ELEMENTARY PHYSICS

FOR

HIGH SCHOOLS

MERCHANT and CHANT

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ELEMENTARY PHYSICS

FOR

HIGH SCHOOLS

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CHAPTER I

MEASUREMENTS

1. Science in Daily Life. During the last fifty years science in all its branches has developed very rapidly, and at the present time its applications have become of the utmost importance in our every-day life. Some of the most prominent of these applications are to be seen in our means of transportation over the land and the water and through the air; and also in the methods of generating, distributing, and utilizing electric energy. Many of to-day's achievements were not even dreamt of by our grandfathers.

Now it may seem strange, but it is none the less true, that this great development came about through our learning to make accurate measurements of the various quantities which enter in our experiments.

2. Fundamental Units. Let us measure a piece of rope. We do so, and find that its length is (say) 52 feet. Here our unit is a *foot*, and it is contained 52 times in the given length. A loaf of bread is said to contain 3 pounds. In this case the unit of *mass* is a *pound*. Again the strength of an electric current is stated as 25 amperes. The unit in this instance is called an *ampere*.

It is evident that there will be as many kinds of units as there are kinds of quantities to be measured; and the magnitude of the units may be just what we choose. But there are three units which we speak of as *fundamental*, namely, the units of *length*, *mass* and *time*. Each is independent of the others and cannot be derived from them. It can also be shown that the measurement of any quantity (for instance, the power of a steam-engine) ultimately depends on the measurement of length, mass and time. Hence these units are properly considered fundamental.

3. Standards of Length,—the Yard. One of the commonest units of length is the *foot.* For centuries it has been used by many nations, but the same name did not always mean the same length. Even in a single nation there was considerable variation, which, however, became greater on passing from one nation to another.

At the present time there are two *standards* of length in use in English-speaking countries, namely, the *yard* and the *metre.*

The yard is said to have represented, originally, the length of the arm of King Henry I., but such a definition will not suffice now. It is defined to be the distance between two lines ruled on two gold plugs in a bronze bar, which is preserved in London, England.

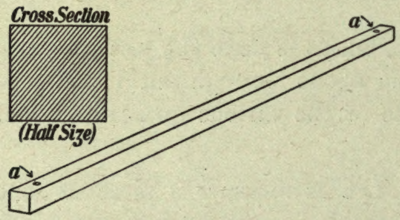

FIG. 1.—Bronze yard, 38 in. long, 1 in. sq. in section. *a, a* are small wells in bar, sunk to mid-depth.

The bronze bar is 38 inches long and has a cross-section one inch square (Fig. 1). At *a, a,* wells are sunk to the mid-depth of the bar, and at the bottom of each well is a gold plug or pin, about $\frac{1}{10}$ inch in diameter, on which the line is engraved.

The inch, the foot, the rod, the mile, etc., are derived from the yard.

4. The Metre. At the end of the 18th century there were in France many standards of length, and it was decided to replace them all by a new unit which was named a *metre.* Its length was intended to be one ten-millionth part of the distance from the pole to the equator, measured through Paris.

The bar, representing this, which was taken as the standard, was completed in 1799. It was made from platinum and is just a metre from end to end, 25 millimetres (about 1 inch) wide and 4 millimetres (about $\frac{1}{6}$ inch) thick.

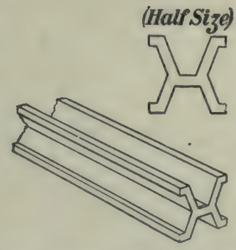

FIG. 2.—View of end and cross-section of the new standard metre bars. The line defining the end of the metre is a short mark on the surface midway between the top and bottom of the bar.

As time passed, great difficulty was experienced in making exact copies of this platinum rod, and as the demand for such continually increased, it was decided to construct a new standard bar of the same length, and to make duplicates for various nations.

The form of the new metre bars is shown in Fig. 2. The material used is a hard and durable alloy composed of platinum 90 parts and iridium 10 parts. The bars are 102 cm. in length over all and 20 square mm. in section.

5. Sub-divisions and Multiples of the Metre. The metre is divided decimally thus:—

1 metre = 10 decimetres = 100 centimetres = 1,000 millimetres.

For greater length multiples of ten are used, thus:—

1 kilometre = 10 hectometres = 100 decametres = 1,000 metres.

The *decametre* and *hectometre* are not often used.

6. Relation between Metres and Yards. In Great Britain the metre is officially stated to contain 39.370113 inches, but in changing from metric to English measures we need not use so many decimal places.

We may take

1 metre = 39.37 inches ; 1 inch = 2.54 centimetres.

It is also useful to remember that, approximately,

10 centimetres = 4 inches ; 30 cm. = 1 foot ; .8 kilometres = 5 miles.

In Fig. 3 is shown a comparison between centimetres and inches.

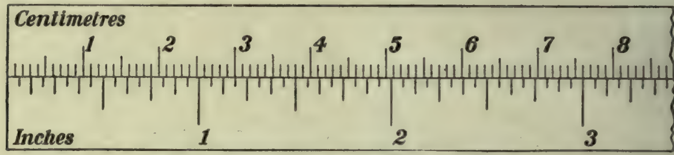

FIG. 3.—Comparison of inches and centimetres.

7. Units of Surface and Volume. The ordinary units of surface and volume (sq. yd., sq. cm., cu. ft., cu. metre, etc.) are at once deduced from the lineal units. The *litre* is a cubic decimetre and hence contains 1,000 cu. cm. As a unit of volume we also use the *imperial gallon*, which is defined to be the volume of 10 pounds of water at 62° F., which is found to be 277.274 cu. inches. (The U. S. or Winchester or wine gallon = 231 cu. in.)

The following relations are also useful:—

1 sq. yd. = 0.836 sq. m.	1 gal. = 4.546 litres.
1 cu. in. = 16.387 cu. cm.	1 litre = 1.76 quarts.

PROBLEMS.

1. How many millimetres in $2\frac{1}{2}$ kilometres?

2. Change 186,330 miles to kilometres. (Light travels 186,330 miles in 1 sec.).

3. How many sq. cm. in a rectangle 54 metres by 60 metres?

4. Change 760 mm. into inches.

5. Reduce 1 cubic metre to litres and to cubic centimetres.

6. Lake Superior is 602 feet above sea level. Express this in metres.

7. Dredging is done at 50 cents per cubic yard. Find the cost per cubic metre.

8. Air weighs 1.293 grams per litre. Find the weight of the air in a room 20 x 25 x 15 metres in dimensions.

9. Which is cheaper, milk at 7 cents per litre or 8 cents per quart?

10. The speed of sound, at 61° F., is 341 metres per second; express this in feet per second.

11. Express, correct to a hundreth of a millimetre, the difference between 12 inches and 30 centimetres.

8. Standards of Mass. We may define the *mass* of a body as the *quantity of matter* in it. According to our present views, matter may change its form, but it can never be destroyed. A lump of matter might be transported to any place in the universe but its mass would remain the same; it would still have the same quantity of matter in it.

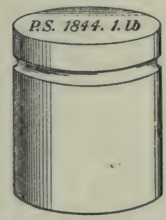

FIG. 4.—Imperial Standard Pound Avoirdupois. Made of platinum. Height 1.35 inches; diameter 1.15 inches. "P.S." stands for *parliamentary standard.*

There are two units of mass in ordinary use, namely, the *pound* and the *kilogram.*

The standard pound avoirdupois is a certain piece of platinum preserved in London, England, of the form shown in Fig. 4. The *grain* is $\frac{1}{7000}$ of the pound and the *ounce* is $\frac{1}{16}$ of the pound or 437.5 grains.

The original standard kilogram was also constructed of platinum, and it is still carefully preserved in Paris. It was intended to represent the mass of 1,000 c.c. (1 litre) of water when at its maximum density (at 4° C.). Thus 1 c.c. of water = 1 gram. Duplicate standard kilograms have been made for various nations out of the platinum-iridium alloy (Fig. 5).

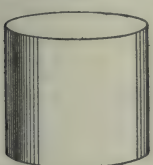

FIG. 5.—Kilogram, made of an alloy of platinum and iridium. Height and diameter each 1.5 inches.

The relation of the pound to the kilogram is officially stated thus:—

1 kilogram (kg.) = 2.2046223 pounds avoir.,

but, as before, in changing from metric to English measures we need not use so many decimal places.

We may take

1 kg. = 2.20 pounds av.; 1 gram = 15.4 grains ; 1 oz. av. = 28.3 grams.

9. Unit of Time. If we reckon from the moment when the sun is on our meridian (noon), until it is on the meridian again, the interval is a *solar day.* But the solar days thus determined are not all exactly equal to each other. In order to get an invariable interval we take the average of all the solar days, and call the day thus obtained a *mean solar day*. Dividing this into 86,400 equal parts we obtain a mean solar *second*. This is the quantity which is "ticked off" by our watches and clocks. It is used universally as the fundamental unit of time.

10. Measurement of Length. A dry-goods merchant unrolls his cloth, and, placing it alongside his yard-stick, measures off the quantity ordered by the customer. Now the yard-stick is intended to be an accurate copy of the standard yard kept at the capital of the country, and this latter we know is an accurate copy of the original preserved in London, England. In order to ensure the accuracy of the merchant's yard-stick a government official periodically inspects it, comparing it with a standard yard which he carries with him.

11. More Accurate Measurements. Suppose next we wish to find accurately the diameter of a ball or of a cylinder. We may use a calliper such as that shown in Fig. 6. The jaws are

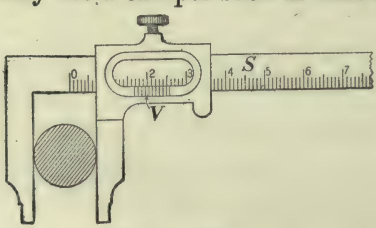

Fig. 6.—Calliper.

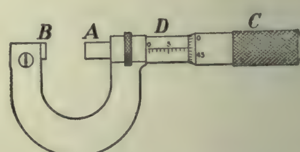

Fig. 7.—Micrometer wire gauge.

pushed up until they just touch the object, and the diameter is read from the graduations on the instrument.

For a small ball or a wire the most convenient instrument is a screw gauge, one of which is illustrated in Fig. 7. *A* is the end of a screw which works in a nut inside of *D*. The screw can be moved back and forth by turning the cap *C* to which it is attached, and which slips over *D*. Upon *D* is a scale, and the end of the cap C is divided into a number of equal parts. By turning the cap the end A moves forward until it reaches the stop B. When this is the case the graduations on D and C both read zero.

In order to measure the diameter of a wire, the end A is screwed up until the wire is just held between A and B. Then from the scales on D and C we can find the diameter required.

There are other devices for accurate measurement of lengths, but in every case the scale, or the screw, or whatever is the essential part of the instrument, must be carefully compared with a good standard before our measurements can be of real value.

12. Measurement of Mass. In Fig. 8 is shown a balance. The pans A and B are suspended from the ends of the beam CD, which can turn easily about a "knife-edge" at E. This is usually a sharp steel edge resting on a steel or an agate plate. The bearings at C and D are made with very little friction, so that the beam turns very freely. A long pointer P extends downwards from the middle of the beam, and its lower end moves over a scale O. When the pans are balanced and the beam is level the pointer is opposite zero on the scale.

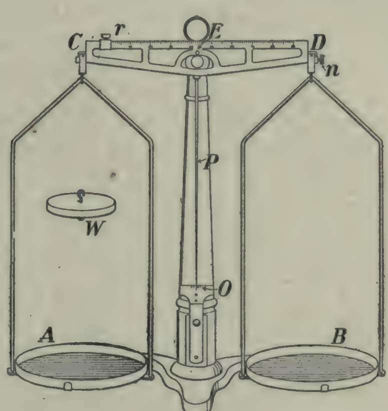

FIG. 8.—A simple and convenient balance. When in equilibrium the pointer P stands at zero on the scale O. The nut n is for adjusting the balance and the small weights, fractions of a gram, are obtained by sliding the rider r along the beam which is graduated. The weight W, if substituted for the pan A, will balance the pan B.

Suppose a lump of matter is placed on pan A. At once it descends and equilibrium is destroyed. It goes downwards because the earth attracts the matter. Now put another lump on pan *B*. If the pan *B* still remains up we say the mass on *A* is heavier than that on *B*; if the pans come to the same level and the pointer stands at zero the two masses are equal.

It is the attraction of the earth upon the masses placed upon the pans which produces the motion of the balance. The attraction of the earth upon a mass is called its *weight*, and so in the balance it is the weights of the bodies which are compared. But if the weights of two bodies are equal their masses are equal, and so the balance allows us to compare masses.

13. Sets of Weights. We have agreed to take a lump of platinum-iridium as our standard of mass (§ 8).

In order to duplicate it we simply place it on one pan of the balance, and by careful filing we make another piece of matter which, when placed on the other pan, will just balance it.

Again, with patience and care two masses can be constructed which will be equal to each other, and which, taken together, will be equal to the original kilogram. Each will be 500 grams.

Continuing, we can produce masses of other denominations, and we may end by having a set consisting of

1,000,				
500,	200,	200,	100	
50,	20,	20,	10	
5,	2,	2,	1	
.5,	.2,	.2,	.1	grams

and even smaller weights.

If now a mass is placed on pan *A* of the balance, by proper combination of these weights we can balance it and thus at once determine its mass.

The balances and the weights used by merchants throughout the country are periodically inspected by a government officer.

14. Rules for the Use of the Balance. The balance should always be handled with care and the following rules be observed :—

1. Keep the balance dry and free from dust.

2. See that the balance is properly adjusted, so that it will, when unloaded, either rest in equilibrium with the pointer at the zero mark on the scale, or will swing equally on either side of zero.

3. Place the body, whose mass is to be ascertained in the left-hand scale-pan, and place the weights in the right-hand scale-pan. Until some experience in judging the mass of a body has been obtained, try all the weights in order, commencing with the largest and omitting none. When any weight causes the right-hand pan to descend remove it. Never select weights at random.

In the balance shown in the figure any addition under 10 grams is obtained by sliding the rider r along the beam. It gives $\frac{1}{10}$ gram directly, and $\frac{1}{10}$ of this may be obtained by estimation.

Before beginning, the balance should be tested. Push the rider r over to its zero mark and then if the pans do not balance (as indicated by the pointer P) turn the nut n until they do.

4. To determine the equilibrium do not wait until the balance comes to rest. When it swings equally on either side of zero, the mass in one pan equals that in the other.

5. Place the largest weight in the centre of the pan, and the others in the order of their denominations.

6. Keep the pans supported when weights are to be added or taken off.

7. Small weights should not be handled with the fingers. Use forceps.

8. Weigh in appropriate vessels substances liable to injure the pans. For counterpoise use shot and paper.

9. Never use the balance in a current of air.

Exercise—Find the value of 1 oz. in grams, 1 kilogram in pounds, 1 quart in c.c. and in litres.

APPARATUS :—*Balance, with both British and metric weights, quart measure, glass vessel graduated in c.c.*

(*a*) Place an ounce weight on the left-hand pan of the balance (Fig. 8) and place metric weights on the right-hand pan to balance it.

(*b*) Next place the kilogram weight on the left pan, and keeping the rider at the zero point, add British weights on the right until they balance the kilogram. Express your result in pounds and decimals.

(*c*) Carefully pour water from the graduated vessel into the quart measure until it is just filled. Then add up the amount poured in. Or, fill the quart measure and empty the water into the glass graduate. Express the quart in c.c. and also in litres. (1 l. = 1,000 c.c.)

15. Density. Let us take equal volumes of lead, aluminium, wood, brass, cork. These may conveniently be cylinders about ½ inch in diameter and 1½ or 2 inches in length.

By simply holding them in the hand we recognize at once that these bodies have different weights and therefore different masses. With the balance and our set of weights we can accurately determine the masses.

We describe the difference between these bodies by saying that they are of different densities, and we define density thus:—

The DENSITY *of a substance is the mass of unit volume of that substance.*

If we use the foot and the pound as units of length and mass, respectively, the density will be expressed by the number of pounds in 1 cubic foot. For example, water at 4° C. has a density 62.4; iron, about 440; white pine, about 26, pounds per cubic foot.

Next let us take 1 cm. and 1 gram as our units of length and mass, respectively, and see what numbers will represent the densities of some substances.

We know that

1 litre of water = 1,000 c.c. = 1 kilogram = 1,000 grams,
or 1 c.c. of water = 1 gram,

and hence in this case the density of water is represented by 1.

The following are the densities of some other substances :— Cast-iron, 7.0 to 7.1; silver, 10.5; mercury, 13.6; white pine, 0.3 to 0.5 grams per c.c.

Note also that if we know the volume and the density of a body we can at once calculate its mass. For example, the volume of a piece of cast aluminium is 150 c.c. and its density is 2.56 grams per c.c. Then the

$$\text{Mass} = 150 \times 2.56 = 384 \text{ grams.}$$

Exercise—Find the volume of a rectangular solid, also its density.

APPARATUS :—*Block of wood, metre stick, balance.*

Apply the metre stick to each *edge* of the block, thus measuring each dimension of the block four times. Take the average; and then, by multiplying the three dimensions together obtain the volume.

Take the measurements in inches as well as in cm., and from the volumes obtained calculate the number of c.c. in 1 cu. in.

Next, weigh the block with the balance, and calculate the number of grams in 1 c.c. of it.

16. Relation between Density and Specific Gravity. We have seen that the number expressing the density of a substance differs according to the units of length and mass which we use.

Specific gravity is defined to be the number of times the weight of a given volume of the substance contains the weight of an equal volume of water. This is expressed by a simple number, which is the same, no matter what units we use.

For example, suppose we have a cubic foot of a substance, and that it weighs 440 lbs. Now the weight of a cubic foot of water is 62.4 lbs.

Then specific gravity $= \frac{440}{62.4} = 7.05$. [What substance is it?]

If we took 2, 3, or any number of cu. ft. we would get the same number for the specific gravity, which we see, therefore, does not depend on the volume of the substance used.

Again, suppose we have 50 c.c. of the substance, which, by means of the balance, we find weighs 352.5 grams. Now 50 c.c. of water weighs 50 grams.

$$\text{Then specific gravity} = \frac{352.5}{50} = 7.05,$$

which is the weight of 1 c.c. of the substance, and is the same as the density when we use these units.

Hence, when we use a centimetre as the unit of length and a gram as the unit of mass, the number representing the specific gravity of a substance is the same as that representing its density.

PROBLEMS

1. Find the mass of 140 c.c. of silver if its density is 10.5 gm. per c.c.

2. The specific gravity of sulphuric acid is 1.85. How much will 100 c.c. weigh? How many c.c. must one take to weigh 100 gm.?

3. A rolled aluminium cylinder is 20 cm. long, 35 mm. in diameter, and its density is 2.7. Find the weight of the cylinder.

4. A piece of granite weighs 83.7 gm. On dropping it into the water in a graduated vessel, the water rises from 130 c.c. to 161 c.c. (Fig. 9). Find the density of the granite.

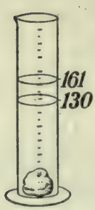

Fig. 9.

5. A tank 50 cm. long, 20 cm. wide and 15 cm. deep is filled with alcohol of density 0.8. Find the weight of the alcohol.

6. A rectangular block of wood 5 x 10 x 20 cm. in dimensions weighs 770 grams. Find the density.

7. The density of anthracite coal is about 54 lbs. and that of bituminous coal about 49 lbs., per cubic foot. A coal bin is 9 x 7½ x 4 ft. in dimensions. Find the number of tons it will hold (*a*) of anthracite, (*b*) of bituminous coal.

8. Write out the following photographic formulas, changing the weights to the metric system :—

DEVELOPER

Water	10 oz.
Metol	7 gr.
Hydroquinone	30 "
Sulphite of Soda (desiccated)	110 "
Carbonate of Soda (desiccated)	200 "
Ten per cent. solution Bromide of Potassium	40 drops

FIXING BATH

Water	64 oz.
Hyposulphite of Soda	16 "

When above is dissolved add the following solution :—

Water	5 "
Sulphite of Soda (desiccated)	½ "
Acetic Acid	3 "
Powdered Alum	1 "

PART II—MECHANICS OF SOLIDS—BODIES AT REST AND IN MOTION

CHAPTER II

Velocity, Acceleration

17. Rest and Motion. When we get out in the open air and look about for a few minutes we see numerous examples of rest and motion. The houses, the fences and the trees are at rest; while the carriages and motor-cars on the road, the railway-train in the distance, or the birds flying across the field, we declare to be in motion.

We agree at once that we can arrange bodies into the two classes, namely, those at rest and those in motion; but a brief consideration will show that this arrangement is not so simple after all,—that, indeed, a body considered from one point of view may be at rest while from another it may be in motion.

Two persons sit together in a railway-train. Each is at rest with respect to the other, but both are in motion with respect to a third person on the ground outside. It is impossible to think of a single object as at rest, which, when looked at in another way, would not be considered to be in motion. Thus motion is quite as natural a state as rest.

18. Velocity or Speed. A body is in motion when it is changing its position; and there is another idea which we usually associate with this change of position, namely, the time taken to do it. This brings in the notion of *speed* or *velocity*. The latter term is often used to include also the *direction* of the motion, while the former refers only to the *rate* at which the body moves. But in this work this distinction will not be insisted on.

Suppose you wish to go from Toronto to Montreal, a distance of 330 miles. You find that one train requires 10 hours, while another one would take 48 hours. You do not hesitate long to choose the one you will use. The rate of motion is of great importance to us.

In the first case the average speed is $330 \div 10 = 33$ miles per hour; in the second case, $330 \div 48 = 6\frac{7}{8}$ miles per hour.

$$\text{Thus we see,} \qquad \text{Speed} = \frac{\text{Space}}{\text{Time}}.$$

Usually the speeds we have to deal with are not constant, the body moves faster at some times than at others. This is well illustrated in the motion of a railway-train. On a long level track the speed is approximately uniform, but on climbing a hill or approaching a station the speed changes.

PROBLEMS

1. A train leaves Winnipeg at 10.40 p.m. and reaches Regina next morning at 9.40 as shown by the same time-piece. The distance is 357 miles. Find the average speed.

2. A train leaves Montreal at 9.45 p.m. Monday and reaches Vancouver on Saturday at 9.10 a.m., Pacific time, which is 3 hours slow of Montreal or Eastern time. The average speed, including stops, was $26\frac{1}{4}$ miles per hour. Find the distance.

3. A train travels at the rate of 60 miles per hour; find the speed in feet per second.

4. An eagle flies at the rate of 30 metres per second; find the speed in kilometres per hour.

5. A sledge party in the arctic regions travels northward, for ten successive days, 10, 12, 9, 16, 4, 15, 8, 16, 13, 7 miles, respectively. Find the average velocity.

6. If at the same time the ice is drifting southward at the rate of 10 yards per minute, find the average velocity northward.

19. Acceleration. We have all enjoyed the sport of coasting down hill on a sleigh or a toboggan. We start off very gently but with every second the speed increases, until at the bottom it is very great. The sleigh then runs up the opposing hill, rapidly loses its speed and finally comes to rest.

When the velocity is not uniform we say the motion is *accelerated.* If there is an increase in the velocity, the acceleration is positive; if a decrease, it is negative. The latter is sometimes called a retardation. On going down hill the acceleration is positive, but when slowing up on the opposite hill it is negative.

Suppose the sleigh is allowed to start from rest (*i.e.*, without being pushed), and that at the end of one second its speed is 2 feet per second; if it continues to gain speed at the same rate, the speed at the end of 2 seconds will be 4 feet per second; at the end of 3 seconds, 6 feet per second; and so on. At the end of 20 seconds the speed will be 40 feet per second. In this case the rate of increase, or the *acceleration*, is uniform, namely, 2 feet per second in each second.

Next, let a stone be thrown upon the ice with a speed of 20 feet per second, and let the friction of the ice gradually reduce the speed by 1 foot a second during every second. Here the acceleration is negative. It is evident that, as the speed during each second is reduced by 1 foot per second, the entire speed will be lost, and the stone will come to rest, in 20 seconds.

We shall consider one more example, namely, that of a freely-falling body, which is a good illustration of uniform acceleration.

Let a stone be dropped from a high tower. As everyone knows, it will rapidly gain in speed. At the end of the 1st second its speed will be about 32 feet per second; in one second more the speed will be 64 feet per second; at the end of the 3rd second it will be 96 feet per second; and so on. At the end of 30 seconds the speed would be 30×32 or 960 feet per second, while in 6 minutes from the beginning it would be $6 \times 60 \times 32 = 11{,}520$ feet, or over two miles per second!

If a body is projected vertically upwards it gradually loses its speed at the same rate, namely, 32 feet per second during every second. Thus if a rifle bullet be shot vertically upwards with a speed of 2000 feet per second, it will lose each second 32 feet per second. At the end of the 1st second the speed will be 1968 feet per second; at the end of the second, 1936; of the 3rd, 1904; and so on; so that it will lose its entire speed in $2000 \div 32 = 62\frac{1}{2}$ seconds. It will then begin to descend, gaining every second a speed of 32 feet per second, and after $62\frac{1}{2}$ seconds it will reach the ground again with a speed of 2000 feet per second.

These results are not accurately true, as we have neglected the resistance of the air, which is considerable when the velocity is high. As a matter of fact, the bullet will lose more than 32 feet per second during the first second going upward.

PROBLEMS

1. A bicyclist coasts down a hill, gaining every second a speed of $1\frac{1}{2}$ feet per second. It takes 16 seconds to go down; find the speed at the bottom; He is then carried up the opposite hill, losing each second 2 feet per second; how long will it take his machine to come to rest?

2. A body falling freely gains per second 980 centimetres per second. Find the velocity at the end of 2, 8, 20 seconds.

3. In playing bowls, a bowl was delivered at the rate of 5 feet per second. If it lost each second $\frac{1}{2}$ foot per second, how long before it came to rest?

4. A base-ball is thrown upwards with a velocity of 60 feet per second. Find its velocity at the end of 1, 2, 3 seconds. How long will it take to reach the ground again?

5. A stone sliding on the ice at the rate of 200 yards per minute is gradually brought to rest in 2 minutes. Find the acceleration in feet and seconds.

20. Space Passed Over. If we know the average speed of a body and the time it has been moving we can easily find the distance it has moved. If it has moved for 5 seconds at the average rate of 90 feet per second, the space passed over is $5 \times 90 = 450$ feet.

Consider now a body dropped from a height and allowed to fall freely. What is the average speed during the first second? At the beginning it is 0 feet per second, and at the end it is 32 feet per second. The increase has been uniform, and so the average is $\frac{1}{2}(0+32)=16$ feet per second. Hence, the space passed over is $1\times16=16$ feet.

It continues to fall, and at the end of 2 seconds the speed is 64 feet per second. The average speed for the first two seconds is $\frac{1}{2}(0+64)=32$ feet per second, and as the time is 2 seconds, the space is $2\times32=64$ feet.

At the end of 3 seconds the velocity is 96 feet per second, and the average is $\frac{1}{2}(0+96)=48$ feet per second. The space passed over in these 3 seconds $=3\times48=144$ feet.

In this way we can calculate the space passed over during any time.

Next, take the case of a body thrown upwards. Let the initial speed be 128 feet per second. At the end of the 1st second this is reduced by 32 feet per second, and hence the speed at that moment is 96 feet per second. The reduction in speed has been uniform, and hence the average speed during this second was $\frac{1}{2}(128+96)=112$ feet per second. Hence during this 1st second the space passed over is $1\times112=112$ feet.

During the 2nd second the speed will be further reduced by 32 feet per second, and at the end of it, will be 64 feet per second. The average speed, then, for the first two seconds is $\frac{1}{2}(128+64)=96$ feet per second, and the space passed over in these 2 seconds $=2\times96=192$ feet.

During the 3rd second the speed will be further reduced by 32 feet per second, and at the end of it, will be 32 feet per second. The average speed for the first three seconds is $\frac{1}{2}(128+32)=80$ feet per second, and the space passed over in these 3 seconds $=3\times80=240$ feet.

The velocity still possessed is 32 feet per second. This will be lost in 1 second; that is, the body will rise for a total of 4 seconds. During this time the average velocity is $\frac{1}{2}(0 + 128) = 64$ feet per second, and the space passed over, or the height to which the body rises, is $4 \times 64 = 256$ feet.

It will then descend, gaining speed in the reverse order, and will reach the ground in 4 sec., or 8 seconds from the time of leaving it.

PROBLEMS

1. A stone is dropped down a well and in $3\frac{1}{2}$ seconds reaches the bottom. Find the speed it had on reaching the bottom and then the depth of the well.

2. A motor-cyclist riding at the rate of 45 miles an hour is thrown off and strikes a telephone pole. First, find his speed in feet per second. Next, find for how long a time a body would have to fall to acquire this speed. Lastly, find the distance the body would have to fall.

3. A stone is thrown on the ice with a speed of 75 feet per second, and the retardation every second is 4 inches per second. Find how long it will move and how far it will go.

4. A body falls freely. Calculate the space passed over in 1, 2, 3, 4, 5 seconds; and then deduce the space passed over in the 1st, 2nd, 3rd, 4th, 5th seconds.

21. All Bodies if Unimpeded Fall at the Same Rate.

This is what Galileo proved in 1590 by letting bodies of various sizes fall from the Leaning Tower of Pisa. Now common observation shows that a piece of lead falls much faster than a feather or a piece of paper. We at once suspect the reason for this however—it is the resistance of the air.

FIG. 10.—Tube to show that a coin and a feather fall in a vacuum with the same acceleration.

If the air were got rid of, these bodies would all fall at the same rate. The long tube shown in Fig. 10 is used for this experiment. Into it are put a coin, or other bit of metal, and a feather, and then by means of an air-pump the air is removed from the tube. If now the tube be quickly turned end for end the two bodies are seen to fall together.

PROBLEMS

Unless otherwise stated, take as the measure of the acceleration of gravity, with centimetres and seconds, 980 ; with feet and seconds, 32.

1. A body moves 1, 3, 5, 7 feet during the 1st, 2nd, 3rd, 4th seconds, respectively. Find the average speed.

2. Express a speed of 36 kilometres per hour in cm. per second.

3. A body falls freely for 6 seconds. Find the velocity at the end of that time, and the space passed over.

4. The velocity of a body at a certain instant is 40 cm. per sec., and its acceleration is 5 cm. per sec. per sec. What will be its velocity half-a-minute later?

5. What initial speed upwards must be given to a body that it may rise for 4 seconds?

6. The Eiffel Tower is 300 metres high, and the tower of the City Hall, Toronto, is 305 feet high. How long will a body take to fall from the top of each tower to the earth?

7. On the moon the acceleration of gravity is approximately one-sixth that on the earth. If on the moon a body were thrown vertically upwards with a velocity of 96 feet per second, how high would it rise, and how long would it take to return to its point of projection?

8. A body moving with uniform acceleration has a velocity of 10 feet per second. A minute later its velocity is 40 feet per second. What is the acceleration?

CHAPTER III

Momentum, Force

22. Mass and Velocity Combined. Let us take a base-ball, which weighs about 5 ounces, and a hollow rubber ball of about the same diameter but weighing only about one ounce, and 'play catch' with them. The pitcher may deliver them to us with the same velocity, but there is a decided difference when we catch the two balls. The blow given by the base-ball is much more powerful than that given by the other ball. A solid iron ball going with the same speed would give a still more powerful blow and would be dangerous to catch.

We say that the *quantity of motion* is greater in one case than in the other.

On what does this quantity of motion depend? We have supposed that the speed was the same in each case, and hence in this instance the difference in the effect must be due to the difference in the masses of the balls. The base-ball has a mass five times that of the rubber ball.

Now suppose we reduce the speed of the base-ball. Let us toss it gently but still deliver the rubber ball with considerable speed. One can have quite as much motion as the other, and we conclude that quantity of motion depends on the mass and the velocity taken together.

23. Momentum. A special name has been given to this quantity of motion; it is called *momentum*.

If the mass of the rubber ball is 1 oz. and its velocity 60 feet per second, its momentum would be represented by $1 \times 60 = 60$. The mass of the base-ball is 5 oz., and to have the same momentum its velocity need be only 12 feet per second, as $5 \times 12 = 60$.

Momentum = Mass × Velocity.

This notion of momentum is a very important one and should be thoroughly understood.

A row-boat may strike a dock head-on with considerable speed and do little or no damage to it; but if a large ocean liner should strike it in the same way the dock might be cut in two. It is the momentum which does the damage.

A modern 12-inch gun fires a projectile of 850 lbs. with a velocity of 2,900 feet per second. The momentum is enormous, and we are not surprised when the shot crushes through massive fortifications or penetrates the most heavily armoured ship.

PROBLEMS

1. A man weighing 150 lbs. and running with a velocity of 6 feet per second collides with a boy weighing 90 lbs. and moving with a velocity of 9 feet per second. Which has the greater momentum?

2. Compare the momentum of a car weighing 50,000 kilograms and moving with a velocity of 30 kilometres per hour with that of a cannon-ball weighing 20,000 grams and moving with a velocity of 50,000 centimetres per second.

3. A pebble weighing $\frac{1}{2}$ ounce falls freely down a mine shaft for 8 seconds. Compare its momentum with that of a 20 lb. weight thrown with a velocity of 5 feet per second.

4. A gale of 60 miles per hour striking one's hand or cheek does no damage, but if the air is laden with sand it does. Explain this.

24. Force. Let us return again to our base-ball. Consider it lying on the ground. It is evident that if no outside agent interferes, it will continue to lie there at rest.

Next, throw it along the ground. It rolls for a while and then comes to rest; but the smoother the ground is, the longer it continues to move. If it is thrown along a level asphalt pavement it rolls a much longer time and moves much further. If we throw it along good smooth ice it rolls further still—several times as far as on the ground.

We see that the smoother the surface is (*i.e.*, the less the friction) the longer the ball continues to move. What would happen if the surface were *perfectly* smooth and level, *i.e.*, had no friction at all? Of course no one has ever seen such a surface, but we can easily conceive what would happen if we had one. The ball would continue to move at the same rate.

Suppose the base-ball were taken far off in space, away from the influence of sun and planets, and were thrown in any direction with a certain speed, it would continue to move in that same direction with the same speed.

Now in all our experience we have never known of any body which was moving all the time in a single direction with a perfectly constant speed. Why not? In explanation we say that some *Force* has been acting on it and has changed its motion.

We can state our conclusions in the following words:

Every body continues in its state of rest or of uniform motion in a straight line unless it be compelled by external FORCE *to change its state.*

This is known as Newton's First Law of Motion. You see it is just a brief statement of our experience.

25. Force and Momentum. Just as we found that it required greater effort to stop the base-ball than the hollow rubber ball, so it requires a greater effort or greater *force* to put it in motion. To throw a heavy stone requires much greater force than to throw a light one with the same velocity. It is really the quantity of motion, or the momentum, which we must consider. To produce or to destroy much momentum (in a given time) requires the application of a great force. If a definite amount of momentum is produced or destroyed by a certain force, then to produce or destroy one, two, three or a hundred times that amount of momentum we must exert one, two, three or a hundred times the force.

Further, it is evident that the change in the momentum of a body will take place in the direction in which the force acts. A falling body continually increases its momentum since the force of gravity acts in the direction of the motion. If it is thrown upwards the momentum is continually decreased because the force is acting in a direction opposite to the motion.

We can state our conclusions in the following way:

Change of momentum, in a given time, is proportional to the impressed force and takes place in the direction in which the force acts.

This is called Newton's Second Law of Motion.

PROBLEM

1. A tug begins to tow a steamer of mass 2,000 tons and in 10 minutes gives it a velocity of 8 feet per second. If it had been a 6,000-ton vessel, what velocity would have been given in this time?

26. Motion of the Planets. The orbit of the earth about the sun is an ellipse, which, however, is almost a circle. Its speed is about 18½ miles per second.

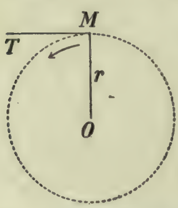

Fig. 11.—Orbit of earth about the sun. O is the sun; the earth is at M.

As we have seen, if the sun (and the other heavenly bodies) were absent, the earth would move along the straight line MT (Fig. 11) at a uniform rate. But the sun at O exerts an attractive force on it and produces a motion towards O, *i.e.*, in the direction of the force. The earth continually tends to move along the tangent, but the force towards the centre is just enough to cause it to bend into its elliptical orbit.

27. Action and Reaction. Let a cord be attached to each end of a spring balance and let two boys take hold and pull in opposite directions until the balance shows a tension of (say)

20 pounds. It is evident that the pull of the first boy on the second is precisely equal to the pull of the second on the first.

If the second boy ties his cord to a post and the first boy pulls again, it is evident that the post will pull the boy just as much as the boy pulls the post.

If a pole of one magnet attracts a pole of a second magnet, the latter exerts an equal attraction on the first. We cannot detect any material cords or rods connecting the two poles, but it is probable, nevertheless, that there is something in the space between the two poles, which has to do with the action.

Again, if you jump from a row-boat you must be careful as the boat goes back while you go forward.

We can state a general principle which embodies all the above observations, thus:

To every action there is always an equal and opposite re-action.

This is known as Newton's Third Law of Motion.

28. Experimental Illustration of Action and Re-action. Suspend two exactly similar ivory or steel balls side by side as in Fig. 12. Now draw A aside to C and let it go. On striking B, A is at once brought to rest, while B starts off with a velocity equal to that which A had, and it swings out to D. Here we may consider the *action* to be the forward movement given to B, while the *re-action* is the equal momentum in the opposite direction, which just brings A to rest.

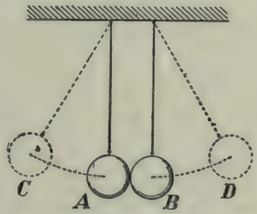

FIG. 12.—The action of A on B is equal to the re-action of B on A.

Suppose now we use soft wax balls which will stick together when they collide. In this case they both move off with half the velocity which A had on striking B. Here A gives up half its momentum and B takes it.

PROBLEMS

1. When an apple falls to the ground does the earth rise to meet it? If it does, why do we not see it?

2. A rifle weighing 8 lbs. delivers a bullet weighing 1 ounce with a velocity of 1,500 feet per second. Find the velocity with which the gun recoils.

3. A hollow iron sphere is filled with gunpowder and exploded. It bursts into two parts, one part being one-quarter of the whole. If the velocity of the larger part is 20 feet per second, what is the velocity of the other?

4. If the sphere B (Fig. 12) has a mass twice as great as A, what will happen (1) when A and B are of ivory? (2) when they are of sticky putty?

29. Combination of Forces. If two forces act on a body in the same direction we simply add them together to get the combined effect. If they act in the same line but in opposite directions, we simply subtract them; but if they act at an angle the resultant is not so easily determined. It can be found, however, in the manner illustrated in the following exercise:

Exercise—Find the resultant of two forces acting at a point (Parallelogram of Forces).

APPARATUS :—*Spring-balances, small ring, cord.*

Fasten three cords (fish-line) to a small ring, and hook spring-balances on the other ends of the cords (Fig. 13). By means of pins in the top of the table, over which the rings of the balances may be placed, or in any other convenient way, exert force on the balances so that the cords are under considerable tension. The balances should move free of the table top.

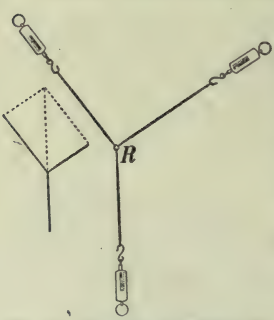

FIG. 13.—Diagram illustrating the parallelogram of forces.

Pin a sheet of paper under the strings and mark a dot precisely at R, the centre of the ring; also make dots exactly under each string and as far from R as possible.

Read each balance, then remove them. With great care draw lines from R through the points under the cords, and on these lines take distances proportional to the tensions of the corresponding strings. Thus if the tensions be 1,000, 1,500, 2,000 grams, take lengths 10, 15, 20 cm.

Using any two of these lines as adjacent sides, complete a parallelogram, taking care to have the opposite sides accurately parallel. Draw the diagonal between these sides and carefully measure its length. Compare it as to length and direction with the third line.

From this experiment we find that if two forces act upon a body and we represent them in magnitude and direction by two lines drawn from a point, then the resultant of the two forces will be represented by the diagonal of the parallelogram which has the two lines as adjacent sides.

CHAPTER IV

Gravitation

30. The Law of Gravitation. There is nothing which we are more certain of than that a body, if unsupported, will fall. The reason we assign for it is, that the earth attracts all bodies to itself.

Down in our deepest mines the earth still attracts bodies towards its centre, and no balloon or aeroplane rises so high that the earth does not pull it back. How far, then, does the earth's attractive force extend? Does it reach as far as the moon, which is about 240,000 miles away?

We believe that it does. Newton showed that the attraction of the earth would account for the motion of the moon about it; and, indeed, that the attraction proceeding from the sun would account for the motions of the earth and all the other planets in their orbits. This force of attraction is called *gravitation*.

31. All Bodies Attract Each Other. Let us pick up two stones from the earth's surface, one in each hand. We know that the earth attracts them as it requires a muscular effort to overcome their weight. The question naturally rises, as we hold the two stones before us, does each stone attract the other? Newton stated that *all bodies in the universe attract each other.*

Suppose, then, that we place two small perfectly made steel balls on a smooth level surface (Fig. 14). If Newton's statement is true, why do not the balls come together?

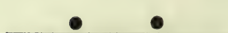

Fig. 14.—Two small balls on a level surface.

The reason is, the force of attraction between them is so small that it cannot overcome the friction of the surface on which the balls rest. Suppose the mass of each ball to be 1 gram and that their centres are 1 cm. apart. Then the attraction between the balls is really so small that we cannot conceive of it, but let us represent it by 1.

Suppose, next, that for one ball we substitute another of 2 grams mass. The attraction is doubled or is 2. If for the second ball also we substitute one of two grams mass, the attraction will be doubled again, or it will be $2 \times 2 = 4$. If the masses of the two balls are 10 grams and 15 grams, respectively (the distance between their centres still being 1 cm.), the attraction between them will be $10 \times 15 = 150$.

Next, let us consider the effect of separating the two balls. Let their distance apart be made 2 cm. Then the attraction is not $\frac{1}{2}$, but $\frac{1}{4}$; if the distance is 3 cm., the force of attraction is $\frac{1}{9}$; if the distance is 10 cm., the force becomes $\frac{1}{100}$; and so on.

Though the attraction between ordinary masses of matter is very small, yet it has been measured many times, and the law which has just been explained has been shown to be true.

32. The Weight of a Body. Consider a mass m at A, on the earth's surface. The attraction of the earth on this mass is what we call its *weight*. If m is a pound-mass, the attraction of the earth on it, or its weight, is a pound-force; if it is a gram-mass, the attraction is a gram-force.

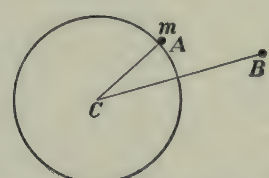

FIG. 15.—Attraction of the earth on a mass on its surface and also twice as far away from the centre.

Now it can be proved that a sphere attracts as though all the matter in it were concentrated at its centre. Consider, then, the earth as concentrated at C and that m is a pound-mass at A, 4,000 miles from C. The attraction on it is 1 pound-force. Next, imagine it taken out to B, a distance of

8,000 miles. The attraction of it is now $\frac{1}{4}$ of a pound-force. If it is removed to 12,000 miles, or 3 times as far, the attraction is $\frac{1}{9}$; and so on.

The moon's diameter is 2,163 miles, its density is about $\frac{6}{10}$ that of the earth, and it is found that gravitation on the moon is only about $\frac{1}{6}$ that on the earth. Hence, if we could visit the moon, retaining our muscular strength, we would be able to lift a 300 lb. mass as easily as a 50 lb. mass here. If we should play base-ball we would find that to throw a ball with a velocity of 50 feet per second, or to stop it, would require just as much effort as here on the earth, but the ball would travel six times as far before coming down to the surface.

PROBLEMS

1. If the earth's mass were doubled without any change in its dimensions, how would the weight of a pound-mass vary?

Could one use ordinary balances and the same weights as we use now?

2. Find the weight of a body of mass 100 kilograms at 6,000, 8,000, 10,000 miles from the earth's centre.

3. The attraction of the earth on a mass at one of its poles is greater than at the equator. Why is this?

4. A spring-balance would have to be used to compare the weight of a body on the sun or the moon with its weight on the earth. Explain why?

CHAPTER V

Work and Energy

33. Meaning of Work. Suppose we draw water from a cistern by means of a bucket on the end of a rope; in doing this we feel that we do a certain amount of work. Similarly, when bricks or other materials are hoisted during the erection of a building, work is done. Again, when land is ploughed, or when a blacksmith files a piece of iron, or when a carpenter planes a board, work is done.

If we analyse each of these cases we find that there are always two factors which enter in the performance of work, namely, *force exerted* and *space* through which it is exerted.

In the case of the water and the building materials, the force exerted is just sufficient to overcome the attraction of the earth, *i.e.*, their weight; while in the other cases sufficient force is exerted to cause the plough or the file or the plane to move forward.

In each case the force acts through a certain space—namely, that through which the water, the bricks, the plough, the file or the plane moved.

$$\text{Work done} = \text{Force exerted} \times \text{Space.}$$

34. Units of Work. In measuring work we must choose a unit of force and a unit of length, and these may be as large or small as we please. If we take as unit of force a pound-force and as unit of length a foot, the unit of work is a foot-pound. If we take a ton as unit of force and a yard as unit of length, we shall measure work in ton-yards.

If 2,000 pounds mass is raised through 40 feet, the work done is $2{,}000 \times 40 = 80{,}000$ foot-pounds.

If 500 kilograms are raised through 20 metres the work done is $500 \times 20 = 10{,}000$ kilogram-metres.

Similarly for any other units we choose.

35. How to Calculate Work. A half-bag of flour, 49 pounds, has to be carried from the foot to the top of a cliff, which has a vertical face and is 50 feet high.

There are three paths from the base to the summit of the cliff. The first is by way of a vertical ladder fastened to the face of the cliff. The second is a zig-zag path 150 feet long, and the third is also a zig-zag route, 400 feet long.

Here a person might strap the mass to be carried to his back and climb vertically up the ladder, or take either of the other two routes. The distances passed through are 50 feet, 150 feet, 400 feet, respectively, but the result is the same in the end, the mass is raised through 50 feet.

The force required to lift the mass is 49 pounds-force, and it acts in the vertical direction. The distance *in this direction* through which the body is moved is 50 feet, and therefore the

$$\text{Work} = 49 \times 50 = 2{,}450 \text{ foot-pounds.}$$

Along the zig-zag paths the effort required to carry the mass is not so great, but the length of path is greater and so the total work is the same in the end.

PROBLEMS

1. Find the work done in exerting a force of 1,000 grams through a space of 1 metre.

2. A block of stone rests on a horizontal pavement. A spring-balance inserted in a rope attached to it, shows that to drag the stone requires a force of 90 pounds. If it is dragged through 20 feet, what is the work done?

3. The weight of a pile driver, of 2,500 pounds-mass, was raised through 20 feet. How much work was required?

4. A coil-spring, naturally 30 centimetres long, is compressed until it is 10 centimetres long, the average force exerted being 200 grams. Find the work done in kilogram-metres.

5. Two men are cutting logs with a cross-cut saw. To move the saw requires a force of 50 pounds, and 50 strokes are made per minute, the length of each being 2 feet. Find the amount of work done by each man in one hour.

6. To push his cart a banana man must exert a force of 50 pounds. How much work does he do in travelling 2 miles?

36. Definition of Energy. A log, known as a pile, the lower end of which is pointed, stands upright, and it is desired to push it into the earth. To do so requires a great force, and therefore the performance of great work.

The method of doing it is familiar to all. A heavy block of iron is raised to a considerable height and allowed to fall upon the top of the log, which is thus pushed downwards. Successive blows drive the pile further and further into the earth, until it is down far enough.

In this case work is done in thrusting the pile into its place, and this work is supplied by the pile-driver weight. It is evident then, that a heavy body raised to a height is able to do work.

Ability to do work is called ENERGY.

The iron block in its elevated position has energy. As it descends it gives up this high position, and acquires velocity. Just before striking the pile it has a great velocity, and this velocity is used up in pushing the pile into the earth. It is clear, then, that a body in motion also possesses energy.

We see, thus, that there are two kinds of energy:

(1) Energy of position or *potential* energy.

(2) Energy of motion or *kinetic* energy.

37. Transformations of Energy. Energy may appear in different forms, but if closely analysed it will be found that it is always either energy of position, *i.e.*, potential energy, or energy of motion, *i.e.*, kinetic energy.

The various effects due to heat, light, sound and electricity are manifestations of energy, and one of the greatest achievements of modern science was the demonstration of the Principle of the Conservation of Energy. According to this doctrine, *the sum total of the energy in the universe remains the same.* It may change from one form to another, but none of it is ever destroyed.

A pendulum illustrates well the transformation and conservation of energy. First let it hang at rest. Then take hold of the bob and pull it aside. In doing so the bob is raised and you give potential energy to it. Now let it go. As it falls it gradually gives up this potential energy and at its lowest point this potential energy is entirely changed into kinetic energy.

38. Matter, Energy, Force. There are two fundamental propositions in physical science:

(1) Matter cannot be destroyed.

(2) Energy cannot be destroyed.

The former lies at the basis of analytical chemistry; the latter at the basis of physics. It is to be observed, also, that matter is the vehicle or receptacle of energy.

Force, on the other hand, is of an entirely different nature. On pulling a string a force (tension) is exerted in it, which completely disappears when we let it go. Energy is bought and sold, force cannot be.

39. Power. A man, unaided, might perform the great work of excavating 100,000 cubic yards of earth, but it would take a long time to do it. If we wish to have it done quickly we must employ greater *power*, or *activity* or *rate of doing work.*

A machine is rated as of 1 *horse-power* if it can do 33,000 foot-pounds of work per minute, or 550 foot-pounds per second.

In calculating the power of an electric dynamo it is found more convenient to use another unit known as a *watt,* and 1 kilowatt = 1,000 watts.

Also, it is found, that 746 watts = 1 horse-power.

PROBLEMS

1. An engine is able to hoist a bucket from the bottom of a mine 400 feet deep once every minute. If each load is 1,000 pounds, find the horse-power of the engine.

2. A labourer digging a drain throws up 4 shovelfuls a minute, raising it a height of 6 feet. If the average weight of each shovelful is 20 pounds, find his rate of working in horse-power.

3. A dynamo is rated as 40 kilowatt ; find the equivalent of this in horse-power.

CHAPTER VI

CENTRE OF GRAVITY

40. Definition of Centre of Gravity. Each particle of a body is attracted to the earth by gravitation. The direction of each little force is towards the centre of the earth, and hence the lines of action are not absolutely parallel. But the angles between them are so very small that we usually speak of the weights of the various particles as a set of parallel forces.

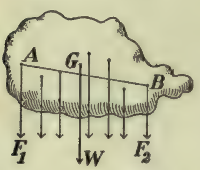

FIG. 16.—The weight of a body acts at its centre of gravity.

The sum of all these little forces is the weight of the body, and *the point G* (Fig. 16) *where the weight acts is called the* CENTRE OF GRAVITY *of the body.* If the body be supported at this point it will rest in equilibrium in any position, that is, if the body is moved about into any position it will stay there.

41. To find the Centre of Gravity Experimentally. Suspend the body by a cord attached to any point A of it.

Then its weight acting at G and the tension of the string acting upwards at A will rotate the body until the point G comes directly beneath A, and the line GW is coincident with the direction of the supporting cord (Fig. 17).

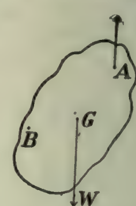

FIG. 17.—How to find the centre of gravity of a body of any form.

Thus if the body is suspended at A, and allowed to come to rest, the direction of the supporting cord will pass through the centre of gravity.

Next let the body be suspended at B. The direction of the supporting cord will again pass through the centre of gravity, which is, therefore, where the two lines meet.

Exercise—Find the centre of gravity of a flat body.

APPARATUS :—*Piece of sheet metal or thin board, cord, small weight.*

First, punch a hole at two points A, B (Fig. 18), near the edge of the body. Support the body at A by means of a pin or a nail driven in the wall, and from the pin let a cord hang down with a small weight on its end. Chalk the cord and then snap it on the plate : it will make a white line across it.

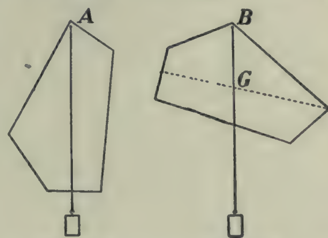

FIG. 18*a* FIG. 18*b*
How to find the centre of gravity of a flat body.

Next, support the body from B (Fig. 18*b*) and obtain another chalk line. At G, the point of intersection of these two lines, is the centre of gravity.

42. Bodies of Simple Form. The centre of gravity of some bodies of simple form can often be deduced from geometrical considerations.

FIG. 19.—Centre of gravity of a uniform rod.

For a straight uniform bar AB (Fig. 19), the centre of gravity is midway between the ends. For a parallelogram, it is at the intersection of the diagonals. (Fig. 20.) For a cube or a sphere, it is at the centre of figure.

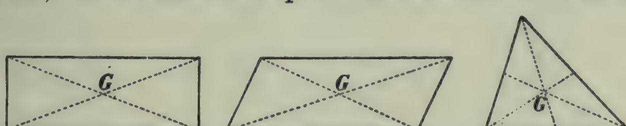

FIG. 20.—Centre of gravity of a parallelogram and a triangle.

For a triangle, it is where the three median lines intersect. (Fig. 20.)

Exercise—Find the centre of gravity and the weight of a graduated rod.

Lay the rod on the edge of the prism (Fig. 21) and observe the graduation C where it balances. The centre of gravity is at this place. Next rest the rod on the prism at another place in its length, and move a weight W along it until it balances again. Now the weight of the rod may be considered as

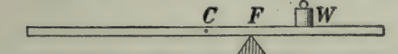

FIG. 21—Finding the centre of gravity of a rod and its weight.

acting at C. Hence the weight of the rod acting at a distance CF from F balances the weight W acting at the distance WF from F. Hence

$$\text{Weight of rod} \times CF = \text{weight } W \times WF.$$

From the graduations on the rod (or by measuring), the distance CF and WF are obtained and the weight of the rod can be deduced at once.

Vary the weight W and the distance WF and obtain at least 5 results. Arrange them in a table and take the average.

43. Condition for Equilibrium. For a body to rest in equilibrium on a plane, the line of action of the weight must

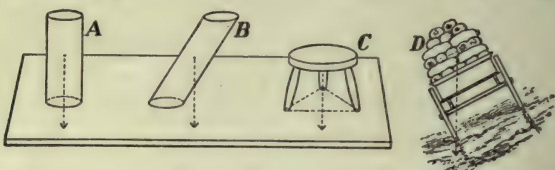

FIG. 22.—A and C are in stable equilibrium ; B is not, it will topple over ; D is in the critical position.

fall within the supporting base, which is the space within a cord drawn about the points of support. (See Fig. 22.)

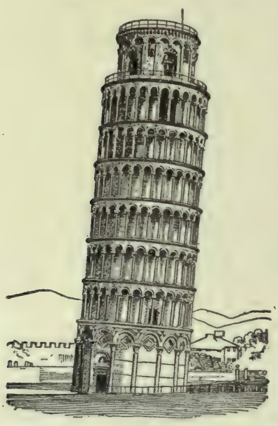

FIG. 23.—The Leaning Tower of Pisa. It overhangs its base more than 13 feet, but it is stable. (Drawn from a photograph.)

The famous Leaning Tower of Pisa is an interesting case of stability of equilibrium. It is circular in plan, 51 feet in diameter and 172 feet high, and has eight stages, including the belfry. Its construction was begun in 1174. It was founded on wooden piles driven in boggy ground, and when it had been carried up 35 feet it began to settle to one side. The tower overhangs the base upwards of 13 feet, but the centre of gravity is so low down that a vertical through it falls within the base and hence the equilibrium is stable.

44. The Three States of Equilibrium. We all know how hard it is to stand an egg on end. With sufficient patience it can be done, but the slightest displacement causes the egg to turn over and lie on its side. An egg on end is said to be in *unstable* equilibrium.

If, however, when the egg is lying on its side we displace it in an oval section (*i.e.*, as though we are going to turn it on end) and then let go, the egg returns to its former position. In this case the equilibrium is said to be *stable.*

Next, roll the egg in a circular section. It shows no tendency to return to its former position, but stays where it is put. The equilibrium is said to be *neutral.*

Thus an egg exhibits the three states of equilibrium, *stable, unstable* and *neutral* (Fig. 24).

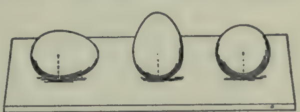

FIG. 24.—Stable, unstable and neutral equilibrium.

Notice that the centre of gravity always tends to take as low a position as possible. If a body is in stable equilibrium a slight motion raises its centre of gravity and on letting it go the body tends to return to its original position. But if it is in unstable equilibrium a slight motion allows it to move to a new position in which the centre of gravity is lower than before. If it is in neutral equilibrium motion does not raise or lower its centre of gravity.

A round pencil lying on its side is in neutral equilibrium; balanced on its end, it is unstable. A cube, or a brick, lying on a face, is stable.

The amount of stability possessed by a body resting on a horizontal plane varies in different cases. It increases with the distance through which the centre of gravity has to be raised in order to make the body tip over. Thus, a brick lying on its largest face is more stable than when lying on its smallest.

PROBLEMS

1. Why is a pyramid a very stable structure?

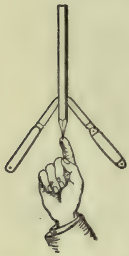

Fig. 25.—Why is the pencil in equilibrium.

2. Why is ballast used in a vessel? Where should it be put?

3. Why should a passenger in a canoe sit on the bottom?

4. A pencil will not stand on its point, but if two pen-knives are fastened to it (Fig. 25) it will balance on one's finger. Explain why this is so.

5. A uniform iron bar weighs 4 pounds per foot of its length. A weight of 5 pounds is hung from one end, and the rod balances about a point which is 2 feet from that end. Find the length of the bar.

6. Illustrate the three states of equilibrium by a cone lying on a horizontal table.

CHAPTER VII

FRICTION

45. Friction Stops Motion. A stone thrown along the ice will, if "left to itself," come to rest. A railway-train on a level track, or an ocean steamship will, if the steam is shut off, in time come to rest. Here much energy of motion disappears and no gain of energy of position takes its place. In the same way all the machinery of a factory when the "power" is turned off soon comes to rest.

In all these cases the energy simply seems to disappear and be *wasted*. As we shall see later, it is transformed into energy of another form, namely, heat, but it is done in such a way that we cannot utilize it.

The stopping of the motion in every instance given is due to *friction*. When one body slides or rolls over another there is always friction, which acts as a force in opposition to the motion.

46. Every Surface is Rough. The smoothest surface, when examined with a powerful microscope, is seen to have numerous little projections and cavities on it (Fig. 26). Hence when two surfaces are pressed together there is a kind of interlocking of these irregularities which resists the motion of one over the other.

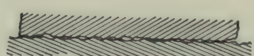
FIG. 26.—Roughness of a surface as seen under a microscope.

47. Rolling Friction. When a wheel or a sphere rolls on a plane surface the resistance to the motion produced at the point of contact is said to be due to *rolling* friction. This, however, is very different from the friction just discussed, as there is no sliding. A wheel, where it rests on a surface, is slightly flattened, and it also makes a depression in the surface. As it rolls along it must continually climb out of this depression. But rolling friction is much smaller than sliding friction.

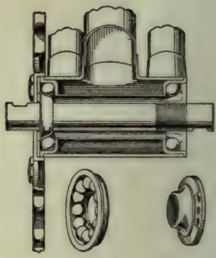

FIG. 28.—Section of the crank of a bicycle. The cup which holds the balls and the cone on which they run are shown separately below. Here the balls touch the cup in two points and the cone in one; it is a "three-point" bearing.

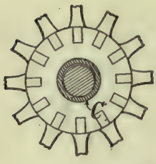

FIG. 27. — Section through a carriage hub, showing an ordinary bearing.

In ordinary wheels, however, sliding friction is not avoided. In the case of the hub of a carriage (Fig. 27) there is sliding friction at the point C.

In ball-bearings (Fig. 28), which are much used in bicycles, automobiles and other high-class machines, the sliding friction is almost completely replaced by rolling friction, as this kind of bearing has great advantages over the other.

PROBLEMS

1. Explain the utility of friction in

(*a*) Locomotive wheels on a railway track. (*b*) Leather belts for transmitting power. (*c*) Brakes to stop a moving car.

2. The current of a river is less rapid near its banks than in mid-stream. Can you explain this?

3. Give two reasons why it is more difficult to start a heavily-laden cart than to keep it in motion after it has started.

CHAPTER VIII

MACHINES

48. Machines. If we want to cut a field of grain or saw a log into lumber, or separate the cream from the milk, we use a machine made for the purpose. Indeed, we have now so many mechanical contrivances, devised for all sorts of occasions, that this time in which we live may properly be called the age of machines.

Some of these machines are simple while others are quite complicated, but if we examine them carefully we shall find that the mechanical principles which enter into their construction are really few in number. We shall consider some of them.

49. The Lever; First Class. Suppose we have to raise a heavy stone. We get a stiff rod, perhaps a crow-bar, thrust one end B of it (Fig. 29) under an edge of the stone, place a block at O under the rod, and then press downwards on the end A. Such a rod is called a *lever* and the block placed under it is the *fulcrum*.

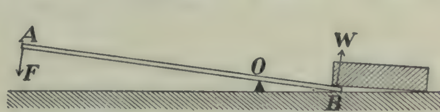

FIG. 29.—Lever of the first class.

Further, let the force which must be exerted at B to raise the stone be W, while that which must be applied at A in order to do so is F.

The lengths AO, BO are called the arms of the lever, and we know from experiment that if AO is twice BO, then the force F is $\frac{1}{2}$ the force W; if AO is three times BO, then the force applied is $\frac{1}{3}$ the force obtained; and so on.

We may state the general *law of the lever* thus:

$$\text{Force applied} \times \text{its arm} = \text{Force obtained} \times \text{its arm},$$
$$\text{or} \qquad F \times AO = W \times BO.$$

Also, the force obtained divided by the force applied is called the *mechanical advantage.* If the force obtained is ten times the force applied the mechanical advantage is 10.

A lever like that just described, in which the fulcrum is between the points where the force is applied and the force is obtained is said to be of the *first class.*

It will be noticed that if the force W is greater than the force F, the point A moves through a greater distance than the point B. What is gained in force is lost in distance moved through.

PROBLEMS

1. Let the lever AB (Fig. 29) be 40 inches long, the arm OB being 4 inches. What is the mechanical advantage? If a force of 50 pounds be applied at F, what force will be obtained at B?

2. In a pair of shears (Fig. 30) a cord to be cut is 2 inches, and the fingers are 5 inches from the pivot. If the fingers exert a force of 6 ounces, what force will be obtained to cut the cord?

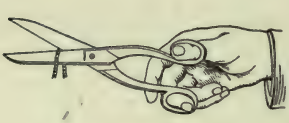

FIG. 30.—Shears, lever of the first class.

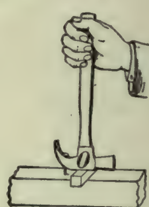

FIG. 31.—Claw-hammer, used as a lever of the first class.

3. To draw a nail from a piece of wood requires a pull of 200 pounds. A claw-hammer is used, the nail being $1\frac{1}{2}$ inches from the fulcrum O (Fig. 31) and the hand being 8 inches from O. Find what force the hand must exert to draw the nail.

4. Name other levers of the first class. (Common balance, pump-handle, etc.)

50. The Lever; Second Class. In levers of the second class the weight to be lifted is placed between the point where the force is applied and the fulcrum.

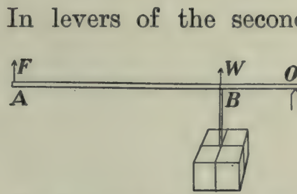

FIG. 32.—Lever of the second class.

As before, the force F is applied at A (Fig. 32), but the force produced is exerted at B, between A and the fulcrum O.

Also, as in the first class, the law of the lever is:

Force applied (F) $\times$ its arm (AO) = Force obtained (W) $\times$ its arm (BO), and the mechanical advantage is $W \div F$.

PROBLEMS

1. In cracking a nut (Fig. 33) the nut is $\frac{3}{4}$ inch, and the hand 7 inches, from the fulcrum. If the hand exerts a force of 6 pounds find the pressure on the nut. What is the mechanical advantage in this case?

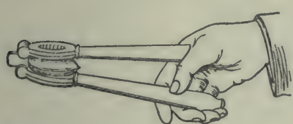
FIG. 33.—Nut-crackers, lever of the second class.

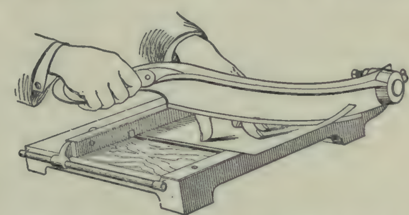
FIG. 34.—Trimming board for cutting paper or cardboard; lever of the second class.

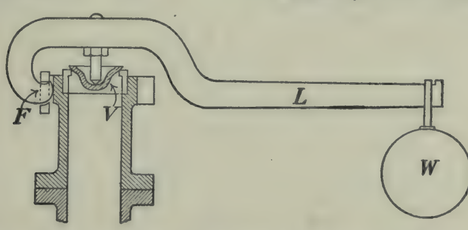

FIG. 35.—A safety-valve of a steam boiler. (Lever of the second class). L is the lever arm, V the valve on which the pressure is exerted, W the weight which is lifted, F the fulcrum.

2. In the safety-valve (Fig. 35) suppose the valve is $1\frac{1}{2}$ inches, and the weight W 12 inches from the fulcrum F. What is the mechanical advantage here? What pressure on the valve will a weight of 20 pounds balance?

3. Show that in a lever of the second class the mechanical advantage is always greater than 1.

4. Name other examples of levers of the second class (trimming board, Fig. 34; wheel-barrow; etc.).

FIG. 36.—A lever of the third class.

51. The Lever; Third Class. In this case the force F is applied between the fulcrum and the weight to be lifted (Fig. 36)

As before, we have $F \times AO = W \times BO$,

$$\text{or } \frac{W}{F} = \frac{AO}{BO}, \text{ the mechanical advantage.}$$

Notice that the weight lifted is always less than the force applied, or the mechanical advantage is less than 1.


FIG. 37.—Sugar-tongs, lever of the third class.

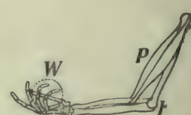

FIG. 38.—Human forearm, lever of the third class. One end of the biceps muscle is attached at the shoulder, the other is attached to the radial bone near the elbow, and exerts a force to raise the weight in the hand.

Examples of levers of this class:—Sugar-tongs (Fig. 37), the human forearm (Fig. 38); treadle of a lathe or a sewing machine.

Exercise—A study of the lever.

APPARATUS:—*Metre rod, hardwood prism, set of weights, spring-balance.*

Lever of Class I. Lay the metre rod on the prism, with the 50 cm. mark exactly over the edge of the prism (Fig. 39). If the stick does not balance, add bits of lead to the lighter end until it does. Put blocks under the ends to reduce the vibration.

FIG. 39.—A lever of the first class.

Place a weight P on some graduation, noting its distance from F. This distance is called the arm of the lever, and the product $P \times FP$ is called the moment of P about F. Move the weight W until it just balances P, and note the length FW.

Make 5 or 6 experiments, changing the weights, and tabulate the results as follows:

P	Arm of P PF	Moment of P $P \times PF$	W	Arm of W WF	Moment of W $W \times WF$

Lever of Class II. Weigh the rod; let it be w grams. Next find the position of the centre of gravity of the rod by balancing it on the prism. Support it at this point by a weight w attached to a string as shown in Fig. 40. Let it be at C.

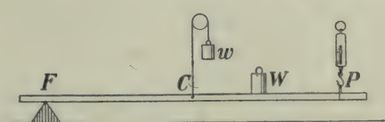

FIG. 40.—A lever of the second class.

Now rest the rod on a prism at a point 2 cms. from one end and attach a spring-balance 2 cm. from the other end. Place a weight W on the rod, noting its distance from the fulcrum F, and observe the reading P of the spring-balance. Make at least 5 different experiments, varying W and FW, and arrange the results as in the table:

Moment of W $W \times CF$	W	Arm of W FW	Moment of W $W \times FW$	P	Arm of P FP	Moment of P $P \times FP$

Lever of Class III. For a lever of the third class support the metre rod at its centre of gravity as in the last exercise, and push it through a wire loop fastened to the table, and transpose the positions of P and W (Fig. 41).

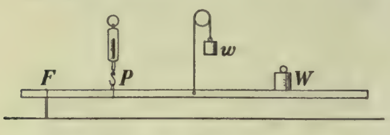

FIG. 41.—A lever of the third class.

Arrange the results in a table as in the other cases.

PROBLEMS

1. Explain the action of the steelyards (Fig. 42). As a lever, to which class does it belong? If the distance from B to O is $1\frac{1}{2}$ inches, and the sliding weight P when at a distance 6 inches from O balances a mass of 5 lb. on the hook, what must be the weight of P?

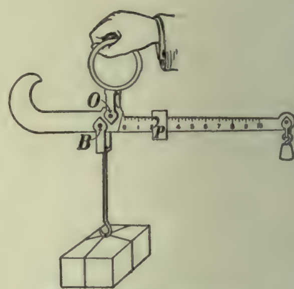

FIG. 42.—The steelyards.

If the mass on the hook is too great to be balanced by P, what additional attachment would be required in order to weigh it?

2. A hand-barrow (Fig. 43), with the mass loaded on it weighs 210 pounds. The centre of gravity of the barrow and load is 4 feet from the front handles and 3 feet from the back ones. Find the amount each man carries.

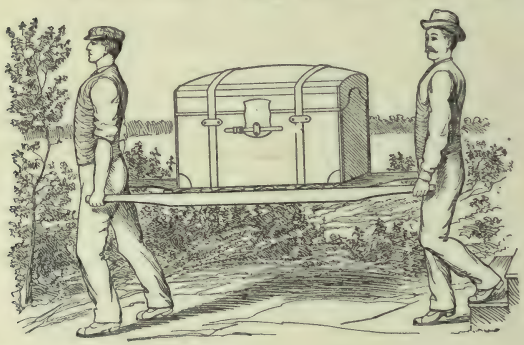

FIG. 43.—The hand-barrow.

3. A cubical block of granite, whose edge is 3 feet in length and which weighs 4,500 lbs., is raised by thrusting one end of a crowbar 40 inches long under it to the distance of 4 inches, and then lifting on the other end. What force must be exerted? What class of lever is this?

52. The Pulley. The pulley is used sometimes to change the direction in which a force acts, sometimes to gain mechanical advantage, and sometimes for both purposes. We shall neglect the weight and friction of the pulley and the rope.

A single fixed pulley such as is shown in Fig. 44, can change the direction of a force but cannot give a mechanical advantage greater than 1. F, the force applied, is equal to the weight lifted, W.

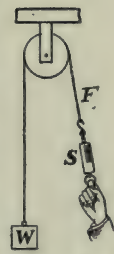

FIG. 44.–A fixed pulley simply changes the direction of force.

By this arrangement a lift is changed into a pull in any convenient direction. It is often used in raising materials during the construction of a building.

By inserting a spring balance, S, in the rope, between the hand and the pulley, one can show that the force F is equal to the weight W. It is evident, also, that the hand, which applies the force, and the weight lifted move through equal distances.

53. A Single Movable Pulley. Here the weight W (Fig. 45) is supported by the two portions, B and C, of the rope, and hence each portion supports half of it.

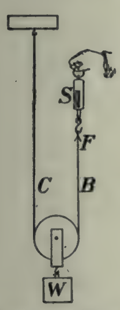

FIG. 45. — With a movable pulley the force exerted is only half as great as the weight lifted.

Thus the force F is equal to $\frac{1}{2}$ W, and the mechanical advantage is 2.

For convenience a fixed pulley also is generally used, as in Fig. 46.

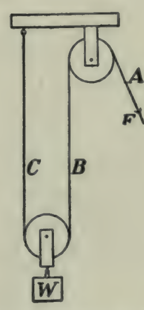

FIG. 46. –With a fixed and a movable pulley the force is changed in direction and reduced one-half.

Here when the weight rises 1 inch, B and C each shorten 1 inch and hence A lengthens 2 inches. That is, F moves through twice as far as W.

54. The Wheel and Axle. The way this machine works is shown in Figs. 47, 48. The force F is applied at the circumference of the wheel, while the weight is lifted by a cord which winds about the axle.

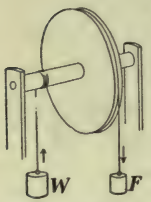

FIG. 47.—The wheel and axle.

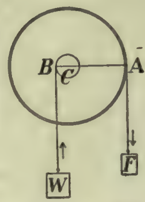

FIG. 48.—Diagram to explain the wheel and axle.

The advantage which is gained by using this machine can be seen in the following way. The wheel and axle turn about the centre C (Fig. 48) and the machine acts like a lever of length AB, with the fulcrum at C. The force F is applied at the end A and the force W is obtained at the end B.

Let R be the radius of the wheel and r that of the axle. Then $R = AC$, and $r = BC$, and from the law of the lever,

$$F \times AC = W \times BC,$$
$$\text{or } F \times R = W \times r;$$

and the advantage $W/F = R/r$.

Hence if the radius of the wheel is 8 times that of the axle the force obtained is 8 times that applied.

Notice, also, that when the apparatus turns round once the force F descends a distance equal to the circumference of the wheel while the weight W rises a distance equal to the circumference of the axle.

55. Examples of Wheel and Axle. The windlass (Fig. 49) is a common example, but, in place of a wheel, handles are used. Forces are applied at the handles and the bucket is lifted by the rope, which is wound about the axle.


FIG. 49.—Windlass used in drawing water from a well.

If F = applied force, and W = weight lifted,

$$\frac{W}{F} = \frac{\text{length of crank}}{\text{radius of axle}}.$$

The capstan, used on board ships for raising the anchor, is another example (Fig. 50).

The sailors apply the force by pushing against bars thrust into holes near the top of the capstan. Usually the rope is too long to be all coiled up on the barrel, so it is passed about it several times and the end A is held by a man who keeps that portion taut. The friction is sufficient to prevent the rope from slipping. Sometimes the end B is fastened to a post or a ring on the dock, and by turning the capstan this portion is shortened and the ship is drawn into the dock.

FIG. 50.—Raising the ship's anchor by a capstan.

PART III—MECHANICS OF FLUIDS; LIQUIDS AND GASES AT REST AND IN MOTION

CHAPTER IX

Pressure of Liquids

56. Transmission of Pressure by Fluids. Liquids differ decidedly from solids in the way in which they transmit force. The strength of the horse is exerted along the traces connecting it to the load, and in the locomotive the pressure of the steam is conveyed to the driving wheels by means of the piston and connecting rods. In these cases the pull or the push is transmitted only in the line of action of the force.

It is quite different in the case of a fluid. Let us take a globe and cylinder of the form shown in Fig. 51, fill it with water and then push in the piston. The water is thrown *in all directions*, not just in the direction in which the force was applied. Next, let us take the apparatus shown in Fig. 52, in which small U-tubes, partially filled with mercury, are connected with the globe. On inserting the piston it is found that the change of level of the mercury, caused by the transmitted pressure, is the same in each tube. This shows that the pressure applied by the piston in the tube is transmitted *equally* in all directions by the water.

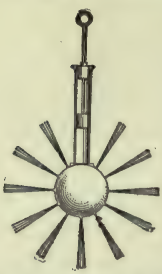

Fig. 51.—Pressure applied to the piston transmitted in all directions by the liquid within the globe.

Fig. 52.—Transmission shown to be equal in all directions by pressure gauges.

We are thus led to Pascal's Law or Principle, which is true of gases as well as of liquids, and which may be stated thus:—*Pressure exerted anywhere on the mass of a fluid is transmitted undiminished in all directions, and acts with the same force on all equal surfaces in a direction at right angles to them.*

57. Practical Applications. Let us consider the apparatus shown in Fig. 53. It has two cylinders A and B, connected together and filled with water, and with closely-fitting pistons P_1, P_2 moving in them. Suppose the area of P_1 to be 1 square centimetre, and that of P_2 to be 10 square centimetres. Then by Pascal's principle a force of 1 kilogram applied by the piston P_1 will transmit a force of 1 kilogram to each square centimetre of P_2, that is, 10 kilograms in all. A weight of 50 kilograms above P_1 will balance a weight of 500 kilograms above P_2. It is evident that this principle has almost unlimited applications, and we find it in various forms.

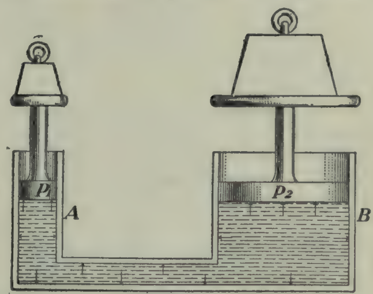

FIG. 53.—Force multiplied by transmission of pressure.

FIG.—54. Bramah's Hydraulic Press.

58. Hydraulic Press. One of the most common forms is that known as Bramah's hydraulic press, which is ordinarily used whenever great force is to be exerted through short distances, as in pressing goods into bales, extracting oils from seeds, making dies, testing the strength of materials, etc. Its construction is shown in Fig. 54.

A and B are two cylinders connected with each other and with a water cistern by pipes closed by valves V_1 and V_2. In these cylinders work pistons P_1 and P_2 through water-tight collars, P_1 being moved by a lever. The bodies to be pressed are held between plates C and D. When P_1 is raised by the lever, water flows up from the cistern through the valve V_1 and fills the cylinder A. On the down-stroke the valve V_1 is closed and the water is forced through the valve V_2 into the cylinder B, thus exerting a force on the piston P_2, which will be as many times that applied to P_1 as the area of the cross-section of P_2 is that of the cross-section of P_1. It is evident that by decreasing the size of P_1, and increasing that of P_2, an immense force may be developed by the machine.

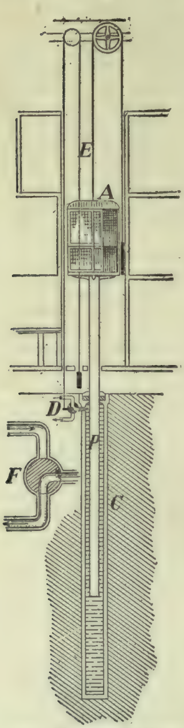

FIG. 55.—Hydraulic elevator.

59. The Hydraulic Elevator. Another important application of the multiplication of force through the principle of equal transmission of pressure by fluids is the hydraulic elevator, used as a means of conveyance from floor to floor in buildings. In its simplest form it consists of a cage A, supported on a piston P, which works in a long cylindrical tube C. (Fig. 55). The tube is connected with the water mains and the sewers by a three-way valve D which is actuated by a cord E passing through the cage. When the cord is pulled up by the operator, the valve takes the position shown at D, and the cage is forced up by the pressure on P of the water which rushes into C from the mains. When the cord is pulled down, the valve takes the position shown at F (below), and the cage descends by its own weight forcing the water out of C into the sewers.

When a higher lift, or increased speed is required, the cage is connected with the piston by a system of pulleys which multiplies, in the movement of the cage, the distance travelled by the piston.

60. Canal Lift-Lock. The hydraulic lift-lock, designed to take the place of ordinary locks where a great difference of level is found

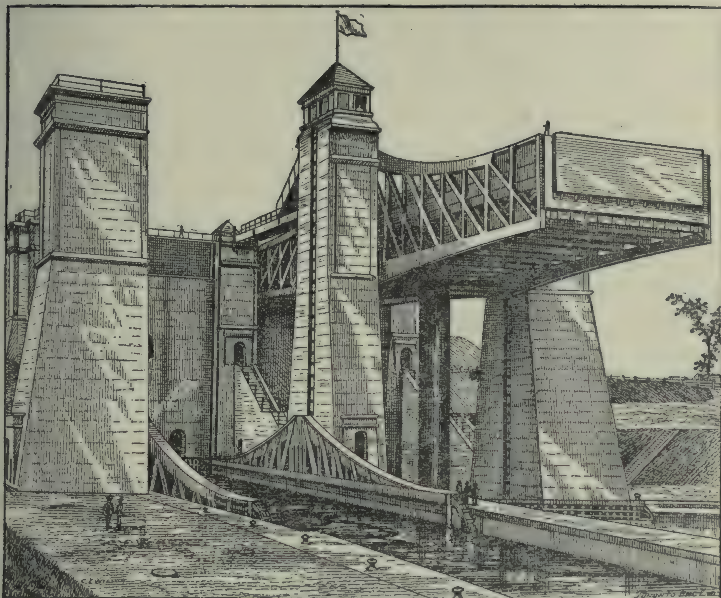

FIG. 56.—Hydraulic lift-lock at Peterborough, Ont., capable of lifting a 140-foot steamer 65 feet.

in short distances, is another application of the principle of equal transmission. Fig. 56 gives a general view of the Peterborough Lift-Lock, the largest of its kind in the world, and Fig. 57 is a simple diagrammatic section showing its principle of operation. The lift-lock consists of two immense hydraulic elevators, supporting on their pistons P_1 and P_2, tanks A and B in which float the vessels to be raised or lowered. The presses are connected by a pipe containing a valve R which can be operated by the lockmaster in his cabin at the top of the central tower. To perform the lockage, the vessel is towed into one tank and the gates at the end leading

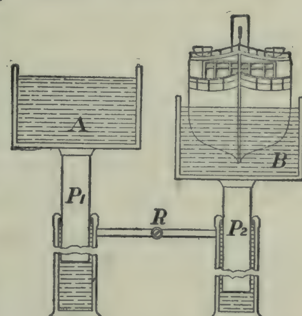

FIG. 57.—Principle of the lift-lock.

from the canal are closed. Then water, to the depth of a few inches, is put into the upper tank and the valve R is opened. The additional weight in the upper tank forces the water from its press into the other, and it gradually descends while the other tank is raised. The action, it will be observed, is automatic, but hydraulic machinery is provided for forcing water into the presses to make up pressure lost through leakage.

61. Pressure Due to Weight. Our common experiences in the handling of liquids give us evidence of force within their mass. When, for example, we pierce a hole in a water-pipe or in the side or the bottom of a vessel filled with water, the water rushes out with an intensity which we know, in a general way, depends on the height of the water above the opening. Again, if we hold a cork at the bottom of a vessel containing water, and let it go, it is forced up to the surface of the water, where it remains, its weight being supported by the pressure of the liquid on its under surface.

62. Relation between Pressure and Depth. Since the lower layers of the liquid support the upper layers, it is to be expected that this force within the mass, due to the action of gravity, will increase with the depth. To investigate this relation, prepare a pressure gauge of the form shown in Fig. 58 by stretching a rubber membrane over a thistle-tube A, which is connected by means of a rubber tube with a U-shaped glass tube B, partially filled with water. The action of the gauge is shown by pressing on the membrane. Pressure transmitted to the water by the air in the tube is measured by the difference in level of the water in the branches of the U-tube.

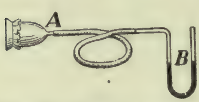

FIG. 58.—Pressure gauge.

Now place A in a jar of water (which should be at the temperature of the room), and gradually push it downward (Fig. 59). The changes in the level of the water in the branches of the U-shaped tube indicate an increase in pressure with the increase in depth. Careful experiments have shown that this *pressure increases from the surface downward in direct proportion to the depth.*

63. Pressure Equal in all Directions at the same Depth. If the thistle-tube A is made to face in different directions while the centre of the membrane is kept at the same depth, no change in the difference in level of the water in the U-shaped tube is observed. Evidently the magnitude of the force at any point within the fluid mass is independent of the direction of pressure. *The upward, downward, and lateral pressures are the same at the same depth.*

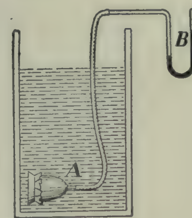

Fig. 59.—Investigation of pressure within the mass of a liquid by pressure gauge.

64. Magnitude of Pressure due to Weight. The downward pressure of a liquid, say water, on the bottom of a vessel with vertical sides is obviously the weight of the liquid. But if the sides of the vessel are not vertical, the magnitude of the force is not so apparent. The apparatus shown in Fig. 60 may be used to investigate the question. A, B, C, and D are tubes of different shapes but made to fit into a common base. E is a movable bottom held in position by a lever and weight. Attach the cylindrical tube to the base, and support the bottom E in position. Now place any suitable weight in the scale-pan and pour water into the tube until the pressure detaches the bottom. If the experiment be repeated, using in succession the tubes A, B, C, and D, and marking with the pointer the height of the water when the bottom is

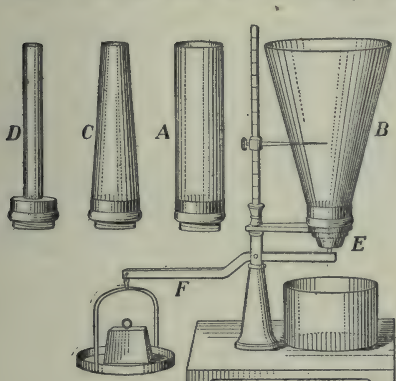

Fig. 60.—Pressures on the bottoms of vessels of different shapes and capacities.

detached, it will be found that the height is the same for all tubes, so long as the weight in the scale-pan remains unchanged. The pressure on the bottom of a vessel filled with a given liquid is, therefore, dependent only on the depth. It is independent of the form of the vessel and of the amount of liquid which it contains.

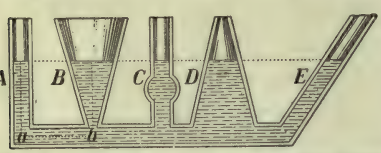

FIG. 61.—Surface of a liquid in connecting tubes in the same horizontal plane.

65. Surface of a Liquid in Connecting Tubes. If a liquid is poured into a series of connecting tubes (Fig. 61), it will rise to the same horizontal plane in all the tubes.

This principle that "water seeks its own level" is of great practical importance. The common method of supplying cities with water furnishes a striking example of it. Fig. 62 shows the main features of a modern system. While there are

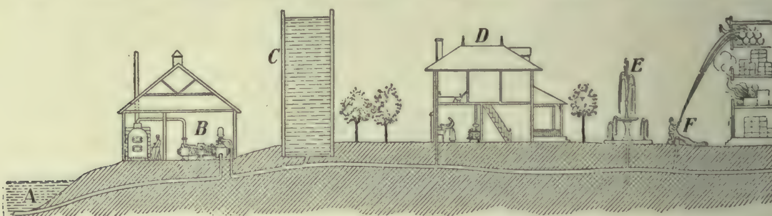

FIG. 62.—Water supply system. *A*, source of water supply; *B*, pumping station; *C*, stand-pipe; *D*, house supplied with water; *E*, fountain; *F*, hydrant for fire hose.

various means by which the water is collected and forced into a reservoir or stand-pipe, the distribution in all cases depends on the principle that, however ramified the system of service pipes, or however high or low they may be carried on streets or in buildings, there is a tendency in the water which they contain to rise to the level of the water in the original source of supply connected with the pipes.

66. Artesian Wells. The rise of water in artesian wells is also due to the tendency of a liquid to find its own level.

These wells are bored at the bottom of cup-shaped basins (Fig. 63), which are frequently many miles in width. The

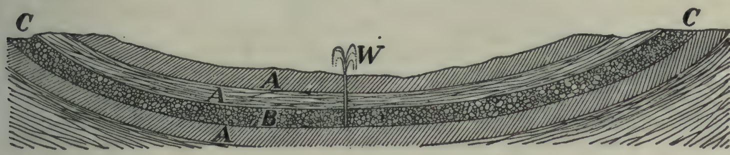

FIG. 63.—Artesian basin. *A*, impermeable strata ; *B*, permeable stratum ; *C*, *C*, points where permeable stratum reaches the surface ; *W*, artesian well.

upper strata are impermeable, but lower down is found a stratum of loose sand, gravel or broken stone containing water which has run into it at the points where the permeable stratum reaches the surface. When the upper strata are pierced the water tends to rise with a force more or less great, depending on the height of the head of water exerting the pressure.

PROBLEMS

1. A closed vessel is filled with liquid, and two circular pistons, whose diameters are respectively 2 cm. and 5 cm., inserted. If the pressure on the smaller piston is 50 grams, find the pressure on the larger piston when they balance each other.

2. The diameter of the large piston of a hydraulic press is 100 cm. and that of the smaller piston 5 cm. What force will be exerted by the press when a force of 2 kilograms is applied to the small piston ?

3. The diameter of the piston of a hydraulic elevator is 14 inches. Neglecting friction, what load, including the weight of the cage, can be lifted when the pressure of the water in the mains is 75 pounds per sq. inch ?

4. What is the pressure in grams per sq. cm. at a depth of 100 metres in water ? (Density of water one gram per c.c.)

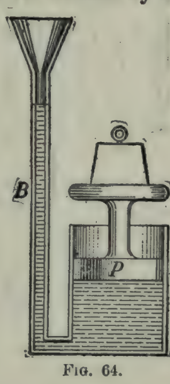

FIG. 64.

5. The area of the cross-section of the piston *P* (Fig. 64), is 120 sq. cm. What weight must be placed on it to maintain equilibrium when the water in the pipe *B* stands at a height of 3 metres above the height of the water in *A* ?

CHAPTER X

Buoyancy of Fluids

67. Buoyant Action of a Fluid. Throw a piece of wood on the water; it floats on the surface. A stone sinks, but if you try to hold it up it does not appear so heavy as when in the air. You can lift a much larger stone if it is immersed in the water than if it is on the shore.

Again, a balloon floats in the air, though we are sure the materials in it weigh hundreds of pounds.

In each case we recognize there is a buoyant force exerted upwards. Let us see just how great it is.

68. To Determine the Amount of the Buoyant Force. In Fig. 65 is shown a balance in which for one of the scale-pans a counterpoise of precisely the same weight is substituted.

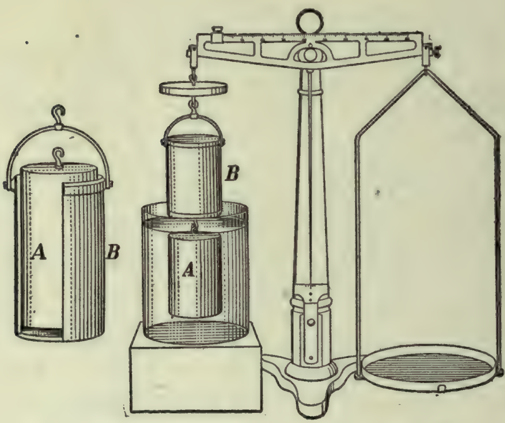

FIG. 65.—Determination of buoyant force.

Now take a brass cylinder A, which fits exactly into a hollow socket B. Hook the cylinder to the bottom of the socket and the socket to the under side of the counterpoise. Then put weights or shot on the balance-pan until equilibrium is obtained.

Next surround the cylinder with water, as shown in the figure. This destroys the equilibrium. Then carefully pour water in the socket B, and just as it becomes full, equilibrium will be restored. Hence, the buoyant force of the water on the immersed cylinder is equal to the weight of a volume of water equal to the volume of the cylinder.

Our experiment has been made with water, but the result reached is true also in the case of gases. This general law is known as the PRINCIPLE OF ARCHIMEDES, and may be stated thus:

The buoyant force exerted by a fluid upon a body immersed in it is equal to the weight of the fluid displaced by the body; or

A body when weighed in a fluid loses in apparent weight an amount equal to the weight of the fluid which it displaces.

This principle is of very great importance, and the pupil should test it for himself.

Exercise—To verify the law of buoyancy or Archimedes' Principle.

APPARATUS:—*Balance, an overflow vessel H* (Fig. 66), *and a vessel K (a beaker or a metal can).*

First weigh the vessel K. Let it weigh 115.4 grams. Then remove the left pan of the balance and substitute for it the counterpoise C, which has as nearly as possible the same weight. If necessary, adjust the balance to equilibrium by means of the nut n.

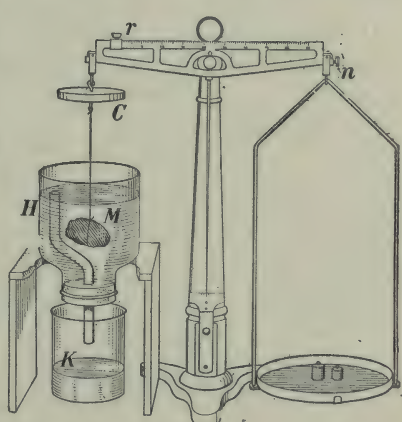

FIG. 66.—When the body M is immersed the water flows out through the bent tube into the beaker K.

By means of a fine thread suspend from C a piece of iron (or other heavy object) M, and carefully weigh it. Let it weigh 473.6 grams. Now gently lift M aside, and underneath C place the vessel H. Pour water in until it overflows, and allow the water to drip off. Next place the vessel K

under the spout, and then lower M into H, allowing it to hang freely in the water and catching in K the water which has overflowed.

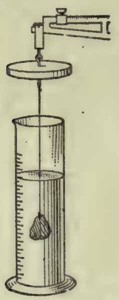

FIG. 67.—Determination of volume of liquid displaced by a solid.

Under these conditions weigh M again. We find it to be 413.1 grams. The difference between this weight and the previous one is 60.5 grams, and is the buoyant effect of the water.

Now weigh the vessel K, containing the overflowed water ; it is 175.9 grams ; and deducting 115.4 grams the weight of the empty vessel, we obtain the weight of the water which overflowed, which is the water displaced by the object M. It is 60.5 grams, which is exactly the apparent loss in weight by immersion in the water.

Instead of the overflow vessel a graduated jar (Fig. 67) may be used to determine the weight of the displaced water. The volume of the water displaced is read from the graduations. In this case we would find it to be 60.5 c.c., which weighs 60.5 grams.

69. Will a Body Float or Sink? It is evident that if a body weighs less than an equal volume of water it will float; if it weighs more, it will sink. A piece of wood or cork will float on the surface, displacing just enough water to weigh as much as they do. If a ship weighs 1,000 tons it will sink into the water until it displaces water weighing 1,000 tons.

PROBLEMS

1. A cubic foot of marble which weighs 160 pounds is immersed in water. Find (1) the buoyant force of the water on it, (2) the weight of the marble in water. (1 c. ft. water = 62.3 lbs. at 62°F.).

2. Twelve cubic inches of a metal weigh 5 pounds in air. What is the weight when immersed in water?

3. If 3,500 c.c. of a substance weigh 6 kgm., what is the weight when immersed in water?

4. A piece of aluminium whose volume is 6.8 c.c. weighs 18.5 grams. Find the weight when immersed in a liquid twice as heavy as water.

5. One cubic decimetre of wood floats with $\frac{3}{5}$ of its volume immersed in water. What is the weight of the cube?

6. A cubic centimetre of cork weighs 250 mg. What part of its volume will be immersed if it is allowed to float in water?

7. Why will an iron ship float on water, while a piece of the iron of which it is made sinks?

CHAPTER XI

Determination of Density

70. Density of a Solid Heavier than Water. To determine the density of a body we need to know its mass and its volume. We find the mass by weighing, while the volume is most easily and accurately found by an application of Archimedes' Principle.

The way of going about the experiment is illustrated in the Exercise in § 68. Turning back to the values given there, we have the following results:

Mass of body	473.6	grams
Weight in water...............	413.1	"
Apparent loss in weight....	60.5	"

Now by Archimedes' Principle this apparent loss is the weight of a volume of water equal to the volume of the body, and as 1 c.c. of water weighs 1 gram, the volume of the body must be 60.5 c.c.

Hence, 1 c.c. of the substance contains $473.6 \div 60.5 = 7.8$ grams, which is the density required.

From this experiment we deduce the following rule: *Weigh the body in air, then in water and subtract. Then*

$$\text{Density (in grams per c.c.)} = \frac{\text{mass (in grams)}}{\text{loss of weight in water (in grams)}}.$$

The number thus obtained also expresses the specific gravity of the body. (See § 16.)

71. Density of a Solid Lighter than Water. Let us find the density of a block of pine wood. There are several methods of making the experiment, of which we shall take two.

Exercise 1. Find the weight of the wood by the balance. Let it be 46.4 grams. Now take the overflow vessel H (Fig. 66), fill it with water, and having weighed the vessel K, place it under H. Lay the wood on the water in H, and by means of a pin press it down until it is fully submerged, catching the overflow water in K. Let the increase in the weight of K be 103.1 grams. Then the water displaced by the body weighs 103.1 grams, and therefore occupies a volume of 103.1 c.c.

Hence, density of the wood $= 46.4 \div 103.1 = .45$ grams per c.c.

Exercise 2. First weigh the wood in air. Let it be 46.4 grams. Then tie a sinker (a piece of lead or a large screw) to it and suspend wood and sinker from the balance, with the sinker hanging below the wood.

Now place a vessel underneath and pour in water until the sinker is immersed. Then weigh; let it be 314.4 grams. Next pour in water until the wood also is immersed, and weigh. Let it be 211.0 grams. Then the difference between the last two weights, $314.4 - 211.0 = 103.4$ grams, is caused by the body being in air in one case and in water in the other.

Hence, 103.4 grams is the weight of the water displaced, and the volume of the wood $= 103.4$ c.c.

Hence, density $= 46.4 \div 103.4 = .45$ (nearly) gms. per c.c.

72. Density of a Liquid by the Specific Gravity Bottle.

Fig. 68.—A specific gravity bottle.

As in the case of a solid, we must determine the volume and the mass of the liquid used. A convenient form of bottle is shown in Fig. 68. It is often constructed to contain a given quantity of liquid, usually 100 c.c. at 15°C., but it need not be of any particular size. To render complete filling easy, the bottle is provided with a closely-fitting stopper perforated with a fine bore through which excess of liquid escapes.

Exercise—To determine the density of alcohol.

First, weigh the bottle empty and dry. Let its weight be 31.4 grams. Then fill with water, carefully wiping off the excess, and weigh again. Let it now be 132.6 grams.

Empty the water, removing it all, fill with alcohol and weigh again. Let it be 112.5 grams.

Subtracting the first from the second weight, we get the weight of the water in the bottle. It is 101.2 grams, and the volume of the bottle therefore is 101.2 c.c.

Subtracting the first from the third weight we get the weight of the alcohol. It is 81.1 grams.

Hence, 101.2 c.c. of alcohol = 81.1 grams,

and, density = $81.1 \div 101.2 = .80$ grams per c.c.

Gasoline or other liquids may be used in the same way.

73. The Hydrometer. This instrument indicates directly the density of a liquid without any calculation whatever. The principle underlying its action may be illustrated as follows:—Take a rectangular rod of wood 1 sq. cm. in section and 20 cm. long, and bore a hole in one end. After inserting enough shot to cause the rod to float upright in water (Fig. 69), plug up the hole. Mark off on one of the long faces a centimetre scale, and then dip the rod in hot paraffin to render it impervious to water.

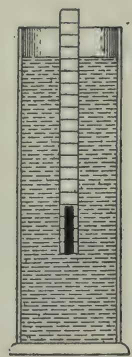

Fig. 69. — Illustration of the principle of the hydrometer.

Now place the rod in water, and suppose it to sink to a depth of 16 cm. when floating. Then the weight of the rod = weight of water displaced = 16 grams.

Next, place it in the liquid whose density is to be determined, and let it sink to a depth of 12 cm., and hence displacing 12 c.c. of the liquid.

Then, since the weight of liquid displaced equals weight of the rod,

12 c.c. of the liquid = 16 grams,

And density of the liquid = $\frac{16}{12}$ gram per c.c.

Or, in general terms,

$$\text{Density of liquid} = \frac{\text{vol. of water displaced by a floating body}}{\text{vol. of liquid displaced by the same body}}$$

A hydrometer for commercial purposes is usually constructed in the form shown in Fig. 70. The weight and volume are so adjusted that the instrument sinks to the division mark at the lower end of the stem in the densest liquid to be investigated and to the division mark at the upper end in the least dense liquid. The scale on the stem indicates directly the densities of liquids between these limits. The float *A* is usually made much larger than the stem to give sensitiveness to the instrument.

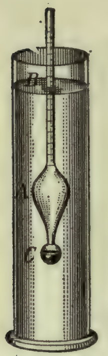

Fig. 70.—The hydrometer.

As the range of an instrument of this class is necessarily limited special instruments are constructed for use with different liquids. For example, one instrument is used for the densities of milks, another for alcohols, and so on.

PROBLEMS

1. A body has a mass of 9 grams. When attached to a balance with a sinker underneath it and in water the weight is 39 grams. If the body and sinker are both immersed in water the weight is 12 grams. Find the density of the body.

2. A body whose mass is 12 grams has a sinker attached to it and the two together displace when submerged 60 c.c. of water. The sinker alone displaces 12 c.c. What it the density of the body?

3. A body whose mass is 60 grams is dropped into a graduated tube containing 150 c.c. of water. If the body sinks to the bottom and the water rises to the 200 c.c. mark, what is the density of the body?

4. If a body when floating in water displaces 12 c.c., what is the density of a liquid in which when floating it displaces 18 c.c.?

CHAPTER XII

Pressure in Gases

74. Has Air Weight? For many centuries this question puzzled investigators, but with our present-day apparatus we can test it without great difficulty.

Let us take a glass flask, such as shown in Fig. 71, fitted with a stop-cock. Attach it to one side of the balance and carefully weigh. Then attach a bicycle pump and force air into it and weigh again. Finally, by means of an air-pump, exhaust the air from it and weigh again. It will be found that the first weight is less than the second and greater than the third, the difference being evidently due to the air added in one case and removed in the other.

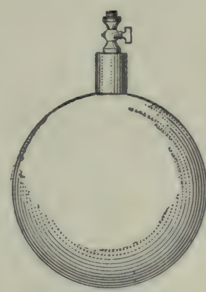

Fig. 71.—Globe for weighing air.

Exact experiments have shown that the mass of 1 litre of air at 0°C. and under normal pressure of the air at sea-level (760 mm. of mercury) is 1.293 grams.

75. Pressure of Air. It is evident that since air has weight it must, like liquids, exert pressure upon all bodies with which it is in contact. Just as the bed of the ocean sustains enormous pressure from the weight of the water resting on it, so the surface of the earth, the bottom of the aerial ocean in which we live, is subject to a pressure due to the weight of the air supported by it. This pressure will, of course, vary with the depth. Thus the pressure of the atmosphere at Victoria, B.C., on the sea-level is greater than at points on the mountains to the east.

The pressure of the air may be shown by many simple experiments. For example, tie a piece of thin sheet rubber over the mouth of a thistle-tube (Fig. 72) and exhaust the air from the bulb by suction or by connecting it with the air-pump. As the air is exhausted the rubber is pushed inward by the pressure of the outside air.

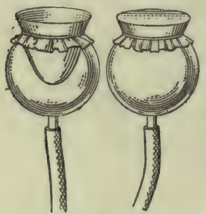

FIG. 72.—Rubber membrane forced inwards by pressure of the air.

Again, if one end of a straw or tube is thrust into water and the air withdrawn from it by suction, the water is forced up into the tube. This phenomenon was known for ages but did not receive an explanation until the facts of the weight and pressure of the atmosphere were established. It was explained on the principle that Nature had a horror for empty space.

76. How to Measure the Pressure of the Atmosphere. It has long been known that water in a suction pump can not be lifted more than 32 feet, and it was early suspected that this was done by the pressure of the atmosphere. Now mercury is almost 14 times as heavy as water, and a corresponding mercury column is $\frac{1}{14}$ of 32 feet or about 28 inches. We can easily test this by experiment.

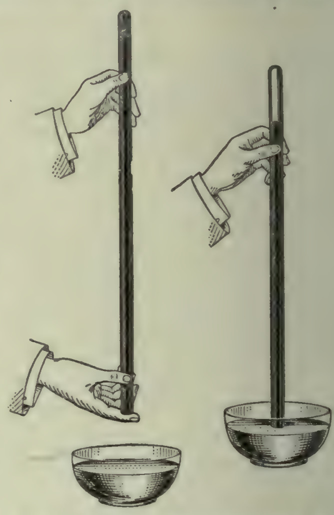

FIG. 73.—Mercury column sustained by the pressure of the air.

Take a glass tube about a yard long (Fig. 73), closed at one end, and fill it with mercury. Stopping the open end with the finger, invert it and place it in a vertical position, with the open end under the surface of the mercury in another vessel. Remove the finger. The mercury will fall a short distance in the tube, and after oscillating will come to rest with the surface of the mercury in the tube between 28 and 30 inches above the surface of the mercury in the outer vessel.

Why does the mercury fall from the top of the tube? The atmosphere presses upon the surface of the mercury in the outer vessel and forces it up into the tube, but it is unable to raise it more than about 28 inches. The blank space above is known as a Torricellian vacuum, named after Torricelli, an Italian, who devised the experiment.

QUESTIONS AND PROBLEMS

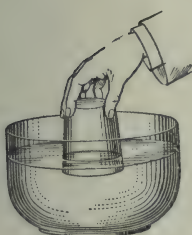

FIG. 74.

1. Fill a tumbler and hold it inverted in a dish of water as shown in Fig. 74. Why does the water not run out of the tumbler into the dish?

2. Fill a bottle with water and place a sheet of writing paper over its mouth. Now, holding the paper in position with the palm of the hand, invert the bottle. (Fig. 75.) Why does the water remain in the bottle when the hand is removed from the paper.

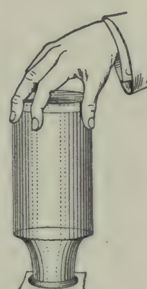

FIG. 75.

3. Take a bent glass tube of the form shown in Fig. 76. The upper end of it is closed, the lower open. Fill the tube with water. Why does the water not run out when it is held in a vertical position?

4. Why must an opening be made in the upper part of a vessel filled with a liquid to secure a proper flow at a faucet inserted at the bottom?

5. Fill a narrow-necked bottle with water and hold it mouth downwards. Explain the action of the water.

6. A flask weighs 280.6 gm. when empty, 284.2 gm. when filled with air, and 3060.6 gm. when filled with water. Find the weight of 1 litre of air.

FIG. 76.

77. Barometer. The object of this instrument is to measure the pressure of the atmosphere, and there are two forms of it in common use—the mercury and the aneroid barometer.

In the former of these the pressure is determined by reading the height of a column of mercury, as in Torricelli's experiment, and the instrument is constructed so that this may be done accurately and conveniently. In Figs. 77, 78, is shown an excellent arrangement. The complete instrument is shown in Fig. 77. The long glass tube is held within a protecting brass tube, and its lower end, drawn out almost to a point, reaches into the mercury in the cistern.

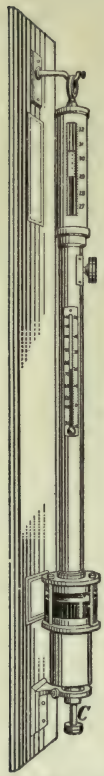

FIG. 77.—The cistern barometer.

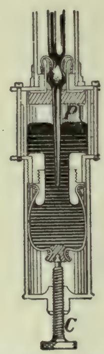

FIG. 78.—Section of the cistern.

A vertical section of the latter is shown in Fig. 78. It has a flexible leather bottom which can be moved up or down by a screw C, in order to adjust the level of the mercury. Before taking the reading, the surface of the mercury in the cistern is brought to a fixed level, indicated by the tip of the pointer P, which is the zero of the barometer scale. The height of the column is then read directly from a scale engraved on the case of the instrument.

The aneroid barometer has no liquid in it at all. In it (Fig. 79) the air presses against the flexible corrugated cover of a circular, air-tight, metal box *A*, from which the air is partially exhausted. The cover, which is usually supported by a spring *S*, responds to the pressure of the atmosphere, being forced in when the pressure is increased, and springing out when it is decreased. The movement of the cover is multiplied and transmitted to an index hand *B* by a system of delicate levers and a chain or by gears. The circular scale is graduated by comparison with a mercury barometer.

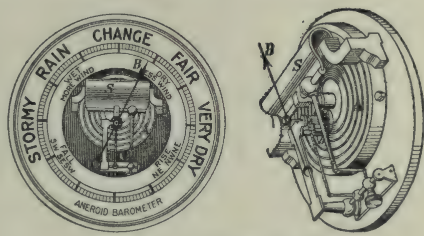

Fig. 79.—Aneroid barometer.

The aneroid is not so accurate as the mercury barometer, but, on account of its portability and its sensitiveness, is coming into very common use. It is specially serviceable for determining readings to be used in computing elevations.

78. Practical Value of the Barometer. By the barometer we can determine the pressure of the atmosphere at any point. If the mercury stands at 76 cm. it can be shown that the atmosphere exerts a pressure of 1,033 grams on every square centimetre of surface which it touches. Also, 76 cm. = 29.9 inches, and the equivalent pressure is 14.7 pounds per square inch.

By continually observing the height of the barometer at any place we learn that the atmospheric pressure is constantly changing. Sometimes a decided change takes place within an hour.

From experience we have learned that a *falling* barometer, that is, a sudden decrease in atmospheric pressure, precedes a storm; that a *rising* barometer is likely to be followed by fair weather; and that a *steady high* barometer means settled fair weather.

Again, by comparing the simultaneous readings of barometers distributed over a large stretch of country we find that the pressure is different at different places. A knowledge of these simultaneous pressures is of great value in forecasting the weather; but the words "stormy, rain, etc.," usually found on the aneroid barometers are of little use. The fact that the hand points to one of these words is no assurance that we shall have the weather indicated.

79. Determination of Elevation. Since the pressure of the air decreases gradually with increase in height above the sea-level it is evident that the barometer may be utilized to determine changes in elevation. If the density of the air were uniform its pressure, like that of liquids, would vary directly as the depth. But on account of the compressibility of air its density is not uniform.

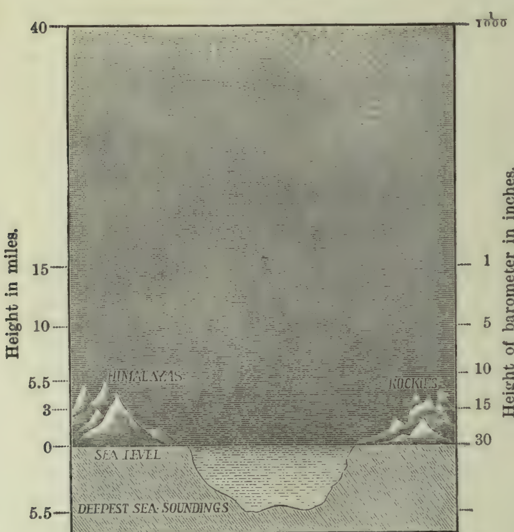

FIG. 80.—Atmospheric pressure at different heights.

The lower layers, which sustain the greater weight, are denser than those above them. For this reason the law giving the relation between the barometric pressure and altitude is somewhat complex. For small elevations it falls at an approximately uniform rate of one inch for every 900 feet of elevation. Fig. 80 shows roughly the conditions of atmospheric pressure at various heights.

80. Compressibility and Expansibility of Air. The fact that air can be compressed has already been referred to. Indeed it is familiar to everybody. The air within a hollow rubber ball may be compressed by the hand; and in the bicycle or automobile tire a comparatively large amount of air is forced to occupy a much smaller volume. Experiments might be multiplied indefinitely to exhibit this effect.

FIG. 81.—Air compressed within a closed tube by pressure applied to piston.

Let us take a tube such as shown in Fig. 81, closed at one end, and having a closely-fitting piston in it. By pushing down the piston the air in the tube can be made to take up but a small fraction of the space originally occupied by it.

Next, let us take a J-tube (Fig. 82) closed at one end and pour mercury into the open end. The higher the column in the open branch, that is, the greater the pressure due to the weight of the mercury, the less the volume in the closed branch becomes.

FIG. 82.—Air compressed within a closed tube by weight of mercury in the long branch.

On the other hand, gases manifest, under all conditions, a tendency to expand. Whenever the pressure to which a given mass of air is subjected is lessened its volume increases. The more liberty allowed to a gas, the more it will take. You must confine it strictly or it will leave you.

Many experiments illustrate this fact. The compressed rubber ball takes its original volume when the pressure of the hand is withdrawn; and when the applied force is removed (in Fig. 81) the piston shoots outwards.

Next, let us place a toy balloon, partially inflated, under the receiver of an air-pump (Fig. 83), and then exhaust the air from the receiver. At once the balloon swells out, and if its walls are not strong it will burst.

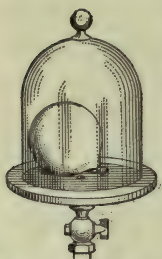

Fig. 83.—Expansion of air when pressure is removed.

Another neat experiment is shown in Fig. 84. A bottle is partially filled with water and through a perforation in a closely-fitting cork a bent tube is pushed, the end going beneath the surface of the water. The other end of the tube is in another bottle, and the whole is then placed under the receiver of the air-pump. On exhausting the air from the receiver the air above the water in the closed bottle expands and forces the water out through the tube into the open bottle.

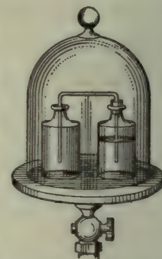

Fig. 84.—Water forced out of closed bottle by the expansion of the air above it.

We have seen (§ 78) that the atmosphere exerts a pressure of almost 15 pounds on every square inch of a surface with which it is in contact. Why, then, are not frail hollow vessels crushed by the hundreds of pounds of pressure on their outer walls? The reason is, there is air also within and its tendency to expand produces a pressure which counterbalances the pressure of the air without.

Exercise—Measure the pressure of the gas in the city mains, or in a vessel into which air is pumped.

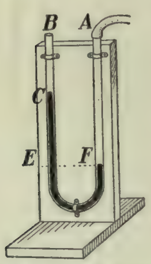

Fig. 85.—Measuring the pressure of the gas.

Use a U-tube as shown in Fig. 85. Pour water (which may be coloured with a little aniline dye) into one end of the tube. It will take, of course, the same height in each arm. What is the pressure on each surface now?

Attach one end *A* of the tube, by means of a rubber tube to a gas-tap, and turn on the gas. The column of water in *A* will be depressed, that in *B* raised. Observe the difference in the levels. Let it be 30 cm.

It is evident that the pressure of the gas at *F* is equal to the pressure of the atmosphere + that due to a column *CE*, 30 cm. high, of water.

Would this height be changed if the diameter of the tube were increased?

PROBLEMS

1. Arrange apparatus as shown in Fig. 86. By suction remove a portion of the air from the flask, and keeping the rubber tube closed by pressure, place the open end in a dish of water. Now open the tube. Explain the action of the water.

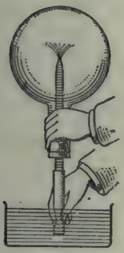

Fig. 86.

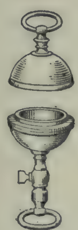

Fig. 87.

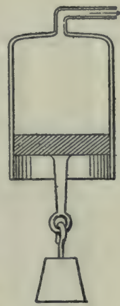

Fig. 88.

2. Guericke, the inventor of the air-pump, took a pair of hemispherical cups (Fig. 87) about 1.2 ft. in diameter, so constructed that they formed a hollow air-tight sphere when their lips were placed in contact, and at a test at Regensburg before the Emperor Ferdinand III and the Reichstag in 1654 showed that it required sixteen horses (four pairs on each hemisphere), to pull the hemispheres apart when the air was exhausted by his air-pump. Account for this.

3. If an air-tight piston is inserted into a cylindrical vessel and the air exhausted through the tube (Fig. 88) a heavy weight may be lifted as the piston rises. Explain this action.

81. Relation between Volume and Pressure—Boyle's Law. From common experience we know that as we try to make the volume of a given mass of gas smaller and smaller we must exert a continually increasing pressure. Suppose we take a hollow rubber ball and compress it. At first, when the volume is reduced slightly, little effort is required; but as the volume becomes smaller the pressure to which we must subject the air within becomes greater.

Also, let us consider again the apparatus shown in Fig. 81. During the first part of the stroke, when there is not much reduction in the volume of the imprisoned air, it is easy to push in the piston; but as the space beneath the piston becomes smaller, the pressure we must exert becomes greater, and at last by no ordinary effort can we reduce the volume further.

We thus reach the general law—the smaller the volume the greater the pressure. But we must study the matter more accurately.

FIG. 89.—Boyle's apparatus.

This is conveniently done by means of the apparatus shown in Fig. 89. It consists of a J-shaped tube, with the shorter branch closed, the longer open ; and behind the two branches are scales by means of which the height of the mercury in them can be read.

First of all, start with the mercury at the same level in the two branches (a, Fig. 90). Then the pressure on the mercury in the long branch is that of 1 atmosphere, and that is the pressure to which the enclosed air in the shorter branch is subjected. Suppose the level of the mercury is 24 cm. below the closed end.

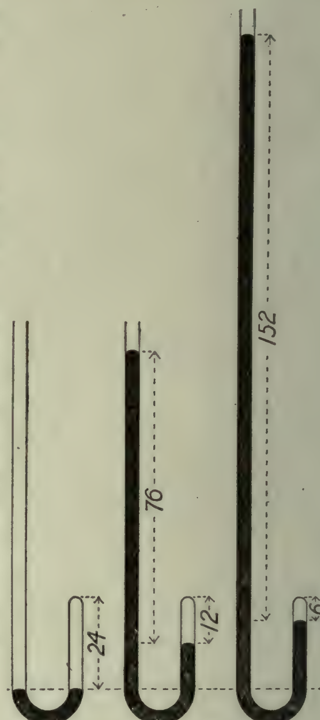

FIG. 90.—Illustrating Boyle's Law.

Now pour mercury in the open end until the mercury in the closed branch is 12 cm. below the closed end, and hence the new volume is half the original volume. It will now be found that the mercury in the long branch stands about 76 cm. above that in the short branch. Now a height of 76 cm. of mercury is equivalent to 1 atmosphere. Hence the pressure exerted now on the enclosed air is 2 atmospheres.

If now we could pour in mercury until that in the short branch is 8 cm. below the closed end, the volume would be $\frac{1}{3}$ of that originally. If the other tube were long enough the mercury in it would be $2 \times 76 = 152$ cm. above the level in the short branch. This, with the atmosphere above it, gives a total pressure of 3 atmospheres upon the enclosed air. Similarly with other reductions in volume.

We see then that if the

Volumes are $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$ .... of the original volume, the
Pressures are 2, 3, 4, 5 .... times the original pressure.

This is known as BOYLE'S LAW, and it is usually stated thus: *If the temperature is kept constant, the volume of a given mass of air varies inversely as the pressure to which it is subjected.*

PROBLEMS

1. In the statement of Boyle's Law the condition is made that the temperature remains constant. Why is this necessary?

2. Gas is forced into a tank whose volume is 2 cu. ft. until the pressure of the gas is 250 pounds per sq. inch. The gas is now allowed to expand into a larger tank, and on measuring the pressure it was found to be 50 pounds per sq. inch. What is the volume of the larger tank?

3. A gas-holder contains 22.4 litres of gas at atmospheric pressure when the barometer stands at 760 mm. What would the volume of this mass of gas be if the barometer fell to 745 mm.?

4. Twenty-five cu. ft. of gas, measured at a pressure of 29 in. of mercury, is compressed into a vessel whose capacity is $1\frac{1}{2}$ cu. ft. What is the pressure of the gas?

5. A mass of air whose volume is 150 c.c. when the barometer stands at 750 mm. has a volume of 200 c.c. when carried up to a certain height in a balloon. What was the reading of the barometer at that height?

6. A cylinder 12 in. long is filled with air at atmospheric pressure, and a piston is then inserted and forced down until it is 2 in. from the bottom. What is the pressure of the enclosed air if the barometer stands at 29 in.?

7. Oxygen gas, used for the 'lime-light,' is stored in steel tanks. The volume of a tank is 6 cu. ft., and the pressure of the gas at first was 15 atmospheres. After some had been used the pressure was 5 atmospheres. If the gas is sold at 6 cents a cu. ft., measured at atmospheric pressure, what should be charged for the amount consumed?

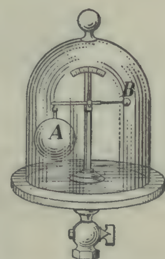

FIG. 91.—Buoyancy of air.

82. Buoyancy of Gases. If we consider the cause of buoyancy we must recognize that Archimedes' principle applies to gases as well as to liquids. If a hollow metal or glass globe A (Fig. 91), suspended from one end of a short balance beam and counterpoised by a small weight B at the other end, is placed under the receiver of an air-pump and the air exhausted from the receiver, the globe is seen to sink. It is evident, therefore, that it was supported to a certain extent by the buoyancy of the air.

A gas, like a liquid, exerts on any body immersed in it, a buoyant force which is equal to the weight of the gas displaced by the body. If a body is lighter than the weight of the air equal in volume to itself, it will rise in the air, just as a cork, let free at the bottom of a pail of water, rises to the surface.

83. Balloons. The use of air-ships or balloons is made possible by the buoyancy of the air. A balloon is a large, light, gas-tight bag filled with some gas lighter than air, usually hydrogen or illuminating gas.

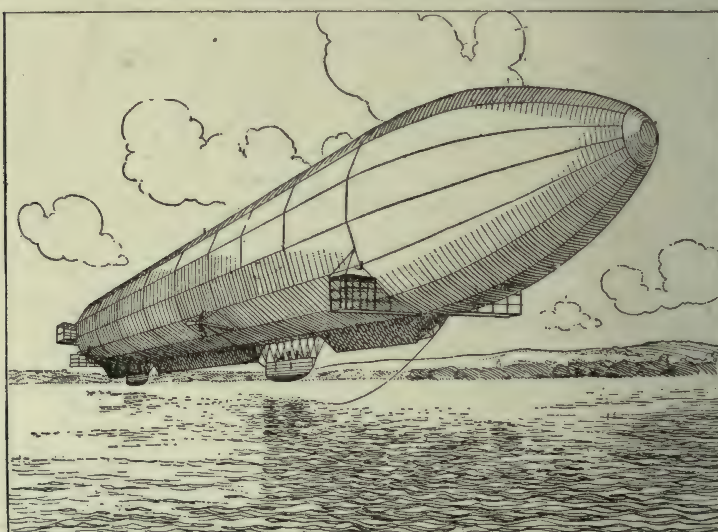

FIG. 92.—Zeppelin's air-ship, over 400 ft. long and able to carry 30 passengers.

Fig. 92 shows the construction of an air-ship devised by Count Zeppelin in Germany. By means of propellers it can be driven in any desired direction.

A balloon will continue to rise so long as its weight is less than the weight of the air which it displaces, and when there is a balance between the two forces it simply floats at a constant height. The aeronaut maintains his position by adjusting the weight of the balloon to the buoyancy of the air. When he desires to ascend he throws out ballast. To descend he allows gas to escape and thus decreases the buoyancy.

QUESTIONS

1. Why should the gas-bag be subject to an increased strain from the pressure of the gas within as the balloon ascends?

2. Aeronauts report that balloons have greater buoyancy during the day when the sun is shining upon them than at night when it is cold. Account for this fact.

3. If the volume of a balloon remain constant, where should its buoyancy be the greater, near the earth's surface or in the upper strata of the air? Give reasons for your answer.

CHAPTER XIII

Applications of the Laws of Gases

84. Air-Pump. The ordinary air-pump, used for removing the air from a vessel, is illustrated in Fig. 93. It depends on the fact that a gas is always trying to expand, and when permitted spreads into all available space.

The action of the pump is as follows :—When the piston P is raised, the valve V_1 is closed by its own weight and the pressure of the air above it. The expansive force of the air in the receiver R lifts the valve V_2 and a portion of the air flows into the lower part of the barrel AB. When the piston P descends, the valve V_2 is closed and the air in the barrel passes up through the valve V_1. Thus at each double stroke, a fraction of the air is removed from the receiver. The action of the pump continues until the expansive force of the air in the receiver is no longer sufficient to lift the valve V_2, or when the pressure of the air below the piston fails to lift the valve V_1. It is evident, therefore, that a partial vacuum only can be obtained with a pump of this kind. To secure more complete exhaustion, pumps in which the valves are opened and closed automatically by the motion of the piston are frequently used, but even with these all the air cannot be removed from the receiver. In recent years pumps on entirely different principles have been constructed in order to secure more complete removal of the air.

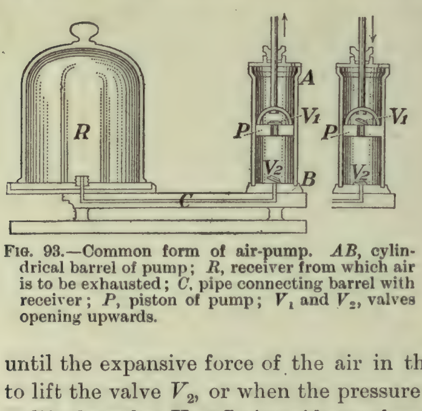

Fig. 93.—Common form of air-pump. AB, cylindrical barrel of pump; R, receiver from which air is to be exhausted; C, pipe connecting barrel with receiver; P, piston of pump; V_1 and V_2, valves opening upwards.

85. Air Condenser. Air-pumps are also constructed for forcing air into a vessel. The simple bicycle-pump is a familiar example. As its piston is drawn back the air leaks in past it and fills the barrel of the pump, and when the piston is pushed in this air is compressed until it lifts the valve in the tire and is forced in.

The usual arrangement of the valves in a condenser is shown in Fig. 94. In this case R is the vessel which we wish to fill with compressed air. When the piston P is raised the inlet valve V_1 opens and the air rushes in from the outside to fill the pump-barrel. On pushing down the piston the inlet valve V_1 is closed and the air is forced through the outlet valve V_2 into the tank. On the up-stroke this valve is closed, thus retaining the air in the tank. It will be seen that at each double stroke (up and down) a barrel-ful of air is forced into the tank.

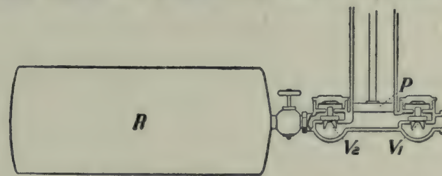

FIG. 94.—Air compressor. P, piston; R, tank or receiver; V_1, inlet valve; V_2, outlet valve.

86. Air-Brakes. Of the many applications of compressed air one of the most useful is the air-brake, now very largely used on ordinary railway and electric cars. The perfecting of this invention has rendered the

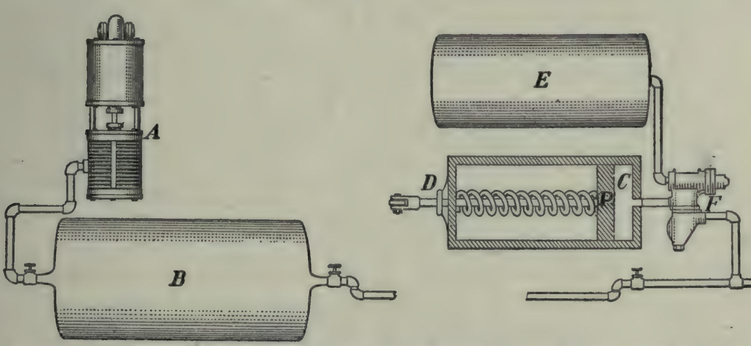

FIG. 95.—Air-brakes in use on railway trains. The left portion is on the locomotive, the right on the car.

handling of trains much simpler and safer. In Fig. 95 are shown the principal working parts of the Westinghouse air-brake in common use in this country.

A steam-driven air-compressor A, and a tank B for holding the compressed air, are attached to the locomotive. The former is usually to be seen on the side of the boiler just in front of the engine cab. The equipment on each car consists of (i) a cylinder C in which moves a piston P which is directly connected by a piston-rod D and a system of levers with the brake-shoes which hang ready to be pushed against the car wheels; (ii) a secondary tank E; and (iii) a system of connecting pipes, and a special valve F. This valve is so constructed that when the air from B is admitted to the pipes it connects B with E, thus maintaining in E the same pressure as in B; but when the pressure of the air in the pipes is removed the valve connects E with C.

When the train is running, pressure is maintained in the pipes, and the brakes hang free, but when the pressure is decreased, either purposely by the engineer or by the accidental breaking of a connection, the air rushes from E into C, forces the piston P forward and the brakes are set. To take off the brakes the engineer again turns the air into the pipes, the value F connects B with E, and the air in cylinder C is allowed to escape, while the piston P is forced into its original position by a spring.

FIG. 96.—Diver's suit.

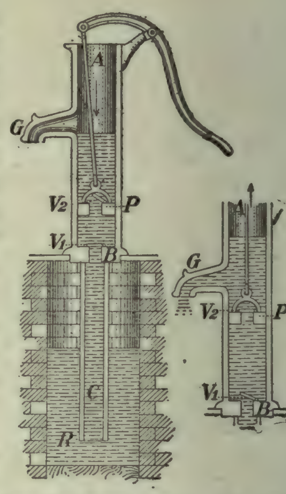

FIG. 97.—Suction-pump. AB, cylindrical barrel; BC, suction-pipe; P, piston; V_1 and V_2, valves opening upwards; R, reservoir from which water is to be lifted.

87. Diving Suits. The modern diver is incased in an air-tight weighted suit (Fig. 96). He is supplied with air from above through pipes or from a compressed-air reservoir attached to his suit. The air escapes through a valve into the water.

Manifestly the pressure of the air used by a diver must balance the pressure of the outside air, and the pressure of the water at his depth. The deeper he descends, therefore, the greater the pressure to which he is subjected. The ordinary limit of safety is about 80 feet; but divers have worked at depths of over 200 feet.

88. Suction or Lift Water Pump. The construction of the common suction-pump is shown in Fig. 97. During the first strokes the suction-pump acts as an air-pump, withdrawing the air from the suction-pipe *BC*. As the air below the piston is removed its pressure is lessened, and the pressure of the air on the surface of the water outside forces the water up the suction-pipe, and through the valve V_1 into the barrel. On the down-stroke the water held in the barrel by the valve V_1 passes up through the valve V_2, and on the next up-stroke it is lifted up and discharged through the spout *G*, while more water is forced up through the valve V_1 into the barrel by the external pressure of the atmosphere. It is evident that the maximum height to which water, under perfect conditions, is raised by the pressure of the atmosphere cannot be greater than the height of the water column which the air will support. The specific gravity of mercury is about 13.6, and taking the height of the mercury barometer as 30 inches, the height would be $\frac{30}{12} \times 13.6 = 34$ feet. This is the extreme limit to which a suction-pump could be expected to work, but on account of air in the water and the vapour from the water an ordinary pump will not work satisfactorily for heights above 25 feet.

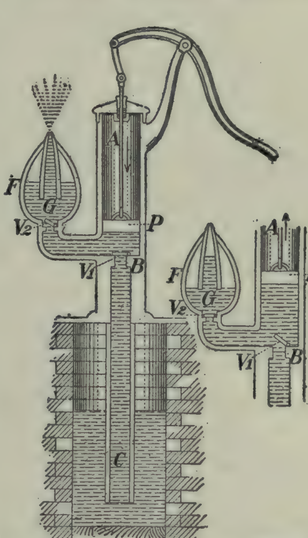

Fig. 98.—Force-pump. *AB*, cylindrical barrel; *BC*, suction-pipe; *P*, piston; *F*, air chamber; V_1, valve in suction-pipe; V_2, valve in outlet pipe; *G*, discharge pipe; *R*, reservoir from which water is taken.

89. Force-Pump. When it is necessary to raise water to a considerable height, or to drive it with force through a nozzle, as for extinguishing fire, a force-pump is used. Fig. 98 shows the most common form of its construction. On the up-stroke a partial vacuum is formed in the barrel, and the air in the suction-tube expands and passes up through the valve *V*. As the plunger is pushed down the air is forced out through the valve V_2. The pump, therefore, during the first strokes acts as an air-pump. As in the suction-pump, the water is forced up into the suction-pipe by the pressure of the air on the surface of the water in the reservoir. When it enters the barrel it is forced by the plunger at each down-stroke through the valve V_2 into the discharge pipe. The flow will obviously be intermittent, as the outflow takes place only as the plunger is descending. To produce a continuous stream, and to lessen the shock on the pipe, an air chamber F, is often inserted in the discharge pipe. When the water enters this chamber it rises above the outlet G which is somewhat smaller than the inlet, and compresses the air in the chamber. As the plunger is ascending the pressure of the inclosed air forces the water out of the chamber in a continuous stream.

90. Double Action Force-Pump. In Fig. 99 is shown the construction of the double-action force-pump. When the piston P is moved forward in the direction of the arrow, water is drawn into the back of the cylinder through the valve V_1, while the water in front of the piston is forced out through the valve V_3. On the backward stroke water is drawn in through the valve V_2 and is forced out through the valve V_4. Pumps of this type are used as fire engines, or for any purposes for which a large continuous stream of water is required. They are usually worked by steam or other power. Air-pumps working on this principle are also used.

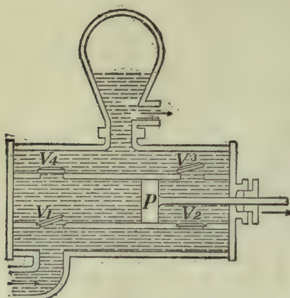

FIG. 99.—Double action force-pump. P, piston; V_1, V_2, inlet valves; V_3, V_4, outlet valves.

Exercise on the Action of Pumps.

First fill a wide-mouth bottle with water, and through a cork insert a glass model of an ordinary pump. Work the pump. It will not pump the water out. Why?

Next, only partially fill the bottle, as in Fig. 100, and try the pump again. It works for a while but then refuses to act. Account for this behaviour.

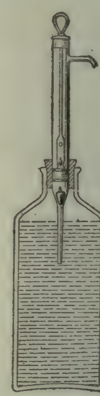

FIG. 100.

91. Siphon. If a bent tube is filled with water, one end placed in a vessel of water, the other end in an empty vessel, and the ends unstopped, the water will flow freely from the tube so long as there is a difference in level in the water in the two vessels. A bent tube of this kind, used to transfer a liquid from one vessel to another, at a lower level is called a siphon.

To understand the cause of the flow consider Fig. 101.

The pressure at A tending to move the water in the siphon in the direction AC
= the atmospheric pressure − the pressure due to the weight of the water in AC;

and the pressure at B tending to move the water in the siphon in the direction BD
= the atmospheric pressure − the pressure due to the weight of the water in BD.

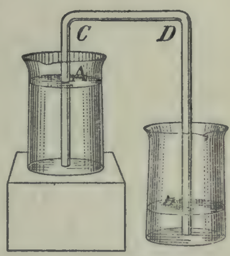

FIG. 101.—The siphon.

But since the atmospheric pressure is the same in both cases, and the pressure due to the weight of the water in AC is less than that due to the weight of the water in BD, the force tending to move the water in the direction AC is greater than the force tending to move it in the direction BD; consequently a flow takes place in the direction $ACDB$. This will continue until the vessel from which the water flows is empty, or until the water comes to the same level in each vessel.

QUESTIONS

1. Upon what does the limit of the height to which a liquid can be raised in a siphon depend?

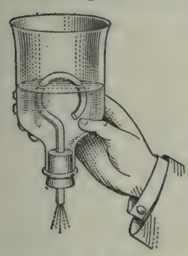
FIG. 102.

2. Over what height can (*a*) mercury, (*b*) water, be made to flow in a siphon?

3. Arrange apparatus as shown in Fig. 102. Let water from a tap run *slowly* into the bottle. What takes place? Explain.


FIG. 103.

4. Natural reservoirs are sometimes found in the earth, from which the water can run by natural siphons faster than it flows into them from above (Fig. 103). Explain why the discharge through the siphon is intermittent.

PART IV—SOME PROPERTIES OF MATTER

CHAPTER XIV

MOLECULES AND THEIR MOTIONS

92. Evidence Suggesting Molecules. Some of the simplest experiments when closely considered lead to most interesting conclusions.

Let us place a piece of wood or some beans, peas, or other such seeds in water. The water soaks into them and they swell in size.

Again, water and alcohol are almost imcompressible. Exert the greatest pressure on them that you can and you will not observe any decrease in volume. But now mix 50 c.c. of water with 50 c.c. of alcohol; the resulting volume is not 100 c.c. but only about 97 c.c.

Also, when copper and tin are mixed in the proportions of 2 of copper to 1 of tin the two substances form an alloy, the volume of which is 7 or 8 per cent. less than the sum of the volumes of the two metals.

Still again, several gases may be inclosed in the same space, or gases may be contained in liquids. Fish live by the oxygen which is dissolved in the water.

These and many other similar phenomena have led us to believe that all bodies are made up of very small particles with spaces between, into which the small particles of other bodies may enter. These particles are too small for us ever to expect to see them with our best microscopes; even if the magnifying power was great enough we would probably not be able to see them as we have good reason to believe that they are always moving so rapidly that the eye could not follow them.

These minute separate particles are called *molecules*. By suitable means in some cases these molecules can be further divided; we then obtain *atoms*, but the substance is no longer the same. We say it has suffered a chemical change. Thus, if we break up the water molecule we obtain oxygen and hydrogen—it is water no more.

93. Diffusion of Gases. The molecules of different gases mix together very freely. This is well illustrated by the following experiment:

Fill one wide-mouthed jar with hydrogen and a similar one with oxygen, which is 16 times as heavy, covering the vessels with glass plates. Then put them together as shown in Fig. 104, the heavier gas being in the lower jar, and withdraw the glass plates. After allowing them to stand for some minutes separate them and apply a match. At once there will be a similar explosion from each, showing that the two gases have become thoroughly mixed.

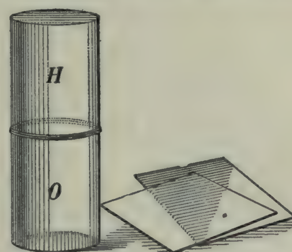

FIG. 104.—Hydrogen in one vessel quickly mixes with oxygen in the other.

In this case the diffusion takes place very rapidly. If the opening between the two jars had been small it might require hours for a thorough mixing, but in time the contents would become identical in composition.

It is through diffusion that the proportions of nitrogen and oxygen in the earth's atmosphere are the same at all elevations. Though oxygen is the heavier constituent there is no excess of it at low levels.

94. Diffusion of Liquids and Solids. Liquids diffuse into each other, though not nearly so rapidly as do gases. The two following simple experiments illustrate this well.

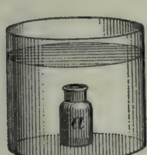

FIG. 105.—Copper sulphate solution in a bottle, placed in a vessel of water. In time the blue solution spreads all through the water.

On the surface of clear water in a tumbler lay a piece of paper, and then carefully pour coloured alcohol (density 0.8) on it. Then remove the paper and the mixing of the two will be seen to commence at once and will proceed quite rapidly.

Let a wide-mouth bottle *a* (Fig. 105) be filled with a solution of copper sulphate and then placed in a larger vessel containing clear water. The solution is denser than the water but in time the colour will be distributed uniformly throughout the liquid.

In the case of solid bodies the mixing of their molecules is very slow, but it takes place nevertheless. If discs of gold and lead be kept in close contact for several weeks and then tested, gold will be detected in the lead and lead in the gold.

We are thus led to believe that all bodies are composed of molecules which are continually in motion. If the temperature of the body rises the motions become more vigorous.

95. Passage of Hydrogen Through a Porous Wall. The molecules of hydrogen are very light and their velocities are very great. As a consequence it is harder to confine hydrogen in a vessel than most other gases, and it diffuses more rapidly. This is well illustrated in the following experiment:

An unglazed earthenware pot, *A* (such as is used in galvanic batteries), is closed with a rubber or other cork impervious to air, and a glass tube connects this with a bottle nearly full of water (Fig. 106). A small glass tube *B*, drawn to a point, also passes through the cork of the bottle and reaches nearly to the bottom of the bottle.

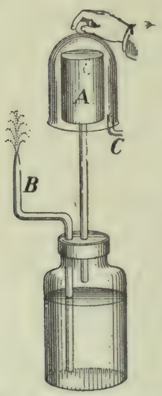

Fig. 106.—Experiment showing rapid passage of hydrogen through a porous wall.

Now hold over the porous pot a bell-jar full of dry hydrogen, or pass illuminating gas by the tube *C* into the bell-jar. Very soon a jet of water will spurt from the tube *B*, sometimes with considerable force. After this action has ceased remove the bell-jar, and bubbles will be seen entering the water through the lower end of the tube *B*.

At first the space within the porous pot and in the bottle above the water is filled with air, and when the hydrogen is placed above the porous pot its molecules pass in through the walls of the pot much faster than the air molecules come out. In this way the pressure within the pot is increased, and this, when transmitted to the surface of the water, forces the water out in a jet. When the jar is removed the hydrogen rapidly escapes from *A* through the porous walls and the air rushes in through the tube *B* and is seen to bubble up through the water.

96. Molecular Motions in Liquids. In liquids the motions of the molecules are not so unrestrained as in a gas, but one can hardly doubt that the motions exist, however.

The spaces between the molecules are much smaller than in a gas and so their collisions together are much more frequent. Moreover the molecules exert an attractive force on each other, the force of cohesion, but they glide about from point to point throughout the entire mass of the liquid. Usually when a molecule comes to the surface its neighbours hold it back and prevent it from leaving the liquid. The molecules, however, have not all the same velocity, and occasionally when a quick-moving one reaches the surface the force of attraction is not sufficient to restrain it and it escapes into the air. We say the liquid *evaporates.*

When a liquid is heated the molecules are made to move more rapidly, and their collisions are more frequent. The result is that the liquid expands and the evaporation is more rapid.

In the case of oils the molecules appear to have great difficulty in escaping at the surface, and so there is little evaporation.

97. Osmosis. Just as the porous pot (§ 95) permitted the gas hydrogen to pass through it more freely than air, so certain substances allow some liquids to pass through them more freely than others. This is well shown in the following experiment:

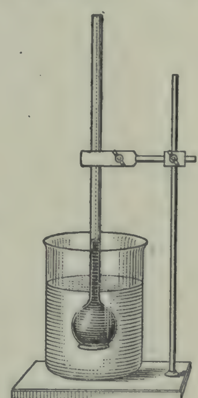
Fig. 107.—Osmosis.

Over the opening of a thistle-tube let us tie a sheet of moistened parchment or other animal membrane (such as a piece of bladder). Then, having filled the funnel and a portion of the tube with a strong solution of copper sulphate, let us support it as in Fig. 107 in a vessel of water so that the water outside is at the same level as the solution within the tube.

In a few minutes the solution will be seen to have risen in the tube. The water will appear blue, showing that some of the solution has come out, but evidently more water has entered the tube. The rise in level continues (perhaps for two or three hours) until the hydrostatic pressure due to the difference of levels stops it.

This mode of diffusion through membranes is called *osmosis*, and the difference of level thus obtained is called *osmotic pressure.* Osmosis plays an important part in the processes of nature. There are many illustrations of it.

Fill a pig's bladder with alcohol, tightly close it and then immerse it in water. The bladder begins to swell and may burst. Next, let it be filled with water and immersed in alcohol; it begins to shrink. In this case water passes freely through the bladder but alcohol cannot.

Currants when purchased at the grocer's are dried up and shrunken, but when placed in water they swell out and become rounded. This shows that the organic substances in the currants cannot pass out while the water passes in.

98. Viscosity. Tilt a vessel containing water; it soon comes to its new level. With ether or alcohol the new level is reached even more quickly, but with molasses much more slowly.

Although the molecules of a liquid or of a gas move with great freedom amongst their fellows, some resistance is encountered when one layer of the fluid slides over another. It is a sort of internal friction and is known as *viscosity.*

Ether and alcohol have very little viscosity; they flow very freely and are called mobile liquids. On the other hand, tar, honey and molasses are very viscous.

Stir the water in a basin vigorously and then leave it to itself. It soon comes to rest, showing that water has viscosity. The viscosity of gases is smaller than that of liquids, that of air being about $\frac{1}{80}$ that of water.

99. Distinction between Solids and Liquids. We readily agree that water is a liquid and that glass is a solid, but it is not easy to discriminate between the two kinds of bodies.

Consider the following experiment. Drive two pairs of nails in a wall in a warm place, and on one pair lay a stick of sealing-wax or a paraffin candle, on the other a tallow candle or a strip of tallow (Fig. 108). After some days (perhaps weeks), the tallow will still be straight and unyielding while the wax will be bent.

FIG. 108.—A paraffin candle bends but a tallow one keeps straight.

Now ordinarily one would consider both the tallow and the wax to be solids, but the latter appears to flow (though very slowly), while the former retains its shape. A liquid offers no *permanent* resistance to forces tending to change its shape. Taking this as our definition of a liquid, the above experiment shows that at ordinary temperatures wax is a liquid, though a very viscous one, while tallow is a true solid.

100. Cohesion and Adhesion. When we attempt to separate a solid into pieces we experience difficulty in doing so. The molecules cling together, refusing to separate unless compelled by a considerable effort. This attraction between the molecules of a body is called *cohesion,* and the molecules must be very close together before this force comes into play. The fragments of a porcelain vessel may fit together so well that the eye cannot detect any cracks, but the vessel falls to pieces at the touch of a finger.

Some substances can be made to weld together much more easily than others. Clean surfaces of metallic lead when pressed together cohere so that it requires considerable force to pull them apart; and powdered graphite (the substance used in 'lead' pencils), when submitted to very great pressure, becomes once more a solid mass.

Cohesion is the natural attraction of the molecules of a body for one another. If the particles of one body cling to those of another body there is said to be *adhesion* between them. The forces in the two cases are of the same nature, and there is really no good reason for making a distinction between them.

The force of cohesion is also present in liquids, but it is much weaker than in solids. If a clean glass rod is dipped in water and then withdrawn a film of water will be seen clinging to it; but if dipped in mercury no mercury adheres. This shows that the adhesion between glass and water is greater than the cohesion between the molecules of water, but the reverse holds in the case of mercury and glass.

101. Other Properties Depending on Cohesion. A body is said to be *plastic* when it can be readily moulded into any form. The more plastic the body, the smaller is the elastic force exerted to recover its form. Clay and putty are good examples of plastic bodies.

A *malleable* body is one which can be beaten into thin sheets and still preserve its continuity. Gold is the best example. The gold leaf employed in 'gilding' is extremely thin. Between the fingers it crumples almost to nothing.

A *ductile* substance is one which can be drawn out into fine wires. Platinum, gold, silver, copper and iron are all very ductile. By judicious work platinum can be drawn into a wire $\frac{1}{2000}$ mm. in diameter. Glass is very ductile when heated, as also is quartz, though to soften the latter a much higher temperature is required.

A *friable* or *brittle* substance is one easily broken under a blow. Glass, diamond and ice are brittle substances

102. Forces at the Surface of a Liquid. On slowly forcing water out of a medicine dropper we see it gradually gather at the end (Fig. 109), becoming more and more globular, until at last it breaks off and falls a sphere. When mercury falls on the floor it breaks up into a thousand shining globules. Why do not these flatten out? If melted lead be poured through a sieve at the top of a tower it forms into drops which harden on the way down and finally appear as solid spheres of shot.

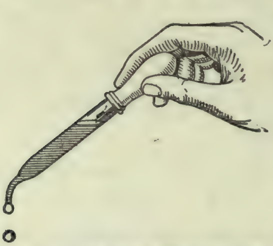

FIG. 109.—A drop of water assumes the globular form.

When the end of a stick of sealing-wax or of a rod of glass is heated in a flame it assumes a rounded form.

These actions are due to cohesion. The surface of a liquid always trys to become as small as possible. Indeed, the liquid behaves as though it was covered by a thin rubber sheet always stretched tight, or in a state of tension, and the phenomena described above are said to be due to *surface tension*. There are many interesting and beautiful experiments illustrating surface tension, a few of which follow.

103. Surface Tension in Soap Films. The surface tension of water is beautifully shown by soap bubbles and films. In these there is very little matter, and the force of gravity does not interfere with our experimenting. It is to be observed, too, that in the bubbles and films there is an outside and an inside surface, each under tension.

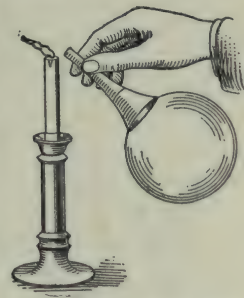

FIG. 110.—Soap bubble blowing out a candle.

In an inflated toy balloon the rubber is under tension. This is shown by pricking with a pin or untying the mouthpiece. At once the air is forced out and the balloon becomes flat. A similar effect is obtained with a soap bubble. Let it be blown on a funnel, and the small end be held to a candle flame (Fig. 110). The outrushing air at once blows out the flame, which shows that the bubble behaves like an elastic bag.

There is a difference, however, between the balloon and the bubble. The former will shrink only to a certain size ; the latter first shrinks to a film across the mouth of the funnel and then runs up the funnel handle ever trying to reach a smaller area.

Again, take a ring of wire about two inches in diameter with a handle on it (Fig. 111). To two points on the ring tie a fine thread with a loop in it. Dip the ring in a soap solution and obtain a film across it with the loop resting on the film. Now, with the end of a wire or with the point of a pencil, puncture the film within the loop. Immediately the film which is left assumes as small a surface as it can, and the loop becomes a perfect circle, since by so doing the area of the film that is left becomes as small as possible.

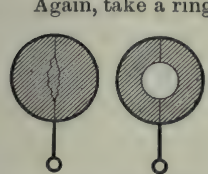

FIG. 111.—A loop of thread on a soap film.

104. Levels of Liquids in Capillary Tubes. In § 65 it is stated that in any number of communicating vessels a liquid stands at the same level. The following experiment gives an apparent exception to this law. Let a series of capillary (Lat. *Capillus*, a hair) tubes, whose internal diameters range from say 2 mm. to the finest obtainable, be held in a vessel containing water (Fig. 112). It will be found that in each of them the level is above that of the water in the vessel, and that the finer the tube the higher is the level. With alcohol the liquid is also elevated, (though not so much), but with mercury the liquid is depressed. The behaviour of mercury can conveniently be shown in a U-tube as in Fig. 113.

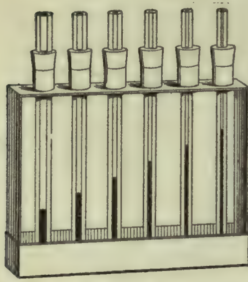

Fig. 112.—Showing the elevation of water in capillary tubes.

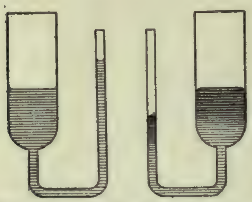

Fig. 113.—Contrasting the behaviour of water (left) and mercury (right).

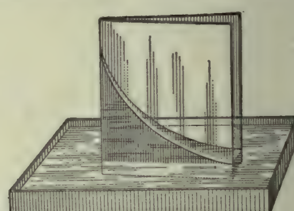

Fig. 114.—Water rises between the two plates of glass which touch along one edge.

Another convenient method of showing capillary action is illustrated in Fig. 114. Take two square pieces of window glass, and place them face to face with an ordinary match or other small object to keep them a small distance apart along one edge while they meet together along the opposite edge. They may be held in this position by an elastic band. Then stand the plates in a dish of coloured water. The water at once creeps up between the plates, standing highest where the plates meet.

105. Other Illustrations of Surface Tension. It is not easy to pour water from a tumbler into a bottle without spilling it, but by holding a glass rod as in Fig. 115, the water runs down into the bottle and none is lost. The glass rod may be inclined but the elastic skin still holds the water to the rod.

Water may be led from the end of an eave-trough into a barrel by means of a pole almost as well as by a metal tube.

When a brush is dry the hairs spread out as in Fig. 116*a*, but on wetting it they cling together (Fig. 116*c*). This is due to the surface film which contracts and draws the hairs together. That it is not due simply to being wet is seen from Fig. 116*b*, which shows the brush in the water but with the hairs spread out.

FIG. 115.—How to utilize surface tension in pouring a liquid.

Capillary action is seen in the rising of water in a cloth, or in a lump of sugar when touching the water; in the rising of oil in a lamp-wick and in the absorption of ink by blotting paper.

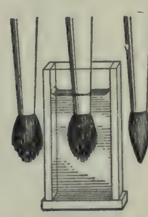

FIG. 116.—Surface tension holds the hairs of the brush together.

106. Small Bodies Resting on the Surface of Water. By careful manipulation a needle may be laid on the surface of still water (Fig. 117). The surface is made concave by laying the needle on it, and in the endeavour to contract and smooth out the hollow, sufficient force is exerted to support the needle, though its density is $7\frac{1}{2}$ times that of water. When once the water has wet the needle the water rises against the metal and now the tendency of the surface to flatten out will draw the needle downwards.

FIG. 117.—Needle on the surface of water kept up by surface tension.

If the needle is magnetized, it will act when floating like a compass needle, showing the north and south direction.

Some insects run over the surface of water, frequently very rapidly (Fig. 118). These are held up in the same way as the needle, namely, by the skin on the surface, to rupture which requires some force.

FIG. 118.—Insect supported by the surface tension of the water.

PART V—SOUND

CHAPTER XV

Production and Transmission of Sound

107. What Causes Sound. When a bell is rung, or a piano played, or a door slammed, we hear a sound. How does this sound arise? A few simple experiments will show the condition of a body when it is giving rise to sound.

Clamp a knitting-needle, or a narrow strip of steel in a vice so that about 15 cm. projects. Then pull the free end aside and let it go. You hear a deep, low note and on looking closely you can *see* that the needle is vibrating. Touch it with the finger. You stop the vibrations and at the same time the sound ceases.

Strike a bell with a pencil or a light piece of wood. In this case you will hardly be able to see any movement in the bell, but you can easily satisfy yourself that it is in vibration by suspending a thin hollow glass bead or a ball of pith so that it just touches the edge of the bell. It will be thrown off vigorously every time it touches the bell.

Next, sound a tuning-fork and test it as you did the bell. The little ball is thrown off, showing that the prongs are in motion. Hold the fork with the stem on the table; the sound is louder. Not only do the prongs move from side to side, but the stem moves up and down (Fig. 119), and in doing so makes the table move up and down.

Fig. 119.

Another interesting way to produce sound is by means of a square or a circular brass plate. Clamp it at the centre and sprinkle sand lightly over it. Now draw a violin bow vertically across the edge of the plate. This makes the plate give out a shrill note and the sand dances about in a curious fashion, settling at last along certain lines. Between these the motion is vigorous, but along them the plate is at rest. By touching with a finger the edge of the plate at one or at two places the plate gives out different notes and the sand takes up different figures (Fig. 120).

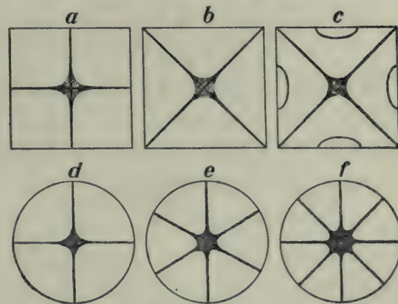

FIG. 120.—Sand-figures showing nodal lines in vibrating plates.

There are many other experiments which might be performed and in every case when we trace out the source of the sound we find that *it arises from a body in rapid vibration.*

108. What Carries the Sound to the Ear? Usually it is the air, but other bodies can convey sound quite as well.

Hold your ear close against one end of a long wooden rod while another person scratches the other end lightly with a pin. You hear the sound distinctly. One can detect the rumbling of a distant railway train by laying the ear upon the steel rail. The Indians on the western plains could, by putting the ear to the ground, detect the tramping of cavalry too far off to be seen. If two stones be struck together under water, the sound perceived by an ear under water is louder than if the experiment had been performed in the air.

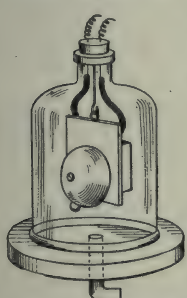
FIG. 121.—Electric bell in a jar connected to an air-pump. On exhausting the air from the jar the sound became weaker.

Thus we see that solids, liquids and gases all transmit sound. Further, we can show that some one of these is necessary.

Under the receiver of an air-pump place an electric bell, supporting it as shown in Fig. 121. At first, on closing the circuit, the sound is heard easily, but if the receiver is now exhausted by a good air-pump it becomes feebler, continually becoming weaker as the exhaustion proceeds.

If now the air is admitted to the receiver the sound at once gets louder.

In performing this experiment we cannot completely get rid of the sound, as there is always some air left in the receiver and the wire or cord by which the electric bell is suspended will also transmit some sound. If the bell were in a perfect vacuum we would see the hammer striking the bell but would hear no sound at all.

109. Velocity of Sound in Air. If we watch a carpenter working at a distance we distinctly see his hammer fall before we hear the sound of the blow. Also, you see the steam coming from the whistle of a locomotive or steamboat several seconds before you hear the sound, and we continue to hear the sound for the same length of time after the steam is shut off.

Evidently sound requires an appreciable time to travel from one place to another. Its velocity in air at 0° C. is 332 metres or 1,089 feet per second, and this velocity increases about 60 cm. for each centigrade degree rise in temperature. The velocity in water is 1,435 m. and in iron 5,130 m. per second.

110. Nature of Sound. As we have seen, sound travels in air at the rate of 332 metres per second, and in liquids and solids much faster than this. Now it is evident that there is no actual passage of particles of matter from the sounding body to the ear. But there is *something* which does pass through this space. What is it?

Perhaps you have been in a small boat when a steamship went by, perhaps a mile away. After some minutes you felt your boat violently rocked about by the "swells" raised by the steamship. A *wave-motion* travelled over the surface of the water and told you of the presence of the large ship.

Something of the same nature occurs in the case of sound. We say it travels by means of waves, but it goes *through* the substances, not over their surfaces.

111. Reflection of Sound. Now, when water-waves strike a pier or the shore (if the water there is not too shallow) they turn and move off in another direction and we say they are *reflected.* We are also used to speaking of light being reflected from a mirror or from the surface of water. Sound-waves are also reflected.

If you stand at a distance of 100 feet or more before a large building off by itself, or before a steep cliff, and clap your hands or give a quick shout, you hear an echo. The sound-waves strike the flat surface and are reflected back to you. If the distance is less than 100 feet the sound is returned, but the reflected portion gets back so quickly that you do not hear it as a distinct separate sound.

Sometimes in a river-valley with steep or wooded shores, or in a mountainous region a succession of echoes can be heard, giving a pleasing effect. Some buildings are so constructed that a faint sound made at one place is reflected to another definite place. A person there hears it, but anyone at points between does not. An illustration of this is in the famous Whispering Gallery of St. Paul's Cathedral, in London, England.

The bare walls of a hall are good reflectors of sound, though usually the dimensions are not great enough to give a distinct echo, but the numerous reflected sound-waves produce a *reverberation* which appears to make the words of the speaker run into each other, and thus prevents them being distinctly heard. By means of cushions, carpets and curtains, which absorb the sound which falls upon them instead of reflecting it, this reverberation can be largely overcome. The presence of an audience has the same effect. Hence, a speaker is heard much better in a well-filled auditorium than in an empty one.

If you speak into one end of a tube your voice may be heard a mile or more away. In this case the waves cannot spread out and lose their energy, but are continually reflected from the inner walls.

PROBLEMS

1. Calculate the velocity of sound in air at 5°, 10°, 40° C.

2. A thunder-clap is heard 5 seconds after the lightning flash was seen. How far away was the electrical discharge? (Temperature, 15° C.)

3. At Carisbrook Castle, in the Isle of Wight, is a well 210 feet deep and 12 feet wide, the interior being lined with smooth masonry. A pin dropped into it can easily be heard to strike the water. Explain why.

4. Why does the presence of an audience improve the acoustic properties of a hall?

5. Explain the action of the ear-trumpet and the megaphone or speaking-trumpet.

6. A man standing before a precipice shouts, and 3 seconds afterwards he hears the echo. How far away is the precipice? (Temperature, 15° C.)

7. In 1826 two boats were moored on Lake Geneva, Switzerland, one on each side of the lake, 44,250 feet apart. One was supplied with a bell *B* (Fig. 122*a*), placed under water, so arranged that at the moment it was struck a torch *m* lighted some gunpowder in the pot *P* (Fig. 122*b*). The sound was heard at the other boat by an observer with a watch in his hand and his ear to an ear-trumpet, the bell of which was in the water. The sound was heard 9.4 seconds after the flash was seen. Calculate the velocity of sound in water.

Fig 122*a*.—Apparatus for producing the sound, in Lake Geneva.

Fig. 122*b*.—Listening to the sound from the other side of the Lake.

CHAPTER XVI

Pitch, Musical Scales

112. Musical Sounds and Noises. The strokes of a carpenter's hammer, the slam of a door, or the rattling of a carriage over a stony road, we consider to be noises, while a plucked guitar string or a flute gives a sound which we recognize as musical. What is the difference between a noise and a musical sound?

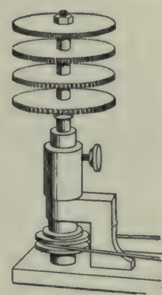

Fig. 123.—Toothed wheels on a rotating machine. On holding a card against the teeth a musical sound is heard.

In Fig. 123 are shown four wheels on an axis which can be made to rotate by a belt from a larger wheel. First make the axis rotate slowly and hold the edge of a card against the teeth of a wheel. We hear each separate tap and there is no music in them. Now gradually increase the speed of rotation, and at last the successive taps are not heard separately but they join together into a musical note.

We reach a similar result, though the effect is more pleasing, if we blow a current of air through holes regularly spaced along a circle near the outer edge of a rotating disc (Fig. 124). When the wheel turns slowly we hear the separate puffs, but when it turns rapidly they blend into a pleasing note.

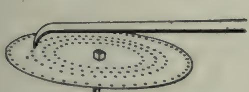

Fig. 124.—Air is blown through the holes in the rotating plate.

If the teeth of the wheel or the holes in the disc were not regularly spaced we would get a noise instead of a musical note.

We conclude that a musical note is produced by a series of rapid, regularly spaced vibrations. If they are spaced irregularly we get a noise. It is possible for a number of musical notes to be so jumbled together that the regular periodic nature is entirely lost, and then the result is a noise.

113. Intensity of Sound. There are three features by which musical tones are distinguished from each other, namely:

(i) *Intensity* or *Loudness*, (ii) *Pitch,* (iii) *Quality.*

The harder you strike a bell or a piano string, or the farther you pluck aside a guitar string the louder is the sound. In these cases the vibrating body swings back-and-forth through a greater space and of course the particles of the air are made to swing through greater spaces, too. The intensity or loudness of a sound, then, depends on the space through which the vibrating body swings, or on the *amplitude* of the vibrations.

When excavating for a tunnel or the foundation of a bridge the men often have to work in an inclosed space in which the air is compressed and so has greater density. Under such circumstances when one speaks in a ordinary tone it sounds as though he were shouting. Intensity, then, depends on the density of the medium which carries the sound.

We all know, too, that the nearer you are to the source of the sound the louder it appears. Intensity decreases as the distance from the sounding body increases.

Quality of sounds will be taken up in Chapter XVIII.

114. Pitch. Let us experiment with our toothed wheels again (Fig. 123). Hold an edge of a card against the teeth of a wheel and rotate it with continually increasing speed. At first the separate taps are heard, then they blend into a musical note which we say is *low*, and as the speed increases the note gets *higher*. With very great speed the note gets very *high* and shrill. If the wheels have different numbers of teeth on them, which is usually the case, and you touch them, one after the other, that wheel which has the greatest number of teeth gives out the highest note.

Pitch is the word we use in describing this feature of sound. When the number of vibrations producing a sound is small the pitch is low, and as the number increases the pitch becomes higher.

For ordinary ears the lowest pitch of a musical note corresponds to about 30 vibrations per second, the highest, to between 10,000 and 20,000 per second. In music the limits are from about 40 to 4,000 vibrations per second, the piano having approximately this range. The lowest note taken by a man's voice has about 60, and the highest note taken by a woman's voice has about 1,300 vibrations per second.

115. Musical Combinations of Notes. A musical note is pleasing in itself, but certain combinations of notes are peculiarly pleasing to the ear. These have been recognized from the earliest times and were cultivated purely on account of their giving pleasure or expressing certain feelings. The old musicians knew nothing about the number of vibrations per second, but it has been found that in a pleasing combination of notes the numbers which express their vibrations per second are related to each other in a peculiar way.

Let us try our toothed wheels again. Make the axis rotate uniformly and touch the four wheels one after the other. The notes seem to follow each other in a very pleasing way—we get what is called a *chord* in music. Now count the teeth on the wheels. We find there are 48, 60, 72, 96, and if each of these is divided by 12 we get the numbers 4, 5, 6, 8. The notes given by the two outer wheels follow each other or blend together most agreeably of all, and we see that there are just twice as many vibrations in one as in the other. These two notes are said to be an *octave* apart.

In Fig. 125 is shown the central part of a piano key-board. The string which sounds when C' is pressed gives a note an octave above that when C is pressed; the number of vibrations for C' is twice that for C. Between these two notes six others

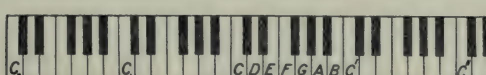

FIG. 125.—Central part of a piano key-board. The notes marked C_2, C_1, C, C', C'', go up by octaves.

are inserted, the eight thus obtained giving a pleasing series which we call a musical scale. By actual experiment we find that the number of vibrations of the notes are simple numbers. C, E, G, C' follow each other as did the four notes given by the toothed wheels.

PROBLEMS

1. From what experience would you conclude that all sounds, no matter what the pitch may be, travel at the same rate? .

2. If the vibration number of C is 300 find that for C'.

3. Why does the sound of a circular saw fall in pitch as the saw enters the wood?

4. Find the vibration numbers of all the C's on the piano, taking middle C as 261.

CHAPTER XVII

Musical Instruments

116. The Piano. Let us raise the top of the piano-case and look inside while some one is playing. Each time a key is pressed a little hammer flies up and strikes a steel string, which gives out its own definite note. The keys at the left-hand or bass end give notes of lower pitch than do those at the right-hand or treble end; and we observe that the strings which give the low notes are longer and heavier than those which give the high notes.

117. The Sonometer. The vibrations of strings are best studied by means of the sonometer, a convenient form of which is shown in Fig. 126. The strings are fastened to steel

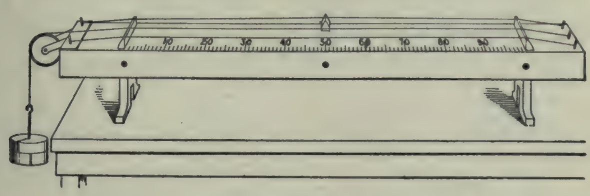

Fig. 126.—A sonometer, consisting of stretched strings over a thin wooden box. By means of a bridge we can use any part of a string.

pins near the ends of the instrument, and then pass over fixed bridges near them. The tension of a string can be altered by turning the pins with a key, or we may pass the string over a pulley and attach weights to its end. A movable bridge allows any portion of a string to be used. The vibrations are produced by a bow, by plucking or by striking with a suitable hammer.

The thin wooden box which forms the body of the instrument strengthens the sound. If the ends of a string are fastened to massive supports, stone pillars for instance, it emits only a faint sound. Its surface is small and it can put in motion only a small mass of air. When stretched over the light box, however, the string communicates its motion to the bridges on which it rests, and these set up vibrations in the wooden box. The latter has a considerable surface and impresses its motion upon a large mass of air. In this way the volume of the sound is multiplied many times. In the piano the strings are stretched over a sounding-board. If it were absent you would hardly hear the sound.

118. Laws of Vibrations of Strings. First take away the movable bridge and pluck the string. It vibrates as a whole and gives out its *fundamental* note. Then place the bridge under the middle point of the string, hold the string down on it with a finger, and pluck again, thus obtaining the note from a string half as long. The note given out is an octave above the other one, and hence has twice the number of vibrations per second. If we push the bridge along until it is one-fourth the length of the string from one end and pluck again we get a note which is one octave above the last one or two octaves above the fundamental, and which has four times its number of vibrations. If we took one-third of the string we would get a note with three times the number of vibrations of the fundamental. We find, then, that if we take $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$ or $\frac{1}{10}$ of the length of the string, we get notes whose numbers of vibrations are 2, 3, 4, 5 or 10 times that of the fundamental.

Next, let us turn the pin at the end with a key or add weights to the end and thus increase the tension of the string. We would find that to get twice the number of vibrations we would have to make the tension four times as great, to get three times the number the tension must be nine times as great, and so on.

Again, by taking strings of the same material we would find that the thicker the string the smaller is the number of vibrations per second. A string of twice the diameter gives a note whose number of vibrations is one-half as great; if the diameter is three times as great, the number of vibrations is one-third; and so on.

Finally, the number of vibrations depends on the density of the string. A platinum string (density 21.5 g. per c.c.) vibrates more slowly than a steel one (density 7.9 g. per c.c.). If the density is four times as great, the number of vibrations is one-half; if it is nine times as great, the number of vibrations is one-third; and so on.

119. Stringed Instruments. The harp is somewhat similar in principle to the piano, but it is played by plucking the strings with the fingers. By pressing pedals the lengths of the strings may be altered so as to 'sharpen' or 'flatten' any note.

The guitar has six strings, the three lower-pitched ones usually being of silk over-wound with fine wire.

FIG. 127.—The guitar. With the left hand the strings are shortened by pressing them against the 'frets,' while the note is obtained by plucking with the right hand.

There are little strips across the finger-board called 'frets,' and by pressing the strings down by the fingers against these they are shortened and give out the other notes (Fig. 127).

There are only four strings on the violin. The other notes are obtained by shortening the strings by means of the fingers, but as there are no 'frets' to guide the performer, he must judge the correct positions of the fingers himself.

120. Vibrations of Air Columns; Resonance. Let us hold a tube about 2 inches in diameter and 18 inches long with its lower end in a vessel containing water (Fig. 128); and over the open end hold a vibrating tuning-fork. Suppose the fork to make 256 vibrations per second.

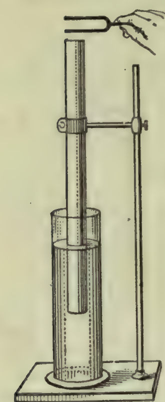

Fig. 128.–Air column in resonance with a tuning-fork.

By moving the tube up and down we find that when it is at a certain depth, the sound we hear is greatly intensified. This is due to the vibrations of the air column above the water in the tube. It must have a definite length for each fork. On measuring it for this one we find that it is approximately 13 inches. If the fork made twice as many vibrations the length of the column would be one-half as great, or $6\frac{1}{2}$ inches; and so on.

The air column is put in vibration by the fork with which it is said to be in *resonance.*

121. Organ Pipes and Flute. The most familiar application of the vibrations of air columns is in organ pipes.

Fig. 129. — Section of a wooden organ pipe.

In Fig. 129 is shown a section of a rectangular wooden pipe; in Fig. 130 is a metallic cylindrical pipe. Sometimes the pipes are conical in shape.

Air is blown through the tube T into the chamber C, and escaping from this by a narrow slit it strikes against a thin lip D. In doing so a periodic motion of the air at the lip is produced, and this sets in motion the air in the pipe, which then gives out its proper note.

Fig. 130. — A metallic organ pipe.

In Fig. 131 is shown a flute. By driving a current of air across the thin edge of the opening, which is near one end, the air column within is set in vibration, much as in an organ pipe. In the tube there are holes which may be opened or closed by the player, opening a hole being equivalent to cutting off the tube at that place. Higher notes are also obtained by blowing harder.

122. Reed Instruments. In the ordinary organ, the mouth-organ, the accordion and some other instruments the vibrating body is a reed, such as is shown in Fig. 133.

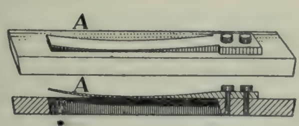

FIG. 133.—An organ reed. The tongue *A* moves in and out of the opening. This is called a *free* reed.

The tongue *A* vibrates in and out of an opening which it accurately fits, the motion being kept up by the current of air which is directed through the opening.

FIG. 131. The flute.

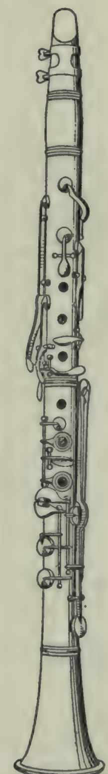

FIG. 132. The clarinet.

In some organ pipes reeds are placed, but the note produced is due chiefly to the air column in the pipe, the reed simply serving to set it in vibration.

In Fig. 132 is shown a clarinet. This instrument has holes in the tube which are covered by keys or by the fingers of the player. The air in the tube is put in vibration by means of a reed made of cane shown in Fig. 134. The reed is very flexible, and the note heard is that of the air column, not of the reed. In this case the reed simply covers and uncovers the opening in the mouthpiece, being too large to pass into the opening. It is called a *striking* reed, that in the organ (Fig. 133) being a *free* reed. In the automobile 'honk' a striking reed is used. On pressing the bulb the reed sets in vibration the air column in the brass portion.

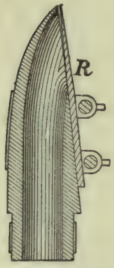

FIG. 134.–Mouthpiece of the clarinet. The reed *R* covers the opening.

CHAPTER XVIII

Quality; Sympathetic Vibrations

123. Quality of Sound. Suppose the same note be sounded on a piano, an organ, a cornet or by the human voice. Even though it has in each case the same pitch and the same intensity, we can recognize the instrument which produces it. There is something which clearly distinguishes one note from the others, and the peculiarity which allows us to make this distinction is called its *quality*.

124. Harmonics or Overtones. We can illustrate the cause of quality by means of experiments with the sonometer.

Let us make some little paper riders, as shown in Fig. 135 and place them at different points of the string. Then rub the string at its centre with a violin bow. All the riders are thrown off. The string vibrates as a whole Fig. 136 (a), and the tone we hear is its *fundamental*.

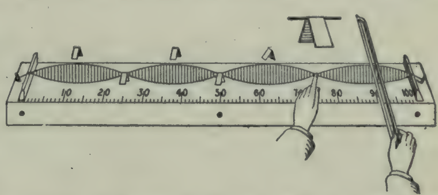

Fig. 135.—Obtaining nodes and loops in a vibrating string. The paper riders stay on at the nodes, but are thrown off at the loops.

Next, touch the string slightly at its mid-point with the tip of a finger or with a feather, and place paper riders on other parts of the string. Quite a different sound is now given, its prevailing tone being an octave above the other, and hence produced by twice as many vibrations per second. The riders are all thrown off, as before. In this case touching the string at its middle is equivalent to placing a bridge there, and the string vibrates in two equal parts as shown in Fig. 136 (b). The tone now given is said to be the first harmonic of the fundamental.

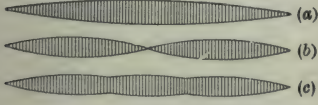

Fig. 136.—Showing how a string vibrates when giving (a) its fundamental, (b) its first harmonic, (c) both of these together.

Again, touch the string at a point one-fourth of its length from one end and rub it with the bow half-way between the finger and the near end, as shown in Fig. 135. Place five riders at points $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, $\frac{1}{2}$, $\frac{5}{8}$ of the length of the string from the far end. Now if you vibrate the string carefully three of them will be thrown off and the other two will retain their seats, showing that the string is vibrating in four equal parts. The prevailing tone now given out is two octaves above the fundamental, and it is called its *third* harmonic. By holding the finger at the proper place and bowing at the right point we can make the string vibrate in 3, 5, 6, or more equal parts, and thus obtain the 2nd, 4th and 5th harmonics.

The points where the string is at rest are called *nodes*, and the points half-way between these are called *loops*.

Now when a string is vibrated, in addition to the fundamental, some of these harmonics are present. In Fig. 136 (*c*) is shown the form the string would appear to have when giving its fundamental and its first harmonic together. If there are other harmonics present the form of the string will be more complicated.

Of course there can be harmonics in the case of other than stringed instruments.

The quality of the note given by an instrument depends on what harmonics are present.

In general, those notes in which the fundamental is relatively strong and the harmonics few and feeble are said to be of a 'mellow' character; but when the harmonics are numerous the note is harsher and has a so-called metallic sound. If a musical string is struck with a hard body the high harmonics come out prominently.

When a violin string is bowed the first seven harmonics are present, and give to the sound its piercing character. In the case of the piano the 1st, 2nd and 3rd harmonics are fairly strong, while the 4th, 5th and 6th are more feeble.

125. Sympathetic Vibrations. A tuning-fork is usually mounted on a box of a definite size. The stem of the fork makes the box vibrate and when the box is of the proper size the air column within it vibrates vigorously. It is said to be in *resonance* with the fork.

Let us place two tuning-forks, which vibrate the same number of times per second, with the open ends of their resonance boxes facing each other and a short distance apart (Fig. 137). Now vibrate one of them vigorously by means of a bow or by striking with a soft mallet (a rubber stopper on a handle), and after it has been sounding for a few seconds bring it to rest by placing the hand upon it. The sound will still be heard, but on examination it will be found to proceed from the other fork.

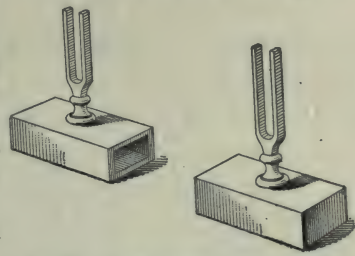

FIG. 137.—Two tuning-forks arranged to show sympathetic vibrations. When one is vibrated the other responds.

This illustrates the phenomenon of sympathetic vibrations. The first fork sets up vibrations in the resonance box on which it is mounted, and this produces vibrations in the inclosed air column. The waves proceed from it, and on reaching the resonance box of the second fork its air column is put in vibration. The vibrations are communicated to the box and then to the fork, which, having considerable mass, continues its motion for some time.

A single wave from the first fork would have little effect, but when a long series comes in regular succession each helps on what the one next before it has started. Thus the effect accumulates until the second fork is given considerable motion, its sound being heard over a large room.

For this experiment to succeed the vibration numbers of the two forks must be accurately equal.

126. Illustrations of Sympathetic Vibrations. The pendulum of a clock has a natural period of vibration, depending on its length, and if started it continues swinging for a while, but at last comes to rest. Now the works of the clock are so constructed that a little push is given to the pendulum at each swing and these, being properly timed, are sufficient to keep up the motion.

Again, it is impossible by a single pull on the rope to ring a large bell, but by timing the pulls to the natural period of the bell's motion, its amplitude continually increases until it rings properly.

When a body of soldiers is crossing a suspension bridge they are usually made to break step for fear that the steady tramp of the men might start a vibration agreeing with the free period of the bridge, and which, by continual additions, might reach dangerous proportions.

PART VI—HEAT

CHAPTER XIX

Sources of Heat; Expansion through Heat

127. Heat Produced by Mechanical Work. Our common experience shows us that we can obtain heat in many ways. Let us consider a few experiments, which will illustrate some of these ways.

Rub a metal button vigorously on your sleeve or on a board and then touch the back of your hand with it. It is unpleasantly hot.

Fig. 138.—Fire-syringe.

Bore with brace and bit into a hardwood block or drill a hole into a piece of iron, and then touch the bit or the drill.

The first inhabitants of our land used to start a fire by rubbing dry sticks together. To succeed in this requires considerable skill and patience, but it can be done as many boy-scouts can assure us.

In Fig. 138 is shown a so-called 'fire-syringe.' Into this drop a bit of tinder and then quickly force the piston down. In the compression it is possible to develop enough heat to ignite the tinder. In some gasoline engines the mixture of gasoline vapour and air is fired by rapidly compressing it.

The next time you are inflating your bicycle tires feel the barrel of your air-pump after you have worked it for a while. You will find it quite warm.

Lead bullets when shot against an iron target have sometimes been melted on striking it.

In each of the above cases work was done, or energy was used up, in producing the heat. The energy which is apparently lost appears as heat. It is energy in another form. If you bring a body to rest you destroy its motion as a whole, but the molecules are shaken up and are made to move about more rapidly. This causes the body to be heated.

128. Heat from Chemical Action. But our most familiar source of heat is in the burning of wood or coal or oil or gas. How does the heat arise here?

We have seen that when a body is separated from the earth it has potential energy or energy of position. Remove its support and it will fall to the earth. During its fall it acquires energy of motion, or kinetic energy, and on striking the earth this energy is changed into energy of molecular motion, that is, heat.

When a body like wood or coal is surrounded by oxygen, the chemical separation of the carbon and oxygen particles is a form of potential energy. When heated to the ignition point they come together and unite, and in their union heat is produced.

129. Heat from an Electric Current. Let us take a short piece of very fine iron or platinum wire and pass the current from three or four dry cells through it. The wire becomes white hot and may be melted. The ordinary incandescent electric lamps are made on this principle. An electric current passes through the fine carbon or metal filament which is thus made white hot. Electric heaters and electric cookers are simply coils of suitable wire heated by the electric current.

In these cases the current is usually produced by a dynamo which is driven by a steam engine or by water power, and so the heat can be traced back to mechanical work. If the current is obtained from cells their chemical energy is used up in producing the heat.

130. Heat from the Sun. Our most important source of heat, however, is the sun. This wonderful body must be very hot as it is such an enormous distance from us and yet it is able to send us great quantities of heat. The coal and wood which we burn come from stores in the earth put there in past ages by the sun. Indeed nearly all our heat and light and power can be traced back to the sun.

The manner in which the heat and light are conveyed to the earth from the sun will be referred to in a later chapter.

131. Expansion of Solids by Heat. Examples of the expansion of solid bodies when heated are very numerous and are commonly observed. The following simple experiments are good illustrations.

Take a brass ball (Fig. 139) which can just pass through a ring when they are both cold, and heat it with a Bunser burner or other convenient means. Try to put the ring through now. It will not go, it is too large; but allow it to stand a while until it cools down and the ring warms up, and it will go through.

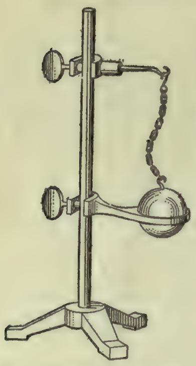

FIG. 139.—Expansion of ball by heat.

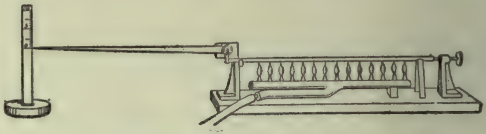

FIG. 140.—Expansion of rod by heat.

In Fig. 140 is a metal rod whose right-hand end rests against an upright support, while the other end passes through another upright and is free to move. This end rests against the short arm of a lever whose other arm is long and is at right angles to the short arm. A small motion in the end of the short arm makes a much greater motion in the end of the long arm, and there is a vertical scale behind it to show how much it moves. On lighting the row of burners under the rod, the end of the long lever is seen to move over the scale, thus showing that the rod has expanded when heated.

Next, let us take a compound bar made by riveting together a copper and an iron strip, and let us heat it uniformly. It bends into the form of an arc of a circle, with the copper strip on the outer or convex side. Both strips expand, but the copper more than the iron. If placed in a cold bath, it bends in the opposite direction, with the iron on the convex side.

FIG. 141.—Bending of compound bar by unequal expansion of its parts.

These experiments illustrate a very general law. Solids with very few exceptions expand when heated and contract when cooled, but different solids have different rates of expansion.

132. Expansion of Liquids and Gases. Liquids also expand when heated. The amount of expansion varies with the liquid, but on the whole, it is much greater than that of solids.

Fill a small flask with water with a little colouring matter in it and then push in the stopper through which a small glass tube passes (Fig. 142). The water rises in the tube, its height being shown by a paper scale attached to it. Now take hold of the upper end of the tube and thrust the flask into hot water, watching sharply the liquid in the tube. At first it falls, but after a minute or less it begins to rise and it soon goes higher than it was at first.

The fall in the liquid at first was caused by the flask expanding before the heat had time to get to the water in it, and the fact that the water rose in the tube higher than it was originally shows that water expands more than glass.

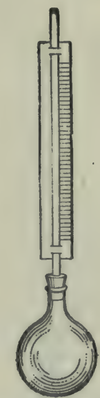

Fig. 142.—Expansion of liquids by heat.

As in the case of solids some liquids expand more than others. For example, alcohol expands more than coal oil and coal oil more than water.

The apparatus just used can also be employed to show that gases expand through heat.

Remove the stopper and tube from the flask and pour the coloured water into a beaker (Fig. 143). Then replace the cork and thrust the open end of the tube under the surface of the water. Now hold the hand about the flask Heat from it causes the air within it to expand, and it is seen to bubble out through the water.

Finally remove the hand from the flask and the contained air cools down and contracts, and water is forced up the tube by the pressure of the outside air on the surface of the water in the beaker.

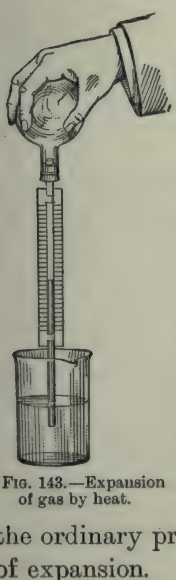

Fig. 143.—Expansion of gas by heat.

Unlike solids and liquids, all gases have, at the ordinary pressure of the air, approximately the same rates of expansion.

133. Applications of Expansion—Compensated Pendulums. A clock is regulated by a pendulum, whose rate of vibration depends on its length. The longer the pendulum, the slower the beat; and the shorter, the faster. Changes in temperature will therefore cause irregularities in the running of the clock, unless some provision is made for keeping the pendulum constant in length through changes in temperature. Two forms of compensation are in common use. The Graham pendulum (Fig. 144) is provided with a bob consisting of a jar with mercury in it. Expansion in the rod lowers the centre of gravity of the bob, while expansion in the mercury raises it. The quantity of mercury is so adjusted as to keep the length of the pendulum the same.

FIG. 144.—Graham pendulum.

FIG. 145.—Harrison pendulum.

In the Harrison, or gridiron pendulum (Fig. 145) the bob hangs from a framework of brass and steel rods, so connected that an increase in length of the steel rods (dark in the figure), tends to lower the bob, while an increase in the length of the brass ones tends to raise it. The lengths of the two sets are adjusted to keep the resultant length of the pendulum constant.

134. Chronometer Balance Wheel. A watch is regulated by a balance wheel, controlled by a hair-spring (Fig. 146). A rise in temperature tends to increase the diameter of the wheel and to decrease the elasticity of the spring. Both effects would cause the watch to lose time. To counteract these retarding effects, the rim of the balance wheel in chronometers and high-grade watches is made from two metals and mounted in sections, as shown in Fig. 146. The outer metal is the more expansible, and as the temperature rises the free ends of the rim turn inwards, thus lessening the effective diameter of the wheel and overcoming the expansion of the wheel as a whole.

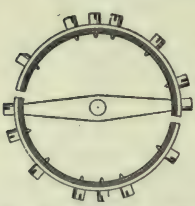

FIG. 146.—Balance wheel of watch.

QUESTIONS

1. A glass stopper which is stuck in the neck of a bottle may be loosened by subjecting the neck to friction by a string. Explain.

2. Boiler plates are put together with red-hot rivets. What is the reason for this?

3. Why does a blacksmith heat a wagon-tire before adjusting it on the wheel?

4. Why are the rails of a railroad track laid with the ends not quite touching?

5. Why does change in the temperature of a room affect the tone of a piano?

6. If a drop of water falls on a hot lamp chimney, or if boiling water is poured into a glass jar, the glass usually cracks. Explain why.

CHAPTER XX

Temperature

135. Nature of Temperature. When the blacksmith throws a piece of red-hot iron into a tub of cold water, the iron evidently loses heat, while the water gains it. When two bodies like the iron and water are in such a condition that one grows warmer and the other colder when they are brought in contact, they are said to be at different temperatures. The body which gains heat is said to be at a lower temperature than the one which loses it. If neither grows warmer when the bodies are brought together, they are said to be at the same temperature.

136. Temperature and Quantity of Heat. A pint of water taken from a vat is at the same temperature as a gallon taken from the same source. They will also be at the same temperature when both are brought to the boiling point, but if they are heated one after the other by the same gas flame, it will take much longer to bring the gallon up to the boiling point than to raise the pint to the same temperature. The change in temperature is the same in the two cases, but the *quantity of heat* absorbed is different. A large radiator filled with hot water may, in cooling, give out enough heat to warm up a room, but a small pitcher of hot water loses its heat with no apparent effect. The quantity of heat possessed by a body evidently depends on its mass as well as its temperature.

137. Determination of Temperature. In a rough way we can tell the temperature of a body by touching it, but the following simple experiments will show that our temperature sense cannot be relied on:

Take three vessels, one containing water as hot as can be borne by the hand, one containing ice-cold water, and one with water at the temperature of the room. Hold a finger of one hand in the cold water and a finger of the other in the hot water for one or two minutes, and immediately insert both fingers in the third vessel. To one finger the water will appear to be hot, and to the other, cold. The experiment shows that our estimation of temperature depends, to a certain extent, on the temperature of the part of the body used to make the determination.

On a very cold winter day if we come from out of doors into a cellar it feels warm, while on a hot summer day it feels cold.

Again, on a very cold day touch a piece of iron and a piece of wood. The former feels much colder, though both are at the same temperature. Thus our estimation of the temperature of a body depends on its nature as well as on our own condition.

How then shall we measure temperature? We have seen that when a body is heated it expands, the higher the temperature, the greater the expansion; and it would seem natural, therefore, to measure temperature by the expansion of some substance. Alcohol and mercury are the substances commonly used, the former being required if we have to measure very low temperatures.

138. The Making of a Mercury Thermometer. First a piece of thick-walled glass tubing with a fine uniform bore is chosen, and a little bulb is blown on one end. Bulb and tube are then filled with mercury. This is done by heating the bulb to expel a part of the air and then dipping the open end of the tube into mercury. As the bulb cools the air within it contracts, and the mercury is forced into it by the pressure of the outside air. The mercury within the bulb is then heated until it boils and expels the remaining air, and the end of the tube is again immersed in mercury. On cooling, the mercury vapour condenses, and bulb and tube are completely filled with mercury. The tube is then sealed.

139. Determination of the Fixed Points. Since we can describe a particular temperature only by stating how much it is above or below some temperature assumed as a standard, it is necessary to fix upon standards of temperature and also units of difference of temperature. This is most conveniently done by selecting two fixed points for a thermometric scale.

The standards in almost universal use are the "freezing point" and the "boiling point" of water

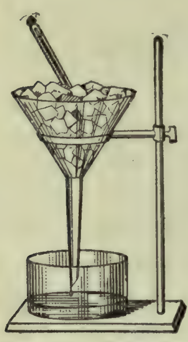

Fig. 147. — Determination of freezing point.

To determine the freezing point, the thermometer is surrounded with moist finely broken ice (Fig. 147), and the point at which the mercury stands when it becomes stationary is marked on the stem.

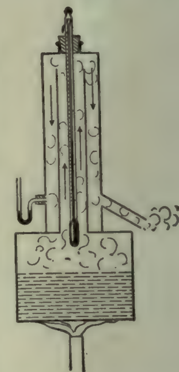

Fig. 148.—Determination of boiling point.

The boiling point is determined by exposing the bulb and stem to steam rising from pure water boiling under a pressure of 76 cm. of mercury (Fig. 148). As before, the height of the mercury is marked on the stem.

140. Graduation of the Thermometer. Having marked the freezing and boiling points, the next step is to graduate the thermometer. Two scales are in common use, the Centigrade scale and the Fahrenheit scale.

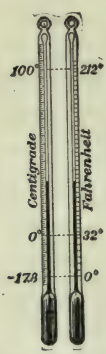

Fig. 149.—Thermometer scales.

The Centigrade scale is now universally employed in scientific work. The space intervening between the freezing point and the boiling point is divided into one hundred equal divisions, or degrees, and the zero of the scale is placed at the freezing point, the graduations being extended both above and below the zero point.

The Fahrenheit scale is in common use among English speaking people for household purposes. The space between the freezing point and the boiling point is divided into one hundred and eighty equal divisions, each called a degree, and the zero is placed thirty-two divisions below the freezing point. The freezing point, therefore, reads 32°, and the boiling point 212° (Fig. 149).

141. Comparison of Thermometer Scales. Sometimes a temperature is stated on one scale and we wish to know how it would be stated on the other.

For example, let us find what reading on the Centigrade scale corresponds to zero on the Fahrenheit scale. (See Fig. 149).

From the way the two scales are made,

100 Centigrade degrees = 180 Fahrenheit degrees,
5 " " = 9 " "

Now zero on the Fahr. scale is 32 Fahr. degrees below the freezing point, and 32 Fahr. degrees $= \frac{5}{9} \times 32 = 17.8$ Cent. degrees. Hence the reading on the Cent. scale corresponding to 0° F. is 17.8 Cent. degrees below 0° C., which is usually written $-17.8°$ C.

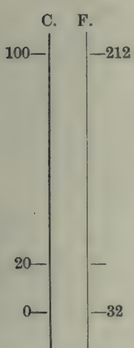

FIG. 150.

Next, suppose the reading on the Cent. thermometer is 20°; what is the corresponding reading on the Fahr. thermometer? Draw a diagram as in Fig. 150.

The Cent. reading is 20°, that is, the temperature is 20 Cent. degrees above the freezing point.

But 20 Cent. degrees $= 20 \times \frac{9}{5} = 36$ Fah. degrees. Therefore the Fahr. reading is 36 degrees above 32, or is 68; that is, 20° C. corresponds to 68° F.

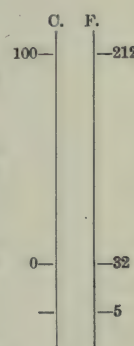

FIG. 151.

Let us take one more example. The temperature as shown on the Fahr. thermometer is 5°; what is the corresponding reading on the Cent. thermometer? (Fig. 151).

In this case the given reading is $32 - 5 = 27$ Fahr. degrees below freezing point.

But 27 Fahr. degrees $= 27 \times \frac{5}{9} = 15$ Cent. degrees.

Hence 5° F. corresponds to $-15°$ C.

PROBLEMS

1. To how many Fahrenheit degrees are the following Centigrade degrees equivalent :—5, 18, 27, 65?

2. To how many Centigrade degrees are the following Fahrenheit degrees equivalent :—20, 27, 36, 95?

3. How many Fahrenheit degrees above freezing point is 65° C.?

4. How many Centigrade degrees above freezing point is 60° F.?

5. Convert the following readings on the Fahrenheit scale to Centigrade readings :—0°, 10°, 32°, 45°, 100°, –25°, and –40°.

6. Convert the following readings on the Centigrade scale to Fahrenheit readings :—10°, 20°, 32°, 75°, –20°, –40°, and –273°.

CHAPTER XXI

Expansion of Water: Expansion of Gases

142. Peculiar Behaviour of Water. As we have seen, when the temperature of a body is raised it usually expands. At certain temperatures, however, water behaves in a peculiar way which we may study in the following experiment:

In Fig. 152 is shown a tall glass or metal jar with a metal trough about the middle of it, and with two thermometers inserted, one at the top, the other at the bottom. The jar is filled with water at the temperature of the room (say 20° C.), and a mixture of finely broken ice and salt or snow and salt is put into the trough. This is called a freezing mixture. When it melts it produces a temperature below the freezing point of water. The reason why it does so will be explained a little later (Chapter XXIII).

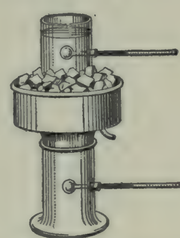

Fig. 152.—Hope's apparatus.

Now let us watch the two thermometers, marking down their readings every minute for 35 or 40 minutes. We find that for a while the upper one remains stationary and the lower one continues to fall until it shows a temperature of 4° C. It now remains steady at this reading and the upper one begins to fall and continues to do so until it reaches the freezing point, 0° C.

The experiment shows that as the water about the centre of the jar is cooled it becomes denser and continues to descend until all the water in the lower part of the jar has reached the maximum density. This occurs when the temperature is 4°C. On further cooling the water in the middle of the jar it becomes lighter and ascends.

The experiment illustrates the behaviour of large bodies of water in cooling as winter approaches. As the surface layers cool they become denser and sink, while the warmer water below rises to the top. This process continues until the whole mass of water reaches a uniform temperature of 4° C. The colder and lighter water then remains on the surface, where the ice forms, and this protects the water below.

143. Expansion of Gases—Charles' Law. The expansion of gases as the temperature rises is much greater than that of liquids, and they all expand by the same amount. If any gases, say air, oxygen and carbon dioxide have equal volumes at a certain temperature, they will still have equal volumes when they are made to have any other temperature. It must be understood, however, that the pressure is the same at the two temperatures.

Exact experiments have been performed to determine the relation between the volume and temperature. It has been shown that when a gas is heated its volume increases for each centigrade degree rise in temperature, $\frac{1}{273}$ of the volume at 0° C.

This is known as CHARLES' LAW, and as it is very important, both in Physics and Chemistry, we shall consider one or two examples on it.

EXAMPLES ON CHARLES' LAW

1. Suppose the volume of a certain mass of gas at 0° C. is 1 cu. foot; find its volume at any other temperature, say 65° C.

We have,

Volume of the gas at 0° C. = 1 cu. ft.
" " " 1° $= 1\frac{1}{273}$ or $\frac{274}{273}$ cu. ft.
" " " 2° $= 1\frac{2}{273}$ or $\frac{275}{273}$ "
" " " 65° $= 1\frac{65}{273}$ or $\frac{338}{273}$ "

2. Let the volume at 0° C. be 39 litres; what will it be at 44° C.?

As before,

Volume of the gas at 0° C. = 39 litres
" " " 1° $= 39 \times 1\frac{1}{273} = 39 \times \frac{274}{273}$ litres
" " 44° $= 39 \times 1\frac{44}{273} = 39 \times \frac{317}{273}$
$= 45.3$ l. (nearly)

3. Given that the volume of a mass of gas at 100° C. is 520 c.c., what will the volume be at 0° C.?

We know that 1 c.c. at 0° C. becomes $1\frac{100}{273}$ or $\frac{373}{273}$ c.c. at 100° C.

Hence, $\frac{373}{273}$ c.c. at 100° becomes 1 c.c. at 0° C.
$\frac{1}{273}$ " " " $\frac{1}{373}$ " "
$\frac{273}{273}$ or 1 c.c. " " $\frac{273}{373}$ " "
520 " " " $\frac{273}{373} \times 520$ "
$= 380.6$ c.c. (nearly)

PROBLEMS

1. Explain where the ice would form and what would happen if water continued to contract down to 0° C.; first, supposing that when water turned into ice it increased in volume, as it does now; second, supposing that it took up a smaller volume than that of the water from which it was formed.

2. The pressure remaining constant, what volume will a given mass of gas occupy at 75° C., if its volume at 0° C. is 22.4 litres.

3. If the volume of a given mass of gas is 120 c.c. at 17° C., what will its volume be at 0° C., pressure remaining constant?

4. If the volume is 108 c.c. at 0° C., find the volume at –1°, –2°, –13° C., pressure remaining constant.

5. A given mass of gas occupies a volume of 546 c.c. at 0° C. Its temperature is raised to 37° C., the pressure being kept constant; find the volume.

If now the pressure is doubled what will the volume become?

CHAPTER XXII

Measurement of Heat

144. Unit of Heat. As already pointed out, the *temperature* of a body must be clearly distinguished from the *quantity of heat* which it contains. The thermometer is used to determine the temperature of a body, but its reading does not give the quantity of heat possessed by it. A gram of water in one vessel may have a higher temperature than a kilogram in another, but the latter may contain a greater quantity of heat. Again, a pound of water and a pound of mercury may be at the same temperature, but we have reasons for believing that the water contains more heat.

In order to measure heat we must choose a suitable unit. When we measure length we use as unit a centimetre, a yard, a mile, etc.; as unit of mass we choose a gram, a pound, a kilogram, etc.; what shall be our unit of heat?

The unit commonly used in scientific work is *the amount of heat required to raise by 1 Cent. degree the temperature of 1 gram of water.* The name given to it is a CALORIE.

To raise 1 gram through 2° requires 2 calories, and to raise 2 grams through 1° requires 2 calories; that is, the greater the change in temperature or the greater the mass whose temperature is raised, the more calories are needed to do it.

We can say, then,

to raise 1 gram of water through 1 Cent. deg. requires 1 calorie,
to raise 4 grams of water through 5 Cent. deg. requires 20 calories,
to raise 150 grams of water through 12 Cent. deg. requires 1,800 calories,

and so on.

To learn better what calorie means, let us perform a simple experiment. Take 300 grams of water in a metal vessel and place it over a burner or on a stove. Stir it with a thermometer and read the temperature. Let it be 10° C. Allow it to stand a few minutes and take the temperature again; let it be 16° C. Then the amount of heat which the water has received = 300 × 6 = 1,800 calories. Heat it further, and let the temperature be 30° C. The water has now absorbed 300 × 20 = 6,000 calories. Continue heating until the water begins to boil; the temperature is now 100° C., and the rise in temperature is 90 degrees. Hence, the amount of heat taken in by the water = 300 × 90 = 27,000 calories.

Next, allow the water to cool down. In a few minutes the temperature will be 90° C., or the fall in temperature is 10 degrees. The water then has given out 300 × 10 = 3,000 calories. Let it continue cooling until it reaches the temperature of the room, say 20° C. Then the fall in temperature is 80 degrees, and the amount of heat given out by it is 300 × 80 = 24,000 calories.

In making calculations regarding steam engines, and in some other engineering work, another unit of heat is often used. It is the amount of heat required to raise by 1 Fahr. degree the temperature of 1 pound of water. It is called a British thermal unit (written B.T.U.).

PROBLEMS

1. How many calories of heat must enter a mass of 65 grams of water to change its temperature from 10° C. to 35° C.?

2. How many calories of heat are given out by the cooling of 120 grams of water from 85° C. to 60° C.?

3. If 1,400 calories of heat enter a mass of 175 grams of water what will be its final temperature, supposing the original to be 15° C.?

4. A hot water coil containing 100 kilograms of water gives off 1,000,000 calories of heat. Neglecting the heat lost by the iron, find the fall in temperature in the water.

5. On mixing 65 grams of water at 75° C. with 85 grams at 60° C., what will be the temperature of the mixture?

6. How many B.T.U's are required to heat 60 pounds of water from 40° F. to 212° F.?

7. Find how many calories there are in 1 B.T.U. (1 pound = 453.6 grams).

145. Capacity for Heat. By our definition, it takes 1 calorie of heat to raise by 1 Cent. degree the temperature of 1 gram of water. If we raised the temperature of 1 gram of turpentine, or mercury or iron by 1 degree, would it require as much heat? We can test it by experiment.

Take two similar small beakers. In one place 100 grams of water and in the other 100 grams of turpentine. Let them both be at temperature 15° C. Now heat up some water until its temperature is 35° C., and pour 100 grams of it into each of the beakers. Stir well and take the temperatures. We find the temperature of the water is 25° C., while that of the mixed turpentine and water is higher, about 29° C.

In the first beaker the water which was in it at first has risen in temperature 10 deg., and so it must have received $100 \times 10 = 1,000$ calories of heat. The warmer water which was poured in has fallen 10 degrees in temperature, that is, it has given up $100 \times 10 = 1,000$ calories. This, of course was given to the cooler water. What one received, the other gave up.

In the second beaker, however, the warm water is now at 29° C., that is it has fallen 6 deg., and hence has given out $100 \times 6 = 600$ calories of heat. But this amount of heat has raised the temperature of the 100 grams of turpentine 14 degrees. We conclude then that turpentine does not require as much heat to raise it through 1 deg. as an equal mass of water does ; or its capacity for heat is not so great as that of water.

In order to illustrate this matter still further let us try another experiment.

Heat equal masses (say 50 grams) of water, mercury and iron (tacks) to the same temperature by placing them in separate test-tubes immersed in a bath of boiling water (Fig. 153). Now provide three beakers containing equal masses (say 100 grams) of water at the temperature of the room, and pour the hot water into the first, the iron into the second, and the mercury into the third. After stirring, take the temperature in each case. The temperatures are quite different, the water in the first being the hottest, and the contents of the third being the coldest.

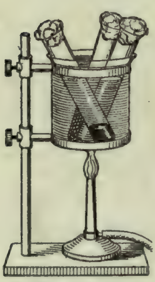

FIG. 153.—The heating of equal masses of different substances to the same temperature in a water bath.

These experiments indicate that the amount of heat absorbed or given out by a body for a given change in temperature depends on the nature of the body, as well as upon its mass and change in temperature. They also show that mercury has a smaller capacity for heat than iron, and iron a smaller capacity than water. Indeed, it is found that water has a greater capacity for heat than any other ordinary substance except hydrogen.

146. Consequence of the High Capacity of Water for Heat. The facts, that water has such a great capacity for heat and that it is so widely spread over the surface of the earth, are of very great importance to many of its inhabitants. For example, consider a land area surrounded by a large body of water. Now it requires four or five times as much heat to raise a given mass of water one degree as to raise an equal mass of ordinary earth. Hence, the water heats up much more slowly than the land and so remains cooler than it. The land being surrounded by cool water, is itself made cooler in the summer. In the winter, on the other hand, as the land cools down the water gradually gives up its store and keeps the temperature of the land from falling too low.

Thus the presence of great bodies of water gives to the neighbouring land a more equable temperature—it does not rise so high in the summer nor fall so low in the winter.

147. Specific Heat. Let us return to our experiment in which we mixed turpentine and water.

We found that 100 grams of water fell in temperature from 35° to 29° C., that is, through 9 degrees, and it therefore gave out 600 calories of heat. This was received by the 100 grams of turpentine which thereby had its temperature raised from 15° to 29° C., that is, through 14 degrees. Then we have the following relation:

To raise 100 grams of turpentine through 14 deg. requires 600 cal.
To raise 1 gram of turpentine through 14 deg. requires 6 cal.
To raise 1 gram of turpentine through 1 deg. requires $\frac{6}{14} = \frac{3}{7}$ cal.

Now, to raise 1 gram of water through 1 degree of temperature requires 1 calorie. Hence, to raise 1 gram of turpentine through 1 degree requires $\frac{3}{7}$ as much heat as is required to raise 1 gram of water. It is also evident that to raise a given mass of turpentine through any number of degrees requires $\frac{3}{7}$ as much heat as to raise an equal mass of water through the same number of degrees.

The number $\frac{3}{7}$ is said to be the SPECIFIC HEAT of turpentine.

The specific heat of iron is 0.11; that is, to raise the temperature of a given mass of iron any number of degrees requires $\frac{11}{100}$ as much heat as to raise the same mass of water through the same number of degrees.

The specific heat of mercury is 0.03; of aluminium, 0.21; of lead, 0.03; of copper, 0.09; of coal oil, 0.05.

148. How to find Specific Heat. We can find the specific heat of most substances by a method similar to that described in section 144. It is called the method of mixture. Suppose we wish to find the specific heat of lead. We can do it in the following way:

Take a definite mass of lead shot and weigh it. Let it be 250 grams. Now place it in a test-tube and heat it in the steam coming from boiling water as shown in Fig. 154. The temperature will be 100° C.

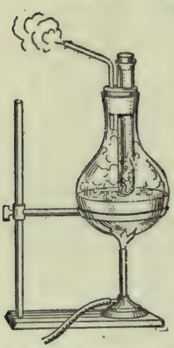

FIG. 154.—Determination of specific heat of a solid.

Next place 100 grams of water at the temperature of the room—say 20° C.—in a beaker and surround it with wool or batting to keep the heat from escaping.

Pour the shot into the water, stir it about and take the temperature of water and shot. Let it be 26° C.

Now, heat lost by the shot = heat gained by the water.

But there were 100 grams of water which rose from 20° C. to 26° C., that is, through 6 degrees. Hence heat gained by water $= 100 \times 6 = 600$ calories.

And there were 250 grams of lead, which fell from 100° C. to 26° C., that is, through 74 degrees. Hence we can say

250 grams of lead in falling 74 deg. loses 600 cal. of heat,

and 250 " " " 1 " " $\frac{600}{74}$ " "

and 1 " " " 1 " " $\frac{600}{74} \times \frac{1}{250} = 0.03$ of heat,

and the specific heat of lead is 0.03.

PROBLEMS

1. Find the number of calories of heat required to raise 1,500 grams of lead 20 degrees in temperature, taking the specific heat of lead as 0.03.

2. If the specific heat of mercury is 0.03, find the amount of heat given out by 1,000 grams of mercury in cooling from 290° C. to 20° C.

3. Find the number of calories of heat required to raise the temperature of 800 grams of alcohol, of which the specific heat is 0.62, from zero to its boiling point 78° C.

4. Which has the greater capacity for heat, 66 grams of mercury (specific heat 0.03), or 2 grams of water ?

5. To raise the temperature of 56 grams of copper by 1 degree requires 5.3 calories. What is the specific heat of copper ?

6. It requires 902 calories of heat to warm 130 grams of paraffin wax from 0° C. to 10° C. What is the specific heat of the wax ?

7. Into 120 grams of water, at a temperature of 0° C., 150 grams of mercury, at 80° C., are poured, and the resulting temperature is 3.2° C. Find the specific heat of mercury.

CHAPTER XXIII

Change of State—Solids and Liquids

149. Fusion. We have all seen the same substance in its different forms,—solid, liquid, gas. Water is the most familiar of all, and we can study its behaviour best by means of a simple experiment.

On a winter day when the temperature out-of-doors is, say, –10° C. (or 14° F.) break into small pieces some ice which has been outside for some time and fill a vessel with it. Test it with a thermometer; it shows –10° C.

Now bring it inside and apply a gentle heat, keeping the fragments of ice well mixed together and continually testing with the thermometer. The temperature gradually rises to 0° C. where it halts and the ice begins to melt. Keep on heating and stirring the contents. Though heat is being applied continually there is no rise in temperature as long as there is any ice left. When the last bit has disappeared the ice has all been changed into water and its temperature is 0° C.

If heat is applied further the temperature of the water rises until it reaches the boiling point. We shall study this in the next chapter.

The change from the solid to the liquid state by means of heat is called *fusion* or *melting*, and the temperature at which fusion takes place is called the *melting point.*

Other crystalline substances, for example, cast-iron, lead, platinum, behave like ice. Each melts at its own definite temperature. On the other hand, amorphous substances, such as wax, glass, wrought-iron, have no sharply-defined melting-point. As they are heated they soften and become plastic. For this reason glass can be blown and wrought-iron can be forged and welded.

150. Solidification. As a substance is cooled down it usually passes through the same state as when heated but in the reverse order. If water is cooled its temperature gradually falls until it reaches 0° C., and there it stays if it is kept stirred until the water is all turned into ice. After that the temperature begins to fall.

151. Change of Volume in Fusion. Most substances shrink in volume on passing from the liquid to the solid state. Perhaps you have noticed that when a bowl of lard or dripping becomes solid the surface is hollowed at the middle. Also, when paraffin wax is being melted the solid wax does not float on top but sinks to the bottom of the liquid.

A few substances, however, behave in the opposite way. Ice, bismuth, antimony and cast-iron are examples. These float on the surface of the liquid as they are being melted.

The expansive force exerted by ice on freezing is well known. The earth is upheaved and rocks are broken up, while vessels and pipes which contain water are burst by the frost. Antimony is added to lead and tin to make type-metal, because the alloy thus formed expands when it solidifies and goes into every little corner of the mould. Gold, silver and copper do not expand on becoming solid and so we have to stamp our coins.

152. Influence of Pressure on the Melting Point. A simple and interesting experiment showing the effect of pressure on the melting point is the following:

Rest a slab of ice on two supports and encircle it with a fine wire (thin steel wire is suitable) from which hangs a heavy weight (Fig. 155). In an hour or two the wire will cut its way through the ice, but the block will not be separated into two pieces. Indeed, if you try to break it, it will probably not break where the wire went through.

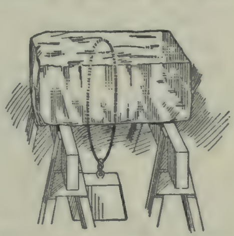

FIG. 155.—Regelation of ice.

Now why does it behave thus? When exposed to the ordinary atmospheric pressure water turns into ice at 0° C., and in doing so it expands. Suppose now we completely fill a very strong vessel, close it securely and then cool it down. If it cannot expand it cannot turn into ice, and if it be cooled down to a very low temperature the vessel must be extraordinarily strong or it will be burst.

Next suppose we put some ice in a vessel and exert a very great pressure on it. If the compression is great enough the ice will be squeezed into a smaller space and it will become water. If the pressure is removed it will promptly become ice again.

This is just what happens in the experiment just described. Under the pressure of the wire the ice melts, but the water thus formed is below the ordinary freezing point. Hence, when it flows above the wire it immediately freezes and firmly unites the two portion of the ice again.

When snow is at a temperature just below its melting-point it "packs" well. On forming a snowball, the additional pressure of the hands causes some of it to melt, and when the pressure is removed that portion freezes and makes the ball hard.

Two pieces of ice are floating on the surface of water. On pressing them together they melt slightly at the point of contact, and on removing the pressure they freeze together there.

153. Heat Used up in Melting. Let us go back to the first experiment in this chapter. We applied heat to ice which at first was at $-10°$ C. Its temperature gradually rose until the melting point, $0°$ C., was reached, no ice being melted during this time. Then the melting began and though considerable heat was applied its temperature remained steadily at $0°$ C. until every bit of ice was turned to water.

What has become of the heat applied during this time? it cannot be detected by the thermometer. It appears to have become hidden in the substance and so it is often called *latent* heat.

The heat is used up in melting the ice, and the more ice there is the greater is the amount of heat needed to melt it.

Some other crystalline substances behave like ice. For example, lead is ordinarily a solid. On applying heat its temperature rises until it reaches $326°$ C. and there it stays until the lead has all become liquid, after which it begins to rise again.

154. To Find the Heat of Fusion of Ice. Let us try to find out how many calories of heat are required to melt a gram of ice.

Exercise 1. Place a quantity (say 200 grams) of ice broken in small pieces, in a metal vessel or in a beaker and put over a burner. Keep the ice stirred and note how long it takes to melt it. Suppose it takes 5 minutes. The ice has been changed into water which is at 0° C.

Now continue to apply the heat for the same length of time, that is 5 minutes, more, and observe how high the temperature rises. It will be about 80° C. Hence, we see that to melt some ice requires as much heat as would raise the temperature of the water which comes from it 80 degrees. But to raise the temperature of 1 gram of water from 0° C. to 80° C., requires 80 calories. This then is the amount of heat required to melt 1 gram of ice which is at the melting point.

The *heat of fusion* of ice is 80 calories per gram.

Exercise 2. Heat 500 grams of water up to (say) 30° C., and then take (say) 110 grams of finely broken ice and drop it into the water. Stir it about until all the ice is melted, and then take the temperature. Let it be 10° C.

Now consider just what happened here. The 500 grams of water was cooled from 30° C. to 10° C., that is, through 20 degrees. It must have given up $500 \times 20 = 10{,}000$ calories of heat.

This heat first of all melted the ice, that is, it turned it from ice at 0° C. to water at 0° C. After that the temperature of the water thus formed was raised from 0° C. to 10° C., or through 10 degrees ; and to do this required $110 \times 10 = 1{,}100$ calories of heat.

We see, then, that of the 10,000 calories of heat given out by the warm water, 1,100 were used in raising the temperature of the water formed from the ice, and the rest, or 8,900 calories, were used up in melting the 110 grams of ice.

To melt 110 grams of ice requires 8,900 calories of heat.

" 1 " " " $\frac{8900}{110} = 81$ " "

According to this experiment the heat of fusion of ice is 81 calories.

155. Heat given out when Water Freezes. We have seen that to melt 1 gram of ice 80 calories of heat are needed. Suppose now the water freezes again. It will give out just this amount of heat in doing so. This is quite a large amount of heat, and if much water freezes it gives out much heat.

The formation of ice tends to prevent extremes of temperature in our lake regions. When the water freezes in the winter this 'latent' heat is set free, and when the ice melts in the spring and summer heat is absorbed in doing so.

156. Freezing Mixtures. Usually when a solid is dissolved heat is used up in the process. When sugar is put in tea heat is absorbed and the tea is cooled.

Exercise 1. Take a beaker of water at the temperature of the room and drop a handful of salt into it. Stir the mixture with a thermometer, and the temperature will be seen to fall several degrees.

Exercise 2. Put some water in a test-tube and then hold it and also a thermometer in a vessel and pack around them alternate layers of broken ice (or snow) and salt. In a few minutes read the temperature; it will probably be about –20° C.; and in a little while the water in the test-tube will be frozen.

A mixture of ice and salt is called a freezing mixture, and the reason why it is so effective is somewhat as follows: When salt and ice are put together they both melt. Just why they do so we cannot say, but they appear to like each other and when mixed will dissolve and form brine. Now salt in dissolving requires heat, and when ice melts it also requires heat—much more than does the salt. They take this heat from anything in their neighbourhood. In this case they took it from the water in the test-tube and it became ice.

In making ice-cream the cream is usually frozen by surrounding it with a mixture of ice and salt.

PROBLEMS

1. Why is it impossible to weld together two pieces of cast-iron?

2. Water is sometimes placed in cellars to keep vegetables from freezing. Explain the action.

3. Why is a quantity of ice at 0° C. more effective as a cooling agent than the same mass of water at the same temperature?

4. If two pieces of ice are pressed together under the surface of warm water they will be found to be frozen together on removing them from the water. Account for this.

5. If we pour just enough cold water on a mixture of ammonic chloride and ammonic nitrate to dissolve them, and stir the mixture with a small test-tube, into the bottom of which has been poured a little cold water, the water in the tube will be frozen. Explain.

6. What quantity of heat is required to melt 35 grams of ice at 0° C.?

7. How much heat is given off by the freezing of 15 kgms. of water?

8. Find the resulting temperature when 40 grams of ice are dropped into 180 grams of water at 90° C.

CHAPTER XXIV

Change of State—Liquids and Vapours

157. Boiling and the Boiling Point. In the last chapter the change of a solid into a liquid was studied, and in this one we shall consider another change, namely, of the liquid into a vapour.

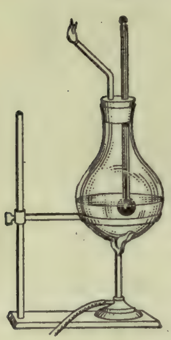

Fig. 156.—Determination of the boiling point of a liquid.

Exercise. Over a burner place water in a flask through the stopper of which pass a thermometer and a glass tube (Fig. 156), and carefully watch the thermometer. As the heat is applied the temperature steadily rises until about 100° C. is reached. This is the boiling point, and no matter how much heat you supply the temperature will not rise above this.

On looking closely, however, you will see bubbles forming at the bottom, rising through the liquid and bursting at the surface. If you keep on applying the heat the water "boils away." It turns into vapour and disappears in the air.

158. Effect of Pressure on the Boiling Point. The boiling point of water under ordinary circumstances is about 100° C., but it depends on the pressure upon the surface of the water, as we can easily prove by experiment.

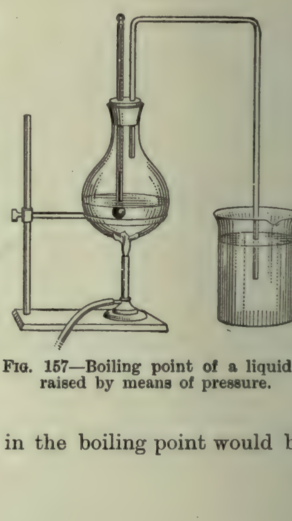

Fig. 157—Boiling point of a liquid raised by means of pressure.

Exercise 1. Remove the short tube shown in Fig. 157, and in its place put a tube bent, as shown in Fig. 157, one end being below the surface of the water in a near-by vessel. In this case the vapour from the boiling water cannot escape directly into the air, but has to push its way through the water. Hence the pressure on the surface of the water in the flask is somewhat increased. Look at the thermometer. The boiling point is higher now. If mercury were used in the vessel in place of the water, the change in the boiling point would be greater still.

Exercise 2. Half-fill a flask with water and boil for a minute or two in order that the escaping steam may carry out the air. While the water is boiling remove the flame, and at the same instant close the flask with a stopper. Invert the flask and support it on a retort stand (Fig. 158), and pour cold water over the flask. The temperature of the water in the flask is below 100° C., but it boils vigorously.

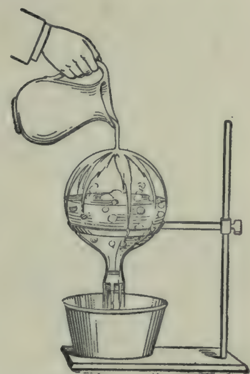

Fig. 158.—Boiling point of a liquid lowered by decrease of pressure.

The action is explained as follows :—The chilling of the flask condenses the vapour within, and thus reduces the pressure on the surface of the water. The water, relieved of this pressure, boils at a lower temperature. If we discontinue the cooling and allow the vapour to accumulate and the pressure to increase, the boiling ceases. The process may be repeated several times. In fact, if care is taken in expelling the air at the beginning, the water may be made to boil even when the temperature is reduced to that of the room.

Since the boiling point is dependent on atmospheric pressure, a liquid in an open vessel will boil at lower temperatures as the elevation above the sea-level increases. The decrease is roughly 1° C. for an increase in elevation of 293 metres (= 961 feet). The boiling point of water at the summit of Mont Blanc (15,781 feet) is about 85° C., and at Quito (9,520 feet), the highest city in the world, it is 90° C.

In such high altitudes the boiling point of water is below the temperature required for cooking many kinds of food, and artificial means of raising the temperature have to be resorted to, such as cooking in brine instead of pure water, or using closed vessels with safety devices to prevent explosions. Sometimes longer boiling is all that is required.

159. Boiling Points of Different Liquids. Each liquid has its own boiling point. For methyl alcohol it is 66, for nitric acid 86, sulphuric acid 338, and so on. For oils it is usually much higher than for water, and hence a spatter of boiling grease burns more than a drop of boiling water. The addition of a salt to water makes its boiling point higher, as can be tested as follows:

Exercise. Effect of Salt on the Boiling Point of Water. Use an arrangement like that shown in Fig. 159. The flask should have a capacity of about 300 c.c., and be about half-full of water. If an ordinary flask is used two holes should be bored through the cork, one for the thermometer, the other for a glass tube.

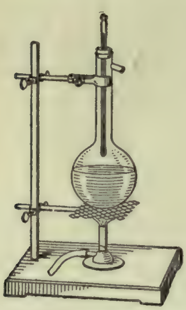

Fig. 159.—Finding the boiling point of a salt solution.

Heat the flask carefully, protecting it from the flame by wire gauze, until the water boils. First have the thermometer bulb in the steam above the water. What temperature does it show? Let it boil for a few minutes; does the temperature change? Then push the bulb down into the water. What is the temperature? Does it remain steady? Next, add about 10 grams of salt, and boil. Place the bulb in the solution, and note the temperature. Then remove the thermometer, wipe the bulb, and replace it so that the bulb is in the steam above the solution. Again, note the temperature. Repeat these observations, using 20 grams of salt in the solution.

160. Heat of Vaporization. When a liquid is changed to a vapour it absorbs heat in doing so, but as the thermometer does not show any change in temperature, this heat is also called *latent*. The more liquid turned into vapour, the greater is the amount of heat needed to do it.

The amount of heat required to change one gram of a liquid into a vapour without changiug its temperature is called its HEAT OF VAPORIZATION.

By means of the following experiment we can find roughly the heat of vaporization of water, or the latent heat of steam, as it is often called.

Put snow or broken ice in some water and let it stand until the temperature has fallen to 0° C. Pour a quantity of the water (say 100 grams) into a vessel and put it over a flame. Note the time and see how long it takes to bring the water to the boiling point, that is, to raise its temperature from 0° C. to 100° C. Suppose the time required is 5 minutes.

Keep on heating until the water has "boiled away," that is, turned into vapour, and observe how long it has taken to do this. It will probably be between 25 and 30 minutes, that is, between 5 and 6 times as long as to heat it to 100° C.

Now to raise 1 gram of water from 0° C. to 100° C. requires 100 calories of heat, and hence to turn it into vapour has taken between 500 and 600 calories.

The true value of the heat of vaporization of water cannot be measured in this simple way; but by other means it has been found to be 536 calories.

161. Heat given up on Condensation. As we have just seen, to vaporize 1 gram of water requires the comparatively large amount of 536 calories of heat. What happens, now, when the vapour turns into water again? Each gram of it gives up this same amount of heat. We see then why a house is warmed when steam is forced into pipes placed about it. The steam condenses and gives out the heat of vaporization.

It is also easy to see how warm moisture-laden winds can change the temperature of a country. When the moisture condenses it gives out great stores of heat. Were it not for this Great Britain would hardly be habitable.

PROBLEMS

1. The singing of a tea kettle just before boiling is said to be due to the collapse of the first bubbles formed in their upward motion through the water. Explain the cause of the collapse of these bubbles.

2. When water is boiling in a deep vessel the bubbles of vapour are observed to increase in size as they approach the surface of the water. Give a reason for this.

3. Why is it necessary to take into account the pressure of the air in fixing the boiling point of a thermometer?

4. How much heat will be required to vaporize 37 grams of water?

5. How many calories of heat are set free in the condensation of 340 grams of steam at 100° C. into water at 100° C.?

6. How much heat is required to raise 45 grams of water from 15° C. to the boiling point and convert it into steam?

7. How much heat is given up in the change of 365 grams of steam at 100° to water at 4° C.?

162. Evaporation at all Temperatures. But a liquid does not have to boil in order to pass into vapour. Water in a shallow vessel when exposed to a dry atmosphere, gradually disappears. It is said to *evaporate.* In this case, however, the vaporizing takes place only at the surface of the liquid, while in boiling vapour is produced throughout the mass.

The rate of evaporation depends on the nature of the liquid. Ether or gasoline disappear rapidly, alcohol not so quickly, though more so than water. Liquids which evaporate rapidly are said to be volatile.

Evaporation is hastened if the temperature is raised, and also if a current of air blows over the surface, carrying away the vapour as it is formed.

163. Cold by Evaporation. As just remarked, ether evaporates rapidly. Pour a little into the hand; it is soon gone, and the hand is made cold. Bathing the forehead or other part of the body has a similar effect. It quickly evaporates and has a cooling effect. To produce evaporation heat is required, and in these cases the heat is taken from that part of the body to which the volatile liquid is applied. Sprinkling the floor in summer cools a room for the same reason. It is very noticeable, too, that wet garments are cold, especially if drying on a windy day. In making artificial ice or in cold storage plants, evaporation is produced on a large scale and the cooling is thus effected.

164. Water Vapour in the Air; Dew Point. Evaporation is constantly taking place from water at the surface of the earth, and consequently the atmosphere always contains more or less water vapour. Let us try the following experiment, which, however, is performed most easily in the summer time.

Exercise. Half-fill with tap water a thin polished metal cup—nickel-plated brass, aluminium or bright tin will do. Keep dropping small pieces of ice in, stirring well all the time, until moisture is seen to gather on the outside. Then take the temperature with a good thermometer. In doing this experiment be careful not to breathe on the cup.

Next, pour in small quantities of water at the temperature of the room until the moisture begins to disappear and then take the temperature again. Take the average of these two temperatures. It is called the *dew-point*.

As has been stated, the atmosphere always contains some water-vapour, and the amount it *can* contain depends upon the temperature. The higher the temperature, the more vapour the air can hold. When a certain space has in it all the vapour it can hold it is said to be *saturated*. If you force more vapour in, some of that already there will condense back into water.

In the experiment the temperature of the air close to the metal cup was continually lowered until at last a temperature was reached when the vapour present saturated it, and then with the slightest fall below that some of the moisture condensed and appeared as dew on the surface of the cup. As the temperature was raised above this the moisture disappeared and the metal was clear again.

165. Relative Humidity. On some days we say the air is moist, or humid or "sticky"; on others, that it is dry. It is found that our sensations do not depend only on the actual amount of vapour present in the air, but on the temperature as well. At this present moment, perhaps, the air outside may be raw and damp, but after having been forced by a fan over a series of steam-heated coils it appears in the laboratory comparatively dry. You must not think that the air has lost any of its vapour; but being at a higher temperature it is capable of containing a great deal more, or it is much further from being saturated.

Now we have instruments, called hygrometers, which measure the amount of moisture in the air. If the amount present is one-half the amount required to saturate the air, the *Relative Humidity*, or simply the *Humidity* is said to be one-half, or 50 per cent., and so on.

166. Relation of Humidity to Health. Humidity has an important relation to health and comfort. When the relative humidity is high, a hot day becomes oppressive because the dampness of the atmosphere interferes with free evaporation from the body. On the other hand, when the air becomes too dry the amount of this evaporation is too great. This condition very frequently prevails in winter in houses artificially heated. Under normal conditions the relative humidity should be from 50 to 60 per cent.

167. Fog and Clouds. If the air is chilled below the temperature for saturation, vapour condenses about dust particles suspended in the air. If this condensation takes place in the layers of air immediately above the surface of the earth, we have a *fog;* if in a higher region, a *cloud.* The cooling necessary for the formation of fog is due to the chilling effects of cold masses at the surface of the earth; in the upper region, a cloud is formed when a layer of warm moist air has its temperature lowered by its own expansion under reduced pressure.

168. Dew and Frost. On a warm summer day drops of water collect on the surface of a pitcher containing ice-water, because the air in immediate contact with it is chilled below the dew-point. This action is typical of what goes on on a large scale in the deposition of *dew*. After sunset, especially when the sky is clear, small bodies at the earth's surface, such as stones, blades of grass, leaves, cobwebs, and the like, cool more rapidly than the surrounding air. If their temperature falls below the temperature of saturation, dew is deposited on them from the condensation of the vapour in the films of air which envelop them. If the dew-point is below the freezing-point the moisture is deposited as frost.

169. Rain, Snow and Hail. The little water globules which form the cloud fall slowly towards the earth. If they meet with conditions favourable to vaporization they change to vapour again, but if with conditions favourable to condensation they increase in size, unite, and fall as rain.

When the condensation in the upper air takes place at a temperature below the freezing-point, the moisture crystallizes in *snow-flakes.* At low temperatures, also, vapour becomes transformed into ice pellets and descends as *hail.* The hailstones usually contain a core of closely packed snow crystals, but the exact conditions under which they are formed are not yet fully understood.

170. Distillation. By the process of distillation we can, (i) separate a liquid from solids dissolved in it, or (ii) separate different liquids which are mixed together, provided they boil at different temperatures.

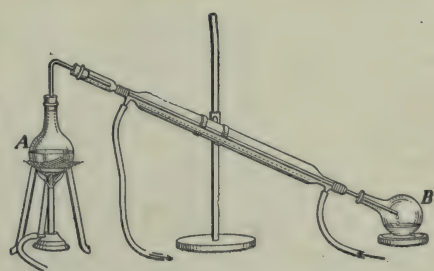

FIG. 160.—Distillation apparatus.

Let us place a solution of salt in the vessel A (Fig. 160) and heat it. The vapour from it passes down to B, being condensed on the way by the jacket-pipe connecting *A* and *B*, which is kept cold by water made to circulate in it. Pure water will be collected in *B* and the salt will be left behind in *A*.

The separation of liquids which have different boiling points is well illustrated in the refining of petroleum :

When the crude oil is heated in a still the dissolved gaseous hydrocarbons are driven off first ; then follow the lighter oils, naphtha, gasoline and benzine ; in turn come the kerosene or burning oils ; and later the heavier gas and fuel oils, etc. To obtain a quantity of any one constituent of a mixture in a relatively pure state, it is necessary to resort to *fractional distillation.* The fraction of the distillate which is known to contain most of the liquid desired is redistilled, and a fraction of the distillate again taken for further distillation, and so on.

QUESTIONS

1. Why does sprinkling the floor have a cooling effect on the air of the room ?

2. Under what conditions will "fanning" cool the face ?

3. Why can one "see his breath" on a cold day ?

4. In eastern countries and at high elevations water is poured into porous earthenware jars and placed in a draught of air to cool. Explain the cause of cooling ?

5. Dew does not usually form on a pitcher of ice-water standing in a room on a cold winter day. Explain.

6. Why does a morning fog frequently disappear with increased strength of the sun's rays ?

CHAPTER XXV

TRANSFERENCE OF HEAT

171. How Heat is Transferred. There are three distinct ways in which heat is transferred from one place to another, namely, by *conduction, convection* and *radiation*; and there are many practical applications of each. We shall consider the three methods in turn.

172. Conduction of Heat. The handle of a silver spoon when you stir a cup of tea soon becomes quite warm, while if you use a glass rod or a wooden stick, some heat reaches the hand but so little that you hardly feel it.

When heat is passed on from the hotter to the colder parts of the same body, or from a hot body to a cold one in contact with it, without any perceptible motion of the parts of the bodies concerned, it is said to be transmitted by *conduction.*

173. Conduction in Solids. The above examples show clearly that solids differ widely in their power to conduct heat. Metals, as a class, may be considered good conductors, and organic bodies, such as wool, silk, wood are poor conductors; but these bodies differ decidedly amongst themselves. We can test this easily by experiment.

Exercise 1. Twist two or more similar wires of different metals —say copper, iron, German silver— together at the ends and mount them as shown in Fig. 161. By means of drops of soft wax attach shot or bicycle balls or small nails at equal intervals along the wires. Heat the twisted ends. The progress of the heat along the wires will be indicated by the melting of the wax and the dropping

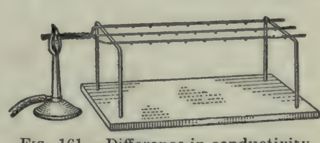

FIG. 161.—Difference in conductivity of metals.

of the balls. When the balls have ceased to drop, we shall find that more have dropped from the copper, which is therefore the best conductor, that the iron comes next in order and the German silver last.

Exercise 2. To compare the conducting powers of some metals. Convenient apparatus is illustrated in Fig. 162. *A* is a vessel, which may be made from a piece of brass tubing 10 cm. in diameter and 20 cm. long, the bottom being closed by a brass disc. A number of holes are bored in this to receive rods (about 2.5 mm. in diameter and 15 cm. long) soldered in position perpendicular to the bottom. Each rod is provided with a small index made from copper wire about 0.8 mm. in diameter (No. 20 wire), bent in the form shown enlarged at *B*. The indexes are made by winding the wire on rods slightly larger than the rods in the bottom of the vessel.

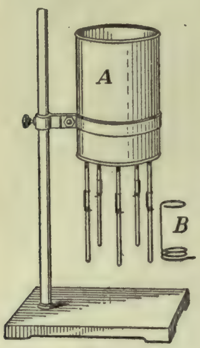

FIG. 162.—Edser's apparatus for finding relative conducting powers of metal rods.

To begin with, the vessel *A* is inverted, an index is slipped on each rod, and a very small amount of paraffin wax is melted around the rings. When the vessel is turned right-side-up, as shown in the figure the solid wax holds the indexes in position.

Now pour boiling water into the vessel. As the rods get heated the wax is melted and the indexes slip down carrying the wax before them, and when the temperatures of the rods have acquired steady values and the wax has ceased to melt, the indexes will have descended to points on the various rods where the wax just solidifies, and which therefore possess equal temperatures.

Now measure the distances from the bottom of the vessel to the projecting point on each index. Suppose these distances are respectively, 15.2, 10.3, 5.4, 3.6, 3.1 cm. Then the conducting powers will be represented by the squares of these numbers, that is, 231.0, 106.1, 29.2, 13.0, 9.6.

The following numbers express the conducting powers of some metals, taking copper as 100:

Silver	133	Aluminium	47	Platinum	12
Copper	100	Brass	32	Lead	11
Gold	71	Iron	23	Mercury	2.4

174. Conduction in Liquids. If we except mercury and molten metals, liquids are poor conductors of heat. This can be easily tested in the case of water by the following experiments:

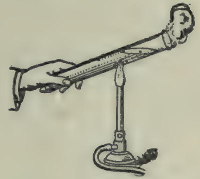

FIG. 163.—Water is a poor conductor of heat.

Fill a test-tube two-thirds full of water and hold it in a flame as shown in Fig. 163. The water at the top will boil while that at the bottom will not be noticeably heated at all.

Pass a tube which has a bulb blown on one end through a cork inserted in a funnel, as shown in Fig. 164. Thrust the open end of the tube under water in a beaker, and pour water in the funnel until its surface is about half a centimetre above the bulb. This will probably cool the air in the bulb, which will then contract, and some water will be drawn up into the tube.

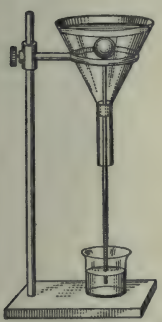

FIG. 164.—Illustration of the non-conductivity of water.

Now pour a spoonful of ether on the surface of the water and set it on fire. Although considerable heat is developed, as can be shown by holding the hand over the flame, the level of the water in the tube changes very little if at all. This shows that practically no heat from the flame was transmitted by the water to the bulb.

175. Conduction in Gases. Gases, however, are still poorer conductors of heat than liquids, so poor, indeed, that it is almost impossible to measure their conducting powers.

Many substances, such as wool, fur, down, etc., owe their poor conductivity to the fact that they are porous and contain in their interstices air in a finely divided state. If these substances are compressed they become better conductors.

Light, freshly fallen snow encloses within it large quantities of air, and consequently forms a warm blanket for the earth, protecting the roots of plants from intense frost.

Heat is conducted with the greatest difficulty through a vacuum. The familiar "Thermos" bottle is really one glass bottle inside another, the space between their walls having the air removed from it. A hot substance in the inner one will remain hot and a cold one will remain cold for a long time.

176. Applications of good and bad Conductors. In constructing furnaces, cooking utensils, etc., we use good conductors because we want heat to pass freely through them; but if we want to keep heat in or out we use poor conductors. A house with double walls is cool in summer and warm in winter. Wool and fur garments are warm because they prevent the heat of the body from escaping through them.

In this connection the action of metallic gauze in conducting heat should be noted. Depress upon the flame of a Bunsen burner a piece of fine wire gauze. The flame spreads out under the gauze but does not pass through it (*B*, Fig. 165). Again, turn off the gas and hold the gauze about half-an-inch above the burner and apply a lighted match above the gauze (*A*, Fig. 165). The gas burns above the gauze. The explanation is that the metal of the gauze conducts away the heat so rapidly that the gas on the side of the gauze away from the flame is never raised to a temperature sufficiently high to light it.

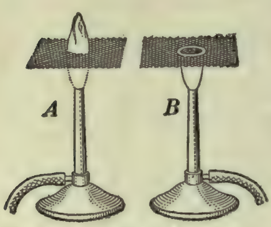

FIG. 165.—Action of metallic gauze on a gas-flame.

This principle is applied in the construction of the Davy safety lamp for miners. A jacket of wire gauze encloses the lamp, and prevents the heat of the flame from igniting the combustible gas on the outside. (Fig. 166.)

177. Why We are Deceived Sometimes. If you go into an unheated room on a cold winter day and take hold of a piece of iron and a piece of wood the iron feels much the colder of the two. On a hot summer day, on the other hand, if the wood and the iron have been exposed to the sun for some time the iron feels much the hotter of the two. In both cases the temperature is the same, but our sense of touch would not lead us to think so.

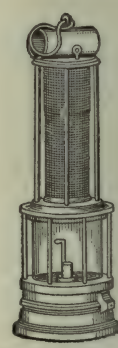
FIG. 166.—Davy safety lamp.

The reason why we are deceived is, the iron is a better conductor than the wood. In the winter both the iron and the wood are at a temperature below that of the hand. When you touch the iron heat quickly passes from the hand to surface of the iron in contact with it and from there it is rapidly conducted throughout the metal. So much heat is taken from the hand that it appears decidedly cold. In the case of the wood, heat passes from the hand to the surface layer of the wood but as the wood is a poor conductor, this heat stays practically on the surface. It is conducted very slowly throughout the mass. As the hand loses very little heat it does not feel cold.

In the summer, heat is rapidly conducted from the iron to the hand and hence it appears hot, while the small amount of heat conducted from the wood to the hand makes the sensation much less marked.

QUESTIONS

1. If a cylinder half brass and half wood be wrapped with a sheet of paper and held in the flame (Fig. 167), the paper in contact with the wood will soon be scorched but that in contact with the brass will not be injured. Explain.

2. Why are utensils used for cooking frequently supplied with wooden handles?

3. Ice stored in ice-houses is usually packed in saw-dust. Why use saw-dust?

4. Why, in making ice-cream, is the freezing mixture placed in a wooden vessel and the cream in a metal one?

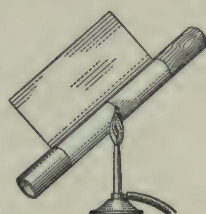

FIG. 167.

5. Water may be boiled in an ordinary paper oyster-pail over an open flame without burning the paper. Explain.

6. The so-called fireless cooker consists of a wooden box lined with felt or other non-conductor. The food is heated to a high temperature and shut up in the box. Why is the cooking process continued under these conditions?

178. Convection Currents. When we applied heat to the top of the water in a test-tube (§ 173) that at the bottom remained cold. If now we apply the heat at the bottom the whole mass is quickly warmed. In this case the heat is carried by currents set up in the fluid.

The presence of these currents can be easily shown in the following way :—Drop a few crystals of potassium permanganate into a beaker of water and allow the tip of a gas-flame to play on the bottom, either at one side as in Fig. 168 or at the centre as in Fig. 169.

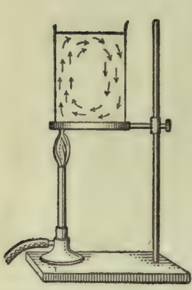

FIG. 168.–Convection currents in water heated by gas-flame placed at one side of bottom.

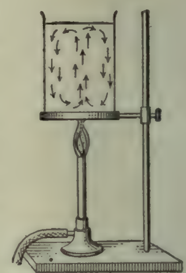

FIG. 169. — Convection currents in water heated by gas-flame at centre of bottom.

Such currents are called *convection currents.* They are formed whenever there are differences of temperature in the parts of a fluid.

That portion of the water close to the gas-flame is heated, it becomes less dense and rises to the top, colder water taking its place at the bottom.

179. Transference of Heat by Convection. This must be clearly distinguished from conduction. In conduction the heat energy is handed on from molecule to molecule throughout the conductor; in convection certain portions of a fluid become heated and change their position within the mass, carrying their heat with them and giving it out as they move about. The water, heated at the bottom of the beaker, rises to the top, carrying its heat with it.

180. Convection Currents in Gases. Convection currents are easily set up in gases. A heated body always causes disturbances in the air about it. The rising smoke shows the direction of the air-currents above a fire. The following simple experiments illustrate the production of convection currents in air.

Hold a hot iron—say a flat-iron—in a cloud of floating dust or smoke particles (Fig. 170). The air is seen to rise from the top of the iron, and to flow in from all sides at the bottom.

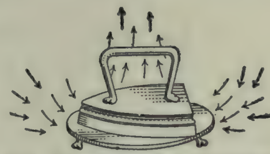

Fig. 170.—Convection currents in air about a heated flat-iron.

Make a box fitted with a glass front and chimneys as shown in Fig. 171. Place a lighted candle under one of the chimneys, and replace the front. Light some touch paper * and hold it over the other chimney.

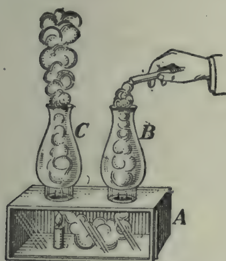

Fig. 171.—Convection currents in heated air.

The air is observed to pass down one chimney and up the other.

When we turn on the draught of a stove or furnace we close the top and open the bottom so that an air current may flow through, and thus supply plenty of oxygen to the fire.

181. Winds. Differences of temperature on the earth's surface give rise to convection currents, like those in the air about the heated iron but on a large scale. For various causes the earth's surface is unequally heated by the sun. The air over the heated areas expands, and becoming relatively lighter, is forced upward by the buoyant pressure of the colder and heavier air of the surrounding regions.

Trade winds furnish an example. These permanent air-currents are primarily due to the unequal heating of the atmosphere in the polar and equatorial latitudes.

We have an example also, on a much smaller scale, in land and sea breezes. On account of its higher capacity for heat, water warms and cools much more slowly than land. For this reason the sea is frequently cooler by day and warmer by night than the surrounding land. Hence, if there are no disturbing forces an off-sea breeze is likely to blow over the land during the day and an off-land breeze to blow out to sea at night (Fig. 172). Since the causes

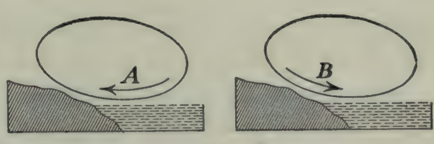

Fig. 172.—Illustration of land and sea breezes. *A*, direction of movement in sea breeze. *B*, direction of movement in land breeze.

* Made by dipping blotting paper in a solution of potassium nitrate and drying it.

are but local, it is obvious that these atmospheric disturbances can extend but a short distance from the shore, usually not more than 10 or 15 miles.

182. Applications of Convection Current. These are very numerous. They are used in cooking, in supplying hot water in our houses, in heating our buildings, in ventilation, and for many other purposes. Some of these are briefly described in the following sections.

183. Cooking; Hot Water Supply. The distribution of heat in ordinary cooking operations such as boiling, steaming and oven roasting and baking is obviously by convection currents.

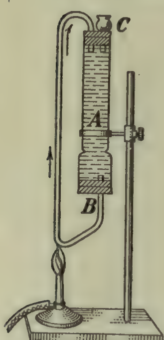

FIG. 173—Illustration of the principle of heating water by convection currents.

When running water is available, kitchens are now usually supplied with equipment for maintaining a supply of hot water for culinary purposes. The common method of heating the water by a coil in the fire-box of a stove or furnace is illustrated in the following experiment.

Use a lamp chimney as a reservoir, and fit up the connecting tubes as shown in Fig. 173. Drop a crystal or two of potassium permanganate to the bottom of the reservoir to show the direction of the water currents. Fill the reservoir and tubes through the funnel C and heat the tube B with a lamp. A current will be observed to flow in the direction of the arrow. The hot water rises to the top of the reservoir and the cold water at the bottom moves forward to be heated.

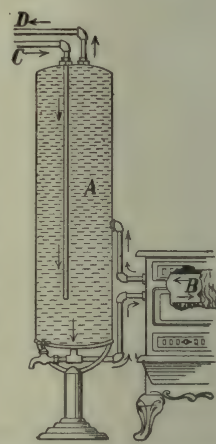

FIG. 174.—Connection in a kitchen water heater. A is the hot-water tank and B is the water-front of the stove. The arrows show the direction in which the water moves.

Fig. 174 shows the actual connections in a kitchen outfit. The cold water supply pipe C is connected with a tank in the attic or with the water-works service pipes. The hot water is drawn off through the pipe D. The direction in which the currents flow is shown by the arrows.

184. Hot-Water Heating. Hot-water systems of heating dwelling houses also depend on convection currents for the distribution of heat. The principle may be illustrated by a modification of the last experiment. Connect an open reservoir B with a flask, as shown in Fig. 175. Taking care not to entrap air-bubbles, fill the flask, tubes, and part of the reservoir with water. To show the direction of the currents, colour the water in the reservoir with potassium permanganate. Heat the flask. The coloured water in the reservoir almost immediately begins to move downwards through the tube D to the bottom of the flask and the colourless water in C appears at the top of the reservoir.

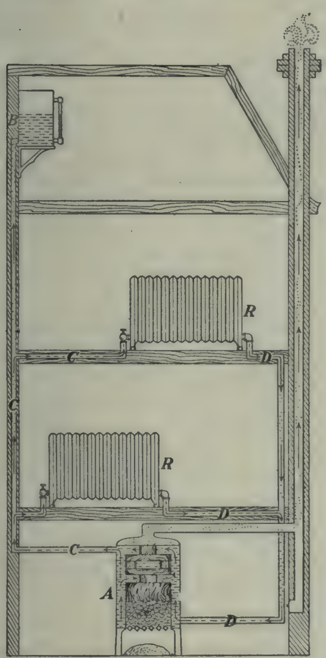

Fig. 176.—Hot-water heating system. A, furnace; C, C, C, pipes leading to radiators, R, R, and expansion tank B; D, D, pipes returning water to furnace after passing through radiators.

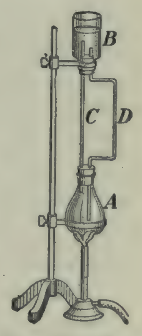

Fig. 175.—Illustration of the principle of heating buildings by hot water.

In a hot-water heating system (Fig. 176) a boiler takes the place of the flask. The hot water passes through radiators in the various rooms of the house and then returns to the furnace. An expansion tank B is also connected with the system. Observe that, as in the flask, the hot water rises from the top of the heater and returns at the bottom of it.

185. Steam Heating. Steam also is employed for heating buildings. It is generated in a boiler and distributed by its own pressure through a system of pipes and radiators. The water of condensation either returns by gravitation or is pumped into the boiler.

186. Heating by Hot-Air Furnaces. Hot-air systems of heating are in very common use. In most cases the circulation of air depends on convection currents. The development of such currents by hot-air furnaces depends on the principle that if a jacket is placed around a heated body and openings are made in its top and its bottom, a current of air will enter at the bottom and escape at a higher temperature at the top. For example, a lamp shade of the form shown in Fig. 177 forms such a jacket about a hot lamp chimney. When the air around the lamp is charged with smoke a current of hot air is seen to pass in at the base of the shade and out at the top.

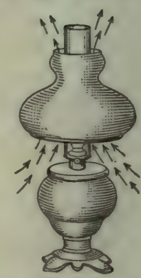

Fig. 177. — Air currents produced by placing a jacket around a heated body.

A hot-air furnace consists simply of a stove *A* (Fig. 178) with a galvanized-iron or brick jacket about it. Pipes connected with the top of the jacket convey the hot air to the rooms to be heated. The cold air is led into the base of the jacket by pipes connected with the outside air or with the floors of the room above.

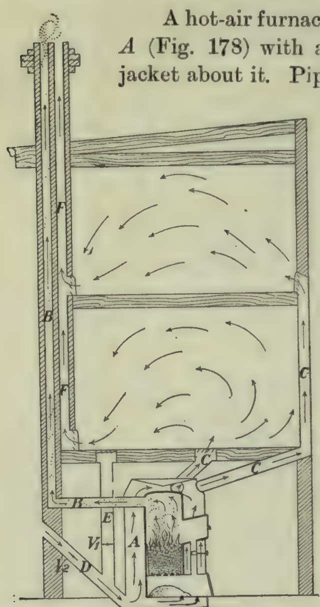

Fig. 178.—Hot-air heating and ventilating system. *A*, stove-jacket; *B*, smoke flue; *C*, warm-air pipes; *D*, cold-air pipe from outside; *E*, cold-air pipe from room; *F*, vent flue; V_1, valve in pipe *E*; V_2, valve in pipe from outside.

187. Ventilation. Most of the methods adopted for securing a supply of fresh air for living rooms depend on the development of convection currents.

When a lighted candle is placed at the bottom of a wide-mouthed jar, fitted with two tubes, as shown in *B* (Fig. 179), it burns for a time but goes out as the air becomes deprived of oxygen and vitiated by the products of combustion. If one of the tubes is pushed to the bottom *A* (Fig. 179), the candle will continue to burn brightly, because a continuous supply of fresh air comes in by one tube and the foul gas escapes by the other.

The experiment is typical of the means usually adopted to secure ventilation in dwelling houses. A current is made to flow between supply pipes and vents by heating the air at one or more points in its circuit.

A warm-air furnace system of heating provides naturally for ventilation if the air to be warmed is drawn from the outside air and, after being used, is allowed to escape (Fig. 178). To support the circulation the vent flue is usually heated. The figure shows the vent flue placed alongside the smoke flue from which it receives heat to create a draught.

The supply pipes and vent flues are as a rule fitted with valves V_1, V_2, to control the air currents. When the inside supply pipe is closed and the others opened a current of fresh air passes into and out of the house ; when it is opened and the outside supply pipe and vent flue closed, the circulation is wholly within the house and the rooms are heated but not ventilated.

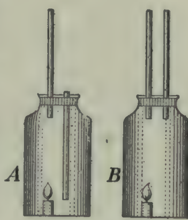

FIG. 179.—Illustration of principle of ventilation. The tubes should be at least ½ inch in diameter.

With a hot-water or steam heating plant ventilation must be effected indirectly. Sometimes a supply pipe enters the room at the base of each radiator and fresh air is drawn in by the upward current produced by the heated coils. More frequently coils are provided for warming the air before it enters the rooms. The coils are jacketed, and the method for maintaining the current differs from the hot-air furnace system only in that the air is warmed by steam coils instead of by a stove. To secure a continuous circulation in large buildings under varying atmospheric conditions, the natural convection currents are often re-inforced and controlled by a power-driven fan placed in the circuit.

188. Transference of Heat by Radiation. The earth receives great quantities of heat from the sun, and as in most of the space between the two bodies there is neither solid, liquid nor gas, the heat cannot come to us by conduction or convection It is said to be transmitted by *radiation.*

Again, if you hold one end of a short copper wire in a Bunsen flame and the other in the hand, heat will soon reach the hand by conduction. If you hold your hand over the flame, it will be heated by convection currents, which move upward. Further, if the hand is held at one side of the flame, it will still be heated, in this case by radiation, and a book or a board held between the flame and the hand shuts off the heat thus received.

Heat radiation differs in many respects from conduction or convection. In the first place the radiation travels in straight lines; you could not cut it off by an obstacle held before the source of heat if this were not so. Then, heat radiation and light radiation are closely related. When the moon comes between us and the sun and produces an eclipse, the sun's light and heat are cut off at the same moment. Also, heat radiation passes freely through a vacuum. Another extraordinary characteristic is that it passes through some bodies without appreciably warming them. The radiation from the sun may pass through a window without warming the glass to any noticeable extent, though in some cases glass will transmit light freely but keep out heat radiation. A glass screen placed before a fireplace acts in this way.

Like light, heat radiation may be reflected and absorbed at the surface of a body. Black bodies absorb while polished surfaces reflect well.

Indeed light and heat are both believed to be transmitted by waves in a substance known as the *ether*, which fills all space. Some waves are especially suited to produce the sensation of heat and others to produce the sensation of light, but the same waves may produce both sensations. The radiation used in wireless telegraphy consists of waves in this same ether. This matter is referred to in the next section.

PART VII.—LIGHT

CHAPTER XXVI

NATURE OF LIGHT; ITS MOTION IN STRAIGHT LINES

189. How Light Comes to Us. We have our candles and oil-lamps and gas-flames and electric lights, but none of these can compare with the sun as a source of light. What is the nature of light, and how is it transmitted to us?

As we have seen, sound requires a material substance to travel through—a solid, a liquid or a gas. But in the great distances separating the earth and the sun or the earth and the stars there is nothing of that sort; indeed, light travels more freely if it does not have to pass through any of these material substances; yet it is believed that light somewhat resembles sound in the manner in which it is transmitted.

On tracing the sound back to its origin we find that it arises from a vibrating body. A body which is producing light is also believed to be vibrating, but the vibrations are so minute and rapid that one cannot see them. The vibrations in the light-source sets up movements in the *ether*, which is believed to fill the great spaces between the heavenly bodies and also the minute spaces between the particles of ordinary matter. We cannot see, or feel, or smell this ether, and yet there is good reason for believing that it is present everywhere. The movements set up in the ether by the light-source spread out in it by means of waves, much as the disturbance in air caused by a vibrating body spreads out in sound-waves.

Light when on its way from a light-source to us is nothing but shakings or waves in this ether, and when these ether waves reach the eye we receive the sensation of light.

Sound and light differ widely in the rate at which they travel. In one second the former goes (in air) one fifth of a mile, while the latter goes the enormous distance of 186,000 miles or 300,000 kilometres.

190. Light Travels in Straight Lines. A lamp placed in the middle of a room sends its light into every corner, and a beacon on a high elevation can be seen in all directions. The sun sends out its light and heat in all directions. We receive but a tiny fraction of it all.

Although we believe that light travels by means of waves in the ether, we usually speak of it as passing in rays, spreading out from the light-source.

When light is admitted into a darkened room through a small opening—a knot-hole in a barn, for example—we can trace its course by means of dust particles in the air, and its path is seen to be a straight line. If you are reading and an object comes between the lamp and your book the light is cut off—it does not travel in a curved path in order to get round the object. If light did not travel in straight lines the carpenter could not tell if an edge was straight by looking along it.

If light spreads out from a point—say, a candle or an arc lamp—a set of rays would form a *divergent pencil,* like *a* Fig. 180 (you notice this is shaped like the sharpened end of

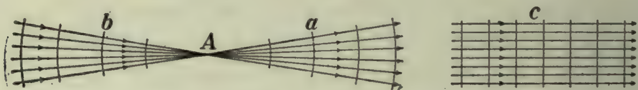

Fig. 180—A convergent pencil, *b*; a divergent pencil, *a*; a parallel beam, c.

an ordinary pencil). If the rays are made to run *to* a point instead of *from* it, we get a *convergent pencil* (*b* Fig. 180), while if the rays move along in parallel lines we have a parallel beam (*c* Fig. 180).

191. The Pin-hole Camera. There are many interesting applications of the fact that light travels in straight lines. One of these is the pin-hole camera, which can be illustrated as follows:—

Take a box *MN* (Fig. 181), bore a hole an inch or two in diameter in one end and knock out the other end. Over the hole stretch tin-foil, in it prick a hole *C* with a pin, place before it a candle *AB* and over the other end of the box stretch a sheet of thin paper.

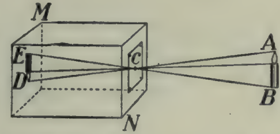

FIG. 181.—Pin-hole camera. *C* is a small hole in the front, and an inverted image of the candle *AB* is seen on the back of the box.

The light from the various portions of *AB* pass through the hole *C* and form on the paper an image *DE* of the candle. This can be seen best by throwing over the head and the box a dark cloth. (Why?) The image is inverted, since the light travels in straight lines and the rays cross at *C*.

If now we remove the paper and for it substitute a sensitive photographic plate, a "negative" may be obtained just as with an ordinary camera; indeed, the perspective of the scene photographed will be truer than with most cameras. The chief objection to the use of the pin-hole camera is that with it the exposure required, compared to that with the ordinary camera, is very long.

It is evident that to secure a sharp, clear image the hole *C* must be small. Suppose that it is made twice as large. Then we may consider each half of this hole as forming an image, and as these images will not exactly coincide, indistinctness will result. On the other hand the hole must not be too small. The size depends chiefly on the length of the camera box.

192. Shadows. Since the rays of light are straight, the space behind an opaque object will be screened from the light and will be *in the shadow.* If the source of the light is small the shadows will be sharply defined, but if not the edges will be indistinct.

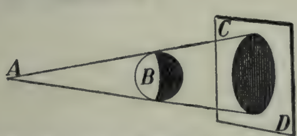

FIG. 182.—If the source be small the shadow will be sharp. *A* is the source, *B* the object, *CD* the shadow.

Let *A* (Fig. 182) be a small source (an arc lamp, for instance) and let *B* be an opaque ball. It will cast on the screen *CD* a circular shadow with sharply defined edges. But if the source is a body of considerable size,* such as the sphere *S* (Fig. 183),

* A lamp with a spherical porcelain shade may be used.

then it is evident that the only portion of space which receives no light at all is the cone behind the opaque sphere E. This is called the *umbra*, or simply the *shadow*, while the portion beyond it which receives a part of the light from S is the *penumbra*. Suppose M is a body revolving about E in the direction indicated. In the position 1 it is just entering the penumbra; in the second position it is entirely within the shadow.

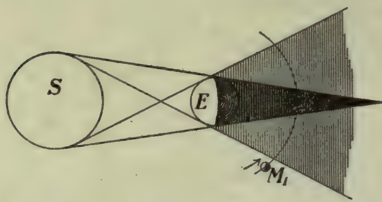

Fig. 183.—S is a large bright source, and E an opaque object. The dark portion is the *shadow*, the lighter portion the *penumbra*.

If S represents the sun, E the earth, and M the moon, the figure will illustrate an eclipse of the moon. For an eclipse of the sun, the moon must come between the earth and the sun, as shown in Fig. 184. Only a small portion of the earth is in the shadow, and in order to see the sun totally eclipsed an observer must be at a on the narrow track over which the shadow sweeps.

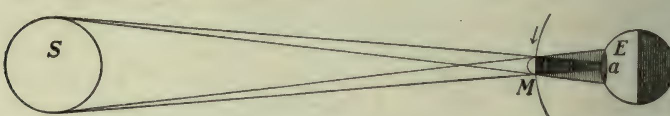

Fig. 184.—Showing how an eclipse of the sun is produced. A person at a cannot see the sun.

193. Transparent, Opaque and Translucent Bodies. Transparent bodies, such as glass, mica, water, etc., allow the light to pass freely through them. Opaque substances entirely obstruct the passage of light; while translucent bodies, such as ground-glass, oiled paper, etc., scatter the light which falls upon them, but a portion is allowed to pass through.

PROBLEMS

1. A photograph is made by means of a pin-hole camera, which is 8 inches long, of a house 100 feet away and 30 feet high. Draw a diagram and find the height of the image ?

2. Why does the image in a pin-hole camera become fainter as it becomes larger (*i.e.*, by using a longer box, or pulling the screen back) ?

3. Why is the shadow obtained with a naked arc lamp sharp and well-defined ? What difference will there be when a ground-glass globe is placed around the arc ? Draw a diagram.

4. On holding a hair in sunlight close to a white screen the shadow of the hair is seen on the screen, but if the hair is a few inches away, scarcely any trace of the shadow can be observed. Draw a diagram and explain this.

CHAPTER XXVII

Reflection of Light

194. Image on a Plane Mirror. Let us hold a book or other object about two feet in front of an ordinary plane mirror. In the mirror you see its *image*, which looks to be behind the mirror, and about as far behind as the book is before it. Now move the book closer and watch the image. It appears to get closer, too. Slowly move the book up until it touches the mirror; at the same time the image slowly moves up until it touches the mirror also.

We see, then, that the nearer the object gets to the mirror, the nearer the image comes to it; also, the line joining the object and its image appears to be at right angles to the mirror. That such is the case can be neatly shown by the following experiment.

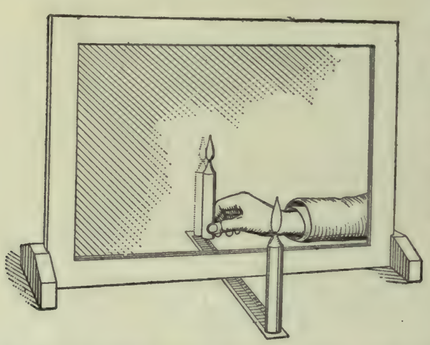

Fig. 185.—A lighted candle stands in front of a sheet of plate glass (not a mirror). Its image is seen by the experimenter, who, with a second lighted candle in his hand, is reaching round behind and trying to place it so as to coincide in position with the image of the first candle.

Before a sheet of thin plate glass (not a silvered mirror) stand a lighted candle on a paper scale which is placed at right angles to the surface of the glass (Fig. 185). We see an image of the candle on the other side. Now move a second candle behind the glass until it coinsides in position with the image.

On examining the scale it will be found that the two candles are both on the paper scale and at equal distances from the glass plate.

You must clearly understand just what takes place here. The rays of light start out from the candle, they strike the glass, are reflected from it and then they come to the eye as if they had started out from a point as far behind the glass as the candle is in front of it. Of course the light does not really come from this point, that is, the image behind the mirror, it only appears to. In this simple experiment we can easily trace how the light has gone, but in some cases the mirror is so perfect and the image so bright and natural that we take it for a real object.

195. Law of Reflection. We must examine more closely how the light is reflected. Let MN (Fig. 186) be a section of a plane mirror, and A a candle in front of it. From A draw AM perpendicular to MN and produce it until B is as far behind MN as A is before it. Then B is the image of A in the mirror. Let the observer's eye be at E.

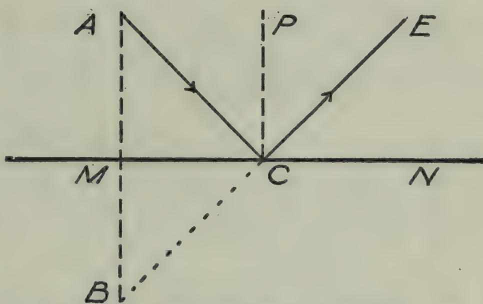

FIG. 186.—Illustrating the law of reflection.

Then a ray starts out from A, strikes the mirror at C, where it is reflected, and it goes in the line BE to the eye E. The ray AC which falls on the mirror is called the *incident* ray and CE is the *reflected* ray. From C erect CP perpendicular to MN; this is called the *normal* to the mirror at C. Also ACP is the *angle of incidence* and

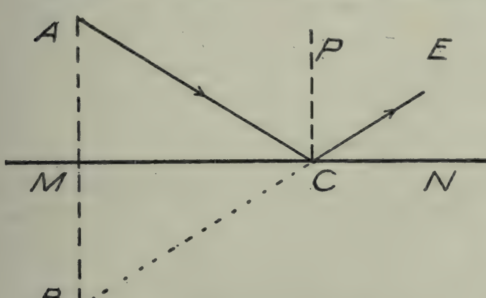

FIG. 187.—Illustrating the law of reflection.

ECP the *angle of reflection.* By geometry it can easily be proved that these angles are equal to each other, and we obtain the following *Law of Reflection*:—

The angle of incidence is equal to the angle of reflection.

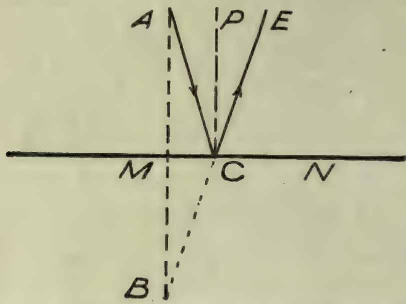

FIG. 188.—Showing how light is reflected. *AC* is incident and *CE* reflected ray.

In Figs. 187, 188 are shown angles of incidence and reflection when the eye is in different positions, and the angles have different magnitudes. In each of these figures a single ray is shown; in Fig. 189 a pencil of rays is shown, starting from *A* and being reflected into the eye.

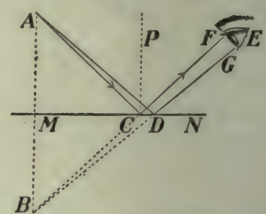

FIG. 189.—*AC* is an incident ray, *CF* the reflected ray, and *CP* the normal to the surface *MN*. Then angle of incidence *ACP* is equal to angle of reflection *FCP*

196. Regular and Irregular Reflection. Mirrors are usually made of polished metal or of sheet glass with a coating of silver on the back surface. When light falls on a mirror it is reflected in a definite direction and the reflection is said to be *regular*. Reflection is also regular from the still surfaces of water, mercury and other liquids.

Now an unpolished surface, such as paper, although it may appear to the eye or the hand as quite smooth, will show decided hills and hollows when examined under a microscope. The surface will appear somewhat as in Fig. 190, and hence the normals at the various parts of the surface will not be parallel to each other, as they are in a well-polished surface.

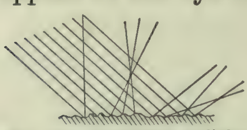

FIG. 190.—Scattering of light from a rough surface.

Hence the rays when reflected will take various directions and will be scattered.

It is by means of this scattered light that objects are made visible to us. When sunlight is reflected by a mirror into your eyes you do not see the mirror but the image of the sun formed by the mirror. Again, if a beam of sunlight in a dark room falls on a plate of polished silver, practically the entire beam is diverted in one definite direction, and no light is given to surrounding bodies. But if it falls on a piece of chalk the light is diffused in all directions, and the chalk can be seen. It is sometimes difficult to see the smooth surface of a pond surrounded by trees and overhung with clouds, as the eye considers only the reflected images of these objects; but a faint breath of wind slightly rippling the surface, reveals the water.

197. How the Eye receives the Light. An object AB (Fig. 191) is placed before a plane mirror MM, and the eye of the observer is at E. Then the image $A'B'$ is easily drawn. The light which reaches the eye from A will appear to come from A', which is the image of A and which is as far behind MM as A is before it.

It is, therefore, by the pencil AaE that the point A is seen. In the same way the point B is seen by the small pencil BbE, and similarly for all other points of the object.

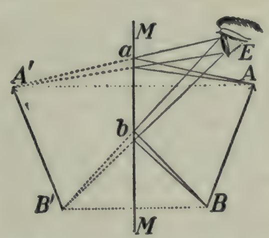

FIG. 191.—How an eye sees the image of an object before a plane mirror.

It will be observed that when the eye is placed where it is in the figure, the only portion of the mirror which is used is the small space between a and b.

An interesting exercise for the student is to draw a figure showing that, for a person standing before a vertical mirror to see himself from head to foot, the mirror need be only half his height.

198. Lateral Inversion. The image in a plane mirror is not the exact counterpart of the object producing it. The right hand of the object becomes the left hand of the image. If a printed page is held before the mirror the letters are erect but the sides are interchanged. This effect is known as *lateral* or *side-for-side inversion.* By writing a word on a sheet of paper and at once pressing on it a sheet of clean blotting-paper the writing on the blotting-paper is inverted; but if it is held before a mirror it is re-inverted and can be read as usual. The effect is illustrated in Fig. 192, which shows the image in a plane mirror of the word STAR.

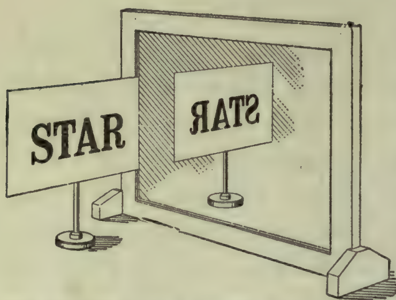

FIG. 192.—Illustrating "lateral inversion" by a plane mirror.

PROBLEMS

1. Why is a room lighter when its walls are white than when covered with dark paper?

2. The sun is 30° above the horizon and you see its image in still water. Draw a diagram to show the incident and reflected rays, and find the values of the angles of incidence and reflection.

3. An automobile with powerful headlights is coming towards you, but you cannot see it well. Why? It throws its light on a carriage ahead of it, and the carriage is well seen. Explain why.

4. Two plane mirrors are at right angles to each other. A ray of light falls on one under an angle of incidence of 30°; it is then reflected and falls on the other. Draw a diagram to show the course of the ray and find the angle of incidence on the second mirror.

199. Spherical Mirrors. Sometimes we use mirrors which are not flat, but whose surfaces are curved—usually parts of spheres. Consider a hollow metal ball, and let us cut a round piece out of it. If this is polished on the inner surface it will form a *concave* mirror; if on the outer surface, a *convex* mirror.

The polished bowl of a silver spoon illustrates the two kinds of mirrors. The inner face is a concave and the outer a convex mirror, only in this case the surface is not a portion of a sphere.

In Fig. 193 MAN represents the section of a spherical mirror. C, the centre of the sphere from which the mirror has been cut, is called the *centre of curvature.* CM, CA, CN are all radii of the sphere, and the length CA is called the *radius of curvature* of the mirror. The line CA, joining the centre of curvature to the middle of the face of the mirror is called the *principal axis.*

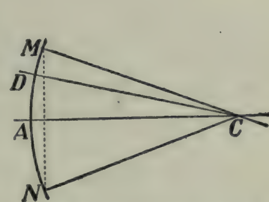

FIG. 193.—A section of a spherical mirror.

200. Reflection from a Spherical Mirror. Let us consider first a concave mirror RA (Fig. 194), of which C is the centre of curvature, and suppose QR is a ray of light striking it at R. How will it be reflected?

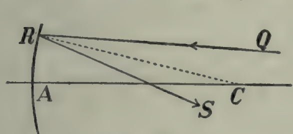

FIG. 194.—Reflection from a concave mirror.

Join CR. This is a radius of the sphere, and so it is at right-angles to its surface. RC then is the normal to the surface at R, and QRC is the angle of incidence. Now the law of reflection states that the angle of incidence is equal to the angle of reflection, and hence to obtain the reflected ray we must draw the angle SRC equal to the angle QRC. Then SRC is the angle of reflection and RS is the reflected ray.

Next, let us take a convex mirror RA (Fig. 195), the right-hand face as seen in the figure being the polished one. QR is an incident ray of light. Joining C to R and producing it we obtain the normal to the mirror at R. Then drawing RS so that it makes the same angle with the normal as QR, we get the reflected ray.

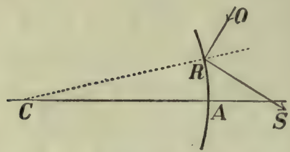

FIG. 195.—Reflection from a convex mirror.

Exercise.—With compasses, ruler and protractor, draw reflected rays for rays incident on both concave and convex mirrors in various directions.

201. Principal Focus. Consider again a concave mirror RA (Fig. 196), and let a ray QR fall on it in a direction parallel to CA, the principal axis. RC is the normal, as before, and drawing RS so that the angle of reflection SRC is equal to QRC, the angle of incidence, we have RS the reflected ray. It cuts the principal axis at F, and it can be proved that F is approximately half-way between A and C.

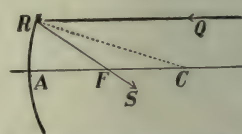

FIG. 196.—The ray QR, parallel to the principal axis AC, on reflection passes through the principal focus F.

If instead of a single ray we have a small beam of rays parallel to the principal axis (Fig. 197) striking the mirror near A they will all come together at F. The point where rays of light come together is called a *focus*, and in this case, where the rays before reflection were parallel to the principal axis, the point F is called the *principal focus* of the mirror.

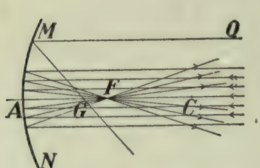

FIG. 197.—A beam of rays parallel to the principal axis passes, on reflection, through F, the principal focus.

For the reflected rays to pass accurately through F, the incident rays should not strike the mirror far from A. If one does, as QM (Fig. 198) the reflected ray will cross the principal axis at G, a little distance from F.

Exercise.—To test these results hold a concave mirror in the sun's rays or in a parallel beam from a projecting lamp and shake chalk-dust in the air. We see the path of the light through the air. Then it converges to the principal focus and after that spreads out again (Fig. 197). By holding a bit of paper at the principal focus it may be set on fire by the sun's rays.

Next, cut a round hole in a piece of paper and place it over the mirror so that the rays can strike it only near the centre A. The reflected rays will now be found to come more accurately to a point than when the whole mirror and a large beam were used.

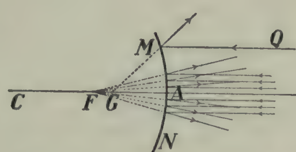

FIG. 198.—Showing reflection of a parallel beam from a convex mirror.

Lastly, try a convex mirror in the same way. The light after reflection from the mirror is spread out as shown in Fig. 198. In this case the reflected rays do not come to a point at all, but if we produce them backwards they will pass through F, half-way between C and A, which is the principal focus of the mirror.

In the case of the concave mirror the rays upon reflection actually pass through F, which is said to be a *real* focus; in the convex mirror they only *appear* to come from F, and it is called a *virtual* focus.

Convex mirrors are not of great practical use. If you look into one, the images you see are always smaller than the objects producing them and they are behind the mirror. Some automobiles have convex mirrors for the chauffeur to see what is going on behind him.

202. Parabolic Mirrors. You have all seen how far a searchlight or the headlight of an automobile or a locomotive can throw its light. This is due to the fact that the rays are projected out in almost a perfectly parallel beam, and as it does not spread out it preserves its strength for a long distance.

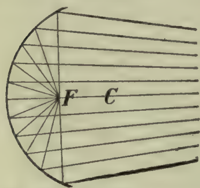

Fig. 199.—If a source of light is placed at the principal focus of a hemispherical mirror the outer rays converge and afterwards diverge again.

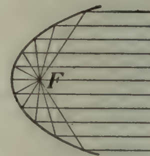

Fig. 200.—How a parabolic reflector sends out parallel rays.

How is it produced? Let us place a candle at the principal focus of a concave mirror which is quite a large fraction of a sphere (Fig. 199). Those rays which strike the mirror near its centre go off parallel to the principal axis, but those striking the mirror near the outer edge converge somewhat. These rays will come together to a focus and then spread out again.

Now a parabola is a curve which exactly overcomes this difficulty. All rays which start out from its principal focus will be reflected parallel to its axis (Fig. 200). Searchlight and headlight mirrors are given this parabolic form.

CHAPTER XXVIII

REFRACTION

203. Familiar Examples of Refraction. Everyone has observed the peculiar appearance of an oar or a stick when it is held in the water so as to make an oblique angle with the surface. Just at the surface the stick is abruptly bent as shown in Fig. 201. From this figure we see that a pencil of light-rays starting from any point on the stick, upon coming out of the water is bent downwards and then goes along to the eye as if it had started from a point higher up in the water. The figure shows the course of the rays and why the stick seems bent.

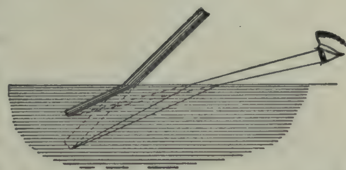

FIG. 201.—The stick appears broken at the surface of the water.

Another simple and interesting experiment is the following:

Place a coin PQ (Fig. 202) on the bottom of an empty bowl or other opaque vessel and then slowly move backwards until the coin is just hidden from your eye by the wall of the vessel. Now while you keep in this position let some one pour water into the vessel. The coin becomes visible again, appearing in the position $P'Q'$. Also, the bottom of the vessel seems to have risen and the water looks shallower than it really is.

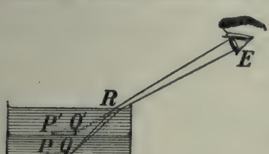

FIG. 202.—The bottom of the vessel appears raised up by refraction.

The reason for this is easily understood from the figure. Rays of light start from Q, go up to R, at the surface of the water, and on coming out into the air are bent downwards. When they reach the eye E they appear as if they had come from Q'. Similarly rays which started from P when they leave the water move as if they had started from P'. Hence the coin PQ appears to be in the position $P'Q'$.

This bending or breaking of the path of a ray of light is called *refraction*.

204. Meaning of Refraction. By means of a mirror let us reflect a beam from the sun or from a projecting lantern down upon the surface of water. Suppose that it goes along PA (Fig. 203). At A, where it reaches the water, some of the light will be reflected up into the air again, while a portion will enter the water. Let AQ be the line along which it moves. Then PA is the incident ray and AQ the refracted ray. At A draw the normal, that is, the perpendicular line, to the surface. Then i, the angle between the incident ray and the normal, is called the *angle of incidence*, and r, the angle between the refracted ray and the normal, is called the *angle of refraction.*

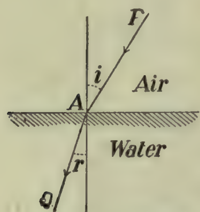

FIG. 203.—Illustrating refraction from air to water.

In the figure, which represents light passing from air into water, the angle r is smaller than i. The angle of refraction is always smaller than the angle of incidence when the second medium is denser than the first one.

Suppose now the light to be moving in the opposite direction, that is, from water out into air. Let it start at Q, reach the surface at A, and thence pass out into the air. It will move along AP. In this case the angle of incidence is r, and it is smaller than the angle of refraction i.

205. Refraction through a Plate. Next, let us trace the course of a ray of light through a glass plate. In the air it is at first moving along PQ, (Fig. 204), the angle of incidence being i. On entering the glass at Q it goes along QR, the angle of refraction being r. At R it comes out into the air again and moves

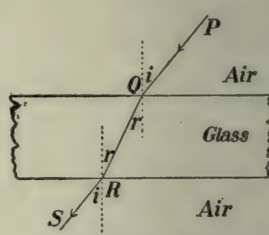

FIG. 204.—Showing the course of a ray of light through a glass plate.

along RS. In this second refraction the angle of incidence is r and the angle of refraction is i.

The direction it takes on coming out is parallel to that it had before entering the plate. The plate, then, does not change the direction of the light, but just displaces it to one side.

Lay a piece of thick plate glass over a line drawn on paper, so that a portion of the line can be seen beside the plate, a portion through it. The line will appear to be broken, that part seen through the glass being displaced somewhat.

206. Refraction through Prisms. A prism, as used in the study of light, is a wedge-shaped piece of glass or other transparent substance contained between two plane faces. The angle between the faces is called the *refracting angle*, and the line on which the faces meet is the *edge* of the prism.

In Fig. 205 is shown a section of a prism whose refracting angle A is 60°. Let us follow the path of a ray of light through it. First it moves in the air along PQ, and entering the prism at Q is refracted so as to move along QR. Upon reaching the surface at R it is refracted out into the air again, finally moving off in the direction RS.

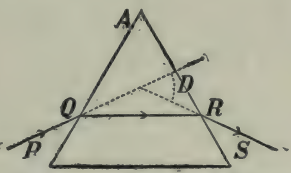

Fig. 205.—The path of light through a prism.

Thus PQ is the direction in which the light was moving at first, and RS the direction at last. Continuing these two lines until they meet, D is the angle between them. This, then, is the angle through which the light has been turned or deviated by the prism.

QUESTIONS

1. Looking into a pail of water, the bottom of the pail appears raised above the table on which it rests. Explain why.

2. A ray of light strikes on the surface of glass. Draw a figure showing the reflected and the refracted ray.

3. In spearing fish one must strike lower than the apparent place of the fish. Draw a figure to explain why.

4. Explain the wavy appearance seen above hot bricks or rocks.

5. A strip of glass is laid over a line on a paper (Fig. 206). When observed obliquely the line appears broken. Explain why this is so.

FIG. 206.—Why does the line appear broken?

6. The illumination of a room by daylight depends to a great extent on the amount of daylight which can enter. Show why a plate of prism glass having a section such as shown in Fig. 207, placed in the upper portion of a window in a store on a narrow street, is more effective in illuminating the store than ordinary plate glass.

FIG. 207. — The plane face is on the outside.

207. Lenses. The most important application of refraction is in lenses. Their different shapes are shown in Fig. 208. They are almost always made of glass and their surfaces are either flat or portions of spheres.

FIG. 208.—Lenses of different types.

Now, although six different types are shown in the figure, they may be divided into two classes :–(1) convex lenses, or those thicker at the centre than at the edge, and (2) concave lenses, or those thinner at the middle than at the edge.

208. Action of a Lens. Hold a convex lens in a beam of sunlight or in a parallel beam sent out by a projecting lantern. The light is refracted on passing through the lens. The ray which passes through the centre of the lens is not bent from its course, but all the others are, those passing through near the outer edge being bent most of all. The consequence is, the rays are brought together to a point F (Fig. 209) which is called the *principal focus,* and the distance from F to the lens is called the *focal length* of the lens.

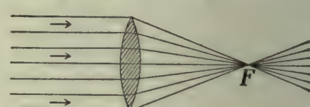

FIG. 209.—Parallel rays converged to the principal focus F.

The directions of the rays can be shown by scattering chalk-dust in the air, and if when you are using sunlight you hold a piece of paper at F a very bright spot will be seen, and the paper will probably be set on fire.

Next, try a concave lens. By it the light is not brought to a point, but is diverged, or spread out, as shown in Fig. 210. If we produce these diverging rays backwards they meet at a point F, which is the principal focus of the lens. The rays on leaving the lens move as if they came from this point; however, as they do not really do so, but only appear to, the focus is said to be *virtual*. In the convex lens the focus is real. The distance from F to the lens is, as before, the focal length of the lens.

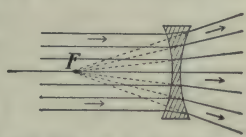

FIG. 210.—In a diverging the principal focus F is virtual.

209. How to find the Focal Length. In the case of the convex lens this is easily done. Hold it in the sunlight and find where the light comes together to a focus by receiving it on paper or ground glass and moving the paper back and forth until the brightest and smallest spot is obtained. Then measure the distance from it to the lens.

If the sunlight is not available, a lamp at a considerable distance or a window at the other side of the room may be used.

The shorter the focal length is, the more powerful the lens is said to be.

210. Uses of Lenses. In our telescopes, microscopes, cameras and other optical instruments the lenses usually form the chief part.

Hold a convex lens a little distance from a candle or other bright source and receive the light that passes through the lens on a piece of paper. At a certain distance there will be formed on the paper an image such as is shown in Fig. 211. By moving the lens nearer to or further from the candle, we can obtain the image at different distances. The further the image is from the lens the larger it is.

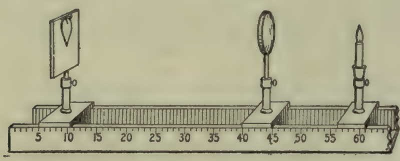

FIG. 211.—An optical bench for studying object and image.

The simple microscope or magnifying glass is a convex lens, and the way it acts is shown in Fig. 212. The object PQ to be magnified is placed near the lens which is held near the eye. The light from PQ passes through the lens, and when it enters the eye it appears to have come from pq which is the image of PQ and which is larger than PQ.

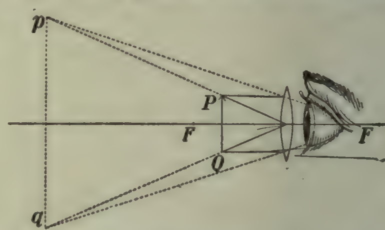

FIG. 212.—Diagram illustrating the action of the simple microscope.

A camera is illustrated in Fig. 213. In the tube A is the lens, and at the other end of the apparatus is a frame C containing a piece of ground glass. By means of the bellows B this is moved back and forth until the scene to be photographed is sharply focussed on the ground glass. Then a holder containing a sensitive plate or film is inserted in front of the frame C, the sensitized surface taking exactly the position previously occupied by the ground surface of the glass.

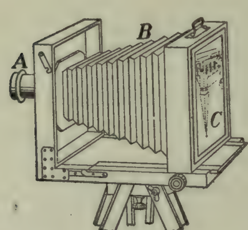

FIG. 213.—A camera.

The exposure is then made, that is, light is admitted through the lens to the sensitive plate, after which, in a dark room, the plate is removed from its holder, developed and fixed.

CHAPTER XXIX

THE SPECTRUM; COLOUR

211. Newton's Experiment with a Prism. About 250 years ago the great Englishman, Sir Isaac Newton, performed an experiment which you should try to repeat. Allowing sunlight to enter a room through a small hole in a window shutter or in the wall, place a glass prism in the path of the beam, as shown in Fig. 214. Now if the prism were away the light would move on in a straight line, shown dotted in the figure, and form on the opposite wall a bright white image. On passing through the prism, however, it is turned from this line, but, in addition, a beautiful oblong *coloured* image is seen on the wall. That end of the image which is furthest from the original direction of the light is violet, the other end is red.

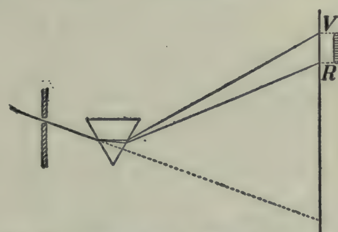

FIG. 214.—Light enters through a hole in the window-shutter, passes through a prism and is received on the opposite wall.

This coloured image is called the *spectrum* of sunlight, and on closely examining it we see all the colours of the rainbow, which are usually given as follows:—red, orange, yellow, green, blue, indigo, violet.

It should be noted, however, that there are not seven separate coloured bands with definitely marked dividing lines between them. The adjoining colours blend into each other, and it is impossible to say where one ends and the next begins. Very often indigo is omitted from the list of colours, as not being distinct from blue and violet.

From Newton's experiment we conclude:

(1) That white light is not simple but composite, that it includes constituents of many colours.

(2) That these colours may be separated by passing the light through a prism.

(3) That lights which differ in colour differ also in the amount by which they are refracted, violet being refracted most and red least.

212. A Pure Spectrum. It is often inconvenient to use sunlight for this experiment, and we may substitute for it the light from a projecting lantern.

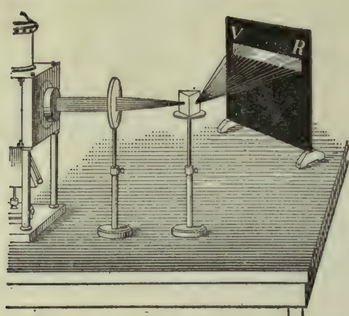

FIG. 215.—Showing how to produce a pure spectrum.

A suitable arrangement is illustrated in Fig. 215. The light emerges from a narrow vertical slit in the nozzle of the lantern, and then passes through a converging lens, so placed that an image of the slit is produced as far away as is the screen on which we wish to have the spectrum. Then a prism is placed in the path, and the spectrum appears on the screen.

You should notice, however, that this is the spectrum of the electric light (or whatever light we are using in the lantern), not of sunlight. Each source of light has its own spectrum.

The spectrum produced in the way just described is *purer* than that obtained by Newton's simple method, that is the colours are more clearly separated from each other.

213. Colours of Natural Objects. If you look through a piece of red glass at a candle or at the sky, these objects appear red. A piece of ribbon, examined in ordinary light looks red. Let us try to find out the reason for these colours.

Arrange the projecting lamp as shown in Fig. 213, but first of all leave out the prism. The light now goes straight forward and on a screen is shown a bright white image of the narrow slit in the nozzle of the lantern. Now in front of the slit hold a piece of red glass. The image on the screen is red now. What has the glass done to the light?

Removing the red glass, place the prism in position as shown in Fig. 213 and get the spectrum on the screen. All the colours from red to violet are present as represented in the upper part of Fig. 216. Again hold the red glass over the slit. The portion of the spectrum now on the screen is the red, with perhaps a little of the orange (Fig. 216, lower part). All the rest, namely, the yellow, green, blue and violet portions, have been absorbed or suppressed by the glass

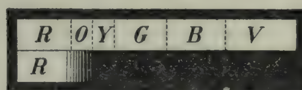

FIG. 216.—A red glass transmits only red and some orange.

The colour is present not because the glass has brought anything new into the light but because it has removed some of the parts which make up white light, and those which are left combined together give the colour seen.

Next, let us examine the red ribbon. Produce the spectrum on the screen as before and then hold the ribbon in the different parts of the spectrum in succession. When held in the red it appears red, its natural colour, but when held in any other portion it looks black, that is, it shows no colour at all. This tells us, then, that a red object is red because it absorbs light of all other colours and reflects or scatters only the red.

In order to produce this absorption and scattering, however, the light must penetrate some distance into the object,—not very far, indeed, but yet far enough for the absorption to take place.

Similarly with green, or blue, or violet ribbons; but, as in the case of the coloured glass, the colours will usually be far from pure. Thus a blue ribbon will ordinarily reflect some of the violet and the green, though in red light it will probably appear quite black.

Let us think for a moment what happens when sunlight falls on various natural objects. The rose and the poppy appear red because they reflect mainly red light, absorbing the other colours of the spectrum. Leaves and grass appear green because they contain a green colouring matter (chlorophyll) which is able largely to absorb the red, blue and violet, the sum of the remainder being a somewhat yellowish green. A lily appears white because it reflects all the component colours of white light. When illuminated by red light it appears red; by blue, blue.

A striking way to exhibit this absorption effect is by using a strong sodium flame, that is, a Bunsen flame in which sodium is burnt, in a well-darkened room. This light is of a pure yellow, and bodies of all other colours appear black. The flesh tints are entirely absent from the face and hands, which, on this account, present a ghastly appearance.

We see, then, that the colour which a body exhibits depends not only on the nature of the body itself, but also upon the nature of the light by which it is seen.

At sunrise and sunset the sun and the bright clouds near it take on gorgeous red and golden tints. These are due chiefly to absorption. At these times the sun's rays, in order to reach us, have to pass through a greater thickness of the earth's atmosphere than they do when the sun is overhead, and the colours at the blue end of the spectrum are more absorbed than the red and yellow, which tints therefore are the chief ones seen.

214. Recomposition of White Light. We have considered the decomposition of white light into its constituents; let us now explain several ways of performing the operation of recombining the spectrum colours to obtain white light.

(1) If two similar prisms are placed as shown in Fig. 217, the second prism simply reverses the action of the first and restores white light. The two prisms, indeed, act like a thick plate (§ 205).

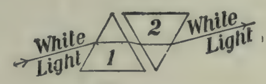

FIG. 217.—The second prism counteracts the first.

(2) By means of a large convex lens, preferably a cylindrical one (a tall beaker filled with water answers well), the light dispersed by the prism may be converged and united again. The image, when properly focussed, will be white.

(3) In each of the above cases the coloured lights are mixed together outside the eye. Each colour gives rise to a colour-sensation. A method will now be explained whereby the various colour-sensations are combined within the eye. The most convenient method is by means of Newton's disc, which consists of a circular disc of cardboard on which are pasted sectors of coloured paper, the tints and sizes of the sectors being chosen so as to correspond as nearly as possible to the coloured bands of the spectrum.

Now put the disc on a whirling machine (Fig. 218) and set it in rapid rotation. It appears white, or whitish-gray. This is explained as follows:

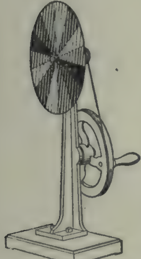

FIG. 218. Newton's disc on a rotating machine.

Luminous impressions on the retina do not vanish instantly when the source which excites the sensation is removed. The average duration of the impression is $\frac{1}{10}$ second, but it varies with different people and with the intensity of the impression. If one looks closely at an incandescent electric lamp for some time, and then closes his eyes, the impression will stay for some time, perhaps a minute. With an intense light it will last longer still. With a *very strong* light it may injure the eye.

If a live coal on the end of a stick is whirled about, it appears as a luminous circle; and the bright streak in the sky produced by a "shooting star" or by a rising rocket is due to this persistence of luminous impressions. In the same way, we cannot detect the individual spokes of a rapidly rotating wheel, but if illuminated by an electric spark we see them distinctly. The duration of the spark is so short that the wheel does not move appreciably while it is illuminated.

In the familiar "moving pictures" the intervals between the successive pictures are about $\frac{1}{40}$ second, and the continuity of the motion is perfect. One comes on before the previous one has disappeared.

If then the disc is rotated with sufficient rapidity the impression produced by one colour does not vanish before those produced by other colours are received on the same portion of the retina. In this way the impressions from all colours are present on the retina at the same time, and they make the disc appear of a uniform whitish-gray. This gray is a mixture of white and black, no *colour* being present, and the stronger the light falling on the disc the more nearly does it approach pure white.

QUESTIONS

1. A ribbon purchased in daylight appeared blue, but when seen in gas-light it looked greenish. Explain this.

2. One piece of glass appears dark red and another dark green. On holding them together you cannot see through them at all. Why is this?

PART VIII—ELECTRICITY AND MAGNETISM

CHAPTER XXX

MAGNETISM

215. Natural Magnets. In various countries there is found an ore of iron which possesses the remarkable power of attracting small bits of iron. Specimens of this ore are known as *natural magnets.* This name is derived from Magnesia, a town of Lydia, Asia Minor, in the vicinity of which the ore is supposed to have been abundant.

FIG. 219.—Iron filings clinging to a natural magnet.

If dipped in iron filings many will cling to it, and if it is suspended by an untwisted fibre it will come to rest in a definite position, thus indicating a certain direction. On account of this it is known also as a *lodestone,* (*i.e.,* leading-stone) Fig. 219.

216. Artificial Magnets. If a piece of steel is stroked over a natural magnet it becomes itself a magnet. There are, however, other and more convenient methods of magnetizing pieces of steel (§ 248), and as steel magnets are much more powerful and more convenient to handle than natural ones, they are always used in experimental work.

Permanent steel magnets are usually of the bar, the horse-

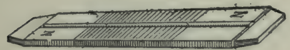

FIG. 220.—Bar-magnets.

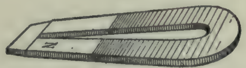

FIG. 221.—A horse-shoe magnet.

shoe or the compass-needle shape, as illustrated in Figs. 220, 221, 222

217. Poles of a Magnet. Scatter iron filings over a bar-magnet. They are seen to adhere to it in tufts near the ends, none, or scarcely any, being found at the middle (Fig. 223). The strength of the magnet seems to be concentrated in certain places near the ends; these places are called the *poles* of the magnet, and a straight line joining them is called the *axis* of the magnet. Suspend a bar-magnet by an untwisted thread so that it can turn freely in a horizontal plane. This axis will assume a definite north-and-south direction, in what is generally known as the *magnetic meridian*, which, in our latitude, is usually not far from the geographical meridian. That end of the magnet which points north is called the *north-seeking*, or simply the *N*-pole, the other the *south-seeking* or *S*-pole. Fig. 222 shows a magnet poised on a pivot. The combination is usually known as a *compass-needle.*

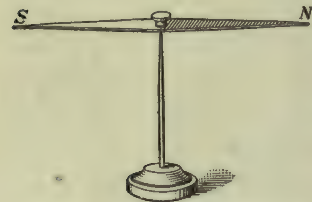

FIG. 222.—A compass-needle magnet.

FIG. 223.—The filings cling mostly at the poles.

218. Magnetic Attraction and Repulsion. Let us bring the *S*-pole of a bar-magnet near to the *N*-pole of a compass-needle (Fig. 224). There is an attraction between them. If we present the same pole to the *S*-pole of the needle, it is repelled. Reversing the ends of the magnet we find that its *N*-pole now attracts the *S*-pole of the needle but repels the *N*-pole.

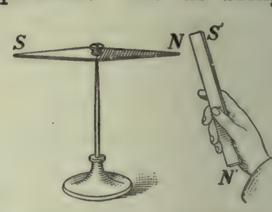

FIG. 224.—The *S*-pole of one magnet attracts the *N*-pole of another.

We thus obtain the law:—*Like magnetic poles repel, unlike attract each other.*

Exercise.—Magnetize two sewing needles by rubbing them, always in the same direction, against one pole of a magnet. Thrust each needle into a cork so that the needle will float horizontally on water. Place one of the needles on the water. In what direction does it set itself? Now place the other needle on the water and push it over near the first one. Note the attractions and repulsions.

It is to be observed that unmagnetized iron or steel will be attracted by *both* ends of a magnet. It is only when both bodies are magnetized that we can obtain repulsion.

219. Magnetic Substances. A magnetic substance is one which is attracted by a magnet. Iron and steel are the only substances which exhibit magnetic effects in a marked manner. Nickel and cobalt are also magnetic, but in a much smaller degree.

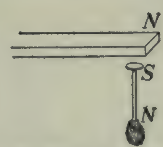

FIG. 225.—A nail if held near a magnet becomes itself a magnet by induction.

220. Induced Magnetism. Hold a piece of iron rod, or a nail,* near one pole of a strong magnet. It becomes itself a magnet, as is seen by its power to attract iron filings or small tacks placed near its lower end (Fig. 225). If the nail be allowed to touch the pole of the magnet, it will be held there. A second nail may be suspended from the lower end of this one, a third from the second, and so on. (Fig. 226.) On removing the magnet, however, the chain of nails falls to pieces.


FIG. 226.—A chain of magnets by induction.

We thus see that a piece of iron becomes a *temporary* magnet when it is brought near one pole of a permanent steel magnet. The magnetizing action of the magnet on the piece of iron is known as *induction*. The polarity of the induced magnet can be tested in the following way:

*Ordinary steel nails are not very satisfactory. Use clout nails or short pieces of stove-pipe wire.

Suspend a bit of soft-iron (a narrow strip of tinned-iron is very suitable), and place the N-pole of a bar-magnet near it (Fig. 227). Then bring the N-pole of a second bar-magnet near the end n of the strip, farthest from the first magnet. It is repelled, showing that it is a N-pole. Next bring the S-pole of the second magnet slowly towards the end s of the strip. Repulsion is again observed. This shows, as we should expect from the law of magnetic attraction and repulsion (§ 218), that the induced pole is opposite in kind to that of the permanent magnet adjacent to it.

Fig. 227.—Polarity of induced magnetism.

221. Retentive Power. The bits of iron in Figs. 225, 226, 227, possess their magnetism only when they are near the magnet; when it is removed, their polarity disappears.

If hard-steel is used instead of soft-iron, the steel also becomes magnetized, but not as strongly as the iron. However, if the magnet is removed the steel will still retain some of its magnetism. It has become a *permanent* magnet.

Thus steel offers great resistance both to being made a magnet and to losing its magnetism. It is said to have great *retentive power.*

On the other hand, soft-iron has small retentive power. When placed near a magnet, it becomes a stronger magnet than a piece of steel would, but it parts with its magnetism quite as easily as it gets it.

222. Field of Force about a Magnet. The space about a magnet, in any part of which the force from the magnet can be detected, is called its *magnetic field.*

One way to explore the field is by means of a small compass needle. Place a bar-magnet on a sheet of paper and slowly move a small compass needle about it. The action of the two poles of the magnet on the poles of the needle will cause the latter to set itself at various points along lines which indicate the direction of the force from the magnet. These lines are called technically *lines of force.* The curves run from one pole to the other. In Fig. 228 is shown the direction


Fig. 228.—Position assumed by a needle near a bar-magnet.

of the needle at several points, as well as a line of force extending from one pole to the other.

Another way to map the field is by means of iron filings. This is very simple and very effective. Place a sheet of paper over the magnet, and sift from a muslin bag iron filings evenly and thinly over it. Tap the paper gently. Each little bit of iron becomes a magnet by induction, and tapping the paper assists them to arrange themselves along the magnetic lines of force. Fig. 229 exhibits the field about a bar-magnet, while Fig. 230 shows it about similar poles of two bar-magnets standing on end.

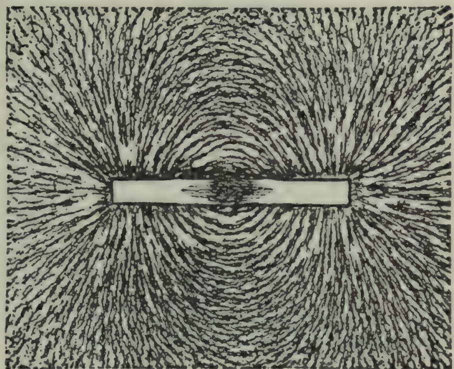

FIG. 229.—Field of force of a bar-magnet.

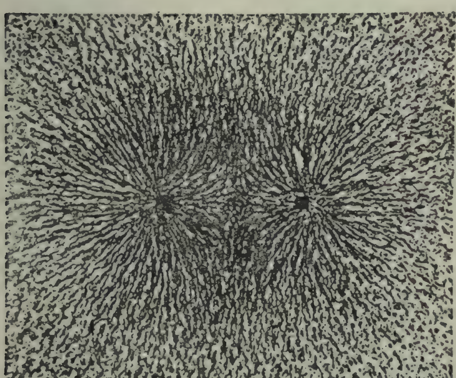

FIG. 230.—Field of force of two like poles.

The magnetic force, as we have seen, is greatest in the neighbourhood of the poles, and here the curves shown by the filings are closest together. Thus the direction of the curves indicates the direction of the lines of force, and their closeness together at any point indicates the strength of the magnetic force there.

There are several ways of making these filings figures permanent. Some photographic process gives the best results, but a convenient way is to produce the figures on paper which has been dipped in melted paraffin, and then to heat the paper. The filings sink into the wax, and are held firmly in it when it cools down.

223. Magnetic Shielding. Most substances when placed in a magnetic field make no appreciable change in the force there, but there is one pronounced exception to this, namely iron.

Place a bar-magnet with one pole about 10 cm. from a large compass-needle (Fig. 231). Pull aside the needle and let it go. It will continue vibrating for some time. Count the number of vibrations per minute. Then push the magnet up until it is 6 cm. from the needle, and again time the vibrations. They will be found to be much faster. Next, put the magnet 3 cm. from the needle; the vibrations will be still more rapid. Thus, the stronger the force of the magnet on the needle, the faster are the vibrations.

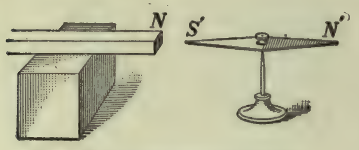

FIG. 231.—Arrangement for testing magnetic shielding.

Now while the magnet is 3 cm. from the needle place between them a board, a sheet of glass or of brass, and determine the period of the needle. No change will be observed. Next, insert a plate of iron. The vibrations will be much slower, thus showing that the iron has shielded the needle from the force of the magnet.

The lines of force upon entering the iron simply spread throughout it, meeting less resistance in doing so than in moving out into the air again. A space surrounded by a thick shell of iron is effectually protected from external magnetic force.

224. Magnetic Permeability. The lines of force pass more easily through iron than through air. Thus iron has greater *permeability* than air, and the softer the iron is the greater is its permeability. Hence, when a piece of iron is placed in a magnetic field, many of the lines of force are drawn together and pass through the iron. This explains why soft-iron becomes a stronger magnet by induction than does hard-steel.

225. Each Molecule a Magnet. On magnetizing a knitting needle or a piece of clock-spring (Fig. 232) it exhibits a pole at each end, but no magnetic effects at the centre. Now break it at the middle. Each part is a magnet. If we break these portions in two, each fragment is again a magnet. Continuing this, we find that each free end always gives us a magnetic pole. If all the parts are closely joined again the adjacent poles neutralize each other, and we have only the poles at the ends as before. If a magnet is ground to powder each fragment still acts as a little magnet and shows polarity.

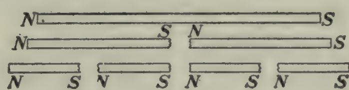

Fig. 232.—Each portion of a magnet is a magnet.

Again, if a small tube filled with iron filings is stroked from end to end with a magnet it will be found to possess polarity, which, however, will disappear if the filings are shaken up.

All these facts lead us to believe that each molecule is a little magnet. In an unmagnetized iron bar they are arranged in an irregular haphazard fashion (Fig. 233), and so there is no combined action. When the iron is magnetized the molecules turn in a definite direction. Striking the rod while it is being magnetized assists the molecules to take up their new positions. On the other hand rough usage destroys a magnet. When the magnet is made as strong as it can be the molecules are *all* arranged in regular order, as illustrated in Fig. 234.

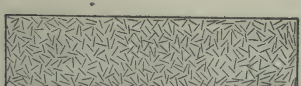

Fig. 233.—Haphazard arrangement of molecules of iron ordinarily.

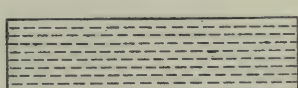

Fig. 234.—Arrangement of molecules of iron when magnetized to saturation.

The molecules of soft-iron can be brought into alignment more easily than can those of steel, but the latter retain their positions much more tenaciously.

226. Effect of Heat on Magnetization. A magnet loses its magnetism when raised to a bright red heat, and when iron is heated sufficiently it ceases to be attracted by a magnet. This can be nicely illustrated in the following way. Heat a cast-iron ball, to a white heat if possible, and suspend it at a little distance from a magnet. At first it is not attracted at all, but on cooling to a bright red it will be suddenly drawn in to the magnet.

227. Mariner's Compass. In the modern ship's compass several magnetized needles are placed side by side, such a compound needle being found more reliable than a single one. The card, divided into the 32 "points of the compass," is itself attached to the needle, the whole being delicately poised on a sharp iridium point. (Fig. 235).

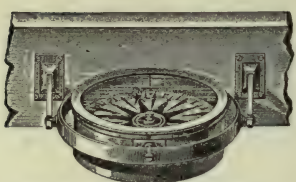

FIG. 235—Mariner's compass.

228. The Earth a Magnet. The fact that the compass needle assumes a definite position suggests that the earth or some other celestial body exerts a magnetic action. William Gilbert, in his great work entitled *De Magnete* (*i.e.*, "On the Magnet"), which was published in 1600, demonstrated that our earth itself is a great magnet.

In order to illustrate his views Gilbert had some lodestones cut to the shape of spheres; and he found that small magnets turned towards the poles of these models just as compass needles behave on the earth.

The magnetic poles of the earth, however, do not coincide with the geographical poles. The north magnetic pole was found by Sir James

Ross on June 1, 1831, on the west side of Boothia Felix, in N. Lat. 70° 5′, W. Long. 97° 46′. In 1904-5 Roald Amundsen, a Norwegian, explored all about the pole. Its present position is about N. Lat. 70°, W. Long. 97°, not far from its earlier position.

The south magnetic pole was only recently attained. On January 16, 1909, three members of the expedition led by Sir Ernest Shackleton discovered it in S. Lat. 72° 25′, E. Long. 155° 16′. In both cases the magnetic pole is over 1,100 miles from the geographical pole, and a straight line joining the two magnetic poles passes about 750 miles from the centre of the earth.

229. Magnetic Declination. We are in the habit of saying that the needle points north and south, but it has long been known that this is only approximately so. Indeed, knowing that the magnetic poles are far from the geographical poles, we would not expect the needle (except in particular places) to point to the true north. In addition, deposits of iron ore and other causes produce local variations in the needle. The angle which the axis of the needle makes with the true north-and-south line is called the *magnetic declination.*

230. Lines of Equal Declination or Isogonic Lines. Lines upon the earth's surface through places having the same declination are called *isogonic* lines; that one along which the declination is zero is called the *agonic* line. Along this line the needle points exactly north and south.

On January 1, 1910, the declination at Toronto was 5° 55′ W. of true north, at Montreal, 15° 4′ W., at Winnipeg, 14° 4′ E., at Victoria, B.C., 24° 25′ E., at Halifax, 21° 14′ W. These values are subject to slow changes. At London, in 1580, the declination was 11° 17′ E. This slowly decreased, until in 1657 it was 0° 0′. After this it became west and increased until in 1816 it was 24° 30′; since then it has steadily decreased and is now 15° 3′ W.

In Fig. 236 is a map showing the isogonic lines for the United States and Canada for January 1, 1910.

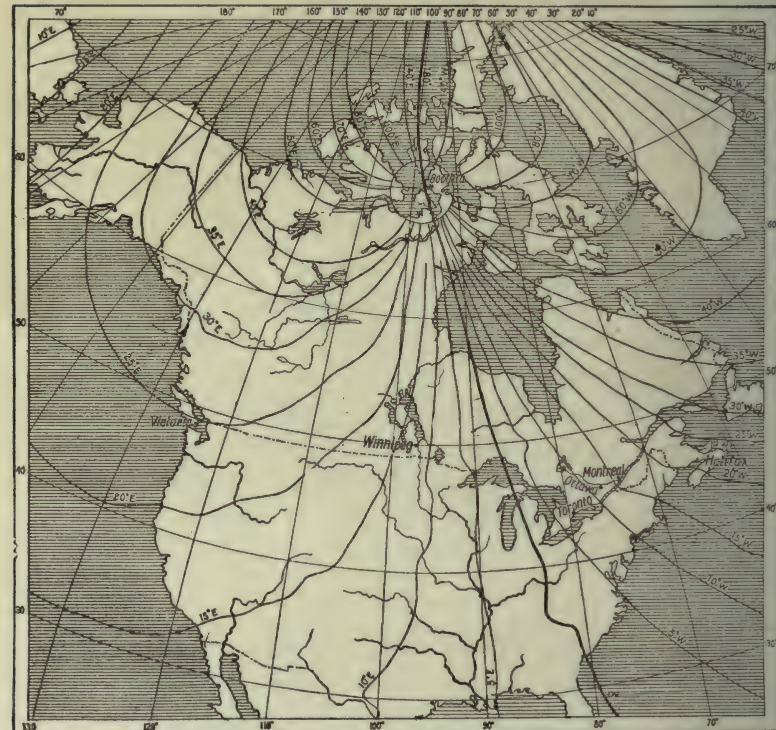

FIG. 236.—Isogonic Lines for Canada and the United States (January 1, 1910).

The data for regions north of latitude 55° are very meagre and discordant; the regions west of Hudson Bay where recent determinations have been made show considerable local disturbance; the lines north of latitude 70° are drawn largely from positions calculated theoretically, but modified where recent observations have been made. The above map was kindly drawn for this work by the Department of Research in Terrestial Magnetism of the Carnegie Institution of Washington.

231. Magnetic Inclination or Dip. Fig. 237 shows an instrument in which the magnetized needle can move in a vertical plane. The needle before being magnetized is so adjusted that it will rest in any position in which it is placed, but when magnetized the N-pole (in the northern hemisphere) dips down, making a considerable angle with the horizon. If the magnetization of the needle is reversed, the other end dips down. Such an instrument is called a *dipping needle.* When using it the axis of rotation should point east and west (*i.e.,* at right angles to the *magnetic* meridian), and the needle should move with the least possible friction.

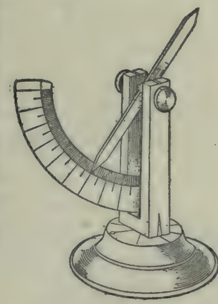

FIG. 237.—A simple dipping needle.

The angle which the needle makes with the horizon is called the *inclination* or *dip.* At the *magnetic* equator the dip is zero (or the needle is horizontal), but north and south of that line the dip increases, until at the magnetic poles it is 90°. Indeed, the location of the poles was determined by the dipping needle.

At Toronto the dip is 74° 37′; at Washington, 71° 5′.

232. The Earth's Magnetic Field. As the earth is a great magnet it must have a magnetic field about it, and a piece of iron in that field should become a magnet by induction. If an iron rod (*e.g.*, a poker, or the rod of a retort stand) is held nearly vertically, with the lower end inclined towards the north, it will be approximately parallel to the lines of force, and it will become magnetized. If struck smartly when in this position its magnetism will be strengthened. (Why?) Its magnetism can be tested with a compass needle. Carefully move the lower end towards the S-pole; it is attracted. Move it near the N-pole; it is repelled. This shows the rod to be a magnet.

Now when a magnet is produced by induction, its polarity is opposite to that of the inducing magnet. Hence we see that what we call the north magnetic pole of the earth is opposite in kind to the N-pole of a compass needle.

Iron posts in buildings and the iron in a ship when it is being built become magnetized by the earth's field.

QUESTIONS

1. You are provided with a steel sewing needle and are required to magnetize it so that its point may be a *N*-pole. How will you do it?

2. You are doubtful whether a steel rod is neutral, or is slightly magnetized; how could you determine its magnetic condition by trying its action upon a compass-needle?

3. Six magnetized sewing needles are thrust through six pieces of cork, and are then made to float near together on water with their *N*-poles upward. What will be the effect of holding (1) the *S*-pole, (2) the *N*-pole of a magnet above them? Try the experiment.

4. A horse-shoe magnet is placed near a compass-needle so as to pull the needle a little way round. On laying a piece of soft iron across the poles of the horse-shoe magnet, the compass-needle moves back toward its natural position. Explain this.

5. Where on the earth's surface does the *N*-pole of a magnetic needle point in a generally southern direction?

CHAPTER XXXI

THE ELECTRIC CURRENT

233. How to Produce an Electric Current. The modern applications of electricity are so numerous and important that every one is becoming more or less interested in the electric current and the work it may be made to do. Our purpose now is to make ourselves familiar with a method of producing a current that we may study some of its properties and applications.

Take a strip of zinc, say, about 10 cm. long and 3 cm. wide and connect it with a strip of copper of the same size by means of a wire[1] about 50 cm. or more in length. Fill a tumbler about two-thirds full of water acidulated with about one-twelfth the quantity of sulphuric acid. Place the zinc and copper strips in the acidulated water, not allowing them to touch, and stretch the wire connecting them in a north and south direction over a compass needle (Fig. 238). We shall see that the needle tends to turn at right angles to the wire. Similarly, if the wire is placed under the needle it tends also to take the same position but, in doing so, turns in the opposite direction.

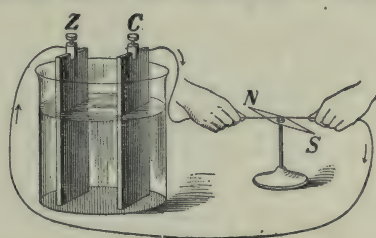

FIG. 238.

The wire evidently possesses new properties when the strips at its terminals are placed in the dilute acid.

The *new properties of the wire* are said to be due to a *current of electricity, which passes through the wire.*

The terms we use in dealing with electric currents are suggested by a study of the flow of liquids in pipes, but we

[1]Copper magnet wire No. 20 will be found most convenient for making ordinary connections.

must not push the analogy between the two cases too far. As to what electricity really is we are in entire ignorance. There may be no actual motion of anything through the conductor, though recent investigations somewhat favour that view, but since the current can do work for us we recognize the presence of energy.

The experiment which we have just performed illustrates the method of producing a current by the *galvanic* or *voltaic cell.* Later, we shall study a more important method of generating a current when we come to study the principle of the dynamo.

234. An Electric Circuit—Explanation of Terms. Immerse the strips in the dilute acid, as in the above experiment, connect a wire to one plate, and, carrying it in a north and south direction over a magnetic needle, bring it near but do not let it touch the other plate.

The needle is not affected.

Now touch the wire to the other plate and the needle is disturbed.

The experiment indicates that a complete circuit is necessary for the flow of the electric current. This circuit comprises the entire path traversed by the current, including the external conductor, the plates, and the fluid between them. The current is regarded as flowing from the copper to the zinc plate *in the external conductor*, and from the zinc to the copper plate *within the fluid* (Fig. 239).

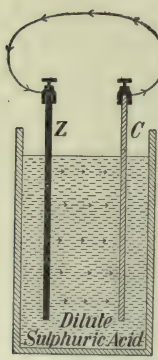

FIG. 239.—Simple voltaic cell.

When the plates are joined by a conductor, or a series of conductors, without a break, the cell is said to be *on a closed circuit*; when the circuit is interrupted at any point, the cell is *on an open circuit.* By joining together a number of cells a more powerful flow of electricity may be obtained, and such a combination is called a *battery.*

That plate of the cell or battery from which the current is led off is called the *positive pole*, the other the *negative pole*. Also, in an interrupted circuit, that end from which the current will flow when the connection is completed is said to be a positive pole or terminal, the other a negative pole or terminal.

235. Chemical Action of a Voltaic Cell. When plates of copper and pure zinc are placed in dilute sulphuric acid to form a voltaic cell, the zinc begins to dissolve in the acid, but the action is soon checked by a coating of hydrogen which gathers on its surface. If the upper ends of the plates are connected by a conducting wire, or are touched together, the zinc continues to dissolve in the acid, forming zinc sulphate, and hydrogen is liberated at the copper plate.

Commercial zinc will dissolve in the acid even when unconnected with another plate. The fact that the impure zinc wastes away in open circuit is possibly explained on the theory that the impurities in it, principally iron and carbon, take the place of the copper plate, and as a consequence currents are set up between the zinc and the impurities in electrical contact with it. Such currents are known as *local currents*, and the action is known as *local action*. This local action is wasteful. It may, to a great extent, be prevented by *amalgamating* the zinc. This is done by washing the plate in dilute sulphuric acid, and then rubbing mercury over its surface. The mercury dissolves the zinc, and forms a clean uniform layer of zinc amalgam about the plate. The zinc now dissolves only when the circuit is closed. As the zinc of the amalgam goes into the solution, the mercury takes up more of the zinc from within and the impurities float out into the liquid. Thus a homogeneous surface remains always exposed to the acid.

236. Detection of an Electric Current. We have seen (§ 233) that when the wire joining the plates of a voltaic cell is brought over a magnetic needle, the needle tends to set itself at right angles to the wire.

A feeble current, flowing in a single wire over a magnetic needle produces but a very slight deflection; but if the wire is wound into a coil, and the current made to pass several times in the same direction, either over or under the needle, or, better still, if it passes in one direction over it and in the opposite direction under it, the effect will be magnified (Fig. 240). Such an arrangement is called a *Galvanoscope.* It may be used not only to detect the presence of currents, but also to compare roughly their strengths, by noting the relative deflections produced.

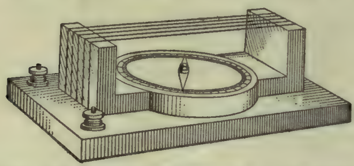

Fig. 240.—Simple galvanoscope. The wire passes several times around the frame, and its ends are joined to the binding-posts.

A more sensitive instrument constructed on the same principle is called a *Galvanometer.*

237. Conductors and Non-Conductors. If a galvanoscope is connected at different times by long fine metallic wires of different metals, the angle of deflection will be found to be different for the different wires; while if certain materials such as cotton or silk thread, wood, glass, etc., be used to make the connection, no deflection is observable.

The results observed are explained *on the theory that bodies differ in their power to conduct electricity, or in the resistance which they offer to the flow of the current.* When a body is a good conductor of electricity, it offers less resistance to the current than a poor conductor of equal cross-section and length, hence a stronger current flows through it, and the needle of the galvanoscope is consequently deflected through a greater angle.

Those substances which readily carry an electric current are called *conductors*, while those which prevent the current from flowing are called *non-conductors* or *insulators.* If a conductor is held on a non-conducting support it is said to be *insulated.* Thus, telegraph and telephone wires are held on glass insulators; and a man who is attending electric street lamps often stands on a stool with glass feet, and handles the lamps with rubber gloves.

GOOD CONDUCTORS : metals.

FAIR CONDUCTORS : the human body, solutions of acids and salts in water, carbon.

POOR CONDUCTORS : dry paper, cotton, wood.

BAD CONDUCTORS, OR GOOD INSULATORS : glass, porcelain, sealing-wax, mica, dry silk, shellac, rubber, resin, and oils generally.

238. Electrolytes. Special attention is directed to the peculiarities of conduction of solutions of acids and salts, included in the above list of fair conductors. They differ from all other conductors in that *they are decomposed when the current passes through them.* Such conductors are known as *electrolytes.*

We have had an illustration of the action of electrolytes in our study of the voltaic cell. The dilute sulphuric acid used in the zinc-copper cell is an electrolyte. As the current passes through it from the zinc to the copper plate (§ 235) it is decomposed and the hydrogen liberated appears at the copper plate.

239. Polarization of a Cell. Connect the plates of a zinc-copper cell with a galvanoscope. The current developed by the cell will be seen gradually to grow weaker. It will also be observed that the weakening in the current is accompanied by the collection of bubbles of hydrogen on the copper plate. To show that there is a connection between the change in the surface of the plate and the weakening in the current, brush away the bubbles and note that the current appears to grow stronger. A cell is said to be *polarized* when the current becomes feeble from the deposition of a film of hydrogen on the plate forming the positive pole, which weakens the current.

Polarization may be reduced by surrounding the positive pole by a chemical agent which will combine with the hydrogen and prevent its appearance on the plate.

240. Varieties of Voltaic Cells. Voltaic cells differ from one another mainly in the remedies adopted to prevent polarization. Several of the forms commonly described have now only historic interest. Of the cells at present used for commercial purposes, the Leclanché, the Dry and the Daniell are among the most important.

241. Leclanché Cell. The construction of the cell is shown in Fig. 241. It consists of a zinc rod immersed in a solution of ammonic chloride in an outer vessel, and a carbon plate surrounded by a mixture of small pieces of carbon and powdered manganese dioxide in an inner porous cup. The zinc dissolves in the ammonic chloride solution, and the hydrogen which appears at the carbon plate is oxidized by the manganese dioxide.

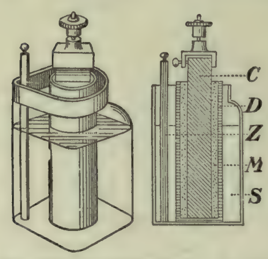

FIG. 241—Leclanché cell. *C*, carbon; *D*, porous cup; *Z*, zinc; *M*, carbon and powdered manganese; *S*, solution of ammonic chloride.

As this process goes on very slowly, the cell soon becomes polarized, but it recovers itself when allowed to stand for a few minutes. If used intermittently for a minute or two at a time, the cell does not require renewing for months. For this reason it is especially adapted for use on electric bell and telephone circuits.

242. The Dry Cell. The so-called *dry* cell is a modified form of the Leclanché cell. The carbon plate C (Fig. 242) is closely surrounded by a thick paste, A, composed chiefly of powdered carbon, manganese dioxide and ammonic chloride. This is all contained in a cylindrical zinc vessel, Z, which acts as the negative pole of the cell. Melted pitch, P, is poured on top in order to prevent evaporation, *i.e.*, to prevent the cell from becoming really *dry*. This cell is largely used for ignition purposes with gas and gasoline engines.

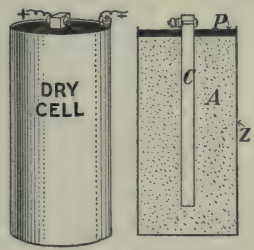

FIG. 242—Dry cell.

243. Daniell Cell. The Daniell cell consists of a copper plate immersed in a concentrated solution of copper sulphate contained in an outer vessel and a zinc plate immersed in a zinc sulphate solution in an inner porous cup (Fig. 243).

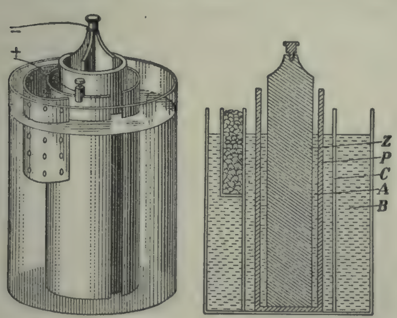

FIG. 243.—Daniell cell. *Z*, zinc; *P*, porous cup; *C*, copper; *A*, solution of zinc sulphate; *B*, solution of copper sulphate.

In a form of the Daniell cell known as the Gravity Cell the porous cup is dispensed with and the solutions are separated by gravity (Fig. 243). The zinc plate, which is usually of the form shown in the figure, is supported near the top of the vessel and the copper plate is placed at the bottom. The copper sulphate being denser than the zinc sulphate, sinks to the bottom, while the zinc sulphate floats above about the zinc plate. The copper sulphate solution is kept concentrated by placing crystals of the salt in a basket in the outer vessel (Fig. 243), or at the bottom about the copper plate (Fig. 244).

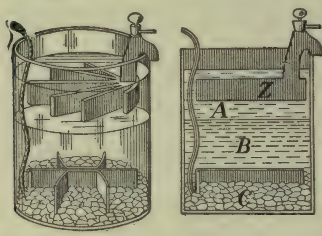

Fig. 244.—Gravity cell. *Z*, zinc plate; *A*, zinc sulphate solution; *B*, copper sulphate solution; *C*, crystals of copper sulphate.

The Daniell cell is capable of giving a continuous current for an indefinite period if the materials are renewed at regular intervals; but the strength of the current is never very great because the internal resistance is high.

These cells are adapted for closed circuit work, when a comparatively weak current will suffice. The gravity type has been extensively used on telegraph lines, but in the larger installations the dynamo and the storage battery plants are now taking their place.

CHAPTER XXXII

Chemical Effects of the Electric Current

244. Electrolysis. In the preceding chapter we have discussed the production of an electric current through the action of an electrolyte on two dissimilar plates. If the action is reversed and a current from some external source is passed through an electrolyte, re-actions similar to those within the voltaic cell take place. As an illustration take the action of an electric current on hydrochloric acid. Connect the poles of a voltaic battery consisting of three or four cells to two carbon rods A and B (Fig. 245), and immerse these in the acid. The current flows in the direction indicated by the arrows, and the rod A by which it enters the electrolytic cell is called the *anode*, the rod B by which it leaves is called the *cathode*. A and B are spoken of as *electrodes*. Gases will collect at the electrodes. On testing, that liberated at A will be found to be chlorine, and that at B, hydrogen. This process of decomposition by the electric current is called *electrolysis* (*i.e., electric analysis*).

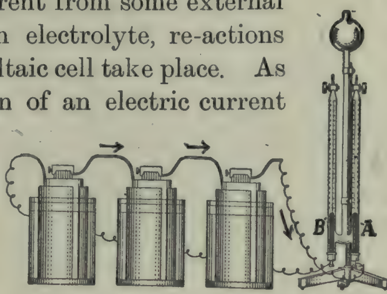

FIG. 245.—Electrolysis of hydrochloric acid. The electrodes A and B are carbon rods fitted in rubber stoppers.

245. Electrolysis of Water. Insert platinum electrodes into the bottom of a vessel of the form shown in Fig. 246. Partially fill the vessel with water acidulated with a few drops of sulphuric acid. Fill two test-tubes with acidulated water and invert them over the electrodes. Connect the electrodes with a battery of three or four voltic cells. Gases will be seen to bubble up from the electrodes, displacing the water in the test-tubes.

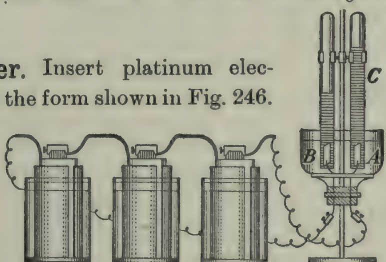

FIG. 246.—Electrolysis of water.

On testing each gas with a lighted splinter, that collected at the anode will be found to be oxygen, and that at the cathode, hydrogen. It will also be observed that the volume of the hydrogen collected is twice that of the oxygen.

246. Electrolysis of Salts. Connect by means of two copper wires the poles of a battery with two platinum strips and dip them into a solution of copper sulphate. After two or three minutes remove them and observe the strips.

The strip made the cathode will be found to be covered with a deposit of copper. Now without removing the deposit, place the strips again in the solution and then reverse the direction of the current by changing the wires at the poles of the battery.

The bright strip (the cathode) will now be covered with copper while the copper on the other strip will have disappeared. In other words copper would appear to have been carried from one strip to the other.

Exercise.—Weigh two strips of copper, attach them respectively to the poles of a voltaic cell, and, without allowing them to touch, dip them into a solution of copper sulphate.

The gain in weight of the cathode equals the loss in weight of the anode.

247. Electroplating. Advantage is taken of the deposition of a metal from a salt by electrolysis in order to cover one metal with a layer of another, the process being known as *electroplating*.

The metallic object to be plated is connected by a conductor with the negative pole of a battery or dynamo, and immersed in a bath containing a solution of a salt of the metal with which it is to be plated. A plate of this metal is also immersed in the bath and is connected by a conductor with the positive pole of the battery or dynamo; that is, the object to be plated is made the cathode, the metal with which it is to be plated is made the anode, and the electrolyte is a salt of this metal. (Fig. 247). When the current passes through the solution from the plate to the object, the salt is decomposed and the metal is deposited on the object; at the same time a part of the metal of the plate made the anode enters the solution, the strength of which accordingly remains constant. The metal is thus transferred from the plate to the object as in the experiment in the preceding section.

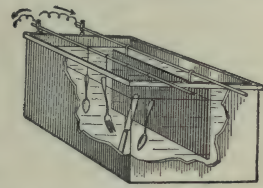

FIG. 247—Bath and electrical connection for electroplating.

Exercise.—Plate a piece of bright iron with copper, using copper sulphate as the solution and a plate of copper as the anode.

CHAPTER XXXIII

Magnetic Effects of the Current

248. Electromagnets. We have already learned (§ 233) that an electric current deflects a magnetic needle. It has, therefore, apparently the power of producing magnetic effects. Let us investigate this subject.

Make a helix, or coil of wire, about three inches long, by winding insulated copper wire (No. 16 or 18) about a lead-pencil. Connect the ends of the wire with the poles of a voltaic cell, and move a compass-needle about the coil.

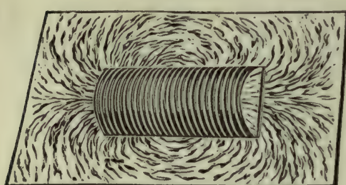

Fig. 248.—A helix carrying a current behaves like a bar-magnet.

Next, make a helix somewhat larger in diameter, say about three-quarters of an inch, and place it in a rectangular opening made in a sheet of cardboard (Fig. 248). This can be done by cutting out two sides and an end of a rectangle of the proper size and then passing the free end of the strip lengthwise through the helix, and replacing the strip in position. Sprinkle iron filings from a muslin bag on the cardboard around the helix and within it. Attach the ends of the wire to the poles of a battery and gently tap the cardboard.

In each experiment we find that the helix through which the current is passing behaves exactly like a magnet, having N and S poles and a neutral equatorial region. The field, as shown by the action of the needle and the iron filings, resembles that of a bar-magnet. (Compare § 222.)

Fig. 249.—The essential parts of an electromagnet.

Now introduce a core of soft-iron into such a coil (Fig. 249). The magnetic effect is increased. Next, open the circuit and test the magnetic power of the core. It has lost its magnetism. The combination of the helix of insulated wire and a soft-iron core is called an *Electromagnet*.

249. Why an Electromagnet is More Powerful than a Helix Without a Core. When the iron core is inserted into the coil a greater number of lines of force pass from end to end through it, because the permeability of iron is very much greater than that of air. The effect of the core, therefore, is to increase the number of lines of force which are concentrated at the poles, and consequently to increase the power of the magnet.

The strength of the magnet may be still further increased by bringing the poles close together so that the lines of force may pass within iron throughout their whole course. This is done either by bending the core into horse-shoe form, as shown in Fig. 250, or by joining two magnets by a 'yoke' as shown in Fig. 251. The lines of force thus pass from one pole to the other through the iron body held against them.

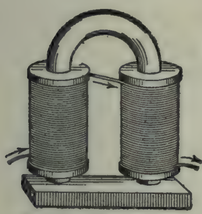

FIG. 250.—An electromagnet—horse-shoe form.

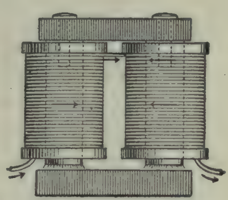

FIG. 251.—An electromagnet—yoke form.

Exercise.—Make an electromagnet by winding several courses of double covered magnet wire about a rod of soft iron one-half an inch in diameter and three inches long. Try the power of the magnet by connecting it with a battery and using it to lift pieces of soft iron.

250. Practical Applications of the Magnetic Effects of the Current. Electromagnets are used for a great variety of practical purposes. The following sections contain descriptions of some of the more common applications.

251. The Electric Telegraph. The electric telegraph in its simplest form is an electromagnet operated at a distance by a battery and connecting wires. The circuit is opened and closed by a *key*. The electromagnet, fitted to give signals, is called a *sounder*. When the current in the circuit is not sufficiently strong, on account of the resistance of the line, to work a sounder, a more sensitive electromagnet called a *relay* is introduced which closes a local circuit containing a battery directly connected with the sounder.

252. The Telegraph Key. The key is an instrument for closing and breaking the circuit. Fig. 252 shows its construction. Two platinum contact points, P, are connected with the binding posts A and B, the lower one being connected by the bolt C which is insulated from the frame, and the upper one being mounted on the lever L which is connected with the binding post B by means of the frame. The key is placed in the circuit by connecting the ends of the wire to the binding posts.

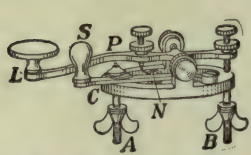

FIG. 252.—Telegraph key.

When the lever is pressed down, the platinum points are brought into contact and the circuit is completed. When the lever is not depressed, a spring N keeps the points apart. A switch S is used to connect the binding posts, and close the circuit when the instrument is not in use.

253. The Telegraph Sounder. Fig. 253 shows the construction of the sounder. It consists of an electromagnet, E, above the poles of which is a soft-iron armature A, mounted on a pivoted beam B. The beam is raised and the armature held by a spring S, above the poles of the magnet at a distance regulated by the screws C and D. The ends of the wire of the magnet are connected with the binding posts.

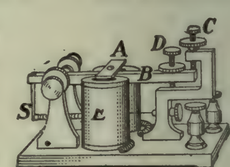

FIG. 253—Telegraph sounder.

254. The Telegraph Relay. The relay is an instrument for closing automatically a local circuit in an office, when the current in the main circuit, on account of the great resistance of the line, is too weak to work the sounder. It is a key worked by an electromagnet instead of by hand. Fig. 254 shows its construction. It consists of an electromagnet R, in front of the poles of which is a pivoted lever L carrying a soft-iron armature, which is held a little distance from the poles by the spring S. Platinum contact points, P, are connected with the lever L and the screw C. The ends of the wire of the electromagnet are connected with the binding posts B, B, and the lever L and the screw C are electrically connected with the binding posts B_1, B_1.

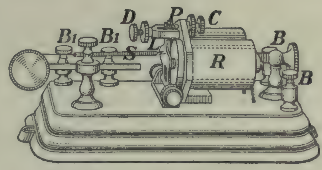

FIG. 254.—Telegraph relay.

Whenever the magnet R is magnetized the armature is drawn toward the poles and the contact points P are brought together and the local circuit completed.

255. Connection of Instruments in a Telegraph System. Fig. 255 shows a telegraph line passing through three offices

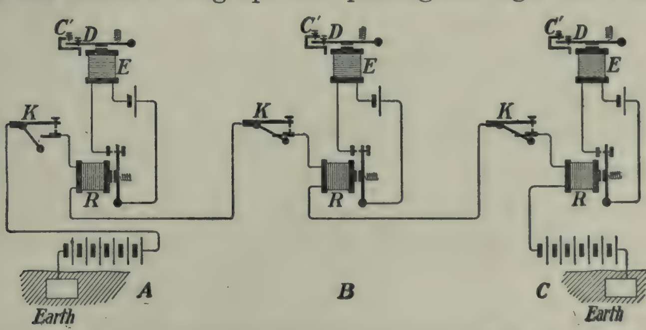

FIG. 255.—Connection of instruments in a telegraph circuit.

A, B, and C, and indicates how the connections are made in each office.

When the line is not in use the switch on each key K is closed and the current in the main circuit flows from the positive pole of the main battery at A, across the switches of the keys, and through the electromagnets of the relays, to the negative pole of the main battery at C, and thence through the battery to the ground, which forms the return circuit, to the negative pole of the main battery at A. The magnets R, R, R, are magnetized, the local circuits completed by the relays, and the current from each local battery flows through the magnet E of the sounder.

When the line is being used by an operator in any office A, the switch of his key is opened. The circuit is thus broken and the armature of the relay and of the sounder in each of the offices is released.

When the operator depresses the key and completes the main circuit, the armature of the relay in each office is drawn in, and the local circuit is completed. The screw D of each sounder is then drawn down against the frame, producing a 'click.' When he breaks the circuit at the key, the local circuit is again opened and the beam of each sounder is drawn up by the spring against the screw C', producing another 'click' of different sound. If the circuit is completed and broken quickly by the operator, the two 'clicks' are very close together, and a "dot" is formed; but if an interval intervenes between the 'clicks' the effect is called a "dash." Different combinations of dots and dashes form different letters. The transmitting operator at A is thus able to make himself understood by the receiving operator at B or C.

Exercise.—Connect a set of telegraph instruments with main and local batteries and study the action of the instruments when the circuit is closed and opened.

256. The Electric Bell. Electric bells are of various kinds. Fig. 256 shows the construction of one of the most common forms. It consists of an electromagnet M, M, E, in front of the poles of which is supported an armature A by a spring S. At the end of the armature is attached a hammer H, placed in such a position that it will strike a bell B when the armature is drawn to the poles of the magnet. A current breaker, consisting of a platinum-tipped spring D, attached to the armature, is placed in the circuit as shown in the figure.

When the circuit is completed by a push-button P, the current from the battery passes from the screw C to spring D and through the electromagnet to the battery. The armature is drawn in and the bell struck by the hammer; but by the movement of the armature the spring D is separated from the screw C, and the circuit is broken at this point. The magnet then releases the armature, the spring S causes the hammer to fall back into its original position and the circuit is again completed. The action goes on as before and a continuous ringing is thus kept up.

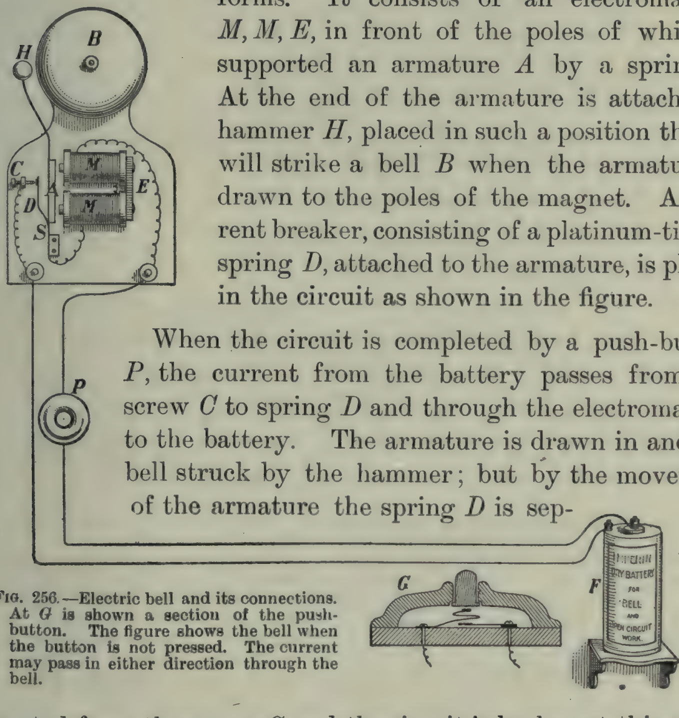

Fig. 256.—Electric bell and its connections. At G is shown a section of the push-button. The figure shows the bell when the button is not pressed. The current may pass in either direction through the bell.

Exercise.—Connect an electric bell in a circuit with a battery and push button. Trace the connection in the circuit and study the action of the bell when the circuit is closed.

257. Telephone. Arrange apparatus as shown in Fig. 257. The iron rod has a coil of fine insulated wire wound around one end of it, and in front of this end is suspended a small soft-iron disc. A battery is placed in the circuit with the coil, and the circuit is completed by attaching the wires to two small metal plates separated by a small wedge-shaped piece of graphite or stove polish. Place the finger on the upper plate, and press upon it with different degrees of force.

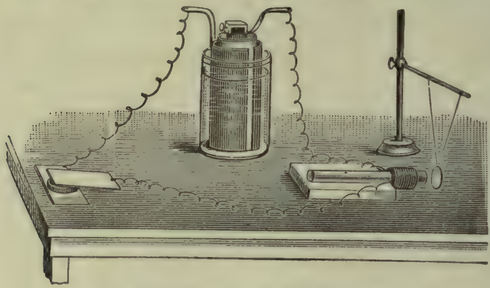

Fig. 257.—Principle of the Telephone.

The disc is seen to move to and fro. The movement is caused by the varying strength of the current in the circuit. When the pressure is increased at the graphite, the resistance is lessened and the current grows stronger and the electromagnet draws the disc forward. When the pressure is lessened the current becomes weaker and the disc falls back.

This experiment illustrates roughly the principle of action of the telephone. The loose connection with varying resistance is the essential part of the *transmitter*, and the electromagnet the essential part of the *receiver*.

The *transmitter* now in common use is illustrated in Fig. 258.

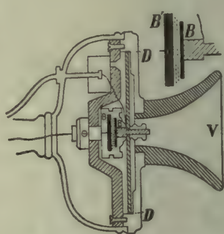

Fig. 258.—The microphone transmitter used in the Bell system.

At the back of the mouthpiece is a metallic diaphragm *D*, *B* is a carbon button attached to the diaphragm, and *B*′ another carbon button attached to the frame of the instrument, opposite to *B*. The space between the carbon buttons is loosely packed with coarse granulated carbon. (See upper small figure.) The electrical connections are made at *B* and *B*′.

The *receiver* has an iron diaphram C, supported in front of one end of a permanent bar-magnet A, about which is wound a coil of fine insulated wire B, as shown in Fig. 259.

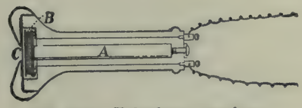

FIG. 259.—Telephone receiver.

A magnet of the horse-shoe type is now usually employed in the receivers of the Bell system (Fig. 259).

The transmitter and receiver may be connected as shown in Fig. 260. In actual practice transformers are connected in the circuit to modify the battery current, but the omission of these instruments in no way affects the explanation of the principle of action of the essential instruments. This action may be described as follows:

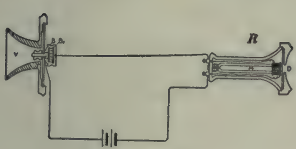

FIG. 260.

Sound-waves cause the diaphragm of the transmitter to vibrate. When it moves forward, the pressure upon the granular carbon is increased, and the resistance at this part of the circuit is decreased. The strength of the current passing through the coil of the receiver is consequently increased, and, as a result, the diaphragm of the receiver is drawn inward. When the diaphragm of the transmitter moves backward, the pressure upon the granular carbon is decreased, the resistance is, therefore, increased, and the current in the circuit decreased. Through the decrease in current the magnet in the receiver loses some of its power, and the diaphragm in front of it springs backward.

Hence the vibrations of the diaphragm of the transmitter are accompanied by similar vibrations of the diaphragm of the receiver, which will reproduce the sound-waves which caused the diaphragm of the transmitter to vibrate.

CHAPTER XXXIV

Induced Currents—The Dynamo and the Motor.

258. Production of Induced Currents. Let us take a coil of very fine insulated wire wound on a hollow spool of the form shown in Fig. 261 and connect the ends of the wire to a sensitive galvanometer. Thrust the pole of a bar-magnet into it and then withdraw it; slip the coil over one pole of a horseshoe magnet into it and then remove it. In both cases the galvanometer indicates a current, in one direction when the pole passes within the coil, and in the opposite direction when it is withdrawn, but in each case *the current lasts only while the magnet and coil are in motion relative to each other.*

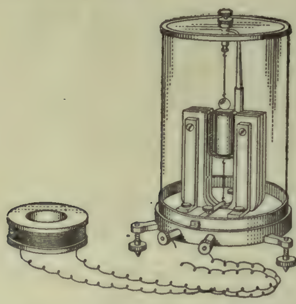

Fig. 261.—Apparatus for showing that when a magnet is thrust into or withdrawn from a closed coil a current is induced in the coil.

If the coil used in the preceding experiments is slipped over the pole of an electromagnet connected with a battery as shown in Fig. 262 and then withdrawn, effects similar to those observed in the case of the permanent magnet will be seen.

Again, if the coil is slipped over the electromagnet and placed in a central position between its poles it will be found that whenever the battery circuit is closed or opened, a current is produced in the galvanometer circuit, and that the needle is deflected in one direction on closing the circuit, in the opposite on opening it, but that in this case, as in previous experiments, the current in the galvanometer circuit is only momentary.

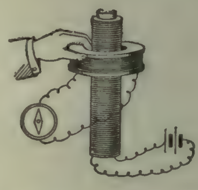

Fig. 262.—Currents induced in a closed coil by moving it in the field of an electromagnet.

These experiments all tend to show that *whenever, from any cause, the number of magnetic lines of force passing through a closed circuit is changed (increased or decreased) an electric current is produced in that circuit.*

Such a current is known as an *induced current.*

The experiments also show that an increase in the number of lines of force passing through a closed circuit causes an induced current to flow in one direction through the circuit, while a decrease in the number passing in the same direction through the circuit causes a current to flow in the opposite direction.

259. The Principle of the Dynamo. The preceding experiments on the production of induced currents have been introduced mainly to help us to understand the principle of the dynamo. In its simplest form, a dynamo is a coil of wire rotated about an axis in a magnetic field. The principle may be illustrated by connecting to the galvanometer the coil used in the experiments on current induction and rotating it about a vertical axis between the poles of a horse-shoe magnet. Continuous rotation in one direction is prevented by the twisting of the connecting wires about each other. In a working dynamo this difficulty is overcome by joining the ends of the wires to rings, from which the current is taken by brushes bearing upon them. A study of Figs. 263 and 264 will show how the current is generated in the coil and how it is made to flow from brush to brush through the external conductor.

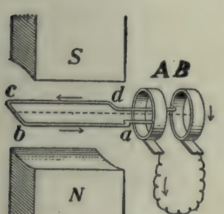

FIG. 263.—Principle of the dynamo.

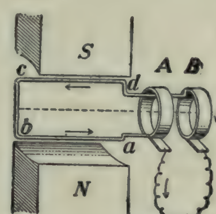

FIG. 264.—Principle of the dynamo.

Let *abcd* be a coil of wire, having one end attached to the ring A and the other to the ring B; and suppose the coil to rotate about a horizontal axis between the poles N and S.

Now the maximum number of lines of force pass through the coil when it is in the position shown in Fig. 263 and the minimum number when it is in the position shown in Fig. 264.

As the coil is rotated the number of lines of force is constantly changing. Hence an induced current will flow from the ring A through the coil $abcd$ and the internal circuit to the ring B at one instant followed by an induced current in opposite direction from B to A at the next instant, the changes in direction taking place in accordance with the changes in direction and number of the lines of force passing through the coil. Thus a current which changes direction at regular intervals is produced in the external conductor. Such is known as an *alternating current.*

260. The Armature of the Dynamo. We have, for simplicity, considered in the preceding section the case of the revolution of a single coil within the magnetic field. In ordinary practice a number of coils are connected to the same collecting rings or plates. These coils are wound about a soft-iron core, which serves to hold them in place and to increase the number of lines of force passing through the space inclosed by them. The coils and core with the attached connections constitute the *armature* of the dynamo.

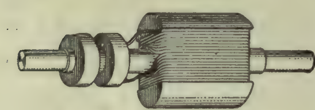

FIG. 265.—Shuttle armature.

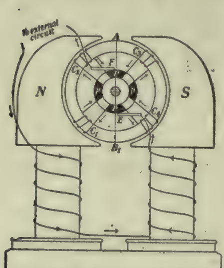

FIG. 266.—Bipolar field.

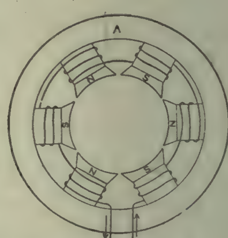

FIG. 267.—Multipolar field.

The armatures vary in type with the form of the core and the winding of the coils. A single coil wound in a groove about a soft-iron cylinder (Fig. 265) forms a *shuttle* armature.

261. Field-Magnets. In small generators, used to develop high tension currents, permanent magnets are sometimes used to supply the fields. The machine is then called a *magneto.* In all ordinary dynamos the field is furnished by electromagnets known technically as *field-magnets.* These magnets are either bipolar (Fig. 266) or multipolar (Fig. 267). In the multipolar type two or more pairs of poles are arranged in a ring about a circular yoke A.

262. Production of a Direct Current—The Commutator. When an electric current flows continuously in one direction it is said to be a *direct* current. The current in an armature coil changes direction, as we have seen, at regular periods. To produce a direct current with a dynamo it is necessary to provide a device for commuting the alternating into a direct current. This is done by means of a *commutator.* It consists of a collecting ring made of segments called *commutator plates,* or *bars,* insulated from one another. The terminals of the coils are connected in order with the successive plates of the ring. Take, for example, the case of a single coil revolved in a bipolar field, as considered in § 257. The commutator consists of two semi-circular plates, (Figs. 268 and 269), and the brushes are so placed that they rest upon the insulating material between the plates at the instant the current is changing direction in the coil. Then since the commutator plates change position every time the current changes direction in the coil, the current always flows in the same direction from brush to brush in the external circuit.

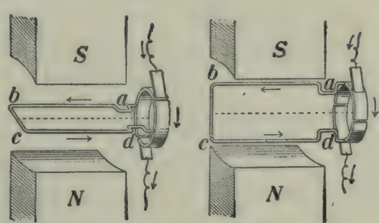

FIG. 268. FIG. 269.

Arrangements for transforming the alternating current in the armature into a direct-current in the external circuit.

263. Excitation of Fields in a Dynamo. In the alternating-current dynamo the electromagnets which form the fields are sometimes excited by a small direct-current dynamo belted to the shaft of the machine; in the direct-current dynamo the fields are magnetized by a current taken from the dynamo itself. When the *full* current generated in the armature (Fig. 270) passes through the field-magnets, which are wound with coarse wire, the dynamo is said to be *series-wound.* A dynamo of this class is used when a constant current is required, as in arc lighting. When the fields are energized by a small fraction of the current, which passes directly from brush to brush through many turns of fine wire in the field coils, while the main current does the work in the external circuit (Fig. 271) the dynamo is *shunt-wound.* This type is used where the output of current required is continually changing, as in incandescent lighting, power distributing, etc. The regulation is accomplished by suitable resistance placed in the shunt circuit to vary the amount of the exciting current.

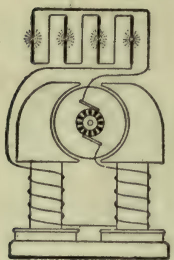

FIG. 270.—Series-wound dynamo.

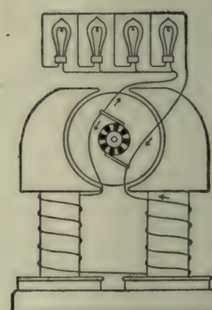

FIG. 271.—Shunt-wound dynamo.

The field-magnets, of course, lose their strength when the current ceases to flow, but the cores contain sufficient residual magnetism to cause the machine to develop sufficient current to "pick up" on the start.

264. The Electric Motor. The purpose of the electric motor is to transform the energy of the electric current into mechanical motion. Its construction is similar to that of the dynamo. In fact, any direct-current dynamo may be used as a motor.

The current supplied to the motor divides, part flows through the field-magnet coils and part enters the armature coils by one of the brushes and leaves it by the other.

Both the field-magnet and the armature cores are thus magnetized, the field-magnet becoming a stationary electro-magnet and the armature a rotary one.

The mutual attractions and repulsions between the poles of the armature and of the field-magnet cause the armature to revolve.

Exercise.—Procure a simple form of direct-current dynamo (with shuttle armature, if possible). Trace the electrical circuits in the armature, and field. Rotate the armature and test with a galvanoscope or electric bell the current generated by it. Now connect the dynamo with a battery and study the action as a motor.

CHAPTER XXXV

Heating and Lighting Effects of the Electric Current

265. Heat Developed by an Electric Current. In discussing the sources of heat (§ 129) we suggested an experiment to show that an electric current may be used to develop heat. The experiment illustrates a general principle. Whenever an electric current meets with resistance in a conductor, heat results. Now, as no body is a perfect conductor of electricity, a certain amount of the energy of the electric current is always transformed into heat energy.

266. Practical Applications. The heat produced by the electric current is applied in many useful ways. We have already referred to electric heaters and cookers (§ 129). Resistance wires and other forms of partial conductors heated by an electric current are used for various purposes, such as performing surgical operations, igniting fuses, heating furnaces, etc. In electric toasters and flat-irons the resistance wire is an alloy of nickel and chromium. This can be kept at red heat for weeks without injury, whereas an iron wire would soon deteriorate.

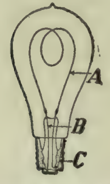

Fig. 272.—The incandescent lamp. *A*, carbon filament; *B*, conducting wires fused in glass; *C*, brass base to which one wire is soldered.

Rods of metal are welded by pressing them together with sufficient force while a strong current of electricity is passed through them. Heat is developed at the point of junction, where the resistance is the greatest, and the metals are softened and become welded together. But the most important application of the heating effects of the electric current is to be found in electric lighting.

267. Incandescent Lamp. The construction of the incandescent lamp in common use is shown in Fig. 272. A carbon filament, made by carbonizing a thread of bamboo or cotton fibre at a very high temperature, is attached to conducting wires and inclosed in a pear-shaped globe; from which the air is then exhausted. The conducting wires where they are fused into the glass are of platinum. When a sufficiently strong current is passed through the carbon filament, which has a high resistance, it is heated to incandescence and yields a bright steady light. The carbon is infusible, and does not burn for lack of oxygen to unite with it. Lamps in which the filament is a fine wire of the metal tungsten are becoming common.

268. Arc lamp. Sharpen two small carbon pencils and connect them by means of copper wires to the poles of a battery of several cells, close the circuit by bringing the points of the carbons together loosely. You will notice a bright point of light at the tips of the pencils.

This experiment illustrates in a feeble way the principle of the *arc light.*

FIG. 273.—The arc light.

When two carbon rods, or pencils, are connected by conductors with the poles of a sufficiently powerful battery or dynamo, touched together, and then separated a short distance, the current continues to flow across the gap, developing intense heat and raising the terminals to incandescence, thus producing a powerful light (Fig. 273).

The arc lamp is provided with a regulator, by which the carbons are kept at a constant distance apart.

ANSWERS TO NUMERICAL PROBLEMS

Page 4. 1. 2,500,000 mm. 2. 299,804.97 km. 3. 32,400,000 sq. cm. 4. 29,921 in. 5. 1 cu. m. = 1,000 l. = 1,000,000 c.c. 6. 183.49 m. 7. 65.4 cents. 8. 9,697.5 kg. 9. The former. 10. 1,118.8 ft. (nearly). 11. 4.79 mm.

Page 12. 1. 1.47 kg. 2. 54.05 c.c. 3. 519.75. 4. 2.7 grams per c.c. 5. 12 kg. 6. 0.77 gm. per c.c. 7. (*a*) 7.29 ; (*b*) 6.61 tons. 8. 283.5, 0.5, 1.9, 7.1, 14.3 grams ; 1,814.4, 453.6, 141.7, 14.2, 85.0, 28.3 grams. (Correct to first decimal place ; accurate enough for photography).

Page 15. 1. $32\frac{5}{11}$ miles per hr. 2. $2{,}898\frac{7}{18}$ miles. 3. 88 ft. per sec. 4. 108 km. per hr. 5. 11 miles per day. 6. 1 mile per day.

Page 17. 1. 24 ft. per sec.; 12 sec. 2. 1,960, 7,840, 19,600 cm. per sec. 3. 10 sec. 4. 28 ft. per sec. upwards, 4 ft. per sec. downwards, 36 ft. per sec. downwards ; $3\frac{3}{4}$ sec. 5. $-\frac{1}{12}$ ft. per sec. per sec.

Page 19. 1. 112 ft. per sec.; 196 ft. 2. 66 ft. per sec.; $2\frac{1}{16}$ sec.; $68\frac{1}{16}$ ft. 3. 225 sec.; $8{,}437\frac{1}{2}$ ft. 4. 16, 64, 144, 256, 400 ft.; 16, 48, 80, 112, 144 ft.

Page 20. 1. 4 ft. per sec. 2. 1,000 cm. per sec. 3. 192 ft. or 58.8 m. per sec.; 576 ft. or 176.4 m. 4. 190 cm. per sec. 5. 128 ft. per sec. 6. 7.82 sec.; 4.37 sec. (approx.). 7. 864 ft.; 36 sec. 8. $\frac{1}{2}$ ft. per sec. per sec.

Page 22. 1. Man's = $\frac{10}{9}$ times boy's. 2. Car's = $\frac{125}{8}$ times cannon-ball's. 3. Pebble's = $\frac{8}{25}$ of weight's.

Page 24. $2\frac{2}{3}$ ft. per sec.

Page 26. 2. 11.73 (nearly) ft. per sec. 3. 60 ft. per sec.

Page 30. 1. Doubled ; yes. 2. $44\frac{4}{9}$, 25, 16 kg.

Page 32. 1. 1,000 gram-metres or 1 kilogram-metre. 2. 1,800 ft.-pds. 3. 50,000 ft.-pds. 4. $\frac{1}{25}$ kg.-m. 5. 150,000 ft.-pds. 6. 528,000 ft.-pds.

Page 35. 1. $12\frac{4}{33}$ h.-p. 2. $\frac{4}{275}$ h.-p. 3. 53.6 (nearly) h.-p.

Page 40. 5. 5 ft.

Page 44. 1. 9 ; 450 pds. 2. 15 oz. 3. $37\frac{1}{2}$ pds.

Page 45. 1. 56 pds. 2. 160 pds.

Page 48. 1. $1\frac{1}{4}$ pds. 2. 90 pds., 120 pds. 3. 225 pds.

Page 59. 1. $312\frac{1}{2}$ g. 2. 800 kg. 3. 11,550 pds. 4. 10,000. 5. 36 kg.

Page 62. 1. 62.3 pds.; 97.7 pds. 2. 4.57 pds. 3. 2.5 kg. 4. 4.9 g. 5. 600 g. 6. $\frac{1}{4}$.

Page 66. 1. $\frac{1}{3}$ g. per c.c. 2. $\frac{1}{4}$ g. per c.c. 3. 1.2 g. per c.c. 4. $\frac{2}{3}$ g. per c.c.

Page 69. 6. 1,291 g.

Page 77. 2. 10 cu. ft. 3. 22.85 l. 4. $483\frac{1}{3}$ in. of mercury. 5. $562\frac{1}{2}$ mm. 6. 174 in. of mercury. 7. $3.60.

Page 99. 1. 335, 338, 356 m. per sec. 2. 5,595 ft. 6. 1,678.5 ft. 7. 4,707.4 ft. per sec.

Page 104. 2. 600. 4. $32\frac{5}{8}$, $65\frac{1}{4}$, $130\frac{1}{2}$, 261, 522; 1,044, 2,088, 4,176.

Page 124. 1. 9, 32.4, 48.6, 117. 2. $11\frac{1}{9}$, 15, 20, $52\frac{7}{9}$. 3. 117. 4. $15\frac{5}{9}$. 5. $-17\frac{7}{9}°$, $-12\frac{2}{9}°$, 0°, $7\frac{2}{9}°$, $37\frac{7}{9}°$, $-31\frac{2}{3}°$, $-40°$. 6. 50°, 68°, 89.6°, 167°, $-4°$, $-40°$, $-459.4°$.

Page 127. 2. 28.55 l. 3. 113 c.c. (nearly). 4. 107.6, 107.2, 102.9 c.c. (nearly). 5. 620 c.c.; 310 c.c.

Page 129. 1. 1,625 cal. 2. 3,000 cal. 3. 23° C. 4. 10 Cent. deg. 5. $66\frac{1}{2}°$ C. 6. 10,320. 7. 252.

Page 133. 1. 900 cal. 2. 8,100 cal. 3. 38,688 cal. 4. The water. 5. 0.95 (nearly). 6. 0.69. 7. 0.03 (approx.).

Page 139. 6. 2,800 cal. 7. 1,200,000 cal. 8. $59\frac{1}{11}°$ C.

Page 144. 4. 19,832 cal. 5. 182,240 cal. 6. 27,945 cal. 7. 230,680 cal.

Page 165. 1. 2.4 inches.

Page 170. 2. 60°. 4. 60°.

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