; from the mercury it passes to the screw *b*, and

then to the battery. A and B are the ends of the secondary coil.

The discharge from a powerful induction coil resembles a miniature lightning flash, and is accompanied by a sharp snapping sound. If the discharge passes through a tube partly exhausted, it takes the form of a narrow pale violet ribbon of light, which connects the two electrodes. As the exhaustion proceeds, we have the tube filled with an aurora-like glow, the colour depending on the nature of the minute quantity of the residual gas, as in the well-known Geissler tubes. If a more perfect pump, as a Sprengel or double Fleuss, be used, we notice that the dark space surrounding the negative electrode seems to increase in area until it occupies the whole of the tube. We again have coloured effects, but the colour depends upon the nature of the substance on which the emanation from the kathode strikes. In the ordinary Röntgen tube it strikes against the glass and gives a yellowish green·glow. If the tube be made of lead glass the glow is bluish. If we enclose, in the tube, some crystallised alumina (in the form of sapphires or rubies) and interpose them in the course of the kathode rays, they glow with a rich red light. Finally the vacuum may be made so perfect that the discharge refuses to pass.

An induction coil may be looked upon as an instrument for transforming a moderate E.M.F. into an enormous E.M.F., transforming upwards. It is obvious that we might use it the other way round and transform a potential of some thousands of

M

volts down to one or two hundred volts. Transformers are actually used in this way for domestic purposes. It is found more economical to transmit currents of high voltage and transform them down to 100 or 200 volts before they enter the houses, to be used for domestic lighting, etc.

Another appendix to the Ruhmkorff coil requires a word of explanation. The *condenser* is really a form of Leyden jar made of layers of tinfoil separated by layers of paper soaked in paraffin wax. It
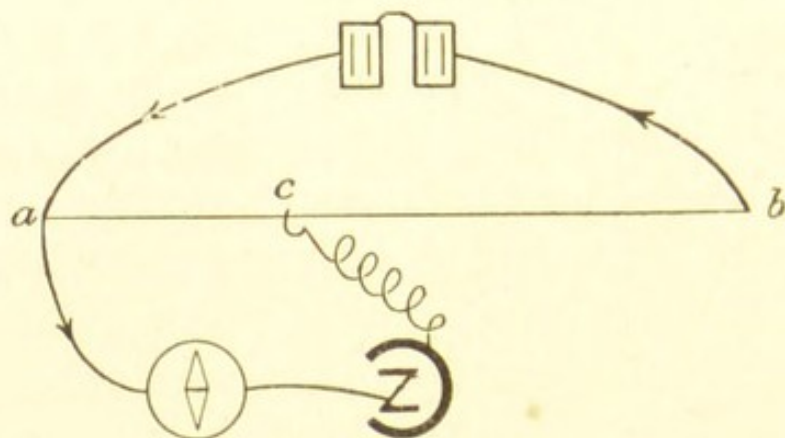

Fig. 154.—Potentiometer.

serves as a sort of reservoir into which the extra current can discharge itself, instead of sparking across the platinum or mercury contact of the automatic vibrator : it is placed under the coil.

Measurement of a Current by the Potentiometer (Fig. 154).—*a b* is a long wire of German silver, with which a battery of two Grove cells is connected, so that the current flows from *a* to *b*. The potential falls from a maximum at *a* to zero at *b*. Much in the same way, if we take a tall cylinder full of water, and attach a long narrow tube *a b* to it

(Fig. 155), the pressure, owing to the friction against the sides of the tube, will gradually diminish as we get further away; so that if we insert vertical glass tubes T T T, we see that the level of the water steadily sinks as we approach the end.

Now, if we take a standard Latimer-Clark cell and couple one pole with *a*, so that the current flows in a direction opposite to that of the Grove cell, introducing a galvanometer into the circuit (Fig. 154), and
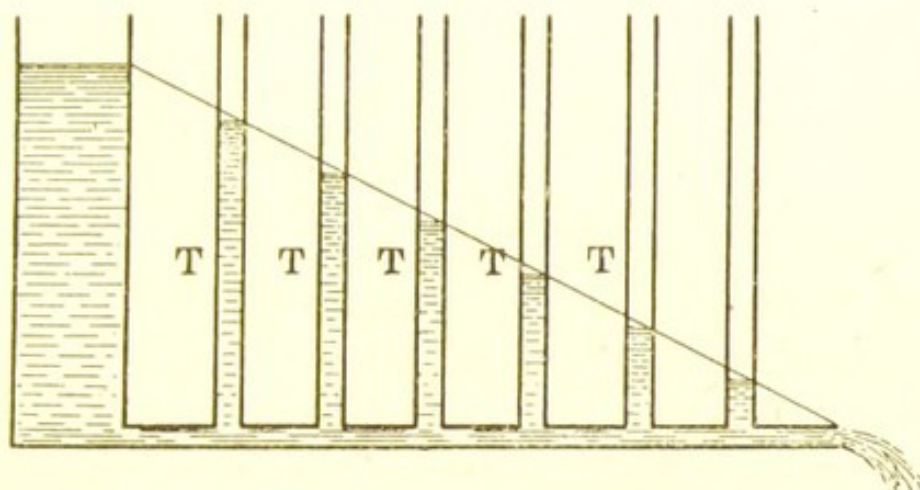

Fig. 155.—Fall of water pressure in long tube.

then with the wire from the other end of the Latimer-Clark cell touch the wire *a b*, until we find a spot where the galvanometer indicates no current in the Latimer-Clark, we have tapped off just enough current to balance the standard cell. We then measure the distance *a c*. The experiment is repeated with the cell, whose strength is unknown, and we find the distance is *a c'*; then *a c* : *a c'* :: 1·43 : voltage of the unknown cell (see Fig. 125 and p. 148).

CHAPTER V.

MAGNETS, NATURAL AND ARTIFICIAL — MAGNETIC FIELD—LINES OF FORCE—MAGNETIC INDUCTION — INCLINATION — DECLINATION — MAGNETIC EFFECTS OF CURRENTS—TELEPHONE—HEATING EFFECTS OF CURRENTS—THERMOPILE—CAPILLARY ELECTROMETER—CONDUCTANCE — RESISTIVITY — CONDUCTORS IN PARALLEL CIRCUIT—BOARD OF TRADE UNIT.

BEFORE studying the magnetic effects of currents it is important to know what a magnet is, and to have some idea of its general properties.

Magnetism owes its name to Magnesia, in Lydia, where the lodestone, a magnetic oxide of iron (Fe_3O_4) was found in classical times. This oxide of iron has the power of attracting iron filings, and if cut and suspended in a suitable manner, will point nearly north and south. If such a lodestone be placed underneath a thin sheet of paper and iron filings be sprinkled on the paper, it will be observed that the filings chiefly cluster round two spots, one at each end of the lodestone, where the magnetic force seems concentrated. These spots are termed the *poles* of the magnet. The one which points to the north when the magnet is suspended is called the *north-seeking* or, more shortly, the *north* pole, and in steel magnets is usually marked with a file mark or stamped

with an " N," or shaped like a *fleur-de-lys ;* the other
end is the *south* pole.

If a needle be drawn lengthwise over the north
pole the end which leaves it last becomes a south
pole, and if the needle be thrust through a piece of
cork and floated on water, it will point north and
south. If a second needle be magnetised, the follow-
ing experiments can be made : The north pole of one
needle being presented to the north pole of the needle
floating on the water, it will be seen that the two
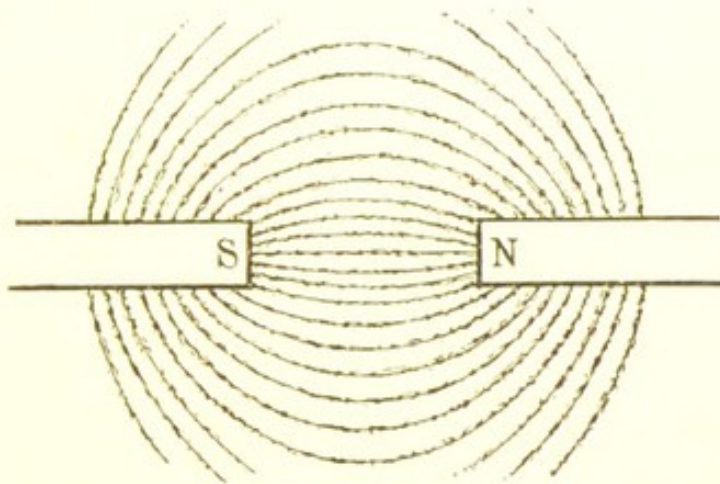
Fig. 156.—Lines of force, N. and S.

north poles repel each other, and that the two south
poles also repel each other, but that the south pole
attracts the north pole, and *vice versâ.* The same
results will be obtained with a steel magnet and a
compass needle.

Lines of Force.—The space which surrounds a
magnet is termed the *magnetic field.* This magnetic
field is traversed by lines of force, which can be
rendered visible by scattering iron filings over a
magnet placed under a sheet of paper. If we place

a north opposite a south pole we have the lines arranged as in Fig. 156. If two north or two south face each other, the lines present the appearance shown in Fig. 157. Magnets may be in the form of bars, in which case they are usually made in pairs and kept in a box with the north pole of one opposite the south pole of the other and a piece of soft iron, called a keeper, at each end (Fig. 158). Sometimes the bar is bent into the well-known horseshoe form, which also is furnished with a keeper. The keeper
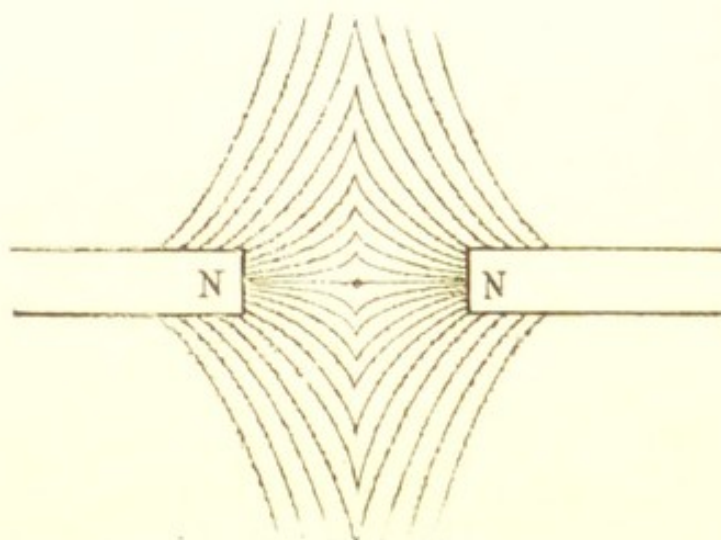
Fig. 157.—Lines of force, N. and N.

serves to concentrate the lines of force and prevents loss of magnetism.

Magnetic Induction.—A piece of soft iron wire has no magnetic properties, and does not attract another piece of soft iron; but if it be brought near the north end of a bar magnet it becomes, for the time, a magnet, the end nearest the bar magnet being a south pole and the lower end a north pole. If a second piece of iron wire be brought into contact with the lower end of the first, it also becomes

a magnet, and so on (Fig. 159). All the pieces of iron wire will fall if the south pole of a second magnet be brought over the north pole of the first. Directly the pieces of iron wire are removed from the magnet they lose their magnetism (*cf.* Electrical Induction, p. 124).

If a piece of *hard steel* wire be brought near the pole of a magnet, it is at first not so powerfully attracted as the soft iron, but when it has been in contact a short time, especially if it be drawn over the magnet, it will be found, on withdrawal, to be
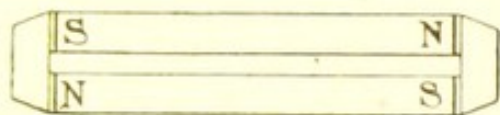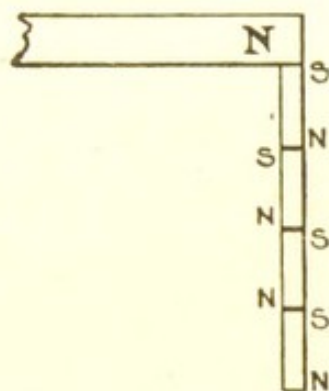
Fig. 158.—Bar magnets.   Fig. 159.—Magnetic induction.

permanently magnetic. It seems as if more energy were required to twist the molecules of the steel so as to become magnetic, but when once set in that position they retain it, whereas the molecules of the soft iron do not. This is known as the *coercive force of steel*. The only other metals which exhibit marked magnetic phenomena besides iron are nickel and cobalt.

Effect of Breaking a Magnet.—If a magnetised needle be broken in half, two magnets are produced. On again breaking each half, four magnets are

produced (Fig. 160). In this respect magnetic differs from electrical induction. As we have seen, positive electricity can be isolated on one conductor and negative on another; but no one has yet separated north from south magnetism.

The magnetic force can be exerted through glass and many other substances. At a red heat all magnetism is lost. Repulsion is the only test for a magnet. Any piece of soft iron is attracted by a magnet.

Inclination.— If a magnetic needle be arranged with its axis horizontal, the north end will dip downwards at an angle between 60° and 70°. This is termed the *dip* or *inclination*. At the magnetic
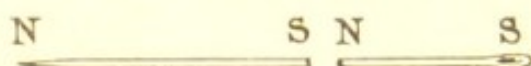
Fig. 160.—Effect of breaking a magnet.

north pole, which does not correspond with the geographical north pole, the dip is 90°; in other words, the needle stands vertical. At the magnetic equator it is horizontal; there is no dip. As we travel southward the *south* end of the needle dips downward.

These effects can be reproduced by passing a dipping needle along a bar magnet (Fig. 161). The earth thus behaves like a huge magnet. It must be observed that, strictly speaking, the end of the needle which points to the north is a south pole, but as this nomenclature would introduce endless confusion, it is always called the north pole, or, to be precise, the north-seeking pole.

Declination.—As the magnetic north pole does not correspond to the geographical north pole, the compass needle does not point due north, but some 16° to the west of the true north. This is called the *declination* of the compass, and varies from year to year. In 1660 the declination was 0° ; before that it was easterly. It attained a maximum westerly value about the year 1800, when it was 24° 6″ west ; since then it has been declining.

If a steel poker be held pointing in the direction indicated by the dipping needle and struck smartly two or three times with a hammer, it will be found
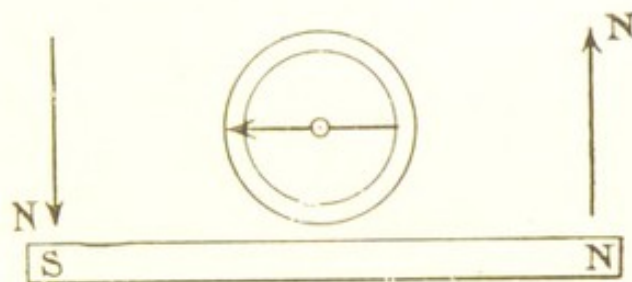
Fig. 161.—Magnet and dipping needle.

to be magnetic, the lower end being a north-seeking pole. The polarity can be reversed by reversing the poker and re-striking. This is due to the inductive action of the earth aided by the vibration produced by the blow. Steel ships, if built with their long axis in the magnetic meridian, become powerful magnets, and their effect on the compass needle has to be neutralised by placing pieces of iron or small magnets close to the binnacle.

The *horizontal component* of the magnetic force—*i.e.*, the force in the direction of the horizontal compass needle, or, as it is termed, the horizontal

intensity—at London is about ·18 dynes; the total force in the line of dip is about ·47 dynes.

The earth's magnetism is subject to changes, some annual, some diurnal, while some take place very slowly. Occasionally irregular disturbances are noted on delicate instruments; such disturbances are termed magnetic storms.

Magnetic Effects of Currents.—When a current of electricity is passed along a copper wire, it acquires the power of attracting iron filings, and becomes magnetic. If a small single cell be floated
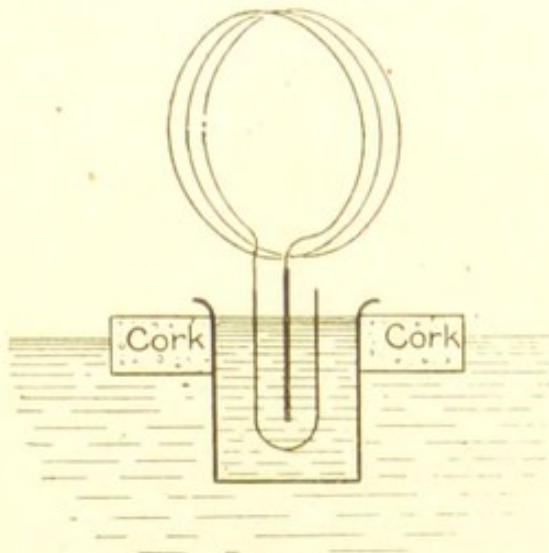
Fig. 162.—Floating cell as a magnet.
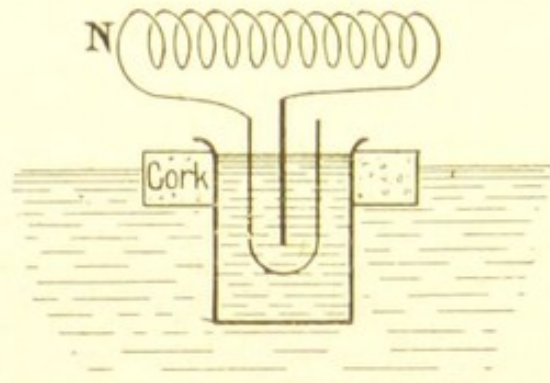
Fig. 163.—Floating cell with spiral acting as a compass needle.

in water and its poles connected by a hoop of insulated copper wire (Fig. 162) the cell behaves like a magnet and sets one side of the hoop to the north and the other to the south. If the north pole of a bar magnet be brought near the side of the hoop which faces the north, the little cell will be repelled and float away; then turning itself round, it rushes on the magnet with its south side foremost.

The magnetic properties of a copper wire carrying a current can be still better seen by a floating cell having its poles connected by a horizontal spiral of copper wire. This sets itself north and south, and behaves just like a compass needle (Fig. 163). The position of the poles, as regards the direction of the current, can be ascertained by the device of the little swimming elf (see p. 165). Thus, suppose we have a single hoop of wire : with the current passing in the direction of the arrow, and the little
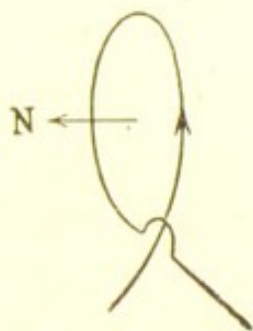
Fig. 164.—Relation between current and pole.
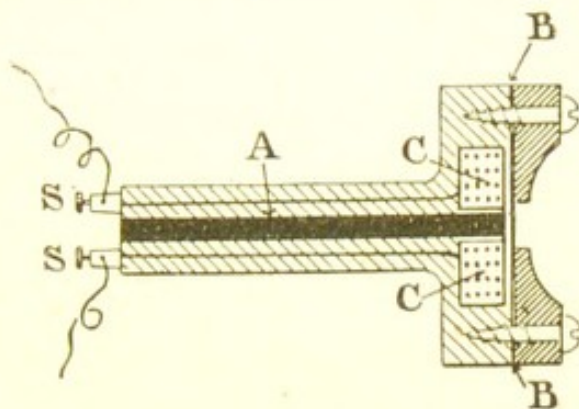
Fig. 165.—Graham-Bell telephone.

elf swimming along with the current with his face towards the centre of the circle, his left hand will indicate the north pole (Fig. 164).

As a battery and a coil of copper wire can thus so closely imitate a magnet, it is not surprising that a magnet can replace a battery and a coil of copper wire. If we take the secondary coil of a Du Bois-Reymond coil, getting rid altogether of the battery and primary coil, and cause the north pole of a magnet suddenly to approach near the coil, we shall have a secondary current excited in the

secondary coil. If now we suddenly remove the magnet, we get a second induced current in the opposite direction to the first, and so we can imitate the effect of making and breaking a current in the primary coil.

The same effect can be produced by making the magnet stationary and moving the coil of wire backwards and forwards through the magnetic field, or by causing the coil to rotate so that the wires cut the lines of force of the magnet; and thus we arrive at the principle of the **dynamo** so largely used at the present day for generating electricity. If we look at Fig. 156 it will be seen that the iron filings arrange themselves along the lines of force. Whenever a copper wire cuts these lines of force an electric current is started in the wire. The larger the number of lines cut in a given time and the more powerful the magnetic field, the stronger is the current produced.

These dynamos are reversible—*i.e.*, if instead of rotating the masses of copper wire in the magnetic field, and so producing a current, we pass a current into them, the current will cause the coil of copper wire to rotate.

The **Graham-Bell Telephone** (Fig. 165) is one of the most useful applications of these induced currents. A permanently magnetised steel rod A is placed in a wooden case. At one end of the magnet is a coil of insulated copper wire, the two ends of which are brought through the wooden case to the two binding screws s and s'. Close to the end

of the magnet is firmly clamped a circular iron plate B. If this plate be suddenly moved backwards and forwards, induced currents are set up in the coil of wire, which currents pass down the wires and, if connected with a second similar telephone, produce corresponding movements of its iron disc. The reproduction is so perfect that if words be spoken to the first telephone they will be audibly reproduced by the vibrations of the plate of the second telephone. The currents so generated can be demonstrated by the aid of the capillary electrometer.
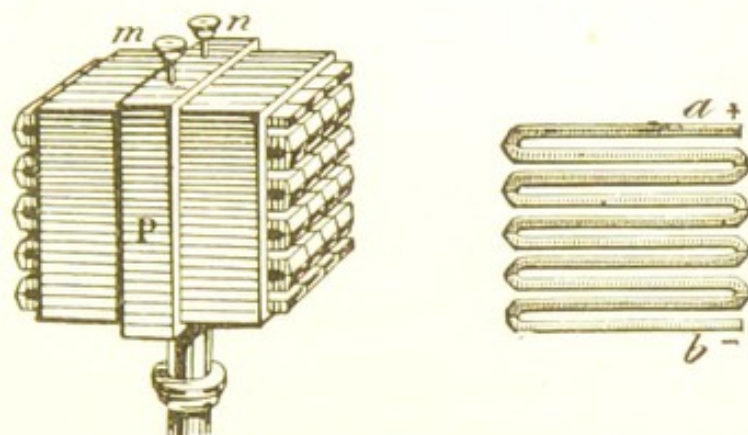
Fig. 165*a.*—Thermopile.

Thermal Effects.—When a current passes through a resistance, part of the electricity is converted into heat. Thus in the ordinary incandescent electric lamp the current passes in by two platinum wires fused into the glass bulb, through the delicate carbon filament of high resistance, which, owing to its resistance, becomes white hot, giving out light and heat.

The heat in calories produced by a current of C ampères flowing for t seconds through a resistance of

$$R \text{ ohms} = \frac{C^2 R t}{4 \cdot 2}.$$

If a bar of antimony A be joined to a bar of bismuth B at one end, and the two free ends be connected with a galvanometer, then when the junction is warmed, a current will be set up, flowing from the antimony to the bismuth, through the galvanometer. If a number of such couples be connected with a galvanometer we have a delicate indicator of temperature, the **thermopile** (Fig. 165*a*). A similar arrangement can be used, instead of a battery, to produce a current.

Capillary Electrometer (Fig. 166).—This instrument was originally suggested by Lippmann. A piece of small glass tubing is thoroughly cleansed with 10 per cent. sulphuric acid, washed out, and dried. It is then drawn out into a very fine capillary tube A; the bore should be so small that it will stand a pressure of a metre of mercury without leaking, and yet be pervious. This is filled with mercury and connected with a bottle of mercury B, which can be elevated so as to force the mercury into the capillary. The capillary dips into a thin-walled glass tube C containing 10 per cent. sulphuric acid and some mercury; two platinum wires P and P', fused into the glass, establish contact with the two masses of mercury. The capillary tube is so placed that it lies close to the thin wall of the glass tube, so that it can be viewed by a microscope; it presents the appearance seen in Fig. 166, D.

The capillary electrometer is an indicator of potential, not of current. If P and P' are connected with the apex and base of a frog's heart, the mercury

meniscus is seen to move with the electrical variation which takes place with each beat of the heart. If P is positive the mercury moves towards the point ; if P is negative the motion is away from the point. For certain purposes, especially in physiology, this
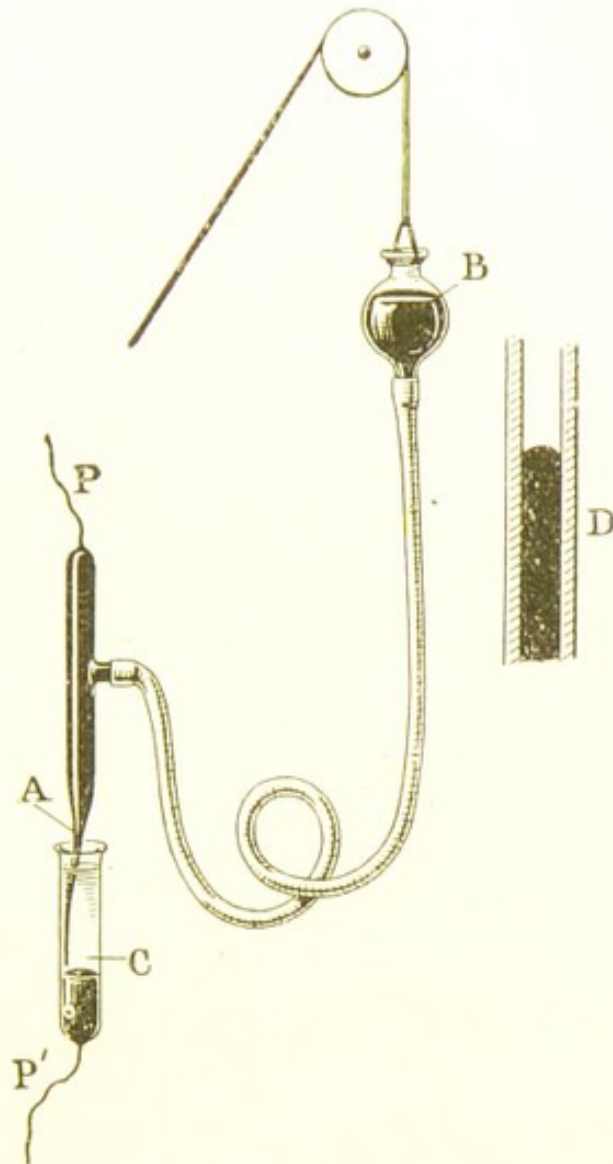
Fig. 166.—Lippmann's capillary electrometer.

instrument is invaluable ; its movements are instantaneous, and there is no back-swing. By its aid the currents developed by the voice when speaking to the telephone can be easily demonstrated, and the

movements of the mercury meniscus can be photographed. When not in use it is most important to keep the wires P and P′ in metallic connection so that the instrument is short-circuited. The cause of the movement is that the surface tension between the mercury and the sulphuric acid is altered when there is a difference of potential between P and P′.

As we have seen (p. 158), the resistance R is measured in ohms, and according to Ohm's law $C = \dfrac{E}{R}$. Where C is the current in ampères, E the potential in volts, the equation can be written $R = \dfrac{E}{C}$, so that the resistance can be measured in volts per ampère. Sometimes the reciprocal of the ohm, $\dfrac{1}{R}$, is used, and is called the conductivity or **conductance,** and is measured in ampères per volt or *mhos* (*mho* is *ohm* spelt backwards). Thus a 20-candle electric lamp may take 0·7 ampère, the supply of electricity being at an electrical pressure of 100 volts. The resistance is $\dfrac{100}{0·7}$, = 143 ohms, and its conductance $\dfrac{1}{143}$ mhos.

The specific resistance, or **resistivity,** is the resistance offered by 1 cm. of a conductor whose cross section is 1 sq. cm., so that the resistance of a conductor $R = \dfrac{\rho l}{a}$, where ρ = resistivity, l = length in centimetres, and a the area of cross section.

Resistivity of various substances at 0° :—

Silver	$1\cdot47 \times 10^{-6}$
Copper	$1\cdot56 \times 10^{-6}$
Aluminium	$2\cdot66 \times 10^{-6}$
Pure Water	$25\cdot00 \times 10^{+6}$
Platinum	$10\cdot92 \times 10^{-6}$
German Silver	$20\cdot00 \times 10^{-6}$
Mercury	$94\cdot07 \times 10^{-6}$
Mica	$1\cdot00 \times 10^{+14}$

It is this enormous difference between conductors like copper and non-conductors like mica that enables us to guide electricity along any path we choose.

Thus Lehfeldt states that a current would rather travel right round the earth by a copper wire about $\frac{1}{50}$ in. in diameter than pass through a thin piece of mica.
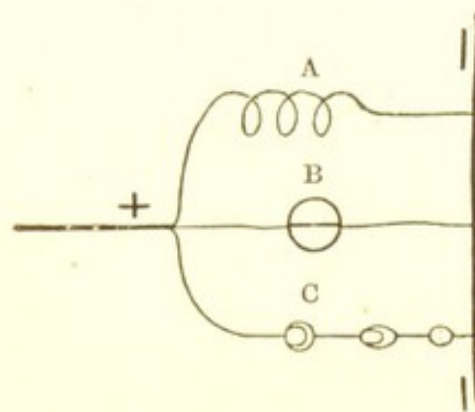
When a current passes through several resistances

Fig. 167.—Divided current.

in *series*, it is evident that the total resistance is the *sum* of the resistances. Thus if a current passes through a lamp with resistance A, a heating stove with resistance B, and a second lamp with resistance C, the total resistance would be A + B + C.

Conductors in Parallel Circuit.—If a current passes through a number of conductors in parallel circuit, the relative current strengths in the branches will be inversely proportional to their resistance, but directly proportional to their conductance. Thus if A B C (Fig. 167) be the resistance of the three

N

branches, the total resistance will be $\dfrac{1}{\dfrac{1}{A} + \dfrac{1}{B} + \dfrac{1}{C}}$

and the total conductance $\dfrac{1}{A + B + C}$.

This principle comes into daily use in determining the resistance and conductance in the domestic use of electricity. The lights, stoves, etc., are usually placed in parallel circuit—*i.e.*, crossing from the positive wire of the supply to the main wire connected with the negative end. Suppose we have a supply at 200 volts, and we have 20 lamps of 200 ohms each, a cooker of 30 ohms and one larger lamp of 40 ohms, coupled in parallel circuit. The conductivities are 20 at $\dfrac{1}{200} = \cdot1$ mho; the large lamp $\dfrac{1}{40}$ $= \cdot025$; the cooker $\dfrac{1}{30} = \cdot033$; the total mhos $= \cdot1 + \cdot025 + \cdot033 = \cdot158$ mho, and resistance $=$ $\dfrac{1}{0\cdot158} = 6\cdot33$ ohms; the current flowing through when all lights were connected would be $\dfrac{200}{6\cdot33}$ $= 31\cdot5$ ampères.

Board of Trade Unit.—This unit of energy, for which in London no greater charge than eightpence can be demanded—the usual charge varies from 2d. to 6d.—equals 3,600,000 joules or 1,000 watt hours, or $1\frac{1}{3}$ horse-power, or 2,653,800 foot-pounds.

A joule = the work done per second when a current of 1 ampère flows through a circuit between

the terminals of which a potential difference of 1 volt is maintained, and, roughly = ·737 foot-pounds.

So if A = current in ampères,

V = potential in volts,

S = number of seconds,

J = A V S.

A pressure of 110 volts is maintained between the electric light mains of a house, and twenty glow lamps in parallel circuit, each taking a current of 0·3 ampères, are turned on for five hours each night for twenty nights. Find the energy in joules.

20 × 0·3 × 110 × 5 × 3,600 × 20 = 237·6 million joules.

Find the cost per hour of a 16-candle lamp which takes 2·5 watts per candle, the price of the Board of Trade unit being 6d.

$\dfrac{2\cdot5}{1000}$ × 16 × 6 = ·24 of a penny or about one farthing.

Part IV.

SOUND.

Origin of Sound.—If a pistol is fired, the heated gases liberated by the explosion compress the particles of air in their immediate neighbourhood. These in their turn squeeze those further away, and so a pulse or wave of alternate compressions and rarefactions is set up in the air, which, eventually reaching the ear of a bystander, shakes his tympanum. The vibration is transmitted by nerves to his brain, and he hears the explosion. The sounds that we usually hear are thus caused by waves set up in the air.

It is important to distinguish the *motion of the particles of the air* from the *motion of the wave* itself. Each individual particle moves but a short distance to and fro in the line of motion, but the wave may traverse a distance of many yards. We can see a similar phenomenon if we watch a gust of wind passing over a field of corn. Each ear of corn moves backwards and forwards perhaps but an inch or two,

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but the wave passes from one end of the field to the other.

Sound and Vibration.—Sound is due to vibration, usually of elastic solid bodies. For instance, when a tuning fork is struck (Fig. 168), each arm begins to vibrate transversely, swinging first to a, then back to a', and so on until the motion gradually ceases. As A swings to a it compresses the particles of air in its neighbourhood, and squeezes them together; they pass on the pressure, and themselves swing back and become more widely separated than they were in their normal state. This can be best seen from the next diagram (Fig. 169), representing the successive positions of particles of air as a sound wave passes. There are nine particles of air a to i represented at rest in the top line. In phase 1, a sound wave strikes particle a and pushes it towards b. In phase 2, b is pushed towards c, a continuing its forward movement. In phase 3, a is swinging back, but b swings on, and c has moved towards d; and so the compression passes, marked by the black particles, until in the eighth second it has reached the last three particles g, h, and i, while a has just finished one complete vibration forwards and backwards and returned to its normal position. Particles at the normal distance from each other are lightly shaded; those squeezed
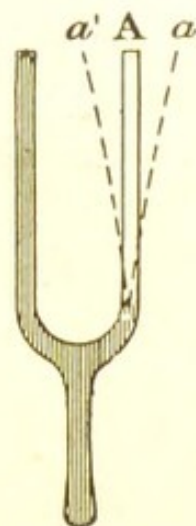
Fig. 168.—Tuning fork vibrating.

together are black ; and those which are further apart than usual are left unshaded.

Motion of Sound Waves.—The sound waves spread out in circles, just as a ripple spreads out in a pond when its surface is disturbed by a stone being
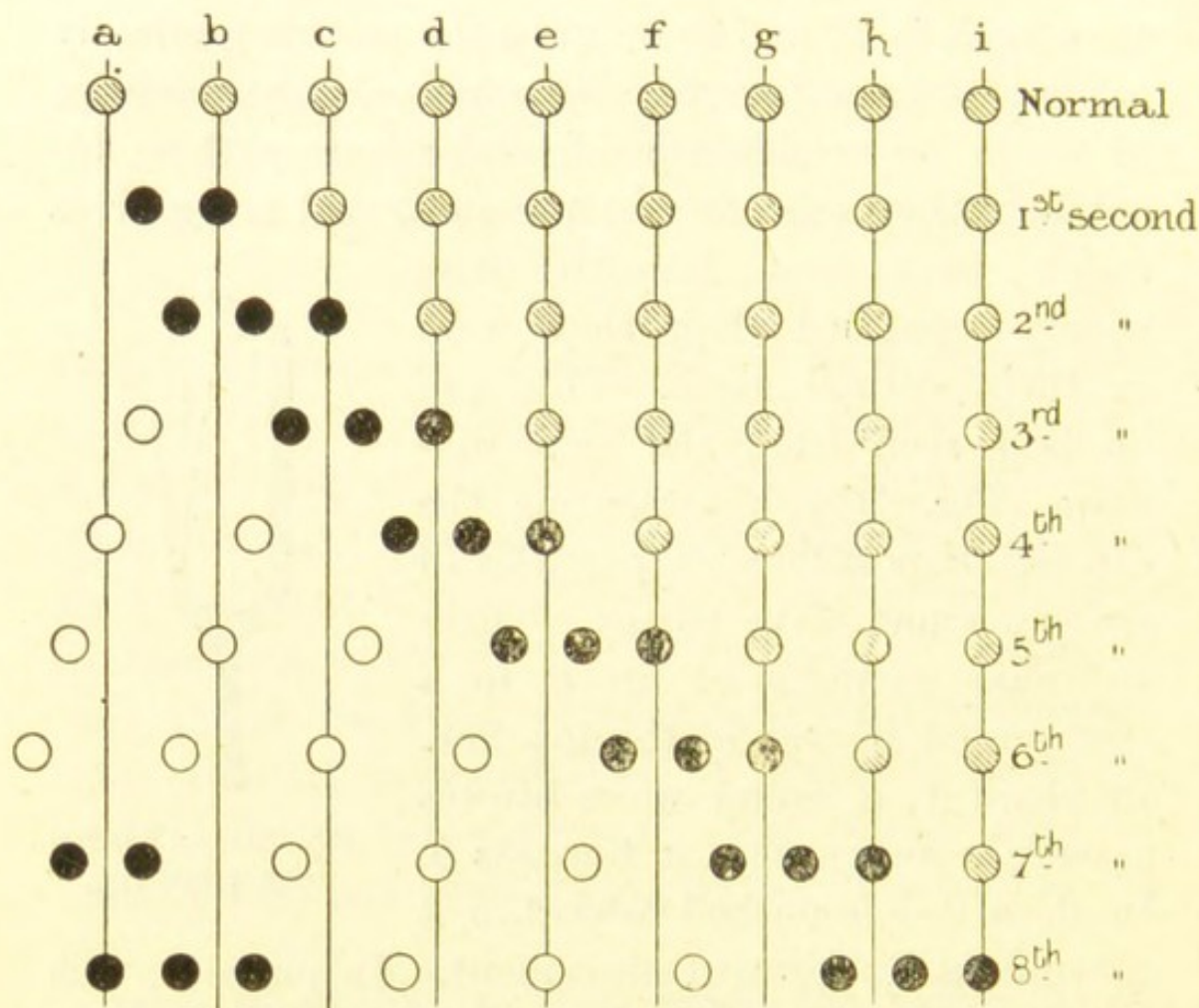
Fig. 169.—Successive phases of particles of air during passage of a sound wave.

thrown in, except that the vibrations of the individual particles of the sound wave move in the same direction as that in which the wave progresses, whereas the particles of water move up and down at right angles to the direction of the wave, the sound

wave producing alternate circles of compression and rarefaction as seen in Fig. 170.

If the sound waves be confined by a smooth tube, as in a speaking tube, the distance at which the sound is audible is greatly increased. Sound, like light, can be reflected from plane and focussed by curved surfaces.
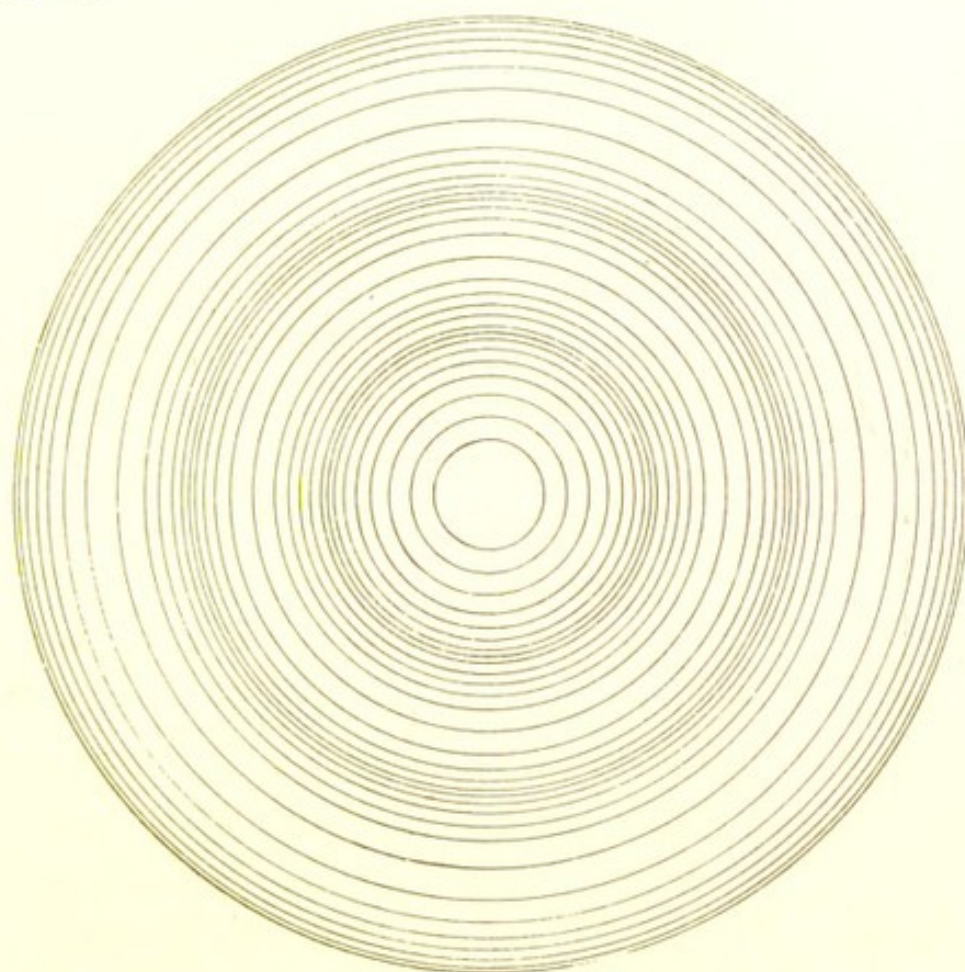
Fig. 170.—Passage of sound wave through air.

Amplitude and Pitch.—The extreme horizontal distance travelled by the particle *a* (Fig. 169) during a complete vibration is called the *amplitude* (Fig. 172) of its vibration. The number of vibrations performed in a given time—*e.g.*, a second—is called the *rate of vibration.* The *pitch* of a note—*i.e.*, whether

it is high or low—depends on the rate of vibration : the greater the number of vibrations in a second the higher is the note. The *loudness* of a note depends on the *amplitude* of the vibrations, the intensity varying as the square of the amplitude. The wave length is the distance of any one particle to the next in the same phase as itself.

Wave motion can be studied by a long piece of india-rubber tube or rope. If one end be fixed and a sudden shake be given to the free end, a hump will be raised on the rope, which will travel to the fixed end and back again. By timing the shakes a second hump may be raised to meet the returning hump in the middle, and the rope can be maintained with two vibrating segments and a comparatively motionless point in the middle (Fig. 171). This stationary point is called a *node*. A string may vibrate as a whole, or it may split up into a number of vibrating seg-

Fig. 171.—String vibrating with one node.

ments and nodes. In Fig. 172 *a* to *b* is the wave length, *a* to *c* is the amplitude. If we halve a string it vibrates twice as fast as the original string, and we get the higher octave of the fundamental note. This vibration of 2 : 1—*i.e.*, when two notes are simultaneously vibrating one twice as fast as the other—is very agreeable to the ear. The interval of a 5th consists of two notes whose vibration rates

are as $3:2$; of a 4th, $4:3$; and of a 3rd, $5:4$. In fact, the simpler the ratio the more pleasant is the combined effect on the ear.

The ratios of the vibration rate of the notes in the scale are :—

1st	2nd	3rd	4th	5th	6th	7th	8th
doh	*ray*	*me*	*fah*	*sol*	*la*	*te*	*doh*
1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	$\frac{2}{1}$

If the 1st vibrates 100 times a second, the 5th will vibrate $100 \times \frac{3}{2} = 150$ times a second.
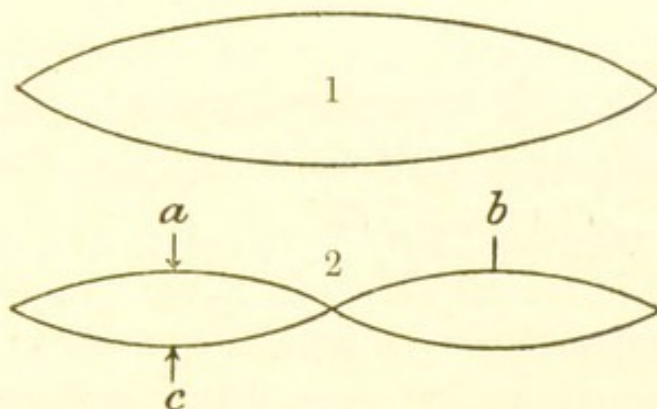
Fig. 172.—1. String vibrating as a whole. 2. When damped in the middle, giving the upper octave.

Air and Sound.—Air is necessary for the transmission of ordinary sound. This can be shown by allowing a clock to strike in the receiver of an air-pump, the clock being placed on a soft cushion to prevent the sound being transmitted through the air-pump plate. If the pump be exhausted, the sound becomes very feeble, and if the receiver be filled with hydrogen and the receiver again exhausted, the sound is almost inaudible.

Velocity of Sound.—Sound travels through the air at the rate of 1,120 feet per second at the

temperature of 15° C., at 0° 1,090 ft. (330·6 metres), at 27° 1,140 ft., the velocity increasing about 2 ft. per second for each degree Centigrade.

Velocity of sound in various media in feet per second :—

Water at 15° C. . . .	4,710
Lead at 20° C. . . .	4,030
Iron . . , . .	16,828
Steel	15,470
Wood along the fibre —	
Fir	15,218
Pine	10,900
Oak	12,622

The formula giving the relation between the velocity of sound and the density and elasticity of a medium is : V varies as $\sqrt{\dfrac{E}{D}}$, so that in a gas, as long as the temperature remains constant, alterations in the pressure make very little difference, as by Boyle's law the elasticity varies with the density.

When a sound wave passes through the air, where the air is compressed the temperature is raised, and is lowered where there is rarefaction. This adds to the elasticity, and increases the velocity through the air about one-sixth, so that if it were not for these changes of temperature the velocity of sound in air would be about 900 ft. per second.

The velocity of sound in air can be determined by observing the time which elapses between the flash and report of a gun, after carefully measuring the distance between the gun and the observer. Neither the amplitude nor the rate of vibration makes any

difference in the velocity of sound. This is obvious to anyone listening to a band at a distance : the sound from the shrill piccolo arrives at the same instant as the deep notes of a bassoon.

If the ear be placed at one end of a long iron rail or pipe, which is struck at some distant point with a hammer, two sounds will reach the ear, the first travelling through the iron, the second through the air. The great conductivity of wood for sound is taken advantage of in the ordinary stethoscope.

Knowing the velocity of sound in air, the distance of an explosion or signal, gun, etc., if the flash can be seen, can be readily calculated. Thus, if a clap of thunder is heard $4 \cdot 8$ seconds after the flash of lightning is seen (as the velocity of light is so enormous, the time that *it* takes to travel any terrestrial distance may be neglected), the distance of the flash is $1,120 \times 4 \cdot 8 = 5,376$ ft., or a little over a mile. Again, if you stand in front of a cliff, or when at sea in front of an iceberg, and shout, if you hear the reflected sound or echo in 6 seconds, as the sound has travelled to the cliff *and back*, the distance of the cliff is $\dfrac{1,120 \times 6}{2} = 3,360$ ft.

Vibration Rate of Tuning Forks.—The rate of vibration of a tuning fork can be easily ascertained by attaching to one of its limbs a thin piece of metal or card and causing it to write on a smoked surface revolving at a uniform and known rate. Suppose we have a surface of smoked paper stretched round a cylinder and rotating so that the surface moves

at the rate of 20 in. per second : after making a tracing (Fig. 173) we count the number of waves, measuring from crest to crest, say in 5 in., and we find there are 25 vibrations ; in 20 in. there will therefore be 100, and the rate of vibration is 100 per second.

Wave Length.—This can be determined by dividing the velocity of sound per second by the number of vibrations per second. In the above case the
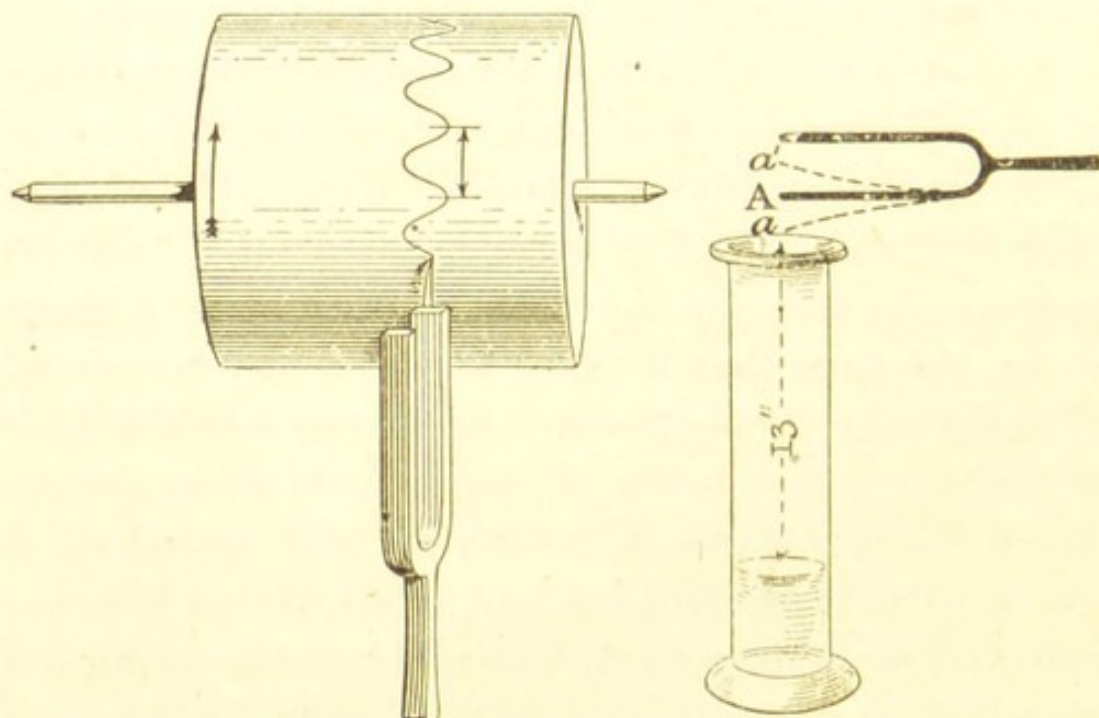
Fig. 173.—Tracing of tuning fork.   Fig. 174.—Resonating jar.

sound wave, starting from the fork, will have traversed 1,120 ft. in the second, and during this time will have made 100 complete vibrations, so that the wave length of each will be $\dfrac{1,120}{100} = 11 \cdot 2$ ft.

Resonance.—If a tuning fork, after being struck, be held in the fingers, the sound is feeble, but if the stem be held firmly on a table the sound is at once

strengthened. The explanation is simple: the table is thrown into vibration, and having a much larger surface than the limbs of the fork, a much larger volume of air is set in vibration.

If a tuning fork be struck and held over a deep glass jar, and the jar be filled up slowly with water, a point will be reached when the sound of the fork will swell out and become very much louder. The air in the jar is, in fact, vibrating in unison with the fork, forming a kind of extempore organ pipe (Fig. 174).

If we take a fork which vibrates 256 times a second, and whose wave length is therefore $\dfrac{1,120}{256} = 52$ in., and determine the conditions under which the above reinforcement of the note takes place, we shall find the distance from the surface of the water to the top of the jar to be 13 in., or one quarter of the wave length. The prong A swings to a (Fig. 174) and compresses the air in the jar, starting a sound wave, which proceeds to the surface of the water and back again (a distance of 26 in.), just as the prong is starting to swing back to a', so the two vibrations keep time. Similarly the rarefaction produced by A in moving to a' will pass to the surface of the water and back again, just as the prong is beginning to return from a' to a, the vibrations of the air thus reinforcing those of the fork. This furnishes a simple method of finding the wave length of a note by multiplying the resonating length by 4; on dividing this into the velocity of sound we get the number of vibrations

per second. A small correction for the width of the jar should be made. The simplest plan is to add three-fifths of the diameter to the length.

Range of Audibility.—The extreme range of audibility is from 16 vibrations a second to 48,000 a second. For musical purposes the range is from 32 to 6,000. The C′, the middle C of a soprano, is about 512. In the time of Handel it was 507. The C′ on the Albert Hall organ is 541, so that our B is about the same pitch as Handel's C.

Noise is due to tumultuous vibrations whose rates have no simple ratio to each other. A musical note depends on regular and rhythmical vibrations, a definite number of impulses striking the ear at regular intervals. How these vibrations are produced is immaterial. They may be a series of taps, as when a card is held against a revolving cog-wheel; or a series of puffs, as in the siren; or the vibrations of strings, the air in pipes, etc.

Quality of a Note.— Besides differing in pitch and in intensity, a note may vary in quality or *timbre*. Thus a note of exactly the same pitch and loudness may be sounded on a flute, on a piano, and on a violin, but an educated ear has no difficulty in distinguishing the notes by their various qualities. The explanation of this difference in quality is to be found in the fact that hardly any note consists exclusively of one set of vibrations—*i.e.*, it is not pure. This can be demonstrated by pressing down the *forte* pedal of a piano, which will raise the dampers from the strings, and then inducing someone with a

powerful baritone voice to sing his top C into the piano ; the C string, in unison, will be heard vibrating, but in addition there will be heard the C an octave above, and the fifth—*i.e.*, the G—above ; so that the note sung was a mixture of the vibrations of all these, and several others more difficult to hear, with the fundamental note.   Helmholtz has shown
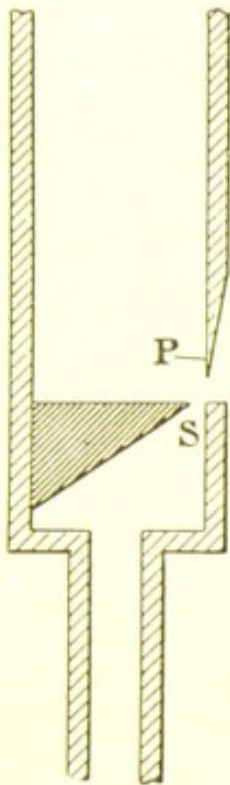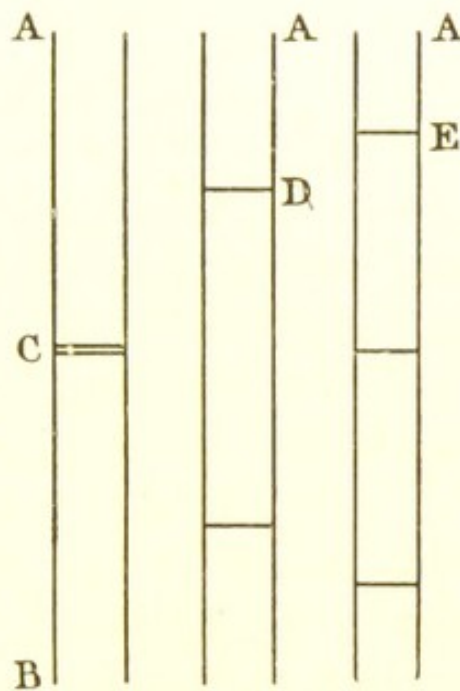
Fig. 175.—Organ pipe.   Fig. 176.—Overtones in organ pipe.

that any desired quality can be produced by mixing suitable overtones of suitable strengths with the fundamental note.

A pure tone is rather dull and sombre—the open diapason pipe in an organ is an example—but when suitable overtones, called on the organ " mixtures," are simultaneously sounded, the total effect is bright and pleasant.

In an open organ pipe (Fig. 175) the wind is projected from a fine slit s against a sharp edge of wood P, producing a flutter of immature sounds. The pipe selects the one to which its column of air can resonate and raises it to the dignity of a musical note. If the pipe be overblown it gives overtones. When sounding its fundamental note an open organ pipe has a node in the middle. The first overtone is produced when the pipe has two nodes (Fig. 176), and the next when it has three. A D is $\frac{1}{4}$, A E $\frac{1}{6}$ of A B.

If an open pipe were cut in half at c and the ends at c were closed, two pipes closed at one end would be produced, each of which would give a note of the same pitch as the open pipe A B. So with a piano string, the first overtone forms a node in the centre, and is therefore an octave above the fundamental note; the second has two nodes, and is a fifth above the last.

When any point on a string is struck or plucked, all the overtones which require that point for a node disappear. The hammers of a piano are so arranged that they strike the string at a point where the production of the most harmonious overtones is encouraged, while those which are discordant are not formed. The production of notes of pleasing quality in singing depends largely on so shaping the mouth, etc., that those overtones which combine harmoniously find suitable resonating cavities.

In a bar or rod the fundamental note is sounded when it vibrates with two nodes. The first overtone

has three nodes. In the tuning fork, as the bar of
steel is bent, the nodes approach until they are close
together (Fig. 177).
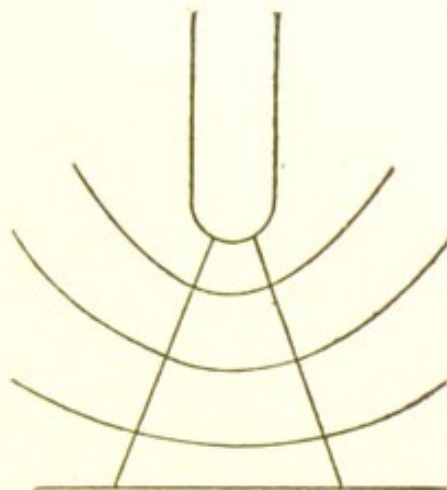
Fig. 177.—Nodes in bar and tuning fork.

O

Part V.

LIGHT.

CHAPTER I.

Light a Vibration.—Light, like heat, is a *form of motion*, and, like sound, it is a *vibration*; but the vibrations are enormously rapid as compared with those of sound. Moreover, the light wave is not transmitted by particles of air, but by the highly elastic, imponderable, all-pervading medium which we call the ether. The vibrations in a light wave are across the line of propagation of the wave, and not lengthwise, as in sound. Light is now known to consist of *electro-magnetic waves*.

If we pass a weak current of electricity through a thin platinum wire in a dark room, the sensory nerves, which are first affected, pronounce it to be hot. But nothing can be seen. If the current be increased, the temperature of the wire rises, and when it is about 500° C. we begin to see it as a dull-red wire. The waves emitted by the wire have become intense

and rapid enough to affect the retina. If the current be still further increased the wire becomes brilliantly white hot.

Rate of Vibration.—As we have seen, if the rapidity of sound-vibration be increased, the " pitch " of the note rises. In light a change in the rapidity of vibration produces *change of colour*. Thus the slowest vibration rate which affects the retina is that of red light, being 400,000,000,000,000 times a second (4.0×10^{14}) ; the quickest vibration rate which is visible is that due to violet light, 760,000,000,000,000 (7.6×10^{14}). Vibrations above and below these extreme rates are not visible.

It will be noted that the range of vibrations—*i.e.*, the " compass of the eye "—is small, less than one octave, compared with the " compass of the ear," which extends to seven octaves.

The **velocity of light** is enormous—about 186,000 miles, or 2.999×10^{10} centimetres, per second.

Bodies, as glass, water, etc., which allow light to pass through freely, and through which we can distinguish objects clearly, are termed *transparent ;* bodies such as tracing paper and ground glass, which allow light to pass, but which do not allow objects to be clearly distinguished, are called *translucent ;* and substances like steel, slate, marble, etc., which stop all light, are termed *opaque.*

Light travels through homogeneous media in straight lines.

A collection of rays is called a pencil (Fig. 178). It may be *parallel*, A, *divergent*, B, or *convergent*, C.

Umbra and Penumbra.—As light proceeds
through the air in straight lines, a luminous *point*
casts a black shadow, the *umbra*, R (Fig. 179). If,
however, the luminous body be of an appreciable
size, a half shadow or *penumbra* surrounds the umbra
P (Fig. 179). Thus the space C D is completely
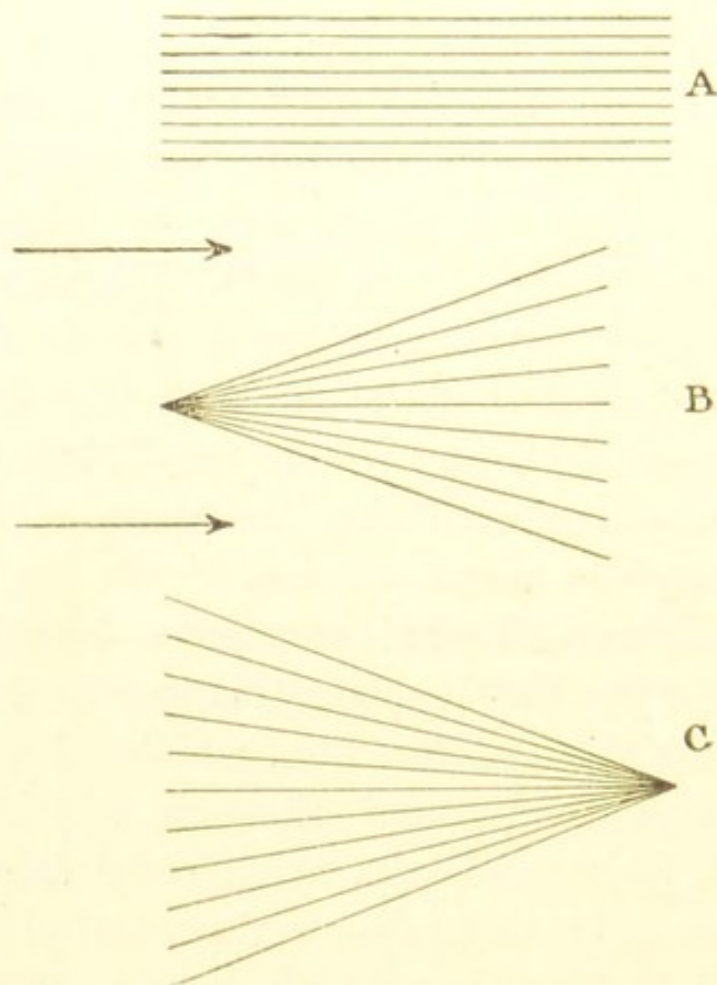
Fig. 178.—Pencils of rays.

shaded, receiving no light from either the edge A or
the edge B, while C E is in half shadow, receiving no
light from B, and D F is similarly situated as regards A.

Law of Inverse Squares.—The intensity of light
varies inversely as the square of the distance between
the source of light and the object. This can be

proved by taking two square pieces of paper of the same size and folding one of the pieces in four. If this be placed 1 ft. from a small source of light, and the other be supported at a distance of 2 ft., the shadow of the folded piece of paper will just cover the other, which has four times as large a surface. In other words, the light falling on an object at a
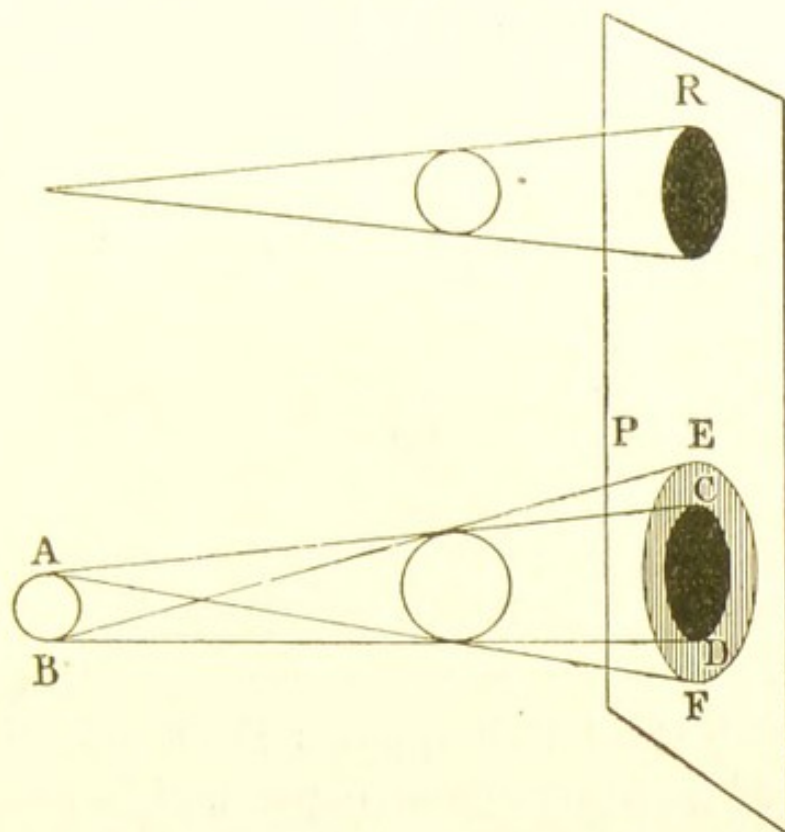
Fig. 179.—Umbra and penumbra.

distance of 1 ft., is at 2 ft. spread over four times as much space, so that each square inch has only one-fourth of the light (Fig. 180). This is usually known as the law of inverse squares.

Photometers.—Most photometers are based on this law of inverse squares.

The *shadow photometer* consists of an upright rod, two shadows from which are cast by the two lights

under comparison, say a candle and a gas flame.
The gas flame is placed at a fixed distance, say 4 ft.,
from the rod, and the candle is moved backwards and
forwards until the two shadows are of equal black-
ness. Suppose the distance to be 1 ft., then the
relative intensities of the gas and the candle are as
$4^2 : 1^2 = 16 : 1$.

Bunsen's Grease-spot Photometer.—A small piece
of wax is melted by a hot iron into the centre of a
piece of ordinary white paper; the grease fills up
the pores and renders the paper translucent if the
paper is held between the light and the observer;
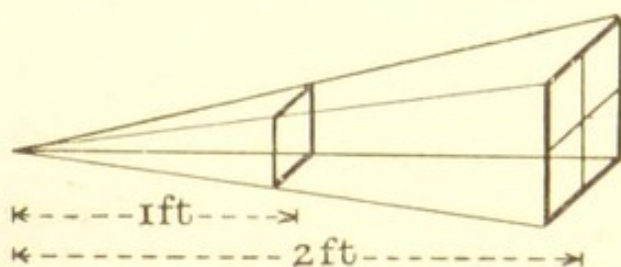
Fig. 180.—Intensity varying as the square of the distance.

but if the observer stand between the light and the
grease spot the latter appears black and the paper
white. If such a piece of paper with a grease spot,
called the *photometer disc*, be moved backwards and
forwards between two sources of light, say a candle
and a lamp, when an equal amount of light falls on
each side of the disc the grease spot will vanish. If
the distances of the respective lights from the disc
be then measured and squared, the numbers will
give their relative illuminating powers—*e.g.*, if from
the disc to the candle the distance be 1 ft., and that
to the lamp be 3 ft., the illuminating power of the
lamp : candle : : 9 : 1.

Reflection.—If a beam of sunlight falls on a looking-glass it is reflected. The reflected ray obeys two laws :

1. *The incident and reflected rays are in the same plane.*
2. *The angles which the incident and reflected rays make with the normal are equal.*

Thus if A B (Fig. 181) be a ray incident on the reflecting surface C D, the reflected ray B E makes with the normal N B an angle E B N equal to the angle A B N.
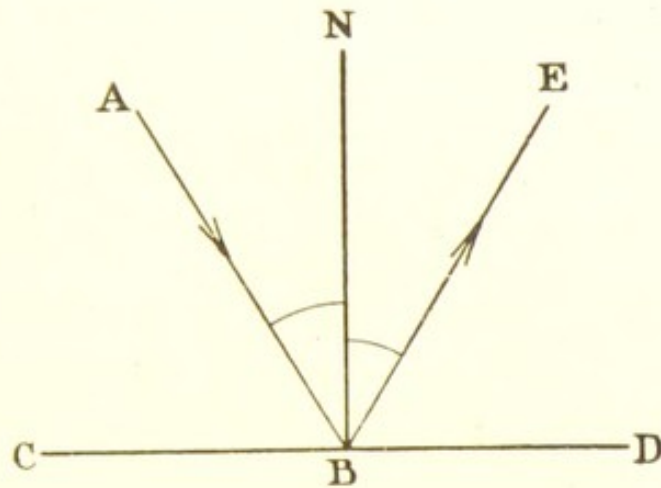
Fig. 181.—Angles of incidence and reflection equal.

This can be proved with the aid of some pins and a piece of looking-glass. Place a pin at s (Figs. 182 and 183). When looked at from a pin at T, s will appear to be in the direction T A. Place a pin at A so that the pins s, A, T appear all in the same line, draw the line C D, and remove the mirror ; join s A and T A, and draw the normal A K ; from centre A describe the circle ; then s K = K T.

Formation of an Image by Reflection.—The image of a reflected object, as seen by the eye, is a

virtual image—*i.e.*, it cannot be thrown on a screen. Thus rays from an arrow A B (Fig. 184) are reflected from the looking-glass C D, and enter the eye in the
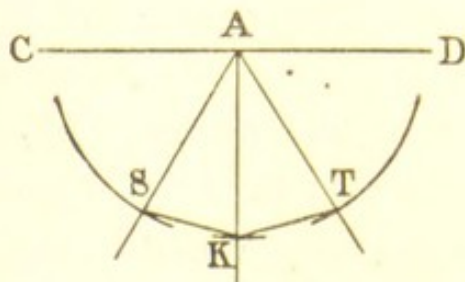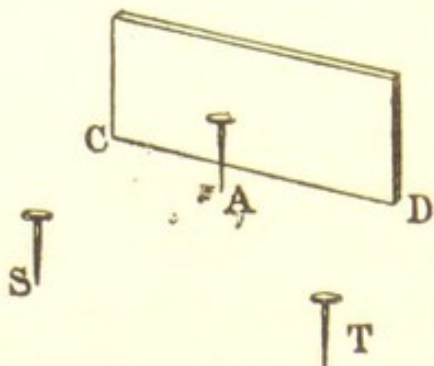
Fig. 182.—Law of reflection.   Fig. 183.—Law of reflection.

direction A' E, B' E, and appear to be in those directions. Produce E A', E B', and draw normals at A and B. The image of the arrow will be formed where
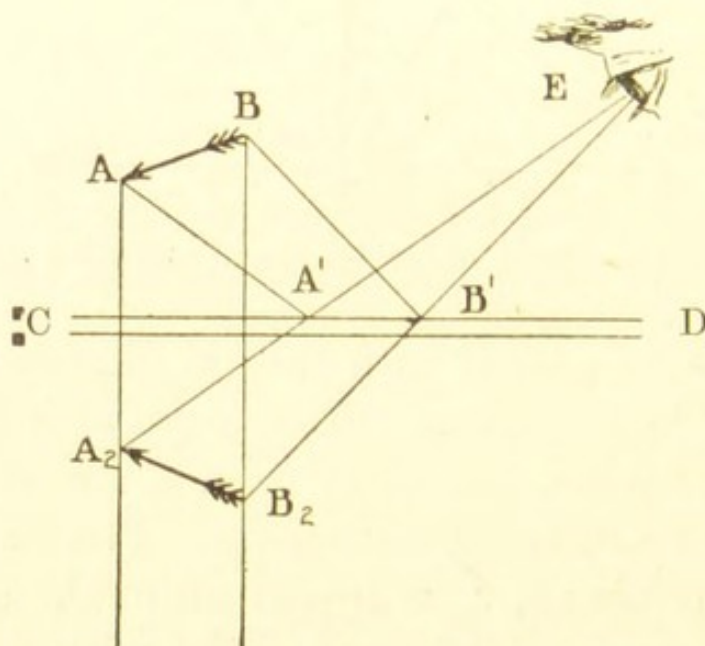
Fig. 184.—Image formed by reflection.

these normals cut the lines produced, E A', E B'—*viz.*, at A₂, B₂, and the image will appear to be just as far behind the mirror as the object is in front. This

can be amusingly demonstrated by giving a monkey a looking-glass and watching him feeling for the virtual image of himself behind the glass.

Two reflections are given by a looking-glass—one from the front surface of the glass and one from the silvered surface at the back.

If two mirrors be inclined at an angle of 60°, we get a series of reflections. Let M C and M B (Fig. 185) be
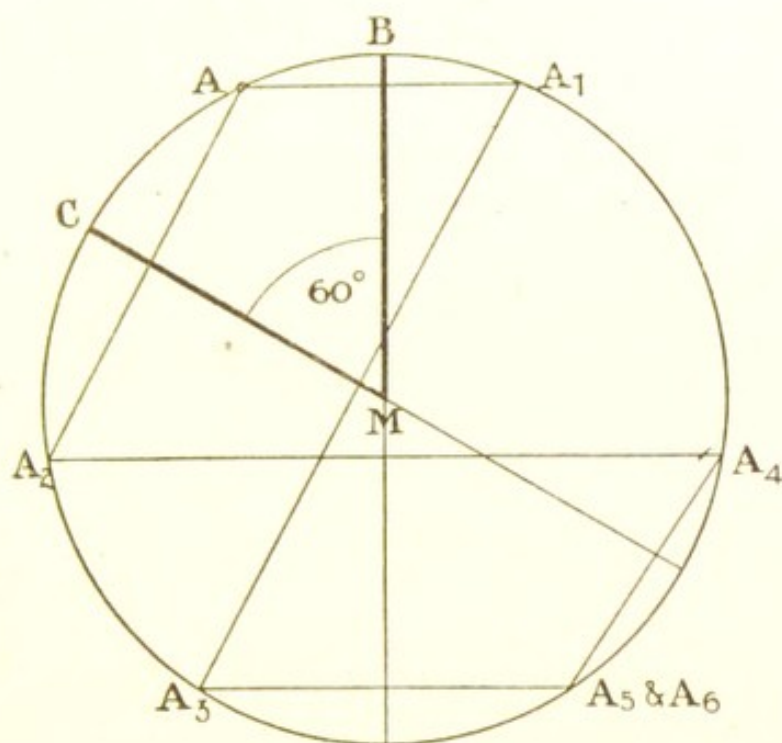
Fig. 185.—Principle of the kaleidoscope.

the two mirrors and A a luminous point. From the centre M describe a circle through A. The first image in the mirror M B will be at A_1, and an image of A_1 will be formed by reflection from M C at A_3, and this in its turn will form one at A_5. Now let us follow the course of a ray reflected first from M C. This will form an image at A_2; its second is A_4, and its third A_6, which coincides with A_5, the third image

from the other mirror. So that any further reflections will coincide with images already formed, and we shall see the object and five images (the *number* of images can be found by dividing 360 by the angle between the mirrors and then subtracting one) arranged more or less symmetrically, and forming a pattern. This is the principle of the familiar *kaleidoscope.*

If the mirrors are parallel, the object and images are reflected backwards and forwards until they
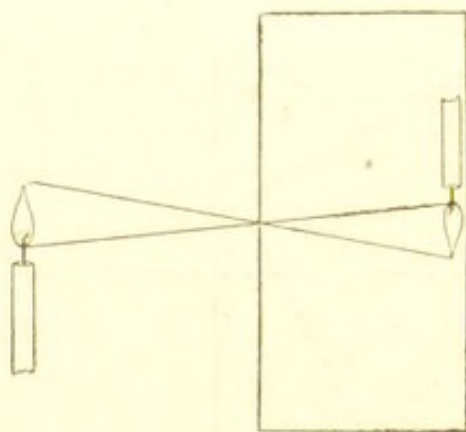
Fig. 186.—Image formed by pin-hole.

become too faint to be seen. This is known as the *endless gallery.*

Formation of Images by a Small Hole: Pin=hole Camera.—If, in a room with one window, the window be covered with an opaque screen in which a small pin-hole is made, a picture of the objects outside will appear on the wall opposite the pin-hole (Fig. 186). This image is real and inverted, and, in fact, photographs have been taken in this way without any lens. If a screen be held near the pin-hole,

the picture will become smaller and brighter. The
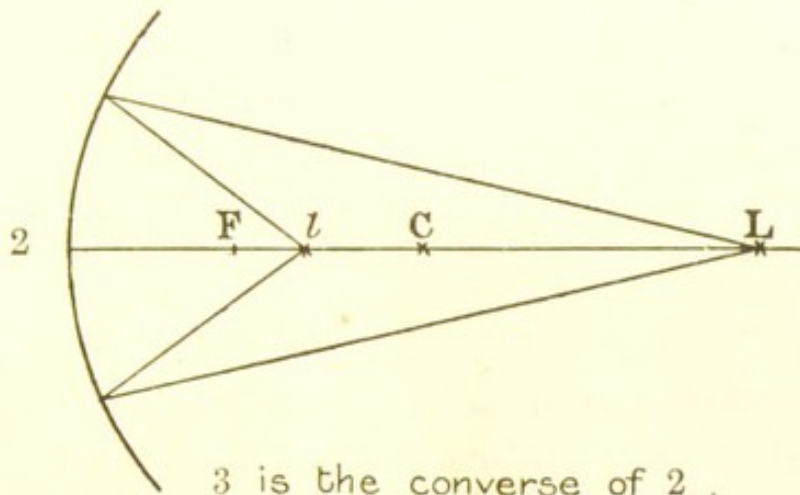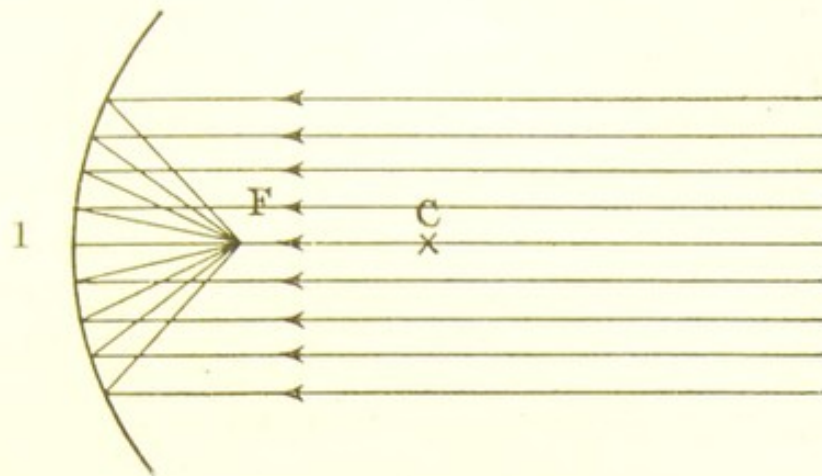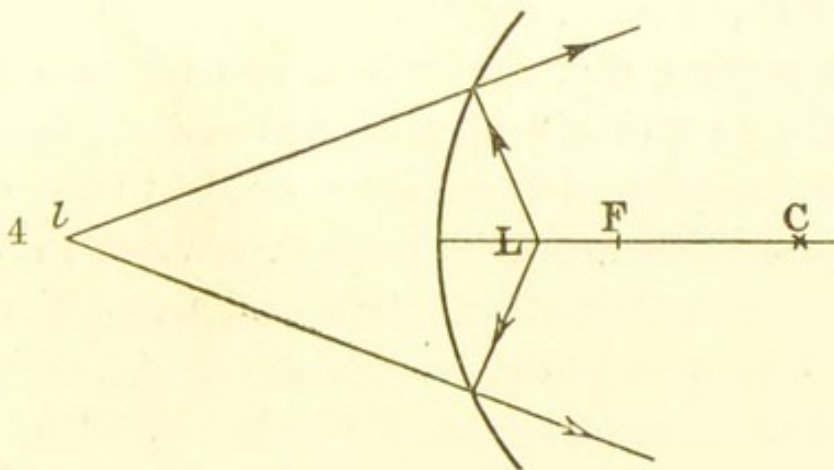
Fig. 187.—Reflection from a concave mirror.

smaller the pin-hole the sharper the image. **If**

two pin-holes are made there will be two pictures ; if three, there will be three, and so on until the images overlap and obscure each other, and we lose all definition and have only a plain illuminated surface with no definite image. The same fact can be shown by replacing the front lens of a magic lantern by a brown paper cap with a pin-hole.

Mirrors may be plane, convex, or concave ; they may be made of polished metal or of silvered glass. Reflection in plane mirrors has already been studied. If the mirror presents a hollow surface to the incident rays it is termed concave ; if the reverse, convex.

Concave Mirrors.—From a point c describe a portion of a circle to represent a concave mirror. The *horizontal* line through c is called the *principal axis* of the mirror (Fig. 187).

1. Parallel rays—*i.e.*, rays which come from an infinite distance—are all reflected, so as to come to a focus at a point half-way between c and the mirror. This is usually lettered F, and is called the *principal focus* of the mirror.

2. Diverging rays come to a focus between F and c, as *l*. As the object L moves nearer the image, *l* moves away from the mirror, or, to put it another way, they both move towards c. When they reach c the ray is reflected on itself, and L and *l* coincide.

3. When L passes c, and is nearer to the mirror, *l* moves further away till L reaches F, when the reflected rays are parallel, and never meet. F is therefore the best position for the light in a lighthouse reflector.

4. When L passes F the reflected rays diverge and a *virtual* focus is formed at *l* behind the mirror. The foci to which rays not parallel converge are termed *conjugate* foci.

Convex mirrors have no real, but only a virtual focus. As before, the point to which parallel rays come to a virtual focus behind the mirror F (Fig. 188) is the principal focus, and is half-way between the centre of curvature and the mirror. If the object is at L the image is between F and the mirror, at *l*, but always virtual.
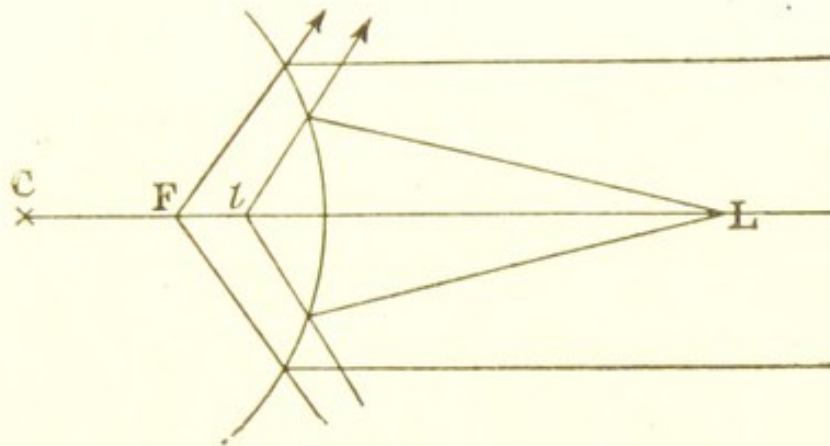
Fig. 188.—Reflection from a convex mirror.

Images in Mirrors.

Concave Mirrors.—There are four cases :—1. When the object is beyond C, as A B (Fig. 189) : to find the position of the image (1) join A C and produce the line ; the image will be somewhere in this line, as it is normal to the mirror, the ray being reflected on itself. (2) Draw lines parallel to the principal axis through A and B, cutting the mirror at x x′ ; from these points, x and x′, draw lines through F ; where they intersect A C and B C the image A′ B′ will be

formed ; it is between F and C, and is real, smaller, and inverted.

2. If the object is at C the object and image coincide.

3. If the object is between C and F it is the converse of 1 ; the object and image change places, and the image is real, inverted, and magnified.
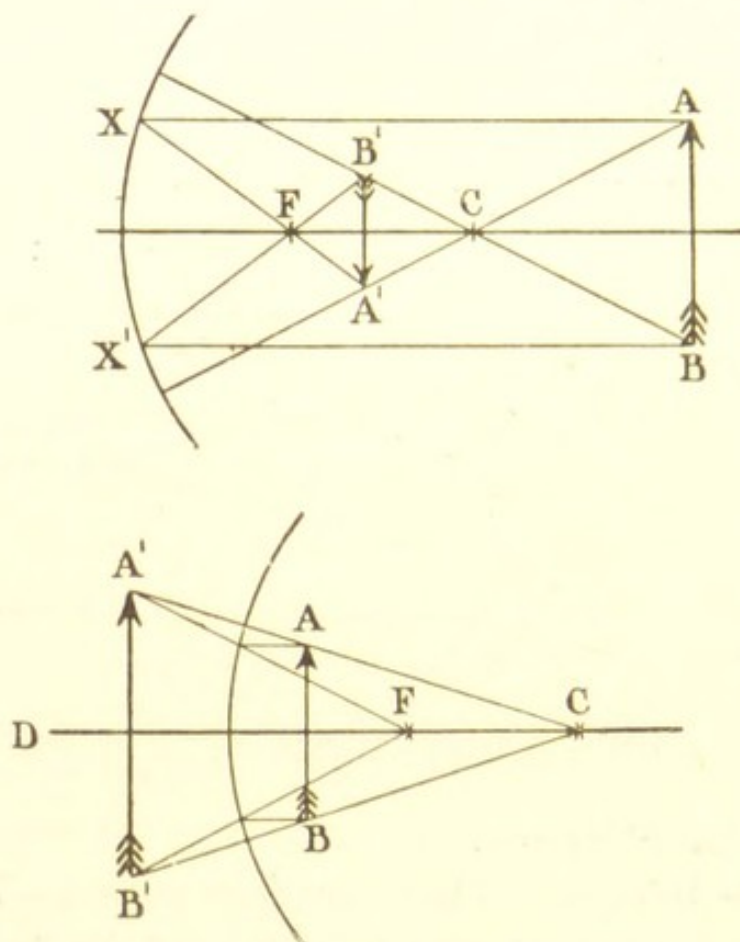
Fig. 189.—Images in concave mirror.

4. If the object is between F and the mirror the image is virtual (behind the mirror), erect, and magnified (Fig. 189, D).

So if one looks into a concave mirror, at some distance, the face appears small and inverted. As the mirror is brought nearer the image becomes larger,

then suddenly vanishes and reappears, as the face approaches the mirror, upright and magnified.

Convex Mirrors.—With a convex mirror the image is always smaller, virtual, and erect (Fig. 190).

If u be the distance of the *object* from the mirror, v the distance of the image, and f = the focal length of the mirror $\left(= \dfrac{\text{radius}}{2} \right)$, then the formula for mirrors is $\dfrac{1}{v} + \dfrac{1}{u} = \dfrac{1}{f} = \dfrac{2}{r}$.

As regards relative size, $\dfrac{\text{image}}{\text{object}} : \dfrac{v}{u}$.
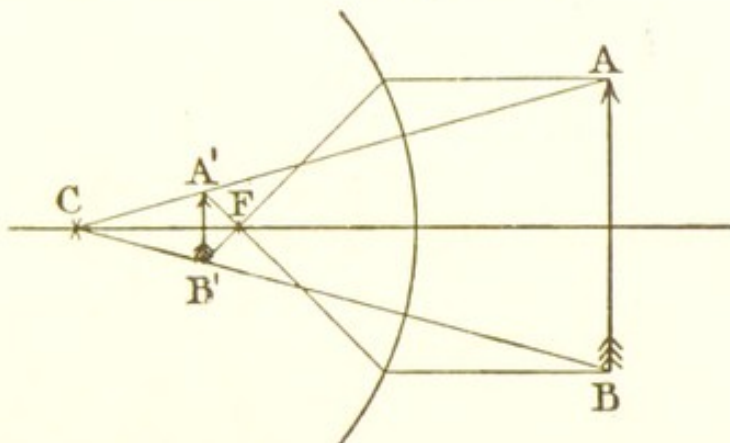
Fig. 190.—Image in convex mirror.

Distances measured in the direction opposed to that of the incident rays are reckoned positive, those in the same direction negative. For a concave mirror r and f are positive, for convex negative; a positive result = a real image, a negative result = a virtual image. No sign is given to an unknown quantity.

An object is 15 cm. in front of a concave mirror of 30 cm. focal length : find the position of the image and its size

$$\frac{1}{v} + \frac{1}{15} = \frac{1}{30} \therefore \frac{1}{v} = \frac{1}{30} - \frac{1}{15} = -\frac{1}{30},$$

so the image is virtual and 30 cm. behind the mirror,

$$\frac{v}{u} = -\frac{30}{15} = -2,$$

so the image is virtual and twice as large as the object.

An object 3 cm. long is 20 cm. in front of a convex mirror 12 cm. focal length : find the position of the image.

$$\frac{1}{v} + \frac{1}{20} = -\frac{1}{12}$$

$$\frac{1}{v} = -\frac{1}{12} - \frac{1}{20} = -\frac{2}{15}$$

$$\therefore v = -7.5,$$

so the image is virtual and 7·5 cm. behind the mirror.

CHAPTER II.

Refraction.—When a ray passes from one medium to another—*e.g.* from air to water, from glass to air, etc.—if it strikes the surface perpendicularly, the ray continues its course without deviation. If it strikes the surface obliquely its course is diverted. If passing *from rare to dense*, as air to water, the ray is bent *towards* the normal ; if from *dense to rare*, as glass to air, the ray is bent *away* from the perpendicular.
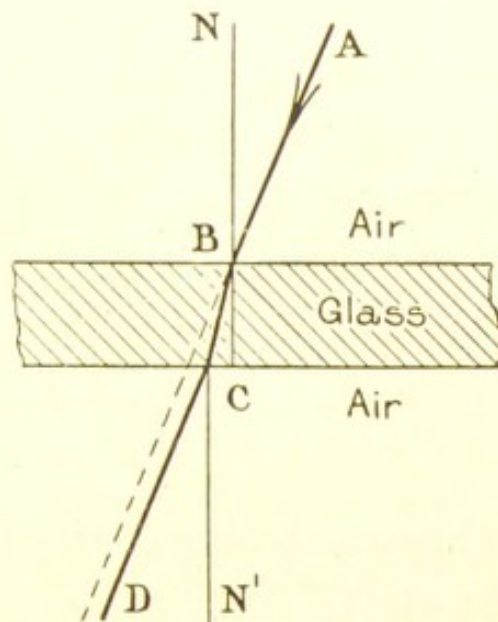
Fig. 191.—Course of refracted ray.

If the dense medium has parallel surfaces the emerging ray is parallel to the incident ray. Thus a ray A (Fig. 191) strikes the parallel-sided piece of glass at B. Instead of keeping on its course along the dotted line it is bent towards the normal N B in the direction B C. On emerging it is bent away from

P   225

the normal N in the direction C D. So a stick under water seems bent (Fig. 192). A coin or fish under water appears further away than it really is; clear ponds appear to be only three-quarters as deep as they really are. Thus if a coin be placed in an empty jam-pot at C (Fig. 193) it cannot be seen by an eye at A because the view is blocked by the top of the pot. If water be poured in, the coin will become visible, for the rays from C when they reach the surface at D are bent away from the perpendicular, so that
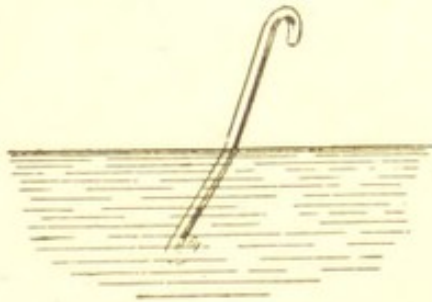
Fig. 192.—Bent appearance of stick under water.
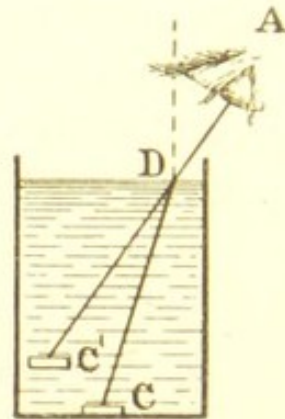
Fig. 193.—Coin under water.

they reach the eye in the direction D A, and the coin is seen at C′.

Snell's Law of Sines.—If a ray coming from A strikes a surface of glass at B it will be bent towards the normal, and pursue the course B C (Fig. 194). From the centre B describe a circle cutting B A at D and B C at E, and drop perpendiculars D N and E M. Then the ratio $\dfrac{N\,D}{E\,M}$ is constant for any two media, whatever the angle of the incident ray; this

is known as Snell's law, *viz., the sine of the angle of incidence bears to the sine of the angle of refraction a constant ratio for any two media.* (The sine is the ratio of the perpendicular D N to the hypotenuse B D.)

This ratio $\dfrac{\text{sine of angle of incidence}}{\text{sine of angle of refraction}}$ is called the *refractive index* and is usually indicated by the Greek letter μ (*mu*).
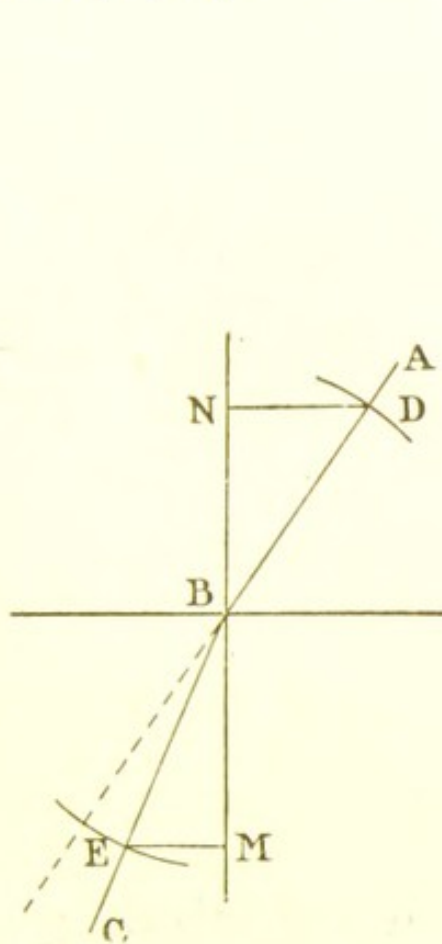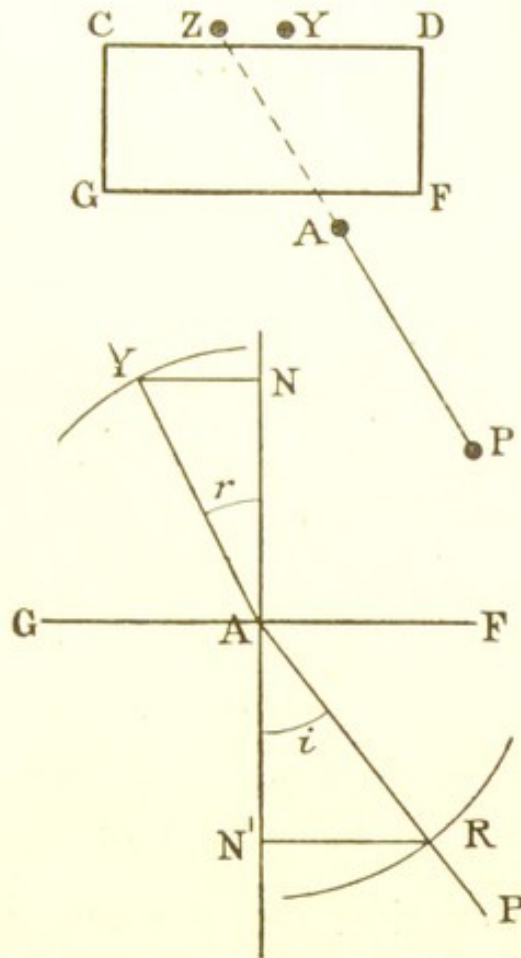
Fig. 194.—Snell's law.   Fig. 195.—Proof of Snell's law.

If the ray proceeds from a rare to a dense medium μ is greater than 1 ; from a dense to a rare medium μ is less than 1.

Thus air to water $\mu = \frac{4}{3}$; air to glass, $\frac{3}{2}$. This law can be verified thus :—A thick rectangular block of

glass, such as is used for a letter-weight or a cutting
shape, C G F D (Fig. 195), is laid on a sheet of white
paper and a pin placed at Y ; this is looked at from
A and appears to be at Z. A pin is inserted at P, so
that P A Z seem to be in a line. Then draw the line
G F and remove the glass block ; draw the normal
N N′, join A with P and with Y ; from A describe a
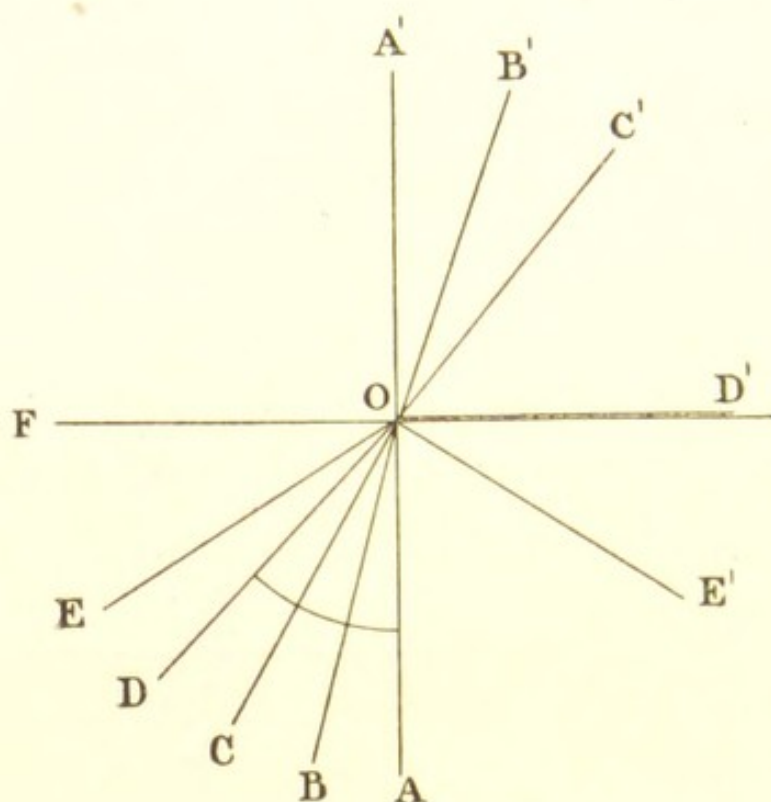
Fig. 196.—Critical angle.

circle cutting A P at R and A Y at Y ; drop the per-
pendiculars R N′ and N Y ; then N′ A R is the angle
of incidence and N A Y the angle of refraction, and

$$\mu = \frac{\text{sine } i}{\text{sine } r} = \frac{\text{N}′ \text{R}}{\text{N Y}} = \text{(in one case)} \frac{15}{10} \text{ cm.} = \frac{3}{2}.$$

Critical Angle.—As we have seen, if a ray strikes
the surface between two media at right angles
there is no refraction. Thus the ray A A′ in emerging

from the surface D′ F, suffers no deviation. So if we look perpendicularly down at a stone in a pond, we see it in its true position. A ray starting from B (Fig. 196) is refracted to B′, one from C to C′, whilst a ray from D is refracted along the surface to D′. A ray from E does not emerge, but is totally reflected to E′ and would be seen by an eye under water as in a looking-glass. This total reflection is very perfect and brilliant, as practically no light is lost. The angle D O A at which total reflection just begins is
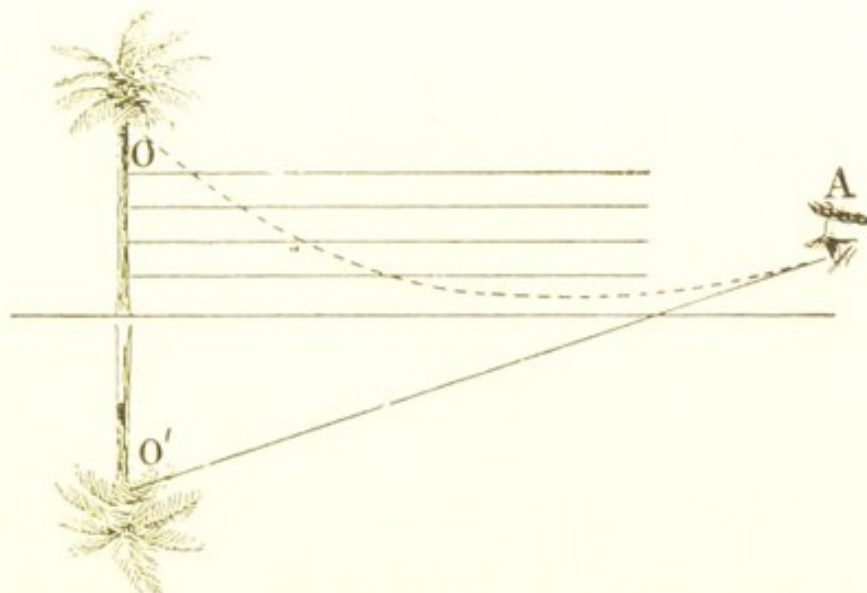
Fig. 197.—Mirage.

called the *critical angle*, because if the angle of incidence is greater than the critical angle the ray is totally reflected, and if less, the ray is refracted in the ordinary way.

The critical angle, water to air, = 48° 30′ ; glass to air, 41° 75′ ; diamond to air, 23° 41′. The relation between the refractive index μ and the critical angle (δ) is $\mu = \dfrac{1}{\sin \delta}$ or $\sin \delta = \dfrac{1}{\mu}$.

The *mirage* can be explained as the result of the combined action of refraction and total internal reflection. It appears *in the air* when the lowest layers of the air are cooler than those above, and *below the ground level* if the air is hottest near the surface, as in Fig. 197, which gives a diagram of the formation of the image of a tree in a hot sandy desert. If we trace the course of a ray from a point o as it passes from the dense to the rarer air, it is bent more and more from the normal until it passes the critical angle, when it is internally reflected and reaches the
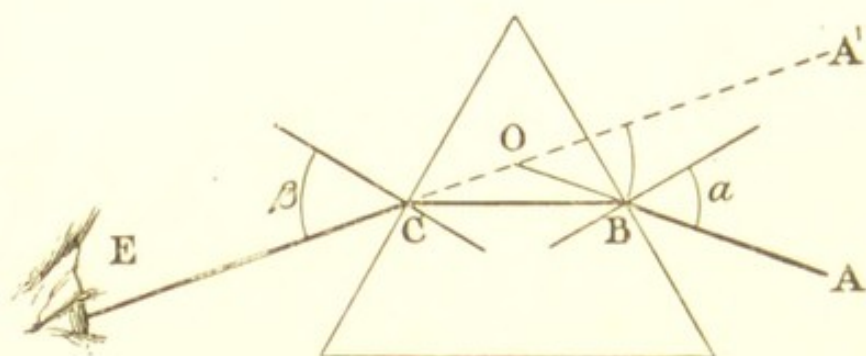
Fig. 197*a*.—Refraction through a prism.

eye in the direction o′ A, so that the tree appears inverted at o′. In all cases of mirage there must be comparatively still layers of air of different densities.

Prisms.—If we look through a glass prism at an object A (Fig. 197*a*) it appears to be at A′. The rays from A striking the prism are bent towards the normal. On emerging into the air they are again refracted, and strike the eye in the direction A′ E. By gently turning the prism the image A′ will be seen to move farther away, and then (still turning the prism in the same direction) come back again. The

position in which the image A′ and the object A are nearest to each other is termed the position of *minimum deviation.* The angle A O A′ is the angle of deviation of the ray from its original direction A O. This position of minimum deviation is attained when the ray B C, passing through the glass, is parallel to the base of the prism and the angles α and β are equal.

If i be the angle of the prism, d the angle of minimum deviation, and μ the index of refraction—

$$\text{then } \mu \sin \frac{i}{2} = \frac{\sin i + d}{2}.$$

For heavy flint glass and yellow light $\mu = 1\cdot6224$. If $i = 60$, find d.

$$1\cdot6224 \times \sin 30 = \frac{\sin 60 + d}{2}$$

$$= 1\cdot6224 \times 0\cdot5 = \frac{\sin 60 + d}{2}$$

$$\therefore \frac{\sin 60 + d}{2} = \cdot8112 = \sin 54° \ 13',$$

$$\therefore 60 + d = 108° \ 26', \text{ and } d = 108° \ 26' - 60 = 48° \ 26'.$$

By this formula the index of refraction of any substance which can be cut into a prism of known angle can be determined.

A right-angled prism is used sometimes for reading a thermometer. When the latter is placed in the mouth, an object at A is seen by total reflection at A′ (Fig. 198).

Lenses.—If two similar triangular prisms be placed base to base, the rays from a distant source of

light will, when refracted, meet in a point P (Fig. 199). If the surfaces be ground into curves we have a convex lens.

There are two great classes of lenses, *convex and concave.* Fig. 200 gives their forms and names.
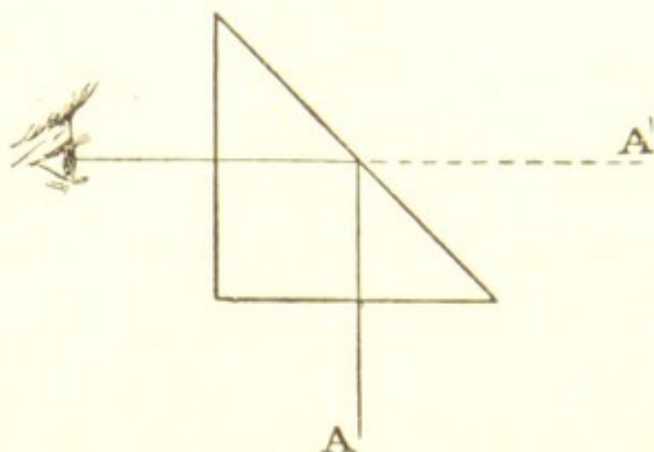
Fig. 198.—Total reflection.

In the convex group the lens is thickest at the centre ; in the concave group the greatest thickness is at the edges.
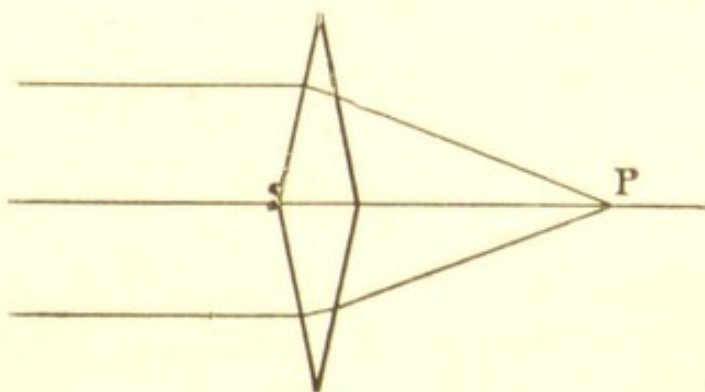
Fig. 199.—Parallel rays and double prism.

Double Convex Lens.—1. Rays at an infinite distance form a parallel pencil and converge to a point on the principal axis F (Fig. 201), termed the *principal focus*, and the distance between the lens and the principal focus is called the *focal length*.

2. If the object o moves nearer, but is still beyond F, the rays come to a conjugate focus at F′ (Fig. 201, 2).

3. If the object is at F, the rays emerge parallel (the converse of 1).

4. If the object is between F and the lens, only a virtual focus is formed at F′ (Fig. 201, 4).

Images Formed by Convex Lenses.—1. When the object is beyond the principal focus, as the arrow

| Double convex. | Plano-convex. | Concavo-convex, converging meniscus. | Double concave. | Plano-concave. | Convexo-concave, diverging meniscus. |
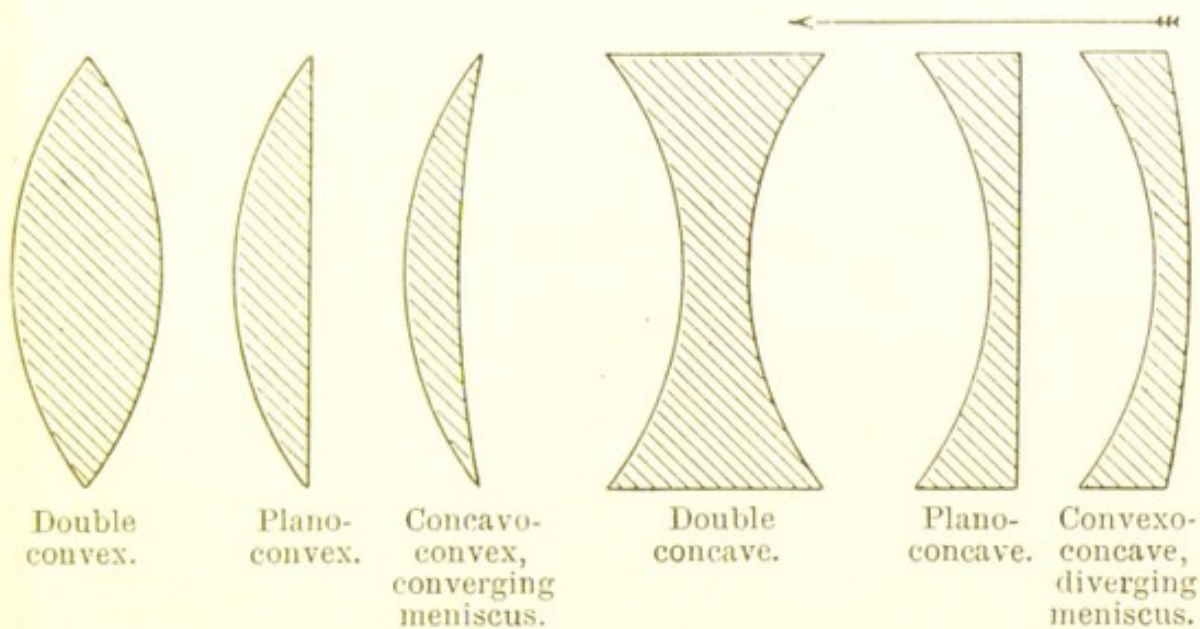
Fig. 200.—Lenses.

A B (Fig. 202, 1), to find the position of the image (*a*) draw lines from A and B through the centre of the lens C : the images will be somewhere on these lines (*b*). Draw lines parallel to the principal axis through A and B to cut the lens at x and x', then draw lines from x and x' to F and produce them : the image will be formed where they cut the lines A C and B C. The image is real and inverted (camera lens).

2. When the object is between F and the lens,

draw lines as in 1 (Fig. 202). The image is erect,
magnified, and virtual (magnifying glass, simple
microscope).

The *Stanhope lens* consists of a piece of glass rod,
one end of which is ground flat and polished, while
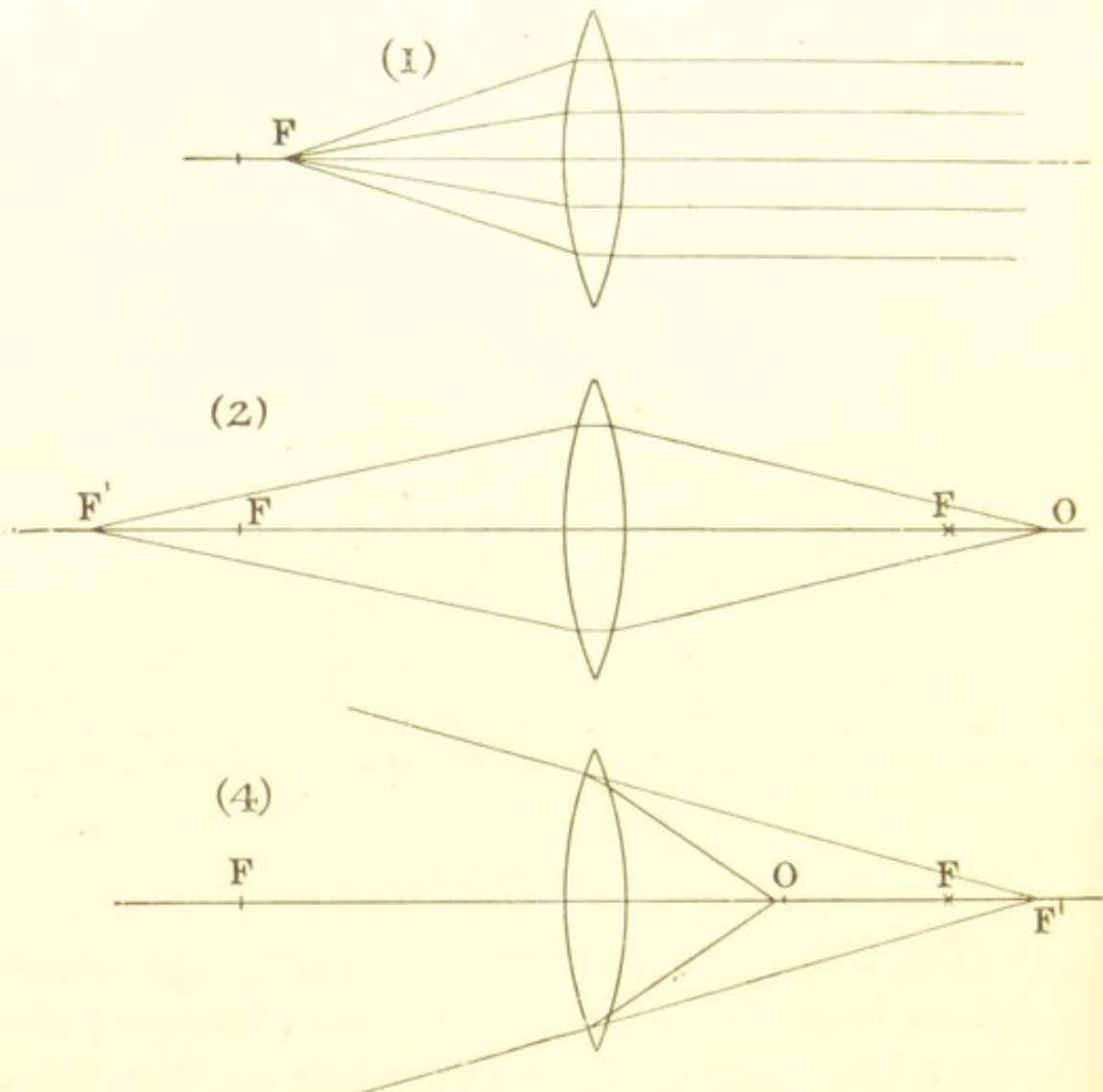
Fig. 201.—Convex lens.

the other has a convex surface forming a lens whose
focal length is such that objects held on the flat face
are in the focus of the lens. It is often used for
magnifying small photographs cemented on the flat
surface A (Fig. 203).

Concave Lens.—No real image is formed by a concave lens: the image is always virtual and erect (Fig. 204).
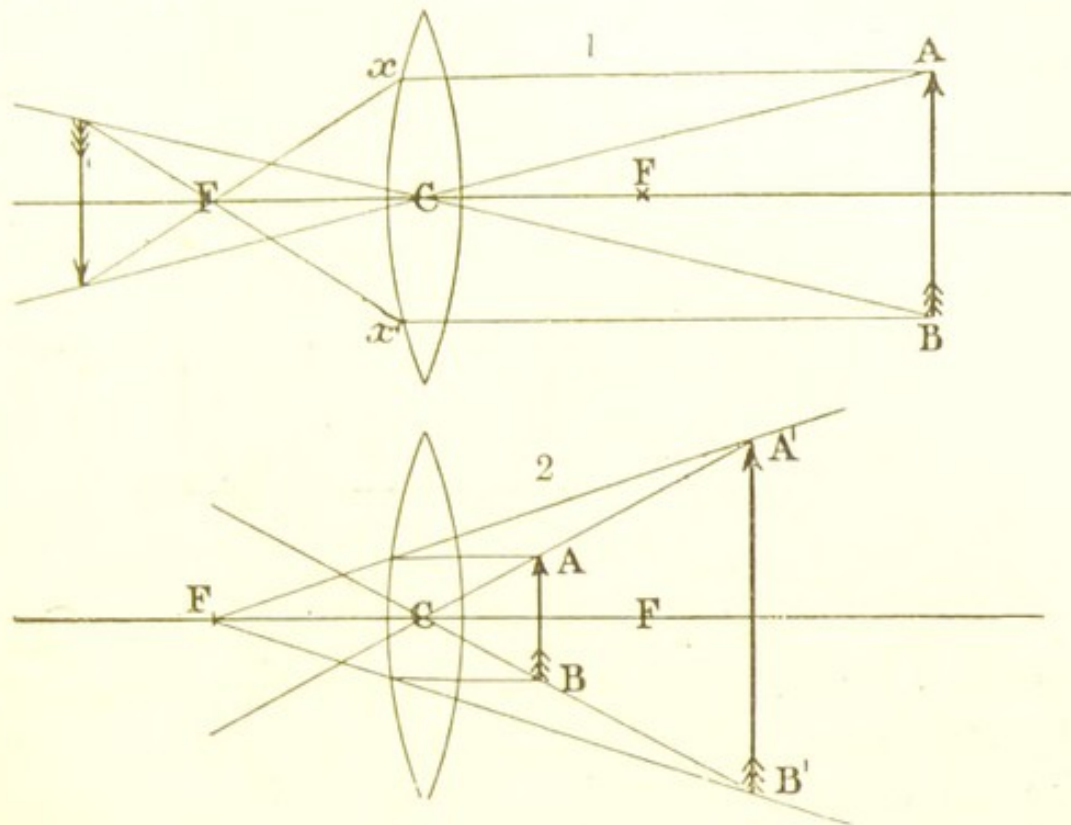
Fig. 202.—Images with convex lens.

Combinations of Lenses.

The *compound microscope* consists of two convex lenses, a very powerful, but small, lens, termed the *object glass* or *objective* o (Fig. 205), which forms an inverted magnified and real image at A, the object *a b* being placed close to the objective. This real

Fig. 203.—Stanhope lens.

image at A is viewed by a second convex lens E, termed the *eye-piece*, which acts as a magnifying glass and produces a more enlarged image at B B.

The *magnifying power* is practically determined by
viewing with one eye a very finely-divided scale (*stage
micrometer*) through the microscope and comparing
this with an ordinary scale (held at the distance of
distinct vision, about 10 in.) seen by the other eye.
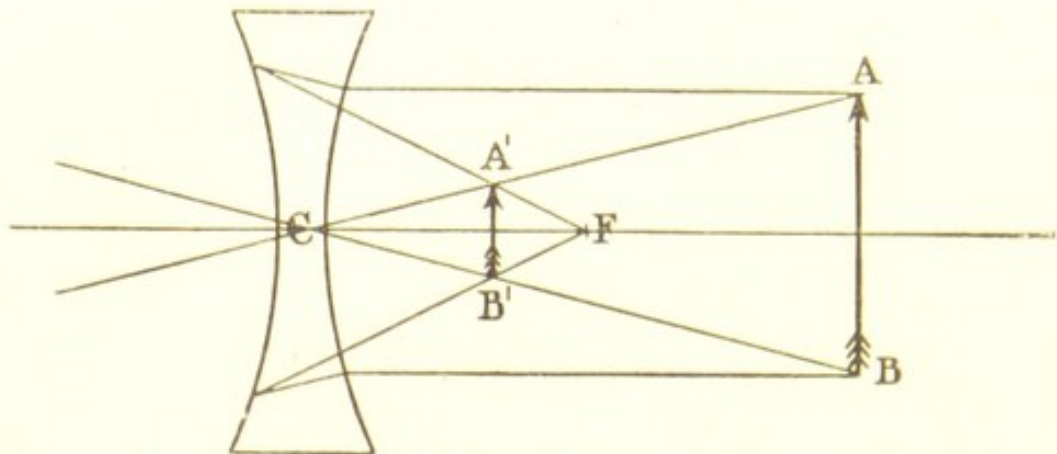
Fig. 204.—Image in concave lens.

With a little patience and practice the images seen
by the two eyes can be made to overlap and can thus
be compared. If one-hundredth of a millimetre,
when viewed through the microscope, appears to be
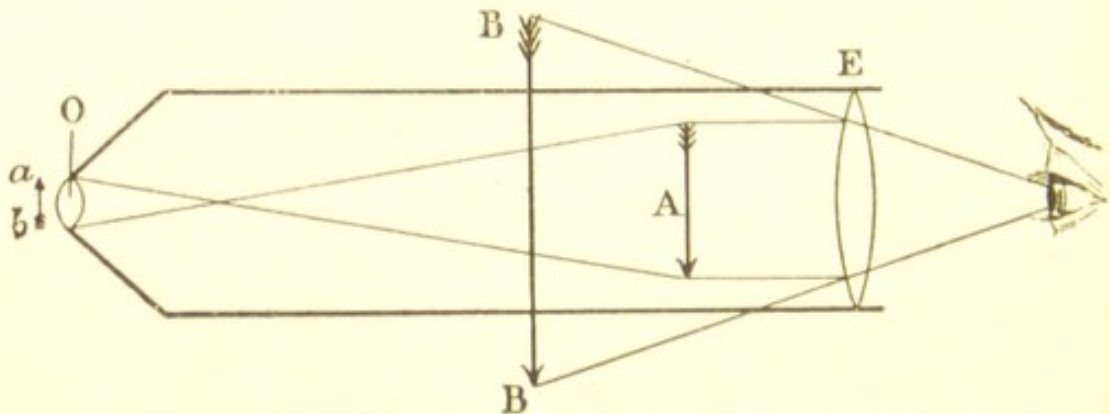
Fig. 205.—Diagram of compound microscope.

of the same length as nine millimetres seen by the
unaided eye, the magnifying power is as $\dfrac{1}{100}$: 9, or as
1 : 900. This, in fact, gives the ratio of B B to *a b*
(Fig. 205).

The Astronomical Telescope.—This consists, like the compound microscope, of two convex lenses. The object glass forms an inverted real image, which the eye-piece magnifies, forming a virtual image. The difference between the two instruments is that, as the objects—sun, moon, etc.—viewed by the telescope cannot be brought near the object glass, the entire magnification is performed by the eye-piece (Fig. 206).
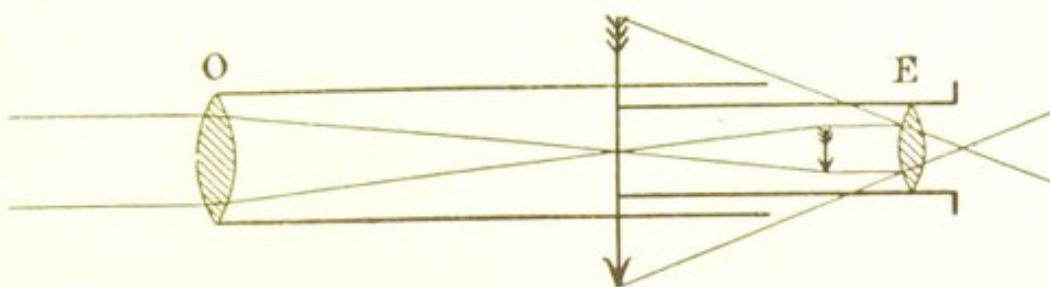
Fig. 206.—Astronomical telescope.

As the rays from the circumference of a lens do not come to a focus in quite the same spot as those from the centre, it is usual, both in the microscope and the telescope, to insert behind the eye-piece a
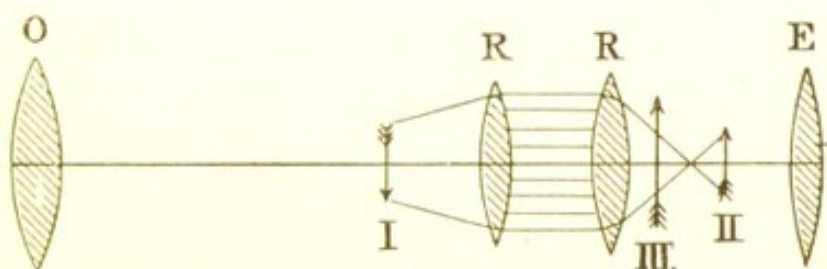
Fig. 207.—Diagram of terrestrial telescope.

thin circular plate of metal with a circular hole, called a *stop* or *diaphragm ;* this cuts off the outer rays and gives a sharper image, although some light is lost. In the microscope there is also an adjustable stop to the objective.

As the image formed by the astronomical telescope is inverted, for terrestrial purposes two similar convex lenses R R (Fig. 207) are introduced between the object glass and the eye-piece, so that the image is re-inverted and becomes erect. These extra lenses do not magnify, and the image loses somewhat in brightness owing to the slight loss of light in passing through two lenses. The object glass forms the image I, which is rendered erect at II, and magnified at III.

Galileo's Telescope (Opera Glass).—This consists of one convex and one concave lens, arranged
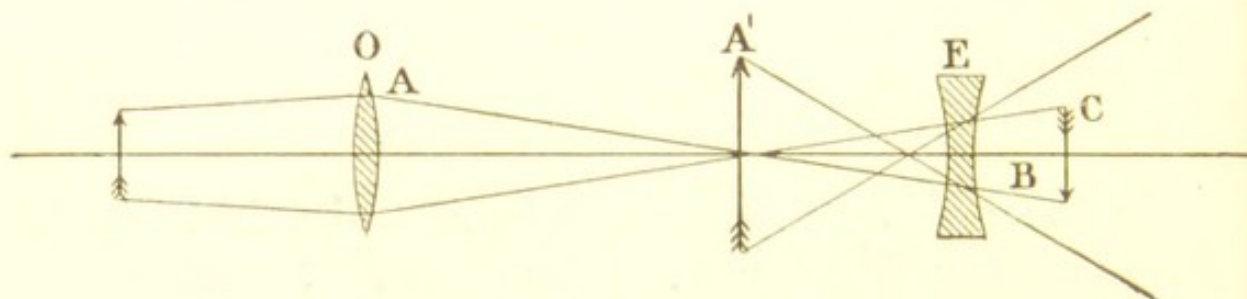
Fig. 208.—Galileo's telescope.

at a distance equal to the difference between their focal lengths. No real image is formed, but the combination is short, handy, and gives a well-lighted image.

The object glass o (Fig. 208) would form an inverted real image at C, but the ray A B is intercepted by the concave lens E, bent upwards, and forms a virtual image at A, which is magnified, erect and virtual.

The *magic lantern* contains two lenses, one a large convex or plano-convex lens C C, in the principal focus of which is placed the illuminant L, so that

parallel rays are thrown on the object B. In front
is a convex lens A, the *projecting lens*, which forms a
magnified inverted image on the screen, as seen in
Fig. 209.

Long Sight and Short Sight.—In a normal eye
the various refractions at the cornea, lens, etc.,
are arranged so as to form a sharp inverted image
on the retina. In youth the tissues are elastic, and
the eye has a considerable *depth of focus*—that is,
it can produce sharp pictures of objects which are
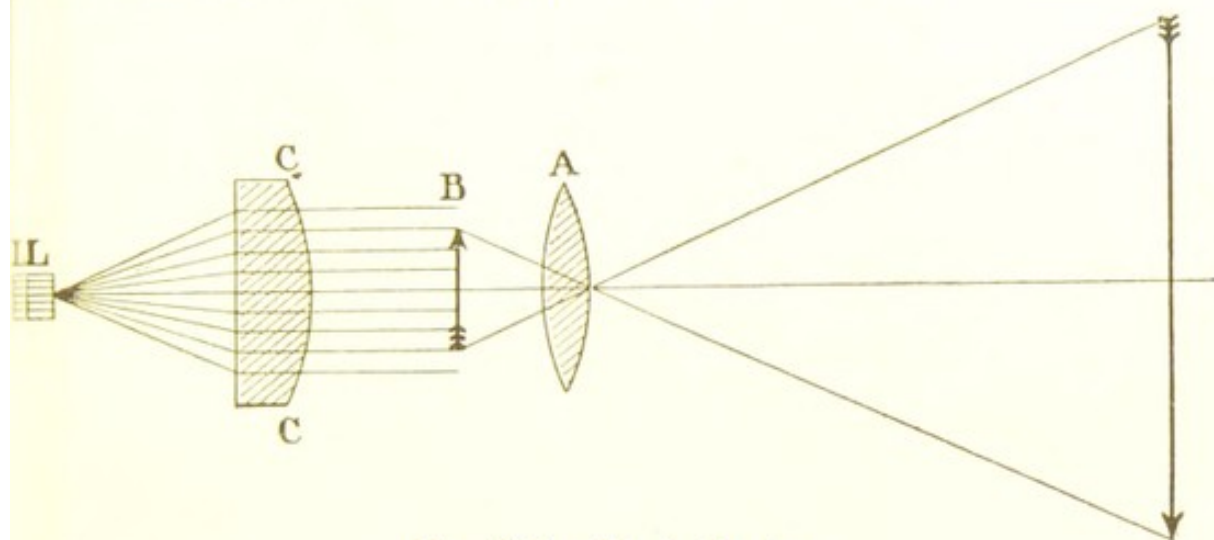
Fig. 209.—Magic lantern.

at distances greater and less than its geometrical
focus. As age comes on the tissues lose their elas-
ticity, the lens becomes flatter, and the individual be-
comes *long-sighted* (presbyopia). He can form sharp
images of distant objects, but the lens is not convex
enough to focus near objects ; he begins to hold his
newspaper at arm's length, instead of the normal
distance of 10 inches. The image of near objects is,
in fact, formed behind the retina (I., Fig. 210). To
correct this we must aid the eye by means of a convex

lens, which increases the convergence of the rays and brings them to a sharp focus *on* the retina R.

In *short sight* or myopia (II., Fig. 210), we have the converse of the above. The lens is too powerful, and forms an image *in front* of the retina R. In some cases, as the person gets older, this is partially remedied by the flattening of the cornea, but it is usually necessary to correct this defect with a concave glass, which diminishes the convergence of the rays and so brings them to a focus on the retina.

Diopters.—The unit of c u r v a t u r e (curvature $= \dfrac{1}{\text{radius of curvature}}$) of a lens usually adopted for spectacles, etc., is a *diopter*, D, which is the reciprocal of a metre; so if the curvature or focal length of a lens be 1 metre, this $= \dfrac{1}{1}$ or
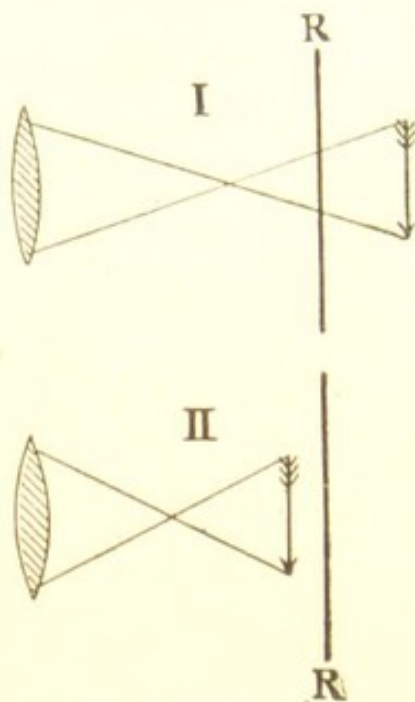
Fig. 210.—I., Long sight; II., Short sight.

1 D; if the focal length be $\frac{1}{2}$ metre $= \dfrac{1}{0 \cdot 5} = 2$ D; if the focal length be $\frac{1}{10}$ metre $= \dfrac{1}{0 \cdot 1} = 10$ D, etc. As a metre may be taken, roughly, as 40 inches, a convex lens of 10 inches focal length $= \dfrac{1}{\frac{10}{40}} = \dfrac{40}{10} = 4$ D.

Concave lenses would be $-$ 2 D, etc.

The power of a lens is also commonly stated by giving its focal length in inches or centimetres, + for convex, − for concave. Thus − 20″ would mean a concave lens whose principal focus was 20 inches from the lens measured along the principal axis.

To Determine the Focal Length of a Convex Lens.—1. Focus the image of a distant object—the sun, a window, tree, etc.—on a piece of white paper : when the image is sharp, the perpendicular distance between the image and the lens is the focal length.

2. If v be the distance of the image from the lens,
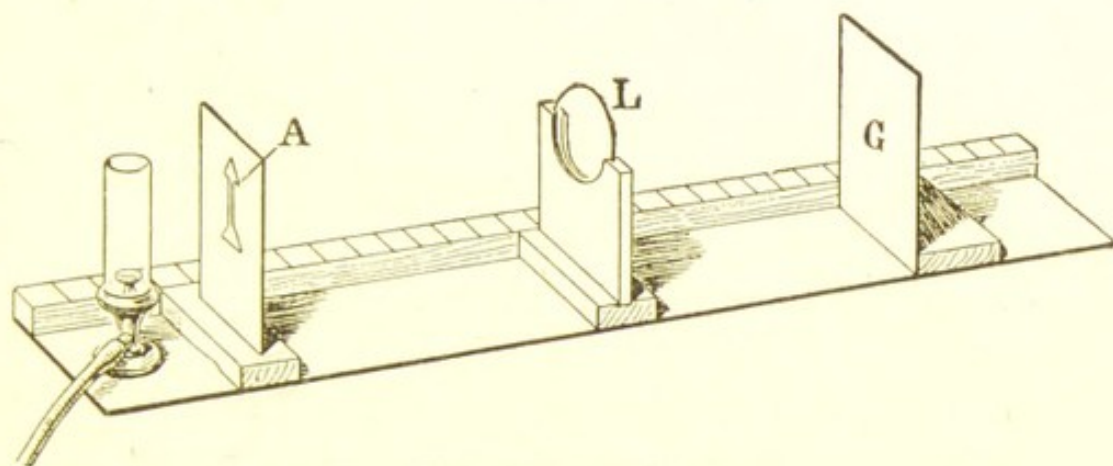
Fig. 211.—Optical bench.

and u that of the object from the lens, and f the distance of the principal focus,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

arrange the lens L (Fig. 211) on a graduated scale ; provide also a screen of ground glass G and well-illuminated arrow A, or cross, cut out of thin sheet zinc ; place them as shown in the illustration, shift the lens and screen so as to get sharp images, and calculate the value of f from various determinations of u and v.

Q

E.g., an object is 8 inches from the centre of the lens, the image is 24 inches on the other side : u is measured from the lens in a direction opposite to the incident ray, and is therefore $+$; v is measured in the same direction as the incident ray, and is therefore $-$

$$\frac{1}{-24} - \frac{1}{8} = \frac{1}{f} \qquad \frac{-4}{24} = \frac{1}{f} \text{ and } f = -6$$

—a convex lens of 6-in. focus.
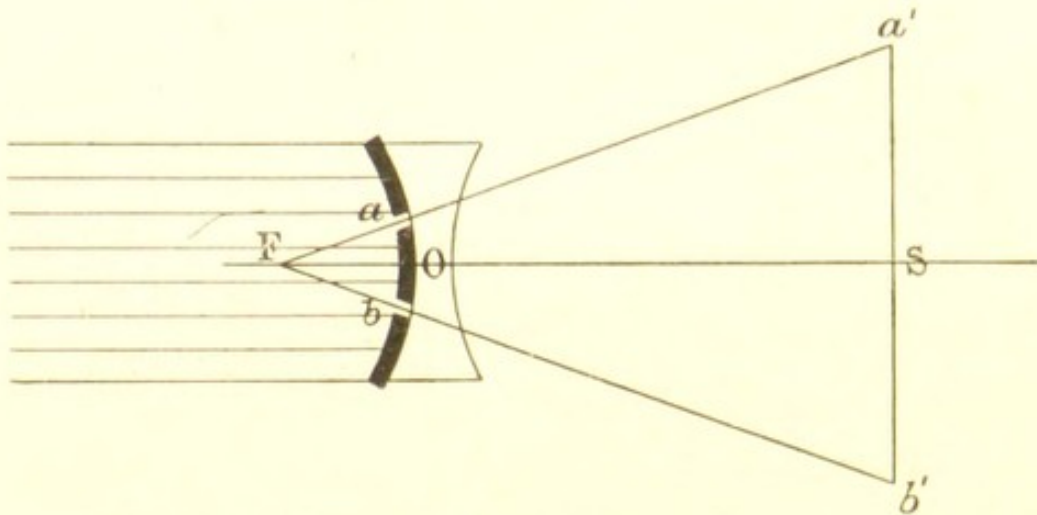
Fig. 212.—Determination of focus of concave lens.

3. Arrange the object and image on the optical bench so that they are of the same size, and sharp ; then the distance $\frac{u + v}{4} = f$. So object and image are of the same size when the distance of each from the lens $= 2f$; *e.g.* :

$$u = 6, \ v = 6, \ f = \frac{6 + 6}{4} = 3 \text{ inches.}$$

To Determine the Focal Length of a Concave Lens.—1. Combine it with a convex lens so that the combination behaves as a flat glass plate. If the

focal length of the convex lens be known, that of the concave is obviously the same, but negative.

2. Cover the concave lens with a piece of thin opaque paper (Fig. 212) and make two pin-holes a and b equidistant from the centre; throw a parallel beam so as to obtain two spots of light on a screen, then—

$$\frac{a\,b}{a'\,b'} = \frac{\mathrm{F\,O}}{\mathrm{F\,S}} = \frac{\mathrm{F\,O}}{\mathrm{F\,O} + \mathrm{O\,S}} = \frac{f}{f + \mathrm{O\,S}}$$

measure $a\,b$, $a'\,b'$, and $\mathrm{O\,S}$.
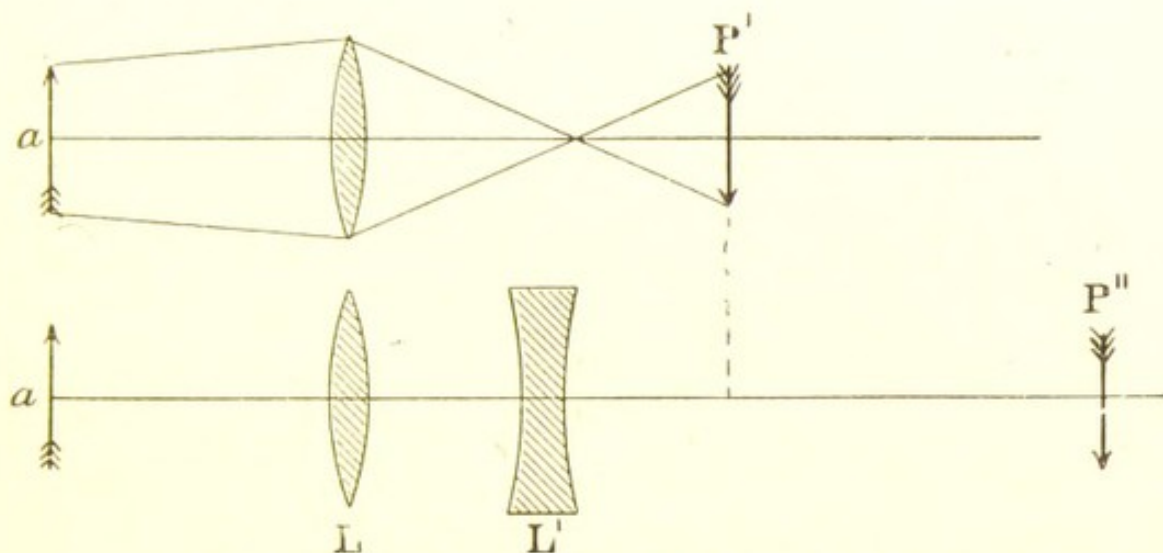
Fig. 213.—Determination of focus of concave lens.

3. Take a convex lens of shorter focus (Fig. 213), and in the optical bench determine the position P′ of an object a (1) with the convex lens alone, (2) with the combination of the convex and concave lenses,

then $\dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{f}$ and $\mathrm{L'\,P'} = u$ and $\mathrm{L'\,P''} = v$.

4. If two lenses of focal length f_1 and f_2 be combined a d the total focal length be F, then—

$$\frac{1}{\mathrm{F}} = \frac{1}{f_1} + \frac{1}{f_2}$$

Take the concave lens f_1 and the convex lens f_2 of shorter focus : find the combined focal length of F and also f_2, then

$$\frac{1}{f_1} = \frac{1}{F} - \frac{1}{f_2}$$

To Determine the Magnifying Power of a Convex Lens.—1. The magnifying power,

$$m.\ p.\ = \frac{10 \text{ inches } + \text{ focal length in inches}}{\text{focal length}}$$

e.g., focal length $= 4\cdot3''$, *m.p.* $= \dfrac{10 + 4\cdot3}{4\cdot3} = 3\cdot3$.

2. $\dfrac{\text{Image}}{\text{Object}} = \dfrac{v}{u} = \dfrac{f}{u + f}$ (see also p. 236).

CHAPTER III.

Dispersion.—As we have seen, when a beam of white light passes through a glass prism, it is bent or refracted. But the prism effects something more : it *analyses* the white light and splits it into its constituent colours. White light consists of three
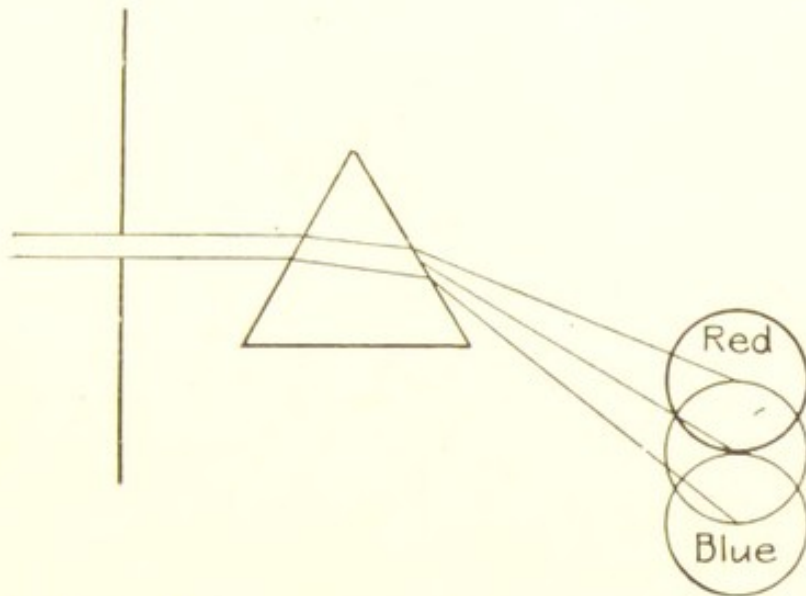
Fig. 214.—Decomposition of a circle of white light.

primary colours—red, green, and blue-violet. These primary colours are bent in different degrees as they pass through the glass ; the red is bent least, the blue-violet most.

If the source of light is a spot, we have three images of the spot—one red, one green, one blue-violet; but as these overlap, the colours are not pure (Fig. 214);

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where the three circles are superposed we have white light. If, however, we take as our source of light a narrow slit, the overlapping is slight, and we get a pure spectrum, a continuous image of the slit in all colours—red, yellow, green, blue, violet. This is called the **continuous spectrum,** and we obtain it whether the source of light is the sun, an electric lamp, a lime-light, or a gas or candle flame. We can recompose these colours so as to reproduce a slit of white light, by passing the beam through a similar prism placed in the reverse position, or through a convex lens of suitable focus (Fig. 215).

Fig. 215.—Recomposition of white light.

It will be remembered that the red rays vibrate the most slowly : 400 million million times in one second ; the violet rays the most rapidly : 760 million million times in one second, and these are the most refrangible.

The vibrations emitted from, say, the sun are not all included in the visible spectrum. Beyond the red end are heat rays—the *ultra-red* rays—and there are also rays beyond the violet end—the *ultra-violet* rays —both quite invisible to the eye. The existence of the ultra-red rays can be demonstrated by a delicate thermometer, or the thermopile, and the ultra-violet rays can be rendered visible by receiving them on a

screen, moistened with an acid solution of quinine, which at once shines with a beautiful blue fluorescence when exposed beyond the violet. Also, various silver salts blacken when exposed to these ultraviolet rays.

Line Spectrum.—If, instead of taking a slit of ordinary white light we take a slit illuminated by a yellow sodium flame and analyse this, we see only one narrow yellow band instead of the continuous spectrum: the rays emitted by the sodium flame consist solely of those which produce yellow light. If we illuminate the slit with the lavender flame of potassium we see one band in the red and one in the blue-violet. These two hues mixed give us the lavender flame of potassium (see frontispiece).

Absorption Spectrum.—If we look at a continuous spectrum from, say, an electric light, and interpose between the electric light and the slit a mass of sodium vapour, we see the continuous spectrum, but with a black line in the place where the yellow sodium line should be. This is an *absorption band*. Whenever rays of light pass through a medium, emitting a certain colour, or, to put it in other words, vibrating at a definite rate, those rays of light which vibrate at the same rate are absorbed and stopped, and we have darkness, as far as they are concerned.

Spectroscopes.—An ordinary spectroscope consists of three essential parts : (1) a narrow parallel-sided slit ; (2) one or more triangular prisms of glass or glass cells filled with carbon bisulphide ; and (3) a lens or lenses to produce distinct vision.

The ordinary spectroscope (Figs. 216 and 217) consists of a brass tube bearing a parallel-sided slit at s, the light from which is focussed by the lens *l*,
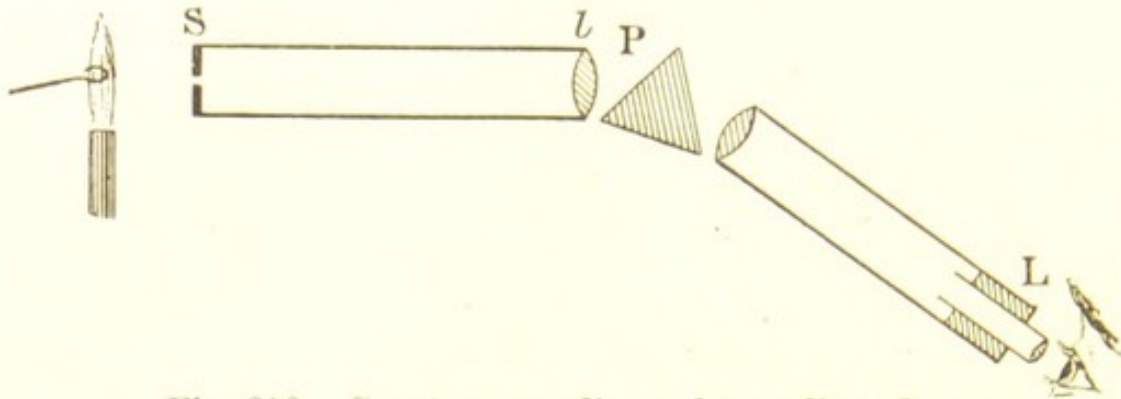
Fig. 216.—Spectroscope directed to sodium flame.

and falls on the prism P, and is viewed by a low magnifying power telescope at L. The space between
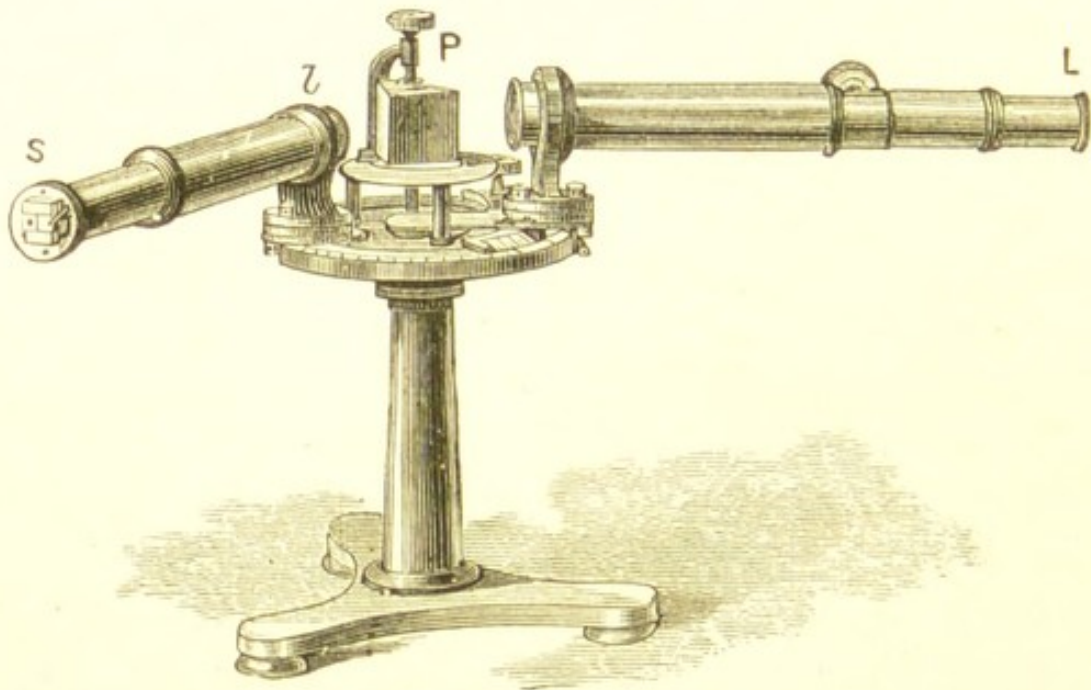
Fig. 217.—Spectroscope.

l and the telescope must be covered over by a piece of black velvet when the instrument is used.

A much more convenient instrument for many

purposes is the *direct vision spectroscope* (Fig. 218), which consists of a number of alternate prisms of crown and flint glass with their edges turned in opposite directions and so arranged that the bending of the light rays by the crown glass is exactly corrected by the refraction of the flint glass in the opposite direction. But the *dispersion* (which does not vary *exactly* with the deviation) is not quite corrected, so that the beam emerges in the *same direction* as that of the incident ray, but the various coloured rays are separated. When, therefore, we look at the slit illuminated by white light we see a continuous spectrum.
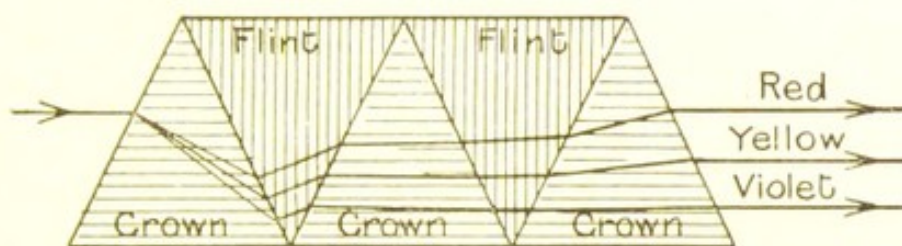
Fig. 218.—Prisms in direct-vision spectroscope.

If such a spectroscope be directed towards the sky on a bright day, it will be seen that the continuous spectrum is crossed by a number of fine black lines —*Fraunhofer's lines.* To see them the spectroscope slit must be very narrow. These absorption bands are parallel to the direction of the slit.

One, in the brightest yellow, coincides in position with the sodium line ; it is called the D line (see frontispiece). There are three prominent bands in the red, A, B, and C ; then in the green will be noticed two, E and *b*, one at the beginning of the

blue F and one towards the violet G, etc. These lines are produced by the absorption of certain constituent vibrations from the colourless white light emitted by the sun's photosphere. The D line is due to the white light traversing masses of sodium vapour, probably in the sun's atmosphere, during its passage from the sun to the eye. Many of these lines have been identified as belonging to the vapours of metals—iron, etc.—which are known on the earth. When a powerful spectroscope—*i.e.,* one with many prisms—is used, the number of these lines is enormous.

Coloured solutions also cut out portions of the continuous spectrum. If we interpose a solution of potassium bichromate between a gas flame and the spectroscope, all the blue is cut out; a solution of copper sulphate and ammonium hydrate cuts out all but the blue. If we combine the two, the whole spectrum is cut out, and we have darkness. A solution of potassium permanganate cuts out the yellow, the place where it was being represented by a black band, and leaves the red and violet on either side of the black band. A solution of blood, if dilute (see frontispiece), cuts out two bands of colour near the yellow red, and gives the characteristic absorption spectrum of oxyhæmoglobin.

So, to sum up, we have :—

(1) The *continuous spectrum* emitted by bodies at a white heat.

(2) *Absorption spectra* produced by the interposition of coloured fluid, masses of glowing

vapour, etc., between a body giving a continuous spectrum and the spectroscope.

(3) *Bright line* or *emission spectra*, emitted by glowing masses of metallic vapours, sodium, calcium, etc., which give bright coloured lines in various parts of the spectrum.

Ordinary coloured substances have no colour in themselves, but when light falls upon them it is reflected, and the surface, absorbing some of the constituents of white light, emits the rest. Thus the surface of a red poppy absorbs from white light all colours but red, a blue gentian all colours but blue.

If a black photographic dish be filled with a solution of potassium bichromate, it is impossible to tell whether the solution is coloured or not, but if we sink in it a piece of white opal glass the yellow colour is at once seen.

Colouring matters and coloured lights are often confused : *e.g.*, green light is a pure colour, and cannot be made by mixing, but every child who has a paint-box knows that blue and yellow paints form green. The explanation is that the yellow paint is not pure, but is a mixture of yellow and green ; similarly the blue is a mixture of blue and green. Now, if we mix pure blue and yellow lights we get white light. Blue and yellow are termed *complementary colours*, so in mixing paints the pure blue and yellow neutralise each other, to form a greyish white, and the green from both appears.

If we illuminate a coloured object, say a red geranium blossom, with a light which has no red in it, the

flower appears black. This is the cause of the ghastly corpse-like hue shown by the tongue, lips, etc., when illuminated by a sodium flame. This being pure yellow, in its light all the other colours appear black.

The *rainbow* is caused by a combination of refraction, total reflection, and dispersion.

Parallel rays from the sun strike a spherical raindrop at A (Fig. 219). Some of the rays are refracted,
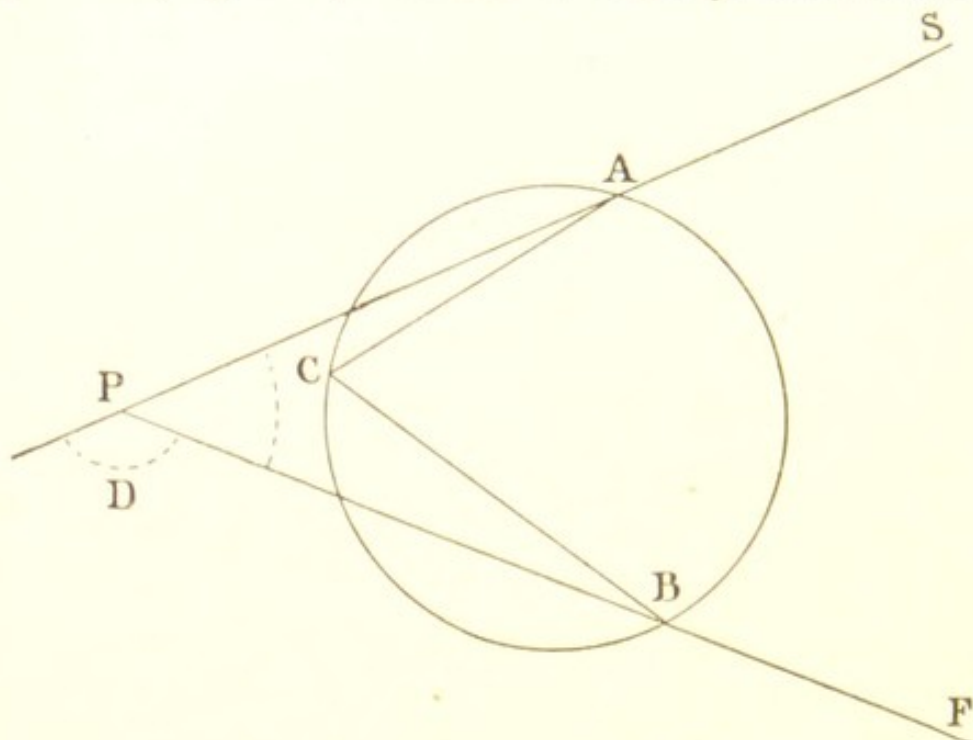
Fig. 219.—Path of sun's ray through drop of water in a rainbow (*after Aldous*).

and some reflected, passing out at B. The incident and reflected rays meet at P; the angle of deviation is D. If S A C B be in the position of minimum deviation, the angle S P B is about 42° for red light and 40° for violet light, so an observer facing the rain-cloud with the sun shining behind him will receive a series of red impressions from rays similar to B F, and inside these he will have a circle of yellow, green, blue, and violet rays.

Part VI.

PRACTICAL EXERCISES.

Section I.—Measurement of Length, Thick= ness, Area, Surface, Cubic Capacity or Volume.

AFTER each experiment or measurement the result obtained should be carefully and neatly entered in a note-book, kept for the purpose, with any calculations resulting therefrom. The mere fact of measuring, etc., will do but little to educate the student, unless all results are carefully noted *at the time.*

LENGTH, THICKNESS, ETC.

1. Measure in centimetres and in inches the diameter and thickness of a penny, a shilling, a table, etc.

2. Determine the thickness of a piece of glass, of a cover-glass, of a hair, with the aid of the micrometer screw (p. 8). In turning the screw, hold the head lightly between finger and thumb, so as to avoid any chance of straining the screw.

3. Measure the thickness of a plano-convex lens with the spherometer (p. 9) in millimetres.

4. Mark the rim of a penny with a scratch with a knife-blade or a small three-square file. Roll the penny on a sheet of white paper without slipping, and measure the length of the circumference.

5. Calculate the length of the circumference from its diameter by the formula—

$$\text{Circumference} = 2\,\pi\,r.$$

$$r, \text{ the radius, } = \frac{\text{diameter}}{2}, \ \pi = \frac{22}{7}.$$
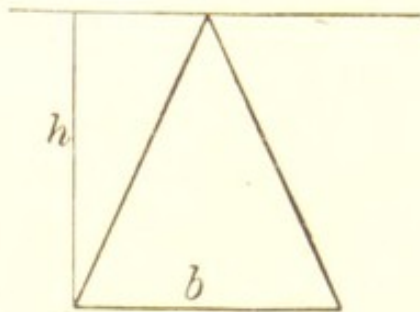
Fig. 220.—Calculating area
of triangle.
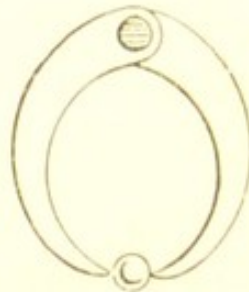
Fig. 221.—Callipers.

AREA.

1. Calculate the area of one face of a penny from the formula—

$$\text{Area of a circle} = \pi\,r^2.$$

2. Calculate the area of a square piece of card.

3. Determine the area of a triangular piece of paper.

$$\text{Area} = \frac{\text{base} \times \text{vertical height}}{2} \ (\text{Fig. 220}).$$

4. Describe a circle on a sheet of paper 30 centimetres in diameter, cut out of the circle a square of 20 centimetres, and find the area of the remainder.

5. Calculate the area of the surface of a cylinder brass tube, etc.

$$\text{Area} = 2\,\pi\,r \times \text{height.}$$

6. Calculate the area of the surface of a sphere.

$$\text{Area} = 4\,\pi\,r^2.$$

The diameter of a sphere can be determined by callipers (Fig. 221) or by means of two square blocks of wood and a scale (Fig. 222).
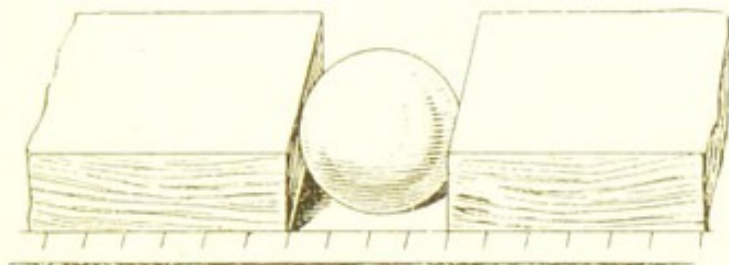
Fig. 222.—Measuring diameter of a sphere.

7. Calculate the area of the surface of a cone.

$$\text{Area} = \pi\,r\,s \ (\text{Fig. 223}).$$

8. Determination of area by weighing. Cut out accurately a square piece of cardboard, 10 centimetres in the side, and weigh it.

Dividing this weight by 100, we get the weight of one square centimetre.

Cut out a circular piece from the same cardboard and weigh it, and, knowing the weight of

Fig. 223.—Calculating surface of cone.

one square centimetre, calculate the area of the circle.

VOLUME OR CUBICAL CONTENTS.

1. Calculate the volume of a sphere.

$$\text{Volume} = \frac{4\,\pi\,r^3}{3}.$$

2. Calculate the volume of a pyramid.

$$\text{Volume} = \text{base} \times \frac{\text{height (vertical)}}{3}.$$

3. Calculate the volume of a cone.

$$\text{Volume} = \frac{\pi\,r^2\,h}{3}.$$

INTERNAL DIAMETER OF A TUBE.

Take a piece of paper, divided into square milli-metres, 10 centimetres by 1 centimetre, join the opposite corners, and cut down the diagonal line. Use this wedge-shaped piece of paper to determine the internal diameter of a glass tube.

USE OF THE VERNIER.

1. By means of sliding callipers, furnished with a vernier (p. 6), read off the diameter of a piece of glass tube, the diameter of a penny, etc.

2. Take a reading of the height of the barometer, using the vernier (p. 7).

VERIFICATION OF BURETTE OR PIPETTE.

By weighing the quantities of water they deliver. Having filled the burette or pipette with dis-tilled water, 10 or 20 c.c are carefully run into a weighed beaker and the increase in weight is noted.

Section II.—Specific Gravity or Relative Density.

1. Bend a glass **U** tube, place mercury in one limb and water in the other. Measure the heights of the columns of mercury and of water, and calculate their respective gravities, knowing that the heights vary inversely as the specific gravities.

2. Place a little mercury in the **U** tube and carefully pour in water on one side and alcohol on the other. Note the respective heights of the two liquid columns and calculate the specific gravity of the alcohol.

3. Determine the specific gravity of alcohol by Hare's apparatus (p. 21).

4. Place some water in the **U** tube and attach one limb of the **U** tube to the gas supply by an india-rubber tube. Turn on the gas and measure the pressure in millimetres of water.

5. Take the specific gravity of a glass stopper, a piece of lead or iron, by the method of Archimedes (p. 22).

6. Weigh out 20 to 50 grams of lead shot and determine the specific gravity of lead by dropping the shot into a burette containing water, and noting the rise in the level of the water (p. 25).

7. Take the specific gravity of lead shot by weighing in a specific gravity bottle filled with water (p. 25).

8. Find the specific gravity of a specimen of alcohol by the specific gravity bottle (p. 19).

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9. Determine the specific gravity of alcohol by the common hydrometer (p. 31).

10. Find the specific gravity of a florin by Nicholson's hydrometer (p. 30).

As before, enter all results in your note-book as soon as they are obtained.

Section III.—Verification of Boyle's Law— Correcting the Reading of a Barometer— Capillarity—Diffusion of Gases.

BOYLE'S LAW.

Verify Boyle's law—that the volume of a gas varies inversely as the pressure—by the apparatus (Fig. 39 and p. 50).

Introduce a convenient quantity of air in bulb A, level the mercury in the two tubes A and B, and read off the volume of gas; then raise B, read off the difference of level in the mercury in the two tubes and add the atmospheric pressure to this difference; then the new volume should be, if the barometer stands at 760, $\dfrac{v \times 760}{760 + \text{difference in level}}$. Care should be taken not to handle the tube A, so as to avoid errors from alterations in temperature.

Make several determinations, and see that the volume calculated as above agrees with the volume observed at the new pressure.

READING THE BAROMETER (p. 37).

1. See that the barometer tube is vertical.

2. Read the temperature.

3. Adjust the level of the mercury in the cistern till its surface just touches the ivory point which ends the scale.

4. Adjust the bottom of the vernier to touch the top of the mercury column, taking care that the eye is at the same level.

5. Read off the height with the vernier in inches and in millimetres.

6. Correct by tables for temperature for height above sea level and for capillarity.

Note the expansion of a gas in the air-pump as the pressure is removed (Fig. 2).

Measure by the siphon barometer, fitted up as in Fig. 224, the vacuum produced by the air-pump.
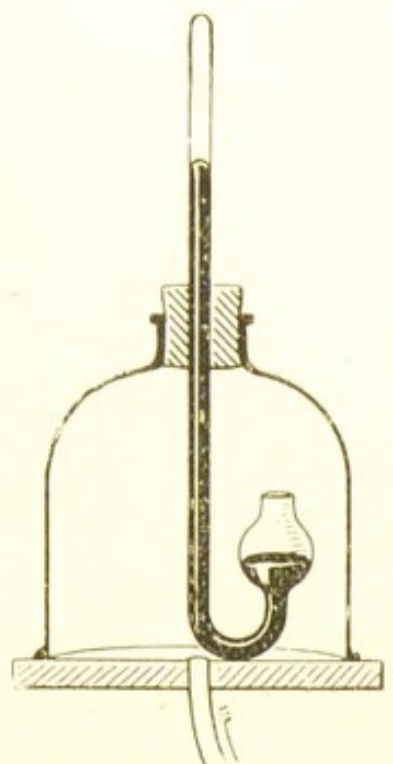
Fig. 224. — Measuring vacuum of air-pump.

CAPILLARITY.

Heat a piece of glass tube in the blowpipe flame till it is quite soft, then *take it out of the flame* and pull it into a capillary tube. In this way make some capillary tubes of various sizes. Break off lengths of 2 in. to 3 in. and observe the heights to which

various fluids—ink, alcohol, etc.—will rise.   Observe also the effect of inclining the tubes (p. 52).

DIFFUSION OF GASES.

Fill a gas jar with carbon dioxide, cover it with a plate, and invert a jar of ordinary air over it (p. 17), remove the plate, and allow to stand for half an hour. Test for CO_2 in the upper jar with solution of calcium hydrate.

Section IV.—Heat.

EXPANSION OF SOLIDS, LIQUIDS, AND GASES.

1. Demonstrate the increase of length of a brass or iron bar or rod when heated as shown in Fig. 225. One end of the bar B rests on a ledge against a firm support at A, the other end rests on a needle N supported by a block c. One end of the needle is thrust through the straw s. On warming the bar B with a Bunsen burner its length increases and the needle is rolled over, the movement being magnified by the straw, the upper end of which moves to the right.

2. Prove that a sphere increases in size by Gravesande's ball and ring (p. 55).

3. Heat a compound bar of brass and iron and observe that the more expansible metal takes the longer side of the curve (p. 69).

4. Determine the exact increase in the length of a rod of brass 1 metre long for a rise of temperature of

50° (20°—70°) with the aid of a spherometer (pp. 65 and 66).

5. Determine the expansion of water, alcohol, etc., by filling a specific gravity bottle (p. 20), with the liquid at various temperatures, and weighing the bottle with its contents (pp. 70 and 71).

6. Fill a large-bulbed thermometer with boiled distilled water (p. 56) and observe carefully, with the
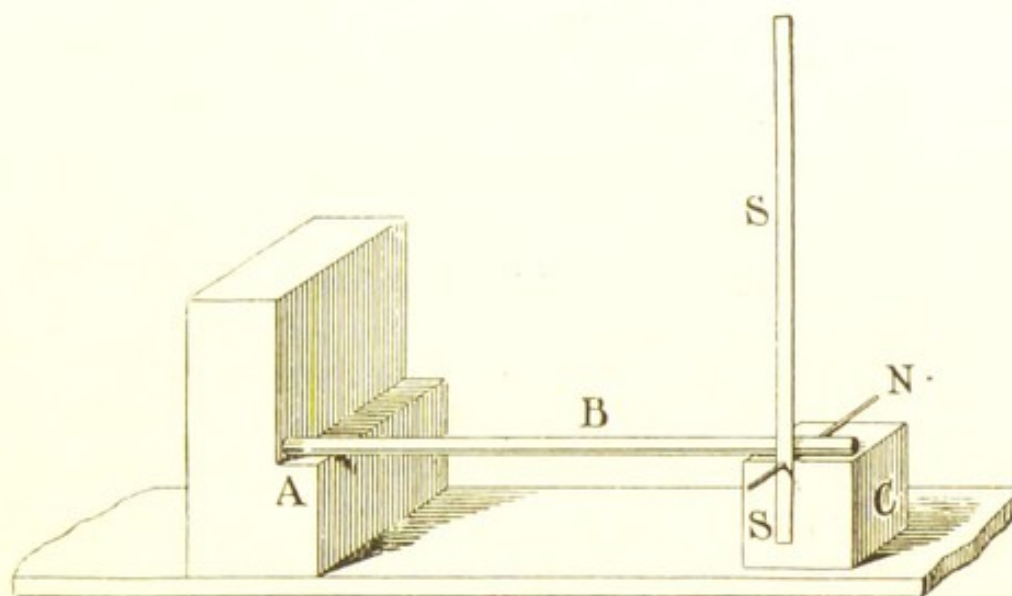
Fig. 225.—Expansion of brass rod.

aid of a scale, the alteration in the volume of the water when cooled from 10° C. to 0° C. (p. 72). Note carefully at what temperature water attains its smallest volume or maximum density.

7. Fit a small flask with a cork and upright glass tube, fill the flask with water and insert the cork and tube, mark the position of the surface of the liquid in the tube; then plunge the flask suddenly into hot water. Note the *drop* of the fluid in the tube owing

to the expansion of the glass flask before the fluid begins to expand.

8. Fill a graduated glass gas tube one-third full with mercury, add an equal volume of water, close the mouth of the tube with the thumb and invert in a trough of mercury; pour some water at a known temperature over the tube and then calculate the real volume of the air at 0° and 760 mm. The column of mercury in the tube, measured in millimetres, must be subtracted from the atmospheric pressure, and also $\frac{1}{13}$th of the column of water in mm., in order to obtain the real pressure to which the gas is subjected (pp. 50 and 73).

DETERMINATION OF MELTING POINT AND BOILING POINT.

1. Determine the melting point of various substances—wax, paraffin wax, naphthalene, etc.—as described on p. 89.

2. Verify the zero point of a Centigrade thermometer, as given on p. 57.

3. Determine the boiling point of various liquids —water, alcohol, etc.—by the apparatus shown in Fig. 226. Note the height of the barometer.

4. Insert a little ether in a bent tube closed at one end (Fig. 78 and p. 89), warm the water in the beaker, note the temperature at which the surfaces of the mercury in the two limbs of the tube are level. This temperature is the boiling point (p. 92).

CONDUCTION.

1. Stir some boiling water with a copper wire and a German silver wire, notice the different rates at which the heat is conducted. A similar difference will be felt if a copper wire and a platinum wire be held in the fingers while the other ends are placed in a Bunsen flame.
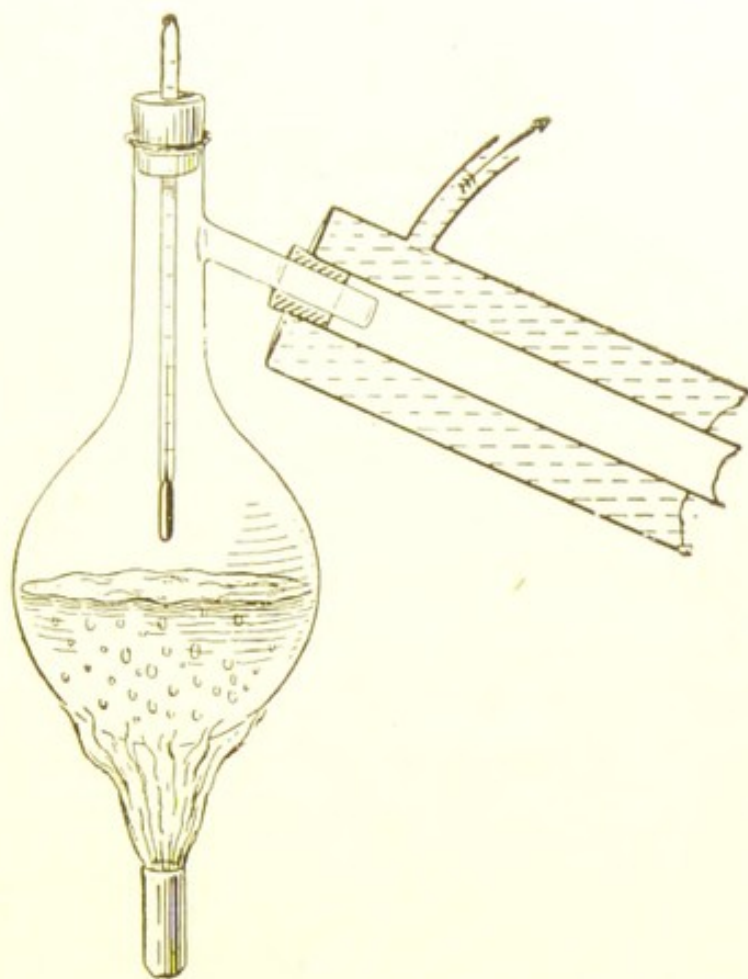
Fig. 226.—Determination of boiling point.

2. Turn on the gas to a Bunsen burner, place a piece of fine copper gauze about two inches above the burner and apply a light *above* the gauze. The gas will burn above, but the gas under the gauze will not be ignited (p. 77).

3. Coil some copper bell-wire round a thick pencil so as to make a close coil about one inch long. Place it over the wick of a lighted candle without touching the wick. The candle will be extinguished.

4. Coat rods of various substances with wax and introduce them into an Ingenhausz trough, fill with boiling water, and measure the various lengths of wax melted (p. 77).

5. Repeat the experiment shown on p. 78 to prove that water is a bad conductor of heat.

RADIATION AND ABSORPTION.

1. Fill a Leslie's cube with boiling water (Fig. 72 and p. 83) and observe the varying amounts of heat given off by the blackened and polished sides, either with a Leslie's differential air thermometer (p. 55) or a thermopile and galvanometer (Fig. 165*a*, p. 189).

2. Place a piece of bright tin-plate and a similar piece, smoked over a paraffin lamp, in front of a fire for a few minutes, and note the difference in temperature (p. 83).

3. Place the hand near the side of an ordinary Bunsen flame, then cut off the air and notice how much more heat is radiated by the luminous flame.

4. Place a sheet of glass in front of a fire for a few minutes and notice how it absorbs the heat radiated from the fire (p. 85); most of the heat rays coming from the fire, being non-luminous, are absorbed by the glass.

VAPOUR PRESSURE.

Measure the vapour pressure of water and of alcohol at various temperatures by the apparatus shown on p. 91.

Compare your results with those on p. 93.

LATENT HEAT.

1. Mix 100 grams of water at 0° C. with 100 grams of water at 80° and note the temperature after mixing.

2. Repeat the experiment, using 100 grams of *ice* at 0° instead of water, and note the resulting temperature. Calculate the latent heat of water (p. 88).

3. Fit up flask, etc., as seen in Fig. 84, p. 96, but in addition fit a piece of straight glass tube to reach down into the liquid and long enough to stand 3 in. or 4 in. above the cork. Measure 100 c.c. of water into the flask B and 200 c.c. into the calorimeter. Boil the water until a rise of about 15° is observed in the water in the calorimeter; note the temperature accurately. When cold re-measure the water in A and B; the loss gives the water converted into steam. Then calculate from your data the latent heat of steam.

DEW-POINT.

Determine this—

(*a*) by stirring small pieces of ice into some water contained in a polished metal vessel until dew forms on the surface. Read off the temperature when this first takes place, then allow the vessel to stand till

the dew disappears, and again note the temperature. The mean of the two readings is the dew-point;

(*b*) by Daniell's hygrometer, p. 102;

(*c*) by Dine's hygrometer, p. 103;

(*d*) by wet and dry bulb thermometer and Glaisher's factors (pp. 104 and 279).

(*e*) Having determined the dew-point, calculate the relative humidity (pp. 93 and 102).

SPECIFIC HEAT.

Weigh carefully some pieces of iron, zinc, lead or aluminium (about 100—200 grams), attach some fine string, and heat in a saucepan of boiling water. Weigh the dry calorimeter and get its water value by multiplying the weight by its specific heat (iron ·113, copper ·095, brass ·094) (p. 111). Measure out 200 c.c. of water into the calorimeter (p. 110), and take its temperature carefully. Note the temperature of the boiling water, withdraw the heated metal and cool it in the calorimeter with constant stirring. Note the rise in temperature. Calculate the specific heat of the metal (p. 111) and compare the result with the numbers on p. 108.

Section V.—Electricity and Magnetism.

FRICTIONAL ELECTRICITY.

1. Rub a stick of sealing-wax with dry flannel, suspend it by a silk thread from a glass support and

note that it is repelled by a second stick of rubbed sealing-wax but attracted by a rod of glass rubbed with silk (p. 124).

2. Prove that electricity is developed on the rubber (p. 127), by the apparatus shown in F g. 106 (p. 125).

3. Charge an electrophorus (p. 129), and with it light a gas burner.

4. Study the action of a Wimshurst machine (p. 130), and with it charge a Leyden jar (p 136).

5. Prove, by means of a Leyden jar with moveable coatings, that the charge resides on the glass (p. 137).

6. Show that a Leyden jar cannot be charged if it stands on a sheet of glass.

7. Charge a gold-leaf electroscope (p. 125), by means of a lightly rubbed glass rod, (*a*) with positive electricity by contact, (*b*) with negative electricity by induction (p. 126).

MAGNETISM.

1. Magnetise some steel needles by drawing them once or twice over the pole of a magnet.

2. Thrust the needles through pieces of cork and float them on some water. Observe that they point north and south.

3. Bring the north end of one needle near the north end of another and observe that they repel each other; similarly two south poles repel, while north attracts south, and *vice versa.*

4. Magnetise a needle and show that the end of

the needle which last leaves the pole of the magnet is of the opposite name to the pole which it has just left.

5. Observe that a piece of soft iron wire attracts *both* ends of a floating magnet.

6. Attach a piece of iron wire to a magnet; it becomes a magnet and attracts a second piece of iron wire (Fig. 159, p. 183). Also the magnetic properties of the iron wire disappear when it is removed from the magnet.

7. Break a magnetised needle in half and show that you have now two magnets, each possessing a north and a south pole.

8. Pass a dipping needle along a bar magnet (Fig. 161, p. 185). Observe that over the north pole of the magnet the dipping needle stands vertical, with its south pole downwards; in the middle of the magnet the needle is horizontal, and when over the south pole the needle is vertical, but with its north pole downwards.

9. Magnetise a poker (p. 185) by holding it in the magnetic meridian and at the dipping angle, and striking it two or three sharp blows with a hammer. Test its polarity with a compass needle. Reverse its polarity by holding it the other way up and striking half a dozen blows with the hammer.

10. Map out the lines of force and magnetic field by placing (*a*) two similar poles, (*b*) two dissimilar poles of a couple of bar magnets under a sheet of thin paper and evenly scattering iron filings on the paper (Figs. 156 and 157, pp. 181 and 182).

GALVANIC OR VOLTAIC ELECTRICITY.

1. Solder copper wires to a strip of sheet copper and to a zinc rod. Immerse the zinc and copper in 10 per cent. sulphuric acid. Bring the ends of the wires to the tongue and observe the curious metallic taste produced by the current.

2. Combine 5 to 10 of these simple cells in series (p. 158), and use the current for the electrolysis (p. 152) of—

       (*a*) acidulated water,
       (*b*) copper sulphate solution,
       (*c*) potassium iodide solution,
       (*d*) potassium sulphate solution.

3. Verify the action of a copper wire conveying a current on a compass needle when above and when below the needle (p. 165).

4. Attach two cells to the primary circuit of a Du Bois-Reymond induction coil (p. 174), interposing a key in the circuit (Fig. 150). Place the moistened fingers on the ends of the secondary coil and notice the shocks on opening and closing the key.

5. Attach the wires from two cells to the screws 3 and 4 (Fig. 152, p. 174). Adjust the screw 5 so that the vibrator acts, study its action (p. 173), and notice that we have now a continuous series of secondary shocks (Faradization).

Compare the action of the vibrator with that of an electric bell.

6. Couple up five cells of a Grove battery with

a large Ruhmkorff coil and compare the discharge (p. 177)—

       (*a*) in air,

       (*b*) in a partial vacuum,

       (*c*) in a Geissler tube,

       (*d*) in a Röntgen tube.

7. Fit up a tangent galvanometer (Fig. 145, p. 168); compare the strengths of currents from various cells.

(For Table of Tangents see p. 282.)

8. Fit up a Wheatstone bridge (Fig. 137, p. 162) and determine the resistance of various lengths of thin German silver wire.

9. Couple up battery, etc., with " Post Office box " (Fig. 138, p. 163) and determine resistance of various wires, etc.

10. Attach a battery to an electro-magnet (Fig. 1) and determine which is the north pole, (*a*) by compass needle, (*b*) from the direction of the current (p. 165).

Section VI.—Light.

1. Prove that the angle of incidence is equal to the angle of reflection with the aid of some large blanket pins and a piece of looking-glass, supported by a block of wood (see Figs. 182, 183, p. 216).

2. Demonstrate the various positions of image and object in a concave and in a convex mirror, as shown in Figs. 189 and 190, and described on pp. 221 and 222.

3. Determine the focal length of a concave mirror. Place the mirror opposite some brightly illuminated object, as a small arrow cut in cardboard, move the mirror backwards and forwards until a sharp image of the arrow is obtained on the cardboard, just by the side of the arrow. The distance between the arrow and the mirror is the radius of curvature of the mirror, and the focal length $= \dfrac{r}{2}$.
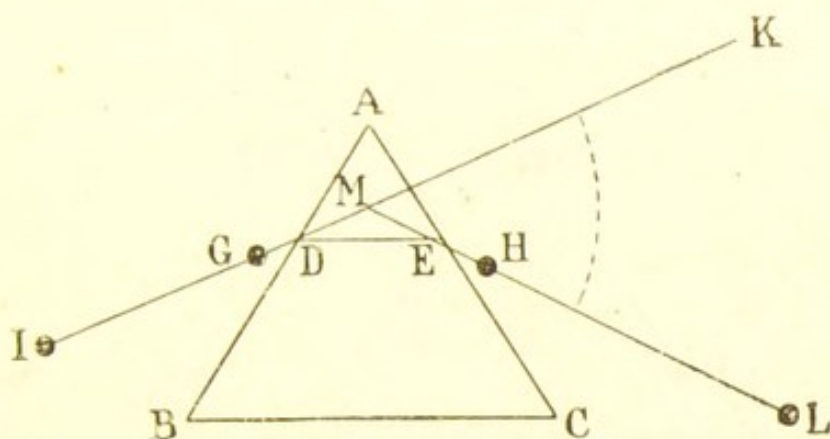
Fig. 227.—Path of ray through prism.

4. Verify Snell's law of sines, as described on p. 228 (Fig. 195).

5. Trace the course of a ray refracted through a glass prism, as follows (Fig. 227) :—

Place the prism on a sheet of white paper, and trace the outline of its base A B C with a pencil. Insert two blanket pins G and H close to the prism, so that A G = A H. Look at G with one eye, and move the eye until G and H are in the same line; place a pin I to indicate this position, so that I G H are in line. In a similar way place the pin L, so

that L H G are in line. Remove the prism, produce
I G to K, cutting the prism at D, and produce L H
to M, cutting the prism at E. The incident ray
strikes the prism at D, is refracted along D E, and
emerges in the direction E L.

K M L is the angle of deviation.
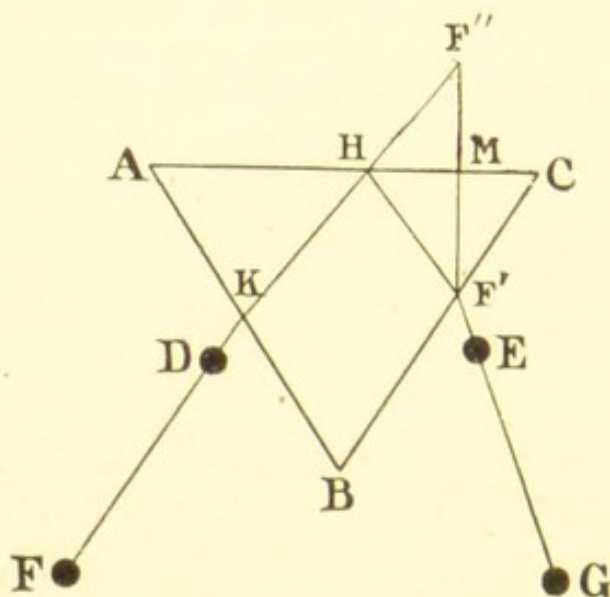
Fig. 228.—Path of totally reflected ray.

6. Trace the path of a totally reflected ray through
a prism (Fig. 228). Trace the base, A B C, of the prism
with a pencil. Insert pins D and E at equal distances
from B. Look along F D for the reflected image of E.
Insert pin F so that F D E are in line. In a similar
way insert pin at G, so that G E D are in line. Join
F D, produce to K, produce G E to F′; from F′ drop
a perpendicular to A C, F″ F′ ; make F′ M = F″ M, and
join F″ K, then K H F′ is the path of the ray through
the prism. It will be noticed that the ray, totally
reflected, is without colour, while the refracted ray is
surrounded by a fringe of colours.

7. To determine the angle of a prism (Fig. 229). Trace the base of the prism A B C, place a pin P some distance away, in the direction G A, place pin D so that the reflection of P in the face B A appears close to A, and D A P are in line; similarly place pin E ; produce B A to F, draw a line through A perpendicular to A B, then angle D A B = B A G, and C A G = C A E,
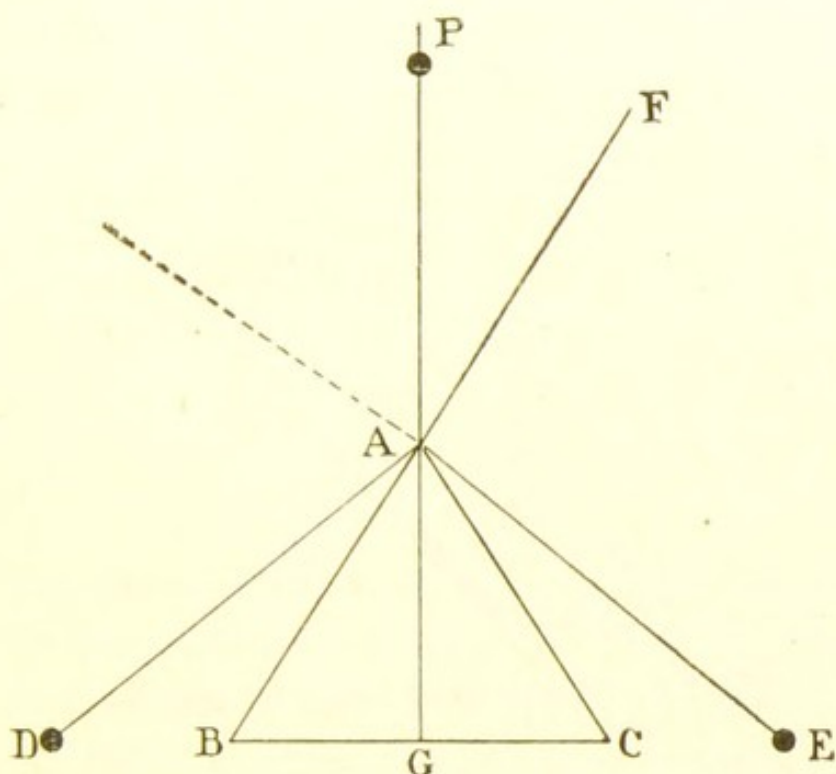
Fig. 229.—Determining angle of prism.

and D A E = 2 B A C, so that the angle of the prism = $\frac{1}{2}$ D A E.

8. Determine the position of the image of a convex lens by parallax. Place two vertical rods—e.g., two retort stands—about 12 inches apart, in front of a window, fix the attention on the farthest rod, and move the head sideways. It will be seen that the

S

farthest rod moves with the head. If the head moves to the right, the farthest rod moves to the right, as compared to the rod nearest the eye. Now fix the attention on the nearest rod and again move the head. This rod will appear to move in the opposite direction to the head; if the head moves to the right the rod moves to the left, etc. So that the more distant of two objects moves with the head, the nearer moves in the reverse direction. If they were equidistant they would, of course, move together.
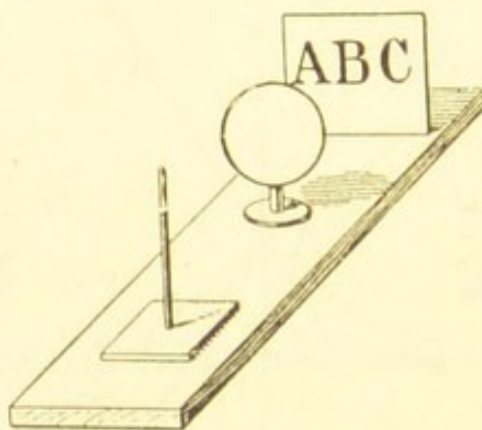
Fig. 230.—Position of image by parallax.

Applying this principle to the lens, set up a row of black letters, say, an alphabet (Fig. 230), place a short focus lens 6 inches in front; on looking through the lens an inverted image of the letters will be seen, the eye being some distance away. Now place a vertical rod between the lens and the eye, and move the head sideways. If the image of the letters is farther away than the rod, the rod will appear to move over the letters in the reverse direction to the

movement of the head; if, on the other hand, the rod is farther away, it will move over the letters in the same direction as the movement of the head. When they are at exactly the same distance the rod will remain on one letter, and move with it to the right or left as the head moves. When this position of the rod is found, substitute a candle for the letters and a screen for the rod, and a sharp image of the candle will be seen on the screen.

9. Demonstrate the images formed by objects at various distances from a convex lens, as shown in Fig. 202, p. 235.

10. Mount two convex lenses to form an astronomical telescope (Fig. 206, p. 237).

11. Determine the focal length of some convex lenses by the various methods given on p. 241 (Fig. 211).

12. Determine the focal length of some concave lenses by the methods given on p. 242 (Fig. 212).

13. Decompose a slit of white light into its constituent colours (p. 245); recompose the colours into a slit of white light by a prism in the reverse position or by a convex lens.

14. Observe with a direct vision spectroscope—

(*a*) a continuous spectrum of a gas flame, etc.;

(*b*) Fraunhofer's lines when the spectroscope is directed to the sky;

(*c*) a bright line spectrum of sodium, calcium, etc.;

(*d*) an absorption spectrum of dilute blood
solution, chlorophyll in alcohol, solutions
of potassium permanganate, didymium
salt, etc. (pp. 247-250. See also coloured
plate).

Section VII.—Sound.

1. Study the vibrating segments and nodes of a
long rope (p. 200). Time your shakings to produce
one vibrating segment without a node, two vibrating
segments with one node, three vibrating segments
with two nodes, etc.

2. Take a tracing of a vibrating tuning fork on a
revolving smoked surface (p. 204); determine the rate
of movement of the surface by timing the number of
revolutions in 5 minutes; then count the number of
vibrations of the tuning fork in a second.

3. Determine the wave-length of a tuning fork by
filling up a jar with water (p. 204); calculate the
wave-length and determine the number of vibrations
per second.

Try the effect of using a wide instead of a narrow
jar.

4. Demonstrate the nodes and vibrating segments
in a string (Fig. 172, p. 201) by placing narrow strips of
paper bent into a V-shape on the string; they will be
thrown off from the vibrating segments but remain
undisturbed on the nodes.

5. Pinch a stretched steel wire in the middle so as to cause it when " bowed " to divide into two vibrating segments and one node, and observe that it gives the upper octave of the fundamental note.

Verify as far as possible the ratios given on p. 201.

APPENDIX.

A.—Table of the Vapour Pressure of Water in Degrees Fahrenheit and Inches of Mercury

0° F.	0.044 in	32° F.	0·181 in.	59° F.	0·500 in.
2	·048	33	·188	60	·518
4	·052	34	·196	61	·537
6	·057	35	·204	62	·556
8	·062	36	·212	63	·576
10	·068	37	·220	64	·596
11	·071	38	·229	65	·617
12	·074	39	·238	66	·639
13	·078	40	·247	67	·661
14	·082	41	·257	68	·684
15	·086	42	·267	69	·708
16	·090	43	·277	70	·733
17	·094	44	·288	71	·759
18	·098	45	·299	72	·785
19	·103	46	311	73	·812
20	·108	47	·323	74	·840
21	·113	48	·335	75	·868
22	·118	49	·348	76	·897
23	·123	50	361	77	·927
24	·129	51	·374	78	·958
25	·135	52	·388	79	·990
26	·141	53	·403	80	1·023
27	·147	54	·418	82	1·092
28	·153	55	433	84	1·165
29	·160	56	·449	86	1·242
30	·167	57	·465	87	1·282
31	·174	58	·482	88	1·323

B.—Table of Glaisher's Factors.

Dry-bulb.	Factor	Dry-bulb.	Factor.	Dry-bulb.	Factor.
10°F.	8·78	40°F.	2·29	70°F.	1·77
12	8·78	42	2·23	72	1·75
14	8·76	44	2·18	74	1 73
16	8·70	46	2 14	76	1·71
18	8·50	48	2·10	78	1·69
20	8·14	50	2·06	80	1·68
22	7·60	52	2·02	82	1·67
24	6·92	54	1·98	84	1 66
26	6·08	56	1·94	86	1·65
28	5·12	58	1·90	88	1 64
30	4·15	60	1·88	90	1·63
32	3·32	62	1·86	92	1·62
34	2·77	64	1·83	94	1·60
36	2·50	66	1·81	96	1·59
38	2·36	68	1·79	98	1·58
				100	1·57

C.—Corrections to be applied to Barometers with Brass Scales to reduce the Observations to 32° Fahrenheit.

Attached Thermometer.	Inches 27	Inches 28	Inches 29	Inches 30	Inches 31
30°F.	− ·004	− ·004	− ·004	− ·004	− ·004
31	·006	006	·007	·007	·007
32	·008	·009	009	·009	·010
33	·011	011	·012	·012	·012
34	·013	·014	·014	·015	·015
35	·016	·016	017	·018	·018
36	·018	·019	·020	·020	·021
37	·021	·021	·022	023	·024
38	·023	·024	·025	·026	·026
39	·025	·026	·027	·028	·029
40	028	·029	·030	·031	·032
41	·030	·031	·033	·034	·035
42	·033	·034	·035	·036	·037
43	·035	036	038	·039	·040
44	·037	·039	·040	·042	·043
45	040	·041	·043	·044	·046
46	·042	·044	045	047	·049
47	·045	·046	048	·050	·051
48	·047	·049	·051	·052	·054
49	·050	·051	053	·055	·057
50	·052	·054	·056	·058	·060
51	054	·056	058	·060	·062
52	.057	059	·061	·063	·065
53	·059	·061	064	·066	·068
54	·062	·064	·066	·068	·071
55	·064	·066	·069	·071	·073
56	− ·066	− ·069	− ·071	− ·074	− ·076

TABLE C—*continued.*

Attached Thermometer.	Inches 27	Inches 28	Inches 29	Inches 30	Inches 31
57° F	− ·069	− ·071	− ·074	− ·076	− ·079
58	·071	·074	·077	·079	·082
59	·074	·076	·079	·082	·085
60	·076	·079	·082	·085	·087
61	·078	·081	·084	·087	·090
62	·081	·084	·087	·090	·093
63	·083	·086	·089	·093	·096
64	·086	·089	·092	·095	·098
65	·088	·091	·095	·098	·101
66	·090	·094	·097	·101	·104
67	·093	·096	·100	·103	·107
68	095	·099	·102	·106	·109
69	·098	·101	·105	·109	·112
70	·100	·104	·108	·111	·115
71	·102	·106	·110	·114	·118
72	·105	·109	·113	·117	120
73	·107	·111	·115	·119	·123
74	·110	114	·118	·122	·126
75	·112	·116	·120	·125	·129
76	·114	·119	·123	·127	·131
77	·117	·121	·126	·130	·134
78	·119	·124	·128	·133	·137
79	·122	126	·131	·135	·140
80	·124	·129	·133	·138	·143
81	·126	·131	·136	·141	·145
82	·129	·134	·138	·143	·148
83	− ·131	− ·136	− ·141	− ·146	− ·151

D.—TABLE OF NATURAL SINES AND TANGENTS.

Arc.	Sine.	Tangent.	
0°	0·000	0·000	90°
1	·017	·017	89
2	·035	·035	88
3	·052	·052	87
4	·070	·070	86
5	·087	·087	85
6	·105	·105	84
7	·122	·123	83
8	·139	·141	82
9	·156	·158	81
10	·174	·176	80
15	·259	·268	75
20	·342	·364	70
25	·423	·466	65
30	·500	·577	60
35	·574	·700	55
40	·643	·839	50
45	·707	1·000	45
50	·766	1·192	40
55	·819	1·428	35
60	·866	1·732	30
65	·906	2·145	25
70	·940	2·747	20
75	·966	3·732	15
80	·985	5·671	10
81	·988	6·314	9
82	·990	7·115	8
83	·993	8·144	7
84	·995	9·574	6
85	·996	11·43	5
86	·998	14·30	4
87	·999	19·08	3
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