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ECLECTIC EDUCATIONAL SERIES.

THE
ELEMENTS OF PHYSICS

A TEXT-BOOK FOR

ACADEMIES AND COMMON SCHOOLS

BY

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PREFACE.

This volume has been prepared, at the request of many teachers, for the use of pupils in academies and common schools. The topics considered have been selected with reference both to the average age of such pupils and to the time usually allotted to the study of Physics.

The object of this book is not merely to give a systematic and symmetrical epitome of the Science, but so to present each topic that the pupil shall receive, from the first, clear, accurate, and scientific ideas. In no other way can the study of any science be made a means of mental discipline. No pains have been spared to attain this result; and it is hoped that, however much has been omitted that many teachers would desire to have presented, the pupil will, at least, have nothing to unlearn.

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THE

ELEMENTS OF PHYSICS.

CHAPTER I.

GENERAL NOTIONS OF MATTER AND FORCE.

1. Matter is any thing that is capable of affecting our senses. The objects that surround us, the food we eat, the water we drink, the air we breathe, are different forms of matter.

2. A body is any separate portion of matter, whether large or small: thus a mountain, a pebble, or a dew-drop, is a body. The different materials of which bodies are composed are called *substances:* thus iron, wood, and sugar are substances.

3. Some substances contain but one kind of matter. These are called *simple substances*, or the ELEMENTS. There are sixty-three elements now known. The most abundant of these are oxygen, silicon, aluminium, iron, calcium, magnesium, sodium, potassium, nitrogen, hydrogen, and carbon.

4. Compound substances are composed of at least two elements, so firmly united that they can not be separated except by chemical processes. These compound substances make up the bulk of the globe: thus water is composed of oxygen and hydrogen; quartz and white sand, of silicon and oxygen; clay, mainly of silicon, oxygen, and aluminium.

5. **Many bodies are mixtures** of several substances: thus gunpowder is a mixture of niter, carbon, and sulphur. The air is also a mixture. The most important of its constituents are oxygen, nitrogen, carbonic acid, and the vapor of water.

6. **Many substances can exist** at different times in three different states: thus water can exist as ice, as water, or as steam.

A body is in the *solid state* when its particles are held firmly together, and retain the shape that has been given them by nature or art. Ice, wood, and tallow are solids.

A body is in the *liquid state* when its particles easily change their relative positions. When a liquid is poured into an open vessel, it adapts itself to the shape of the vessel, except that its upper surface is horizontal. Water, alcohol, and oil are liquids.

A body is in the *aëriform state* when its particles tend to separate from each other, and to occupy a greater volume. Bodies in this state are called *aëriform bodies*, *gases*, or *vapors*. Aëriform bodies can not be retained in an open vessel; and when shut in on all sides, completely fill the vessel in which they are placed. Steam, the air, and illuminating gas are aëriform bodies.

The term *fluid* is applied both to liquids and aëriform bodies: thus we may speak of water as a liquid or as a fluid; or of air as an aëriform body or as fluid.

7. **No one can conceive** of a body which does not possess length, breadth, and thickness. Even the fine particles of dust which are seen only in the path of the sunbeam must have a certain shape or figure, and occupy a certain amount of space. The amount of space that a body occupies is called its *bulk* or *volume*.

The ordinary measures in the United States are derived from an arbitrary unit called the yard; although we may use any one of its divisions or multiples as a unit—as the inch, foot, or mile. The square inch, square yard, etc., are units of surface. The cubic inch, cubic foot, etc., are units of volume.

The wine gallon of the United States contains 231 cubic inches. The imperial gallon of England contains 277.274 cubic inches.

The French unit of length is the metre, which is equal to 39.3685 of our inches. All the French measures increase or decrease in decimal proportion. For the increase the Greek prefixes deca (10), hecto (100), and kilo (1000), are used; for the decrease the Latin prefixes deci ($\frac{1}{10}$), centi ($\frac{1}{100}$), and milli ($\frac{1}{1000}$), are used. A decimetre is drawn in Figure 1, in comparison with a scale of inches. One inch is very nearly 25.4 millimetres.

The French unit of volume is a cubic decimetre, and is called the litre. It contains 61.022 cubic inches, or 2.113 wine pints.

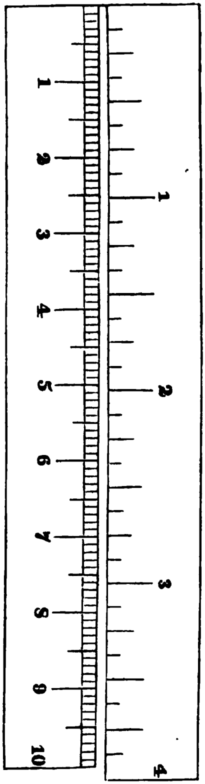

FIG. 1.

8. All bodies may be divided into very minute particles: thus stones may be crushed to powder; the hardest steel may be broken; and even the diamond may be reduced to dust. Wonderful examples of minute divisibility are afforded by odors and coloring matters. Odors can be caused only by particles of matter in the air; and yet how small must those be that enable a hound to follow his game! A grain of musk has perfumed a large apartment for several years without perceptibly losing in weight. An ounce of aniline is capable of coloring two hundred ounces of silk thread. We may separate this thread into 3,000,000,000,000 parts and discern the red color of the aniline in each one of them.

Many chemical tests reveal the presence of exceedingly small quantities of matter. If a grain of iron or of copper be dissolved in nitric acid, and then added to a tumblerful of water, the presence of either metal may be detected in every part of the mixture. This may be done by placing a drop of the solution on a watch-glass and then adding a solution of ferrocyanide of potassium, when the iron solution will be turned blue, and the copper solution will be reddened.

Even by mechanical means we may obtain particles so small that it is difficult to form just conceptions of their size. Gold leaf is sometimes so thin that fifteen hundred leaves placed one above another will not equal the thickness of ordinary paper. One square inch of this leaf weighs less than one twenty-thousandth part of an ounce; and we can divide this into ten-thousand parts, each one of which is distinctly visible to the eye, though weighing less than one two-hundred-millionth part of an ounce.

9. There are many reasons for believing that there is a limit to the divisibility of matter. The smallest conceivable particle of water, or of any compound body, is called a *molecule*. A molecule is so small that no microscope will ever enable us to see it. It is the smallest particle into which a body may be divided without losing its identity.

10. By chemical means a molecule of water may be still further divided into its components oxygen and hydrogen, and thus particles obtained which are the smallest conceivable. These are called *atoms*. An atom is the smallest particle of matter capable of entering into a molecule.

11. How the atoms are arranged to form molecules, or how the molecules are arranged in bodies, is unknown. We know that all bodies expand when heated, and contract when cooled.* Thus, if an empty flask is inverted in a vessel of water, and heat is applied (Fig. 2), the air will expand so much that a portion will be expelled. On cooling, the air remaining in the flask will resume its original volume. We know also that all bodies are made smaller by pressure: thus a bottle of "soda water" contains several times its volume of compressed gas, which expands to its original volume when the cork is removed. All bodies are expansible and compressible. Gases show these properties very readily, but they are also exhibited by solids and liquids.

FIG. 2.

These and similar phenomena render it probable (1) that the molecules of a body do not touch each other, but are separated by vacant spaces or pores; and (2) that the molecules are free to move even in the most rigid bodies. When bodies expand, the molecules separate, and the pores become larger; when bodies contract, the molecules approach, and the pores become smaller.

12. The pores of bodies are of two kinds. (1) Those which exist between molecules are called *physical pores.* These are so small that they can not be seen even by the aid of a microscope. (2) *Sensible pores* are cavities that may be seen, as the pores in bread, or in some kinds of wood.

If water is heated in a glass vessel, bubbles of air sep-

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* When clay is heated, it contracts permanently, because its particles suffer a chemical change.

arate out and cling for a time to the sides of the vessel. These must have come from the physical pores of the water. So also, if a cup be filled to the brim with hot water, two or three spoonfuls of pulverized sugar may be gradually added before the cup overflows. The molecules of the sugar find sufficient space in the pores of the water. Sometimes an actual contraction of volume occurs on mixing two liquids. Thus, if a long and slender test-tube be half filled with water, and strong alcohol be poured carefully in, so as not to mix the two liquids until the tube is quite filled, and then the tube be tightly closed and inverted, the liquids will mix and no longer fill the tube. The explanation of this phenomenon is that the molecules of the alcohol and the water are mutually so arranged as partially to fill the pores previously existing in the two bodies.

13. **We do not believe** it possible that any two particles of matter can occupy the same place at the same time. In other words, we believe that *matter is impenetrable.* If a pebble be dropped into a tumblerful of water, enough water will overflow to equal the bulk of the pebble. The examples given in the preceding section are only apparent exceptions to the property of impenetrability. There are other apparent exceptions, which can be even more readily explained.

If one end of a glass tube be closed by the thumb, and the other end plunged into a vessel of water, the water can not fill the tube because of the impenetrability of the air inclosed in the tube. Nevertheless it will be seen that the water will rise a little way in the tube; but this is because the air is compressed, and so allows space for the water to enter.

An easy experiment, which illustrates the same fact, may be made by wrapping moistened paper around the tube of a funnel, so that it may be made to fit air-tight in the neck of a bottle, as shown in Fig. 3. Now, if water be quickly poured into the funnel, only so much will enter the bottle as corresponds to the compressed or displaced air.

FIG. 3.

14. **Space** which contains no matter is called a vacuum.

15. **Bodies vary greatly** with respect to the pores which they contain. Those that contain large pores are called *rare* bodies; those that have small pores are called *dense* bodies. Density is, therefore, a term which expresses the relative amount of matter which equal volumes of different substances contain. Iron, for example, is denser than stone, but is less dense than gold. In comparing the relative density of bodies, it is convenient to select some substance which shall be taken as the standard of comparison, and reckoned as unity, or 1. Thus the air is a standard of density for all aëriform bodies, and water is a standard of density for liquids and solids. It is also necessary to select some temperature at which the comparison shall be made. The temperature usually taken is 32° F. for all bodies excepting water, which is unity when at 39°.2 F. In the case of gases, it is also necessary that they should be compared when under the same pressure. The pressure assumed is the average pressure of the atmosphere at the level of the sea, which is 14.7 pounds to the square inch, and which equals a column of mercury 29.92 inches high.* These are called the normal conditions of temperature and pressure.

16. **The ratio** which shows how many times heavier any given substance is than an equal volume of water or of air,

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* See Section 31.

under the normal conditions, is the *specific gravity* of the substance. The specific gravity of chlorine gas is 2.47, which means that a given bulk of chlorine, as a pint or a gallon, is 2.47 times heavier than the same bulk of air. The specific gravity of silver is 10.5, which means that a given bulk of silver, as a cubic inch, weighs 10.5 times more than the same bulk of water.

Weights of the Standards.

One cubic inch of air weighs,	at 32° F.,	0.32712	grains.
	at 60° F.,	0.30954	grains.
One cubic in. of water weighs,	at 32° F.,	252.875	grains.
	at 60° F.,	252.456	grains.

Specific Gravities Compared.

	at 32° F.	at 62° F.
Ratio of air to water,	1 to 773.2	1 to 816.8
Ratio of water to air,	1 to .00129363	1 to .0012243

Table of Specific Gravities.

GASES.		SOLIDS.	
Air,	1.	Cork,	0.24
Steam,	.622	Ice,	0.93
Hydrogen,	.069	White Oak,	0.86
Oxygen,	1.106	Ebony,	1.33
LIQUIDS.		Glass,	3.
Pure Water,	1.	Iron,	7.78
Sea Water,	1.026	Copper,	8.85
Olive Oil,	0.915	Lead,	11.35
Sulphuric Acid,	1.84	Gold,	19.26
Saturated Brine,	1.205	Platinum,	21.53

17. Matter is every-where subject to change. When the smith heats a bar of steel, it expands; when he beats it on his anvil, he is changing its form; when he hurls it from him, he is changing its position. If the steel be rubbed on a magnet, it acquires the property of attracting iron filings. It may be melted to a fluid state and cast into any shape. Such changes as these are called *physical changes.* Physical changes are those by which the substance is not altered so as to lose its identity.

On the other hand, in *chemical changes* the identity of the substance is entirely lost. Thus, when steel rusts, the red powder which forms is due to a chemical change in which water has been decomposed into oxygen and hydrogen; the oxygen has united with the iron in the steel, to form a new kind of substance, and the hydrogen has escaped into the air. So, also, the decay of leaves, the burning of wood, the souring of cider, are chemical changes.

18. **Force is** that which causes any change in the form or condition of matter. All the phenomena of the visible universe are caused by the action of force upon matter.

The simplest change in matter is that of position. We determine the motion or rest of a body by its relation to some given point; but as this point may be itself fixed or moving, motion or rest is either (1) absolute, or (2) relative.

19. **Absolute motion** is change of place with regard to a fixed point: relative motion is change of place with regard to a point in motion.

The motion of the heavenly bodies with reference to ideal fixed points in space are examples of absolute motion. Strictly speaking, no bodies are in a state of absolute rest. Every particle on the earth's surface partakes of all the daily and annual motions of the earth; and, therefore, the terms absolute motion and rest, when applied to bodies on the earth's surface, have reference to objects that appear fixed.

A person seated on a steamboat in motion is in absolute motion with respect to the harbor he has left, or to the harbor he is approaching, and is in a state of relative rest with regard to the parts of the vessel. If he walks toward the stern of the boat as fast as the vessel moves forward, he is in a state of relative motion with regard to the parts of the vessel, but is in absolute rest with regard to the harbors.

20. **Velocity** is the rate of motion. It may be found by dividing the space passed over by the time occupied in the transit. Thus, if a locomotive is five hours in going one hundred miles, its velocity is twenty miles an hour.

The formula, $v = s \div t$

Expresses the relation between space, time, and velocity.

21. **A natural unit of time** is the day, but any of its subdivisions—hour, minute, or second—may be assumed as convenience dictates.

Table of Velocities.

	MILES PER HOUR.	FEET PER SECOND.
Man walking,	3	4.4
Man running,	10	14.66
Swift trotting horse,	27	40.
A rifle ball,	1,000	1,466.66
Sound,	762	1,117.6

22. **Motion and rest** are equally natural to a body. When the forces that are acting upon matter exactly balance each other, it is at rest, and is in motion when they do not. We say, then, that matter has the property of *inertia*, by which we mean that it tends to retain its present state, whether of motion or of rest.

It requires some force to set a body in motion, and when it is in motion, it requires force to stop it. The inertia of the air becomes manifest by the resistance it offers to a body moving through it. If we endeavor to run with an open umbrella, we need to employ considerable force to overcome the resistance of the air, because we shall have to displace or set in motion the air which is in front of us.

The heavier a body is, the greater will be its inertia; that is, it will require more force than a lighter body to set it in motion, or to stop it when it is moving. Thus, a small boy will easily "dodge" a larger, because the heavier boy will be unable to change his course at once.

A person standing in a wagon partakes of its condition of motion or rest. If it is suddenly set in motion, he is thrown backward, because his feet are drawn along by the friction against the bottom, before his head can acquire the motion forward. If the wagon is suddenly stopped when in rapid motion, he is thrown forward.

23. **There are many forces** in Nature, and it is convenient to divide them into three classes.

(1) Those which act only upon the molecules of matter, and at distances which are inappreciable to our senses. These are named Cohesion, Adhesion, and Affinity. Taken collectively, they are called the *molecular forces.*

(2) Those which act also upon bodies taken as a whole, and at both sensible and insensible distances. These are Gravitation, Light, Heat, and Electricity.

(3) Those which take part in the phenomena of living plants and animals by controlling or modifying the forces of inanimate nature. These are called the *vital forces.*

24. **Cohesion** causes like molecules to unite in one mass. It keeps the particles of a body together. It is strongly exerted in solids, feebly in liquids, and not at all in aëriform bodies. Thus a dew-drop is spheroidal because of the cohesive force. When the drop is very large it becomes flattened, because the force of cohesion is partly overcome by the force of gravitation.

The following pretty experiment illustrates the tendency of liquids to assume the spheroidal form: Take a wine-glass half full of water, and carefully fill it with alcohol so as not to mix the two liquids; then drop a very little olive oil through the alcohol. It will come to rest in the middle of the glass, and, if the quantity taken is not too great, will assume the shape of a ball.

When the cohesion of solids has been once destroyed, it is difficult to cause the particles to reunite. If a bar of lead be cut in two, the severed parts may be made to cohere by so cutting their faces that they will present a bright and even surface, and then pressing them tightly together with a slight twisting motion. Two plates of polished glass will cohere, under pressure, so firmly that they may be worked as a single piece.

25. Adhesion causes the molecules of different kinds of matter to cling together. Thus, adhesion causes the dust to cling to any thing it falls upon; chalk to cling to blackboards, and dew-drops to leaves. Under the name of Friction it diminishes the work of moving force, (1) by stiffening the joints of machines, (2) by increasing the resistance to be overcome. Friction often acts as a mechanical advantage, as in retaining nails and screws in their sockets, in preventing our feet from slipping when standing or walking, and in enabling us to take firm hold upon objects.

26. Affinity causes the atoms of unlike substances to unite and form new kinds of matter. All chemical phenomena are due to affinity. When iron dissolves in nitric acid a new kind of matter (the nitrate of iron), differing both from the iron and the acid, is formed.

Adhesion and cohesion differ from affinity in this, that their action on bodies does not effect any essential change in the properties of the bodies acted upon. They differ from each other in this, that adhesion acts between unlike particles, and cohesion between like particles. They all agree in this, that their energy increases with the number of molecules that are acted upon. This statement, when applied to solids, may be expressed in these words: the energy of molecular forces increases with the extent of surface exposed to their action.

27. **Gravitation** is a force by virtue of which every particle of matter attracts every other particle of matter toward itself. The term *mass* is used to denote the amount of matter in a body, and it has been established that *gravity is proportional to mass.*

If a stone were dropped from a balloon it would fall toward the earth by reason of the attraction of the earth, or terrestrial gravitation. The earth also tends to fall toward the stone, but its mass is so much the greater that its motion is inconceivably small.

But gravitation does not always produce motion. A stone resting on the top of a table is not free to fall, and, in such a case, the force of the earth's attraction is expended in pressure against its support. This pressure is called the absolute *weight* of the body. Hence, weight is the measure of the earth's attraction.

28. **Gravity** is also influenced by distance, as will be shown hereafter. An iron ball which weighs one hundred and ninety-four pounds at the equator will weigh one hundred and ninety-five pounds at the poles. Hence, weight does not always mean the same as mass, for a body will always contain the same amount of matter in every conceivable place. Nevertheless, as weight is always proportional to mass, we may use weight as a means of estimating mass, or, in most instances, use the two terms interchangeably without sensible error.

29. Universal gravitation is the same force applied to the heavenly bodies. It is by reason of this force that the earth and other planets move round the sun.

30. The unit of weight adopted by the United States and England is the avoirdupois pound of 7,000 grains.

The French unit, called a gramme, is the weight of a cubic centimetre of distilled water, at 39°.2 F. A gramme equals 15.434 grains; a kilogramme equals 15434 grains, or 2.2046 avoirdupois pounds.

Weight in pounds of one cubic foot at 62° *F.*

Air,	0.080728	Wrought Iron,	480.
Water,	62.418	Copper,	556.
Mercury,	848.75	Lead,	712.
Potassium,	53.	Gold,	1224.

Gravitation is made serviceable to man in the force of running water, and in machinery moved by weights, as well as in giving stability to buildings and other structures.

31. The unit of pressure in most frequent use is the pressure of one atmosphere. This pressure is due to the attraction of gravitation. We may ascertain its amount by the experiment of Torricelli.

Fill a glass tube, thirty-two inches long, with mercury, close the open end firmly with the finger, and then invert it in a cistern of mercury, Fig. 4. On removing the finger, the mercury will fall a little way in the tube and leave a vacuum above it. Now, as the weight of the mercury tends to make it flow out of the

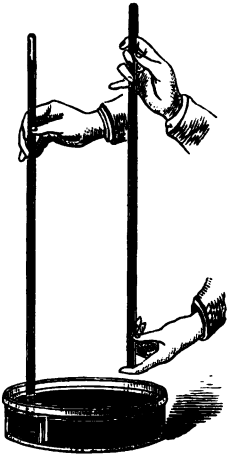

FIG. 4.

tube, the column must be sustained by an equal and opposite force. This force can be nothing else than the pressure of the atmosphere; and, hence, this pressure may be measured by the mercurial column. This apparatus is called a *Barometer*, and is used to measure the pressure of the air. At the level of the sea, and at 32° F., the average height of the mercurial column is 29.922 inches, or 760 millimetres. A column of this height, a square inch in section, weighs 14.73 pounds.

We are accustomed to say that the pressure of the atmosphere is nearly fifteen pounds to every square inch of surface.

Table of Pressures.

	POUNDS ON THE SQUARE FOOT.	POUNDS ON THE SQUARE INCH.
One atmosphere,	2121.12	14.73
One foot of water, at 39°.2 F.,	62.425	0.4335
One inch of mercury, at 32° F.,	70.73	0.4912

32. Heat tends to make the molecules of matter recede from each other. When a body is warmed, it becomes larger; when it is cooled, it contracts.

The apparatus shown in Fig. 5 illustrates the expansion of solids. This consists of a brass ball, so made that, at ordinary temperatures, it will pass easily through the ring, *m*. On heating the ball, it will no longer pass through the ring.

This increase of volume of a heated body must be due to a motion among the molecules, which tends continually to separate them. When this motion increases in intensity, the body becomes warmer; when this motion decreases in intensity, the

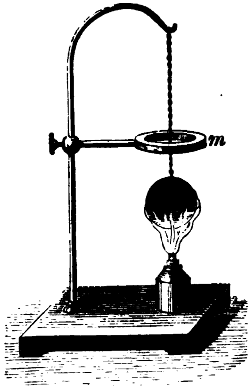

FIG. 5.

body becomes cooler. Hence, we may measure the *intensity* of the heat, or *the temperature* of a body, by the degree of the molecular motion, or by the expansion of bodies.

33. **The Thermometer** is an instrument which measures temperatures. The ordinary mercurial thermometer consists of a very small glass tube (Fig. 6), at one end of which is blown a bulb — the bulb and part of the tube are filled with mercury. When the thermometer is placed near a source of heat, the column of mercury rises, and falls when it is removed, because of the expansion and contraction of the mercury. The glass also expands and contracts, but only one-seventh as much as the mercury; and so we have only to notice the apparent expansion of the mercury.

In order to compare temperatures, we assume as standards the temperatures of melting ice and of water boiling, under the pressure of one atmosphere. These standards are called, respectively, the *freezing* and the *boiling points*.

FIG. 6.

For greater convenience, arbitrary scales have been devised to designate small variations in the mercurial column. The freezing and boiling points are first determined, and the height of the column in each case is marked on the tube, or on the scale attached to it. The space between these is then divided into any number of equal parts, called degrees, and parts of the same length set off above and below the boiling points.

The *Centigrade scale* marks the freezing point by 0°, and the boiling by 100°.

Reaumer's scale marks the freezing point by 0°, and the boiling by 80°.

Fahrenheit's scale marks the freezing point by 32°, and the boiling by 212°.

These scales are distinguished by the letters C, R, and F. The divisions below zero are indicated by the negative sign. Thus, $-10°$ signifies ten degrees below zero; $10°$, or $+10°$, signifies ten degrees above zero.

To compare these scales, we first notice the interval between the freezing and boiling point, and find $C = 100°$, $R = 80°$, $F = 180°$; hence, these are equal, or $1°\,C = \frac{4}{5}°\,R = \frac{9}{5}°\,F$. Now, if we remember that the zero of Fahrenheit's scale is 32° below the freezing point, we may convert one scale into another, thus:

$$\begin{array}{ll}
°F = \frac{9}{5}\,°C + 32° & °F = \frac{9}{4}\,°R + 32° \\
°C = (°F - 32°)\,\frac{5}{9} & °R = (°F - 32°)\,\frac{4}{9} \\
°C = \frac{5}{4}\,°R & °R = \frac{4}{5}\,°C
\end{array}$$

34. The amount of heat in a body must not be confounded with its temperature. It is evident that a pint of boiling water would have the same temperature as a gallon of boiling water, and would equally affect a thermometer. The *relative amount* of heat present in a body is measured by the *thermal unit.* This is the quantity of heat required to raise a pound of water from 32° F. to 33° F. Hence, a gallon of boiling water would contain eight times as many thermal units as a pint, and would be competent to melt eight times as much ice or snow.

35. The force of light is closely related to that of heat. It may seem strange that it is reckoned as a force; but it is easy to show that it may produce change in matter. Thus, if the gases hydrogen and chlorine are mixed in equal quantities in the dark, they will not combine; but if exposed to the free sunlight, they will unite with explosive violence. The photographer's art depends on the force of light. Soak a strip of white newspaper in common salt brine and let it dry; when dry, again moisten it in a darkened room with a sponge dipped in a solution of silver nitrate, and again dry it. This process covers the paper with white silver chloride. Now if this coated paper be placed in the sunlight, it will darken, showing that the light effects a change in the silver chloride. Moreover, in the grand laboratory of nature, light is an essential force. To define it, we select one of its properties and say that "light is that mode of motion which excites in us the sensation of vision."

36. **The force of electricity** is familiar to all, in its applications to the telegraph, in the magnet, and in the flash of lightning.

Its simplest effects may be shown by rubbing a glass rod briskly upon the coat-sleeve, and then presenting the rubbed end to small and dry pieces of paper. If the air is not too damp, the paper will be attracted to the rod, cling to it for a little while, and then fly off. Instead of the bits of paper, we may employ a light pith ball, suspended by a silk thread, Fig. 7. The ball will be first attracted and then repelled by the excited rod. We may use this phenomenon to define electricity as a force which becomes manifest by its peculiar phenomena of attraction and repulsion.

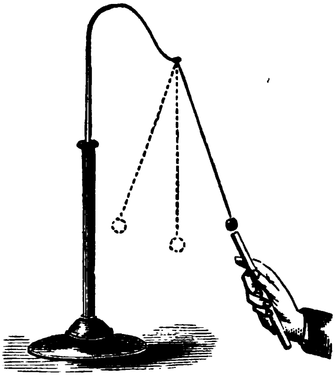

FIG. 7.

37. **These are the only forces** of inanimate nature of which we have any certain knowledge.

They produce, by their action upon matter, secondary forces, which are employed by man in machines. Thus, the strength and elasticity of springs is mainly due to cohesion; the action of glues and cements, to adhesion; the elastic force of steam, to heat; the power of running water, or of falling weights, to gravitation; the muscular strength of men, to cohesion, affinity, etc., modified by the vital forces.

38. **However forces act** upon bodies, the matter of which they are composed is not lost. When gunpowder is exploded, it disappears, leaving only for a moment a trace of smoke. It has, however, only undergone a chemical change, by which a part of its ingredients have been converted into gases. If the explosion is made in a sealed vessel, sufficiently strong to stand the shock, the vessel and its contents will not change in weight by the operation. Matter is indestructible by any force that man can employ upon it.

We are also justified in asserting that force is indestructible. Affinity, electricity, heat, and light, are so closely allied that the action of any one may induce the action of any other: thus a candle burns by reason of affinity, and gives out heat and light. For this reason these four are called *correlative forces.*

NATURAL PHILOSOPHY OR PHYSICS treats of the physical changes which are produced by the action of force upon matter.

RECAPITULATION.

Bodies are classified

- I. With regard to state as
  - Solid, as ice.
  - Liquid, as water.
  - Aëriform, as steam.
- II. With regard to composition,
  - Simple, as oxygen.
  - Compound, as water.

Forces act

- I. Only on molecules,
  - Cohesion.
  - Adhesion.
  - Affinity.
- II. Also, on bodies,
  - Electricity.
  - Light.
  - Heat.
  - Gravitation.

The general properties of matter are—magnitude, weight, impenetrability, mobility, inertia, divisibility, porosity, compressibility, expansibility.

We estimate the action of forces by certain units. Among these are units of measure, units of volume, units of time, units of weight, units of pressure, units of heat.

PROBLEMS.

1. How many centimetres are there in 29.922 inches?

2. How many inches are there in 0.994 metres?

3. How many square inches are there in a circle of one inch radius? of two inches radius? What is the ratio between the two areas? How many square centimetres are there in each circle?

4. How many cubic inches are there in one pint? How many cubic centimetres? How many litres?

5. How many litres are there in a sphere of six inches radius? of one foot radius? What is the ratio between the two volumes? How many gallons are there in each sphere?

6. What will be the weight of each sphere if made of air? of water? of gold? Reckon each in pounds and also in grammes.

7. What will be the edge of a cube containing ten pounds of water? the radius of a sphere containing an equal weight of water?

8. From the table of specific gravities calculate the weight of a gallon of oxygen, of sulphuric acid, of cork, of silver.

9. What does a litre of dry air weigh in grammes?

10. What is the average velocity per minute of a locomotive that passes over 138 miles in six hours?

11. What will be the atmospheric pressure on a surface of six square inches in pounds? in grammes? On a surface of six inches square, in pounds? in kilogrammes?

12. What is the atmospheric pressure on one square centimetre in kilogrammes?

13. Convert 25° C. to °F.; 50° C. to °F. Can you say that 50° C. is twice as hot as 25° C.?

14. Convert 62° F. to °C.; 39°.2 F. to °C.

15. If a gallon of boiling water will melt ten pounds of ice, how much will be required to melt one cubic foot?

CHAPTER II.

PHENOMENA CONNECTED WITH COHESION.

39. The cohesion of solids may be estimated by the resistance which they offer to forces which tend to separate their particles.

There are many ways by which the strength of a body may be tried. Among these are:

(1) *By a stretching force.*—We may hang a rubber tube from a hook, and pull it downward by a weight. The rubber will stretch, and, with a weight sufficiently heavy, will be torn in pieces. The resistance which a body offers to a stretching force is called its *tenacity.* The tenacity of metals is increased by drawing them into wires. A cable made of wires twisted together is far stronger than a chain of equal weight. Wire cables are used in suspension bridges for this reason. The suspension bridge at Cincinnati has a span of one thousand feet.

(2) *By a compressing force.*—If we place a weight on a small bar of wood, it will compress its particles and tend to crush the bar. When the bar is not allowed to bend, it offers the same resistance to pressure that it would to a stretching force.

(3) *By a bending force.*—If we fasten one end of a lath, placed horizontally in a vice, and apply a weight at the other end, it will bend and tend to break. The strength which the substance exhibits depends not only on the material but also on the manner in which the strain is applied. A sudden shock causes a much greater strain than a gradually increasing force of greater amount. So, also, the lath will support

a greater weight when its broad side is placed vertically than when it is horizontal; then, also, the longer it is the less weight it will support. Finally, if both ends are supported, it will sustain half the weight, when it is concentrated at the center, that it will when distributed along its whole length. What is true of the lath, is also true of the beams used in houses, they are placed so as to receive the strain on their edges.

The bones of animals, and the stalks of grain, are hollow. This is the most economical arrangement of a given weight of material. We may illustrate this fact by resting the ends of a flat sheet of paper on bricks, and ascertaining the force necessary to break it down; then repeat the test with a similar sheet of paper after having coiled it into a tube, Fig. 8. If a broad strap is used to hang the weight from, a closely coiled tube of this sort will support three or four times as much weight as before.

FIG. 8.

(4) *By a twisting strain.*—Suppose, when the lath is in the vice, we attempt to twist it. The force will tend to wrench the particles asunder; and it is possible that we may accomplish this with a long and thin lath. The kind of strength that resists a twisting strain is called *resistance to torsion.*

40. The effective strength of any structure is that which is not employed in supporting the weight of the structure itself. It would be impossible to build such roofs and bridges of iron as have been built of wood, because the strength of the material would not be sufficient to support its own weight. Pine, which has nearly half the tenacity, has only one-tenth the weight of iron; so that, for equal weights, pine has more than four times the tenacity of cast-iron. Steel has the greatest tenacity known. A rod of steel, one foot long and a square inch in area, will support a weight of 130,000 pounds.

41. If a body does not give way on the application of a strain, it is frequently permanently changed in shape. A stretching force may draw some bodies into a wire-shape. Such bodies are *ductile.* Glass is very ductile when at a red heat, and may be drawn into very delicate threads. A compressing force flattens some bodies into thin sheets. Such bodies are *malleable.* Most metals are both malleable and ductile, though not in equal degrees. Gold is the most malleable, and platinum the most ductile of metals.

42. A sudden blow often breaks many bodies that in other respects are quite strong. Such bodies are *brittle.* Glass is a good example. A bottle that will resist a great pressure is broken by a gentle blow from some hard substance. A hard substance is frequently also brittle. We measure the *hardness* of a body by the readiness with which it is scratched by another substance. The diamond is the hardest body known. Quartz is hard enough to scratch glass.

43. When steel is strongly heated, and then suddenly cooled, it becomes very hard, and so brittle that it is suitable only for the dies used in coining, and for the hardest files. On the other hand, if it is cooled slowly, it becomes softer, more ductile, and tenacious. This process of slow cooling is called *annealing.* Steel is *tempered* by first hardening it, and then a portion of its hardness is removed by reheating the steel to a lower temperature than at first, and then cooling it gradually. The temper required depends on the use to which the steel is to be applied. Surgical instruments require a hard, keen edge; table knives require more flexibility; and springs require both flexibility and tenacity.

The effect of rapid or slow cooling in glass is about the same as in steel. Melted glass dropped into water solidifies into the curious toy known as Prince Rupert's drops, Fig. 9. The body of these drops is so hard that it will bear a smart blow; but if the tail be broken, the whole flies into minute particles. This brittleness is prevented in glass utensils by carefully annealing. As soon as the glass vessels are blown, they are drawn through a long furnace in which the heat gradually diminishes from one end to the other. The thicker the glass, the longer the time required in annealing.


FIG. 9.

44. **The phenomena just considered** involve a permanent displacement of the particles of a body. If the strain does not exceed a certain limit, the body will resume its previous shape, when the force has ceased to act. The energy with which the particles resume their original position is due to their *elasticity*. Up to the limit of elasticity, the elastic force is exactly equal to the strain, and the elasticity is therefore perfect. Beyond this limit, brittle bodies break: the molecules of most other solids are permanently displaced, or *set*, with new relations to elasticity, exactly similar to the first. Thus: when a wire has been permanently lengthened by a great strain, it is still enabled to manifest perfect elasticity by recovering from a smaller strain.

Flexibility should not be confounded with elasticity. A wire of soft iron is very flexible, though but slightly elastic; that is, it may be readily bent, but does not recover its position when the force is removed. A steel spring is both flexible and elastic.

45. **The elasticity developed by compression** belongs to all bodies, whether solids, liquids, or gases. *All fluids are per-*

fectly elastic. Liquids are but slightly reduced in volume under ordinary pressures. Gases decrease in volume as the pressure exerted upon them increases; if the pressure be doubled, the volume will be one-half, etc. When the pressure is removed, both liquids and gases resume their original volume.

The elasticity of aëriform bodies is exemplified by a boy's pop-gun. The air between the wad and the piston increases in elastic force as it decreases in volume, until the elasticity is sufficient to expel the wad.

The elasticity of such solids as India rubber, ivory, and steel, is very great. If a ball of ivory or of glass be dropped on a slab of marble, it will rebound to a height nearly equal to that from which it fell. If the slab had been covered with oil, it would be found that the ball had left a circular impression on the plate, and had itself received a blot of oil. On repeating this experiment, it will be seen that the size of the spot on the slab and on the ball increases with the height from which it falls. It appears, therefore, (1) that the ball was compressed at the moment of the shock; (2) that the rebound was caused by the effort to regain its shape; (3) that the elastic force increases with the strain.

Lead, clay, and the fats receive a set with only a moderate compressing force, and, therefore, have but little elasticity.

46. The elasticity of musical strings is developed by stretching. The tendency that twisted strings have to untwist exemplifies the elasticity developed by torsion. The elasticity, developed by bending, is splendidly shown in glass threads: in them it is perfect, as they never receive a set, but break when the limit of elasticity is passed.

47. The practical applications of elasticity are innumerable. The elasticity of solids is applied in the springs used in watches, clocks, carriages, bows, spring-balances, etc.

The elasticity of air is turned to account in foot-balls, air-cushions, air-springs, etc.

RECAPITULATION.

The properties which have been considered in this chapter are called *the specific properties of bodies.* They fall into two classes:

- I. Those involving strain of particles,
  - Tenacity,
  - Resistance to pressure,
  - Resistance to bending,
  - Resistance to torsion,
  - Elasticity.
- II. Those involving permanent displacement of particles,
  - Ductility;
  - Malleability,
  - Hardness,
  - Brittleness.

CHAPTER III.

PHENOMENA CONNECTED WITH ADHESION.

48. The force of adhesion gives value to cements: thus glue is used for wood; gum mastic and shellac for glass; dextrine for paper; etc. This choice of cements for different objects shows that adhesion varies with the kind of matter.

Some of the phenomena of adhesion have received specific names, and are of great importance. Among these are the following:

49. Capillary action.—If a clean glass plate is dipped vertically in water, the liquid will rise on each side to the height of nearly one-sixth of an inch, Fig. 10. It must be evident that the weight of this liquid column is supported by the adhesion of the water to the glass. A second plate will support an equal weight; and, hence, if two parallel plates are brought so near each other that both may act on the same molecules of the liquid, the column of the water will rise higher. The nearer the plates, the higher will the liquid rise, Fig. 11. Two plates, one-hundredth of an inch apart, will support a column of water two inches high.

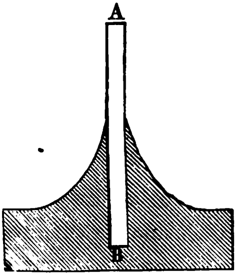

FIG. 10.

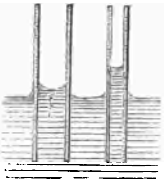

FIG. 11.

When two plates are inclined toward each other, as in Fig. 12, the water takes the shape of the curve known as the equilateral hyperbola.

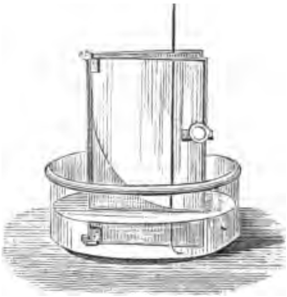

FIG. 12.

Finally, if a tube is substituted for the plates, the molecules of the liquid will be attracted on all sides, and the water will rise to twice the height produced by two plates, separated by a space equal to the diameter of the tube. If the tube has a diameter of one-hundredth of an inch, the column of water will be four inches high.

50. The adhesion which causes liquids to rise on solids is called *capillary attraction,* because it is best exhibited in very small hair-like tubes.

Liquids do not rise in tubes unless they wet them; if they do not wet them, they are depressed. A needle, slightly greased, can be made to float on water, because, not being wet by the liquid, it produces a depression in which it is supported. For the same reason mercury is depressed by a glass plate, but rises freely on lead and some other metals. The amount of ascent and depression varies with the substances used: thus, in a glass tube, alcohol will rise about one-half as much as water — mercury is depressed in a glass tube, and its surface is convex, while water exhibits a concave surface.

51. Familiar illustrations of capillary attraction are seen in the action of lamp-wicks. Blotting paper readily draws ink into its pores, which resemble short capillary tubes. The pores in writing paper are closed by sizing. If one end of a towel is dipped in a basin of water, and the other left hanging over the edge, the whole towel will become wet. Water can not be poured out of a full tumbler without running down the outside because of the adhesion of the water to the glass.

In the droughts of summer the water necessary to the support of vegetation is drawn toward the surface of the ground by capillary action. It is also one of the principal causes of the ascent of sap in plants, and plays an essential part in the circulation of liquids in animal tissues.

52. Solution. — If a lump of sugar is dipped in water, the liquid will rise by capillary attraction until the whole is moistened. If enough water is present, the sugar will entirely disappear in the liquid, thus forming a *solution.* This shows that the adhesive force is sometimes sufficient to overcome the cohesion of solids. Each drop of the solution is sweet like sugar, and fluid like water, showing that the adhesion is perfect, because it is shared by every molecule. A solution is said to be *saturated* when no more of the solid will dissolve in it.

53. The solvent powers of liquids vary exceedingly. An ounce of cold water will dissolve two ounces of sugar, although it can dissolve hardly a grain of sulphate of lime. Fats dissolve in ether, benzine, and bisulphide of carbon; resins dissolve in alcohol; lead and gold in mercury.

When a metal disappears in an acid, as copper in nitric acid, the action has two stages: (1) a chemical action by which the solid and liquid unite to form a substance different from either, as nitrate of copper; (2) a simple solution by which the compound thus formed dissolves in the liquid.

54. Gases also dissolve in liquids.— The rapidity with which water absorbs ammonia may be prettily shown by the following experiment: having fitted a glass tube, tapering at one end, to the cork of a large bottle, fill the bottle with dry ammonia gas. Then invert the bottle in water, Fig. 13. After a little time the water will absorb so much of the gas as to leave a partial vacuum in the bottle; the pressure of the atmosphere will then force the water up the tube and form a small fountain.

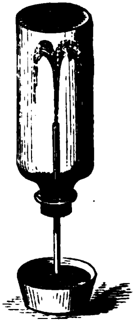
FIG. 13.

One volume of water absorbs 1049 volumes of ammonia, 506 volumes of hydrochloric acid, and nearly twice its volume of carbonic acid.

55. The weight of any gas absorbed by a liquid varies with the pressure; that is, if the pressure be doubled or tripled, the weight of the gas absorbed will be doubled or tripled. The effect of pressure on a gas is to diminish its volume and increase its weight in proportion to the pressure. Therefore the volume of the gas absorbed is the same for all pressures. If the pressure is removed, the gas resumes its original density, and escapes with effervescence. The "soda water" of the confectioner is water charged with carbonic acid gas, absorbed under pressure.

56. Porous solids like charcoal, dry clay, and metals in a state of fine division, often absorb large amounts of gases. One volume of charcoal will absorb 35 volumes of carbonic acid, and 90 of ammonia. A piece of freshly burned charcoal, exposed to the air for a few days, will often increase one-fifth in weight. This phenomenon can be explained by the supposition that the solid, by reason of its porous condition, offers a very large extent of surface, to which the gases adhere, and become condensed. Finely divided platinum absorbs 250 times its volume of oxygen.

57. The absorptive power of charcoal is of great economic value. The variety known as bone-black is used for clarifying sugar. The brown sirups are filtered through a layer of bone-black twelve or fourteen feet in thickness, and are thus obtained perfectly clear, all the coloring matters, whether solid or liquid, being perfectly absorbed. Ale and porter filtered through animal charcoal lose much of their bitterness, and all of their gases. All varieties of charcoal are efficacious in absorbing the gaseous products of decaying animal matters, and, thereby removing noxious effluvia from the air.

58. Solids also adhere to gases.—The transportation of dust by the winds is a proof of this. This action, if continued for a long series of years, may effect great physical changes, as is seen in the shifting sands of the deserts, and in the sandy hills, called dunes, that are formed on the coasts of France.

59. When fluids mix with each other without entering into chemical union, it is because of the mutual adhesion of their molecules. Some liquids, like water and alcohol, or glycerine, are miscible in all proportions. If equal volumes of water and ether are shaken together, and then allowed to stand, they will, in great measure, separate, each liquid dissolving about one-tenth of the other. The adhesion of oil and water is so feeble that they can not be made to mix permanently by any amount of shaking and stirring.

Any two gases will form a permanent mixture when they are placed in the same vessel, if they do not enter into chemical combination.

60. The tendency of fluids to mix with each other is called *diffusion.* Diffusion may take place without stirring or shaking, and even in apparent opposition to the attraction of gravitation. Thus, if a tall jar is partially filled with a solution of blue litmus, or water in which a red cabbage has been boiled, and sulphuric acid is carefully poured through a long funnel (Fig. 14), reaching to the bottom of the jar, the line of separation between the two liquids will be, at first, distinctly marked.

FIG. 14.

Soon the acid will rise and the water will sink, until the two are perfectly mixed. This will, however, require some time, and the progress of diffusion may be traced from hour to hour by watching the gradual change from blue to red. This may be repeated with any two miscible fluids, as cabbage water and a solution of caustic soda.

61. The diffusion of gases may be illustrated by the apparatus shown in Fig. 15, which consists of two bottles, connected by a long glass tube.

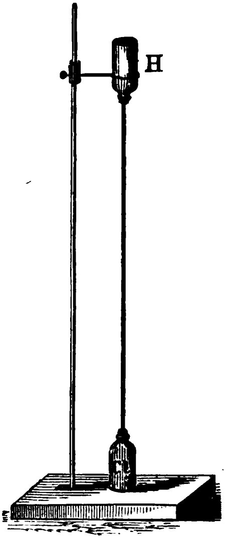

FIG. 15.

Fill the upper with the lighter gas, as hydrogen, and the lower with a heavier, as chlorine. The greenish color of the chlorine enables us to trace its gradual ascent. In a few hours the two gases will mix perfectly and permanently. This experiment should be performed only in a darkened room so as to avoid an explosion.

The diffusion of gases is of the greatest importance in maintaining the purity of the atmosphere. The constituents of the air are of different specific gravities, and would arrange themselves with the heaviest at the bottom if it were not for this beneficent law of nature. The carbonic acid, a product of decay and combustion, would be found at the surface of the earth, and destroy all animal life. As it is, the noxious gases are rapidly diluted when formed, and soon are so perfectly disseminated through the air, that chemical analysis fails to find any essential difference in the air of mountain, plain, or valley.

62. Osmose is a term used to denote the diffusion of fluids when they are separated by a porous partition or septum. The presence of the septum greatly modifies the phenomena of diffusion.

Tie a glass tube to the mouth of a bladder, Fig. 16, fill the bladder with strong brine, sugar sirup, or alcohol, and then immerse it in pure water. After a while it will be found that the liquid has risen in the tube, and that the outer vessel contains some of the substance that was in the interior. Hence, a current has been produced in two directions. The one passing into the bladder is called *endosmose;* the one passing out, *exosmose.* The rate of diffusion is greater in osmose than in simple diffusion.

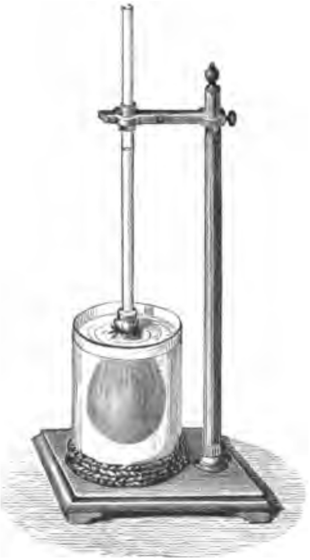

FIG. 16.

Instead of the bladder, an inverted funnel, having its mouth closed by a strip of any animal membrane, or by parchment paper, may be used.

63. Dialysis is the application of osmose to the separation of mixed solutions. If a solution contains alcohol, hydrochloric acid, or crystallizable bodies like sugar, they will pass through the septum; but gum-arabic, gelatine, and other substances that do not crystallize, will not.

64. The osmose of gases may be shown by a striking experiment.

Close the mouth of a long glass funnel with a septum of plaster of Paris. This may be done by making a moderately thick paste of the plaster with water on a plate, inverting the mouth of the funnel therein, and then suffering the plaster to harden. After drying the septum, place the tube in colored water, and invert over the closed mouth a jar filled with hydrogen, Fig. 17. The endosmose of the hydrogen will soon become manifest by the escape of bubbles through the water. Remove the jar, and the hydrogen will escape from the funnel in a contrary direction, as may be seen by the rise of the water in the funnel tube.

FIG. 17.

Although the nature of osmose has not been satisfactorily determined, it is manifest from the porous nature of animal and vegetable membranes, that it must play an important part in the operations of life. In breathing, the lungs give out carbonic acid by exosmose, and absorb oxygen by endosmose. It is probable that the ascent of sap in plants, and the various processes of secretion in animals are either controlled or essentially modified by osmotic action.

RECAPITULATION.

The force of adhesion is shown in

I. Cements and Friction	Solids to solids.
II. Capillary action	Liquids to solids.
III. Solution of solids	Solids to liquids.
IV. Solution of gases	Gases to liquids.
V. Absorption of gases	Gases to solids.
VI. Shifting sands	Solids to gases.
VII. Diffusion of liquids	Liquids to liquids.
VIII. Diffusion of gases	Gases to gases.
IX. Osmose	Diffusion through septa.

CHAPTER IV.

THE LAWS OF MOTION.

65. A body at rest remains at rest; a body in motion will continue moving with uniform velocity in a straight line, unless it is acted upon by some external force. This statement is known as the law of inertia, or as the first law of motion.

It is difficult to furnish examples which will perfectly illustrate this law. Our experience teaches us that a body will not move unless some force acts upon it; but that a moving body will continue in motion, is not so self-evident. Now let us roll a ball along the ground, then on a smooth floor, then on the ice: the fewer the obstacles in the way, the more direct will be its course, the longer will it continue in motion, and the more uniform will be its velocity. So, also, if we spin a heavy top in the air, and then in a vacuum, it will continue moving much longer in the latter case than in the former. All moving bodies on the earth's surface meet with opposing forces, such as gravity, friction, and the resistance of the air. The examples given above show that the more we can reduce these opposing forces, the nearer will the motion correspond to the law. If we could conceive of a body set in motion by a single impulse, and then left to itself, its motion would be in exact conformity to the law.

66. To comprehend the action of a force, three things must be known. (1) The *energy* with which it acts in a unit of time: this may be expressed by the pressure it exerts, or by its power of doing work, and may be represented by a straight line. (2) The *direction*, or the line along which it acts; and (3) *the point of application*, or the point upon which it exerts its action. In stating the theoretical action of forces, such external forces as friction, and the resistance of the air, are generally left out of account. This fact must be borne in mind when experiments are made intended to illustrate the action of forces.

67. A force which acts for an instant and then ceases to act is called an *impulsive force.* Projectiles, like bullets and arrows, are set in motion by impulsive forces. *A constant force* acts with the same energy without ceasing. It is convenient for us to consider a constant force as due to an infinite number of equal successive impulses, each one of which acts through a very brief interval of time. Gravity is a constant force. A locomotive under head of steam that is kept constant is another. A constant force tends to produce a velocity that increases at each successive instant. Thus, a locomotive starts slowly, and rapidly increases its rate of motion; but after awhile it moves with uniform velocity, because the friction and the resistance of the air also increase so that they are exactly equal to the motive power of the engine.

68. Simple motion is produced by the action of a single force. *Compound motion* is produced by the joint action of two or more forces. A ball falling in a perfect vacuum is an example of simple motion. A ball falling in the open air is an example of compound motion.

It is well to consider some other examples of compound motion. Suppose a boat, impelled by oars on quiet water at the rate of four miles an hour, enters a river whose current is three miles an hour, then, (1) if the boat go down the river, its speed will be seven miles an hour; (2) if the boat go up the river, its speed will be one mile an hour; (3) if the boat is rowed directly across the river, its speed will be five miles an hour. Let *AB* be the direction of the boat, and *AC* the direction of the current; that is, let these two lines represent the motion that would be produced if only one force were acting at a time. If both are acting at the same time, the actual direction of the boat will be the line *AD*, which is the diagonal of the parallelogram *ABCD*. This line also represents the intensity of the joint action of the two forces; and the boat will move as if impelled only by a single force in the direction of the line *AD*.

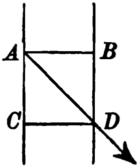

FIG. 18.

A single force that represents the effect of two forces taken together is called their *resultant*. When the forces, as in the third case, are at right angles to each other, the finding of their resultant is the problem of finding the hypotenuse when two sides of a right-angled triangle are given.

Thus, $3^2 + 4^2 = 5^2$.

69. Illustrations of compound motion. — When a steamboat is in motion, all the objects on it partake of the onward motion of the boat. Balls may be thrown and caught with the same certainty as on shore. But the directions which these balls take when referred to the ground beneath the boat will be the resultants of the motion of the boat, and the motions which the players give to the balls. So, also, an acrobat as easily goes through his feats of skill on the back of a horse in rapid motion as he would on the ground.

Conversely, when we have the resultant of two or more forces, we may find its components. As an illustration, take the sailing of a sloop under a wind oblique to the course of the boat. Represent the direction of the wind by the line *Vm*. Its force may be resolved into two components: the one, *tt′*, tangent to the sail, and producing no effect; the other, *mn*, perpendicular to the sail. As the sail is oblique to the axis of the boat, this force will tend to give the boat a lateral motion, called the leeway. Therefore, this force is again decomposed by the keel and the rudder, and the resultant impels the boat on its course.

These are examples of the second law of motion, which is: *If two or more forces act together on a body, each force produces the same effect as if it were acting alone.*

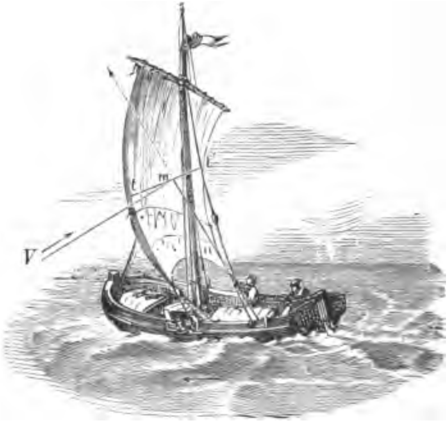

FIG. 19.

70. The measure of force.—We can now understand that if a given force, acting for one second upon a mass, will generate a certain velocity; a double force, acting for one second, will generate twice the velocity. So, also, if it requires a given force to impart a certain velocity to a mass, it will require double the force to produce the same velocity in twice the mass; for if the double mass were halved, and half the force applied to each, placed side by side, the velocity would be the same. Hence, the product of the mass by the velocity is one measure of force. This product is called *momentum*.

Thus, the momentum of a body weighing five pounds, and moving with a velocity of four feet per second, is twenty. That is, it would require twenty units of force, acting in the opposite direction for one second, to produce pressure enough to bring the body to rest. The momenta of large bodies, moving very slowly, are sometimes enormous. The momenta of icebergs are irresistible by any human power, even though their motion be so slow as to be almost imperceptible.

There is also another measure of force, which is termed *energy*, or the power of doing work, which we shall consider hereafter.

71. **The unit of work** is the force required to raise one pound one foot high. This is called the foot-pound. *The unit of power* is the force required to raise one foot-pound in one second of time. A *horse-power* is the mechanical value of a force capable of raising five hundred and fifty pounds one foot high in one second. Its work is, therefore, five hundred and fifty foot-pounds in one second.

72. **Circular motion.** — It follows from the first law of motion that a single force will produce motion in a straight line. It follows from the second law that if a moving body deviates from its original direction, a second force must be acting upon it. If a body moves in a circle, which is a constant series of deviations from a straight line, it must be acted upon by a constant force, in addition to the impulse which urges it in a straight line.

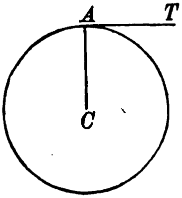

FIG. 20.

If a ball be whirled in a circle by means of a rubber cord held by the hand, we feel the cord stretched by a sensible force pulling outward — the hand resists this by pulling inward. If the cord is cut, the outward force will carry the ball in the direction of the tangent to the circle, as AT;

but when the two forces are equal, the curve is that of a circle. Circular motion is produced by the action of two forces, one of which, at least, is a constant force. The force that tends to draw bodies to the center, is called the *centripetal force;* that which tends to drive bodies from the center, is called the *centrifugal force.*

73. The tendency of revolving bodies to fly off at a tangent is easily illustrated. A stone let go from a sling, the mud flying off from the wheels of a carriage in rapid motion, are examples. If a glass globe, containing a little colored water and some mercury, is swiftly revolved by a twisted string, both fluids will be whirled away from the axis; the mercury, having the greater relative weight, will occupy the equator, with a belt of water on each side, Fig. 21. In laundries clothes are dried by placing them in a wire basket which is then revolved many hundred times in a minute. The centrifugal force may be made to counteract gravity: thus, if a cup of water be balanced on the inner face of a hoop, by beginning with a series of short swings, the cup and its contents may be whirled over the head without spilling the water.

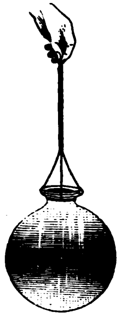
FIG. 21.

74. Newton proved that the shape of the earth is precisely that which a globe of plastic material would take by virtue of centrifugal force. The cause of the flattening of the earth at the poles may be illustrated by passing an axis through two thin hoops of tin, and then twirling them


FIG. 22.

round with moderate velocity; they will take the shape shown in Fig. 22. Of course, the upper part of the hoop must be free to slide up and down on the axis.

75. The third law of motion asserts that *action and reaction are always equal, and are in opposite directions.* When a weight rests upon a table, the table resists the pressure with an equal force. When a ball is fired from a cannon, the cannon recoils with a momentum equal to that of the ball, but its backward velocity is much less because of its greater weight. A bird, in flying, beats the air with its wings, and by giving a stroke whose reaction is greater than the weight of its body, rises with the difference. If we could imagine the bird beating its wings in a vacuum, there could be no reaction, and the bird could not move. So, in walking, we are assisted by the reaction of the ground to the pressure we exert.

76. The reaction of solids may be shown by balls hung from a frame so that their diameters shall lie in the same horizontal line.

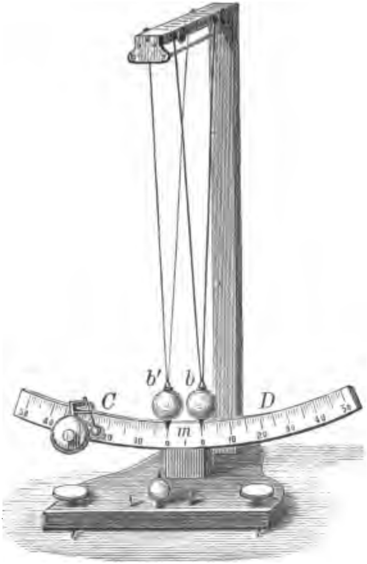

FIG. 23.

Suspend two equal ivory balls from the frame, in Fig. 23, and let *b* fall from *D* upon *b′*. If both balls were perfectly elastic, *b* will lose half its velocity in compressing *b′*, and the body *b′* will destroy an equal amount in regaining its shape; therefore, *b* will lose all its velocity and remain at rest. The other ball, *b′*, will acquire all the velocity of *b*, and move to *C*, a distance, on the other side, equal to *D*.

If the experiment is repeated with non-elastic balls of clay, both will move forward: the momentum of the falling body will be communicated to the one at rest, and the united momenta will be equal to that of the falling ball. They will therefore rise to a less distance than *C*.

77. When bodies strike a fixed plane they rebound by reason of the reaction of the plane. Suppose a perfectly elastic ball falls from *P*, Fig. 24, upon a perfectly elastic plane, *AB*. It will rebound to the height from which it fell. Now suppose it thrown in the direction of *IN*, the force of the collision at *N* will be resolved into two components: the one, *NE*, parallel to the plane *AB*, which represents its velocity, in the direction of the plane; the other component, *ND*, perpendicular to *AB*, represents the elastic force tending to urge the ball in the line *NG*. By reason of these two components the ball will take the direction *NR*, which is the diagonal of the parallelogram *NERG*.

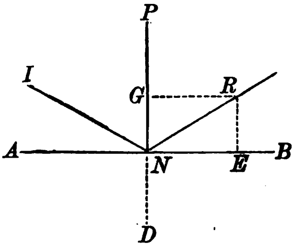

FIG. 24.

The angle *INP* is called the *angle of incidence;* the angle *PNR* is called the *angle of reflection.* In the reflection of perfectly elastic bodies, *the angle of incidence is always equal to the angle of reflection.* When either body is not perfectly elastic, the component *NG* will be proportionally smaller; hence, the body will proceed, after reflection, in a line nearer the plane than *NR*, and the angle of reflection will be greater than the angle of incidence. These facts may be illustrated by bounding balls of rubber, ivory, clay, putty, etc., upon a hard floor.

78. The reaction in soft bodies is not instantaneous, and the destructive effect is less. Thus, if a man leaps from a height into deep water, the reaction is the same as though he alighted on a solid plane, but it is diffused through a sufficient interval of time to render it comparatively harmless. Even soft bodies require some time for the displacement of their particles. If the surface of water be struck sharply with the open palm, the blow is met by considerable resistance. The sport of "skipping stones" on water exemplifies this power of resistance for the moment.

RECAPITULATION.

There are three laws of motion. The first declares that the application of force is necessary to move a body from a state of rest; the second, that if two forces act upon a body at the same time, each acts as if it were acting alone; the third, that the application of a force requires the agency of some external body.

PROBLEMS.

1. Find the resultant of two forces that may be represented by 7 and 11:

(*a*) When they act in the same direction.
(*b*) When they act in opposite directions.
(*c*) When they act at right angles to each other.

2. Find the momentum of a body whose weight is 5 tons, and whose velocity is 5 feet per minute. With what velocity must a second body, whose weight is 5 pounds, move in order that it may have a momentum equal to that of the first body?

3. How many units of work are required to raise 10 cubic feet of water 34 feet high?

4. How many horse-powers are required to raise 6 cubic feet of water each minute to the height of 100 feet?

CHAPTER V.

PHENOMENA CONNECTED WITH GRAVITATION.

79. Weight has been defined as a measure of the earth's attraction. If a lead ball be suspended by a string, it constitutes what is called a plumb line. If a plummet hangs so that its point touches the surface of a vessel of water, the line and the surface of the water will be at right angles to each other, Fig. 25. The direction of the line at any place is called the *vertical*, and a line at right angles to it is called a horizontal line. If vertical lines are drawn at different places on the earth, they will all be directed toward the earth's center. Hence, the *direction of terrestrial gravity* is toward a point at or near the center of the earth, Fig. 26. At places near each other these verticals may be considered as parallel.

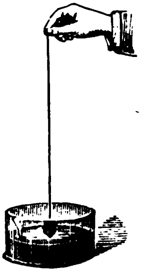

FIG. 25.

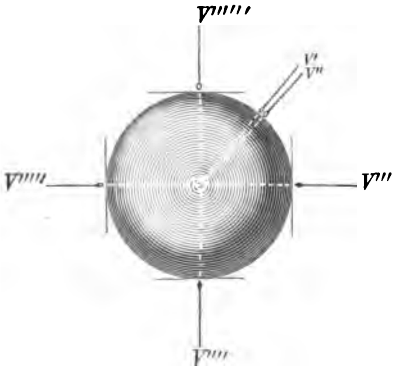

FIG. 26.

80. The center of gravity is the point about which all the parts of a body balance each other. Each particle of a body is drawn toward the earth's center by gravity, and, hence, the effect of gravity on a body, taken as a whole, will be the same as the resultant of an infinite number of equal and parallel forces. If we suspend a body so that it will hang freely from a point, a plumb line attached to the same point will show the direction of this resultant. Now, on repeating this experiment, after suspending the body from another point, a second resultant will be found, and the center of gravity will be the common point of intersection of any two resultants.

81. When the center of gravity is supported, the body will remain at rest. Hence, (1) the weight of a body may be considered as concentrated in the center of gravity; or (2) the center of gravity may be regarded as the point of application of the force of gravity, since it is the only point common to all the resultants. The line of direction of a body will be the vertical passing through the center of gravity, Fig. 27.

FIG. 27.

82. Although a body will remain at rest, or in equilibrium, when its center of gravity is supported, this equilibrium may be one of three kinds:

(1) *A body is in stable equilibrium* if it tends to return to its original position after it has been somewhat displaced. This will always be the case when any change of position *elevates* the center of gravity. A plumb line, when disturbed, finally comes to rest in its original position.

(2) *A body is in neutral equilibrium* when it remains at rest in any adjacent position after it has been displaced. This will be the case when the point of support *coincides* with the center of gravity, as when a wheel is suspended on its axle.

(3) *A body is in unstable equilibrium* when it tends to depart further from its original position after it has been

slightly displaced. This will be the case when the point of support is *below* the center of gravity. Thus, in Fig. 28, the cone *B* is in unstable equilibrium. It may be balanced in this position, but the least displacement will throw the line of direction beyond the point of support, and the cone will topple over. The cone *A* is in stable equilibrium, because its center of gravity is as low as it can be. The cone *C* is in neutral equilibrium, because if it is rolled around the center of gravity will not be raised or lowered.

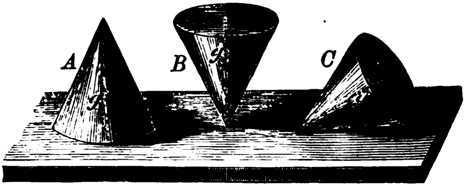

FIG. 28.

The toy shown in Fig. 29 is in stable equilibrium, although the figure without the balls would be unstable. The addition of the balls has the effect of throwing the center of gravity below the point of support. The same principle is illustrated in Fig. 30. A pail is suspended from a stick lying on the edge of a table, and a second stick, *EG*, is placed with one end against the corner of the pail, and the other in a notch cut in the horizontal stick *CD*. By this contrivance the center of gravity of the connected bodies is brought under the edge of the table, and the whole is in stable equilibrium.

FIG. 29.

The pail may now be filled with water without changing the equilibrium.

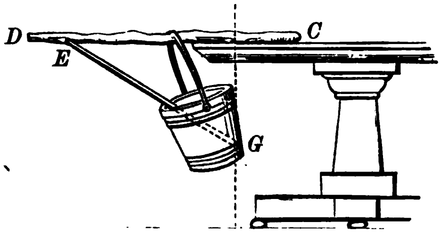

FIG. 30.

83. **The relation which gravity bears** to equilibrium may be shown by the apparatus represented in Fig. 31. It consists of a cork, through which have been thrust, at right angles to each other, two half knitting needles and one whole one, and supported by two wine-glasses placed under one of the shorter needles. By pushing the vertical needle up and down, the position of the center of gravity can be altered at pleasure, and the apparatus brought into either stable or unstable equilibrium. This is a case of a body resting on two points. A man on stilts is another—when at rest, he can be only in a state of unstable equilibrium. A man walking on a tight rope uses a long pole, which he thrusts from side to side to assist him in keeping the center of gravity vertically over the rope. A person walking on the thin edge of a plank, throws out his arms for the same reason.

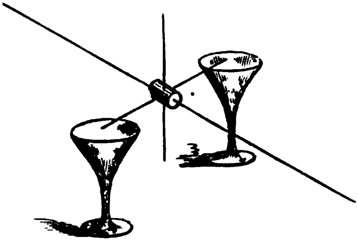

FIG. 31.

84. **The stability** of a body depends on the relation which the center of gravity bears to at least three points not in the same straight line, and on which it is supported.

The base of a body is the polygon formed by connecting the points of support; as, for example, the legs of a table.

A body resting upon a base is stable, when the line of direction falls within the base. The stability of bodies may be estimated by the force required to overturn them. This will be the force required to raise the entire body to the height that the center of gravity would be elevated in order to bring the line of direction beyond the base.

The diagrams in Fig. 32 represent sections of different solids drawn through the center of gravity, G. To turn any of these bodies over the edge *E*, the center of gravity must be raised through the height *HT*. A careful study of these figures leads to the following deductions:

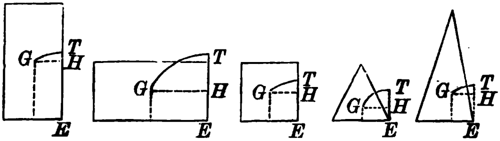

FIG. 32.

(1) The stability of bodies of the same height is increased by widening the base. The legs of chairs are inclined outward. A child's high chair has a very wide base. Candlesticks and inkstands have broad bases.

(2) The stability of bodies is increased by bringing the center of gravity to the lowest possible position. In loading a wagon or a ship the heaviest articles are placed at the bottom. A load of hay is easier overturned than a load of stone.

(3) Of bodies having the same height and base, but of dissimilar figure, the pyramid is the most stable.

Now compare the sections of the inclined figures in Fig. 33, and, we may add,

(4) The stability of a body is the greatest when the line of direction passes through the center of the base.

(5) When the line of direction falls without the base, the body will fall, because the center of gravity is unsupported. The leaning towers in Pisa and Bologna incline far from a perpendicular position. In these the line of direction still falls within the base; but the visitor who sees them for the first time can not help thinking that they are likely to fall.

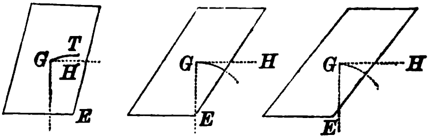

FIG. 33.

85. Practical applications.—The center of gravity in man lies between his hips; his base is the area inclosed by his feet. The different attitudes assumed by persons in standing or moving about are the results of instinctive efforts to keep the line of direction within the base. A man standing with his heels against a vertical wall finds it difficult to stoop to the floor without falling forward. In running, or in climbing a hill, the body is thrown forward, so that its weight may be carried with less effort. In descending a hill, a man leans backward, so that his weight shall not cause him to fall forward.

When a person carries a load, he endeavors to preserve the line of direction, common to himself and the load, within the base. If a heavy load is in the right hand, the body is inclined to the left, and the left hand thrown out. If the load is equally divided between his hands, or placed on his head, there is no tendency to lean to either side. If the load is on his back, he leans forward; if carried in his arms, he leans backward.

RECAPITULATION.

The center of gravity is the point in which the weight of the body may be considered as concentrated.

Equilibrium is stable, neutral, or unstable, according to the position of the center of gravity.

Stability depends on the relation which the center of gravity bears to the base.

CHAPTER VI.

THE LAWS OF FALLING BODIES.

86. Gravitation has been shown to produce pressure; we are now to study how it acts in producing the motion of falling bodies. If we attempt to experiment by dropping different balls from a height, we shall meet with many difficulties.

(1) The resistance of the air. Light bodies, as feathers and leaves, almost float in the air; but if any two bodies whatever, as a coin and a feather, be made to fall through a perfect vacuum, they will reach the ground in exactly the same time. If two bodies have the same weight, but are of different material, as a lead bullet and a cork, the difference in bulk will make so great a difference in the resistance of the air as to make the cork fall perceptibly slower. If the bodies were of the same material, but of different size, the resistance of the air would be slightly in favor of the larger ball, although they would reach the ground in very nearly the same time.

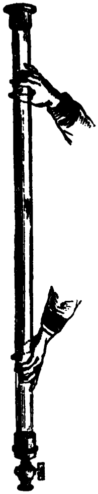

FIG. 34.

(2) If we catch equal balls, dropped from different heights, we shall not only find that the swiftest balls are those which have fallen through the greatest heights, but that the velocity increases so rapidly that we can not readily measure the rate of increase in a free fall. There are several methods by which we may render the initial velocity so slow that it can be accurately measured. The simplest of these methods is that of *Galileo*, who first deter-

mined the law of falling bodies by rolling smooth balls down a polished groove cut in a plane which he inclined at different angles of elevation. When a body rests upon an inclined plane, its weight or gravity is resolvable into two portions, one producing pressure on the surface, and the other tending to produce motion down the plane. This latter portion bears the same ratio to the whole force of gravity as the height of the plane does to its length; and, hence, we may diminish the velocity of the ball at pleasure by lowering the height. Nevertheless, only the absolute motion will be changed; the body will pass, in successive moments, through spaces bearing the same ratio to each other as if it fell freely through the air.

87. To repeat the experiment of Galileo, stretch two parallel wires between the walls of a room, at any convenient angle, as in Fig. 35. On the lower wire hang a weight to a pulley, so that it will move with little friction, and on the other fasten a convenient index, as a bell or a slip of paper, so that it may be struck by the top of the pulley *b*.

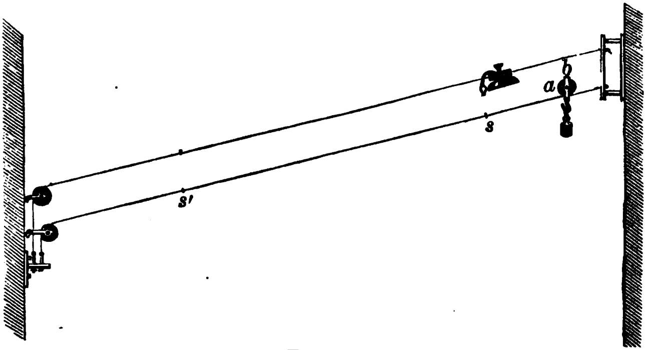

FIG. 35.

Suppose that the inclination of the wire is such that, in the first second, the pulley passes over the space as; in the second, over the space ss'; in the third, over $s's''$; and so on.

If we measure these spaces, taking that of the first second as unity, we shall find that they increase in the series of odd numbers—1, 3, 5, 7, etc.—or at the rate of two spaces for each second. This proves that increase of velocity is uniform; and that for bodies near the surface of the earth *gravity is a constant force.*

Let us now see what we have gained by our experiment. (1) The spaces described by a falling body increase in the series of odd numbers—1, 3, 5, 7. Any term of this series is equal to twice the number of seconds, minus one.

FIRST LAW.—*The space described by any falling body, in any given second, is equal to the product of twice the number of seconds, minus one, into the space described the first second.*

(2) The velocity is all the time increasing at the rate of two spaces for each second; therefore we have the

SECOND LAW.—*The velocity acquired by a falling body at the end of any given second is equal to the product of the number of seconds into twice the space described the first second.*

This product, it must be borne in mind, is the space a body would describe in the next second were gravity to cease to act, and not the space it actually describes.

(3) The total space passed through at the end of the first second is 1; at the end of the second second, $1 + 3 = 4$; at the end of the third second, $1 + 3 + 5 = 9$. This series increases in the order of the squares of the number of seconds; therefore we have the

THIRD LAW.—*The total space described by a falling body at the end of any given second is equal to the product of the square of the number of seconds into the space described the first second.*

It is evident that these laws are true, not only for any inclination of the plane, but also for a free fall. If in the experiment the height of the plane had been one foot and the length sixteen feet, the pulley would have traveled in the first second, one foot; in the second, three feet; in the third, five feet, and so on. Therefore, a body falling freely through the air would pass, in corresponding time, through sixteen times these spaces; or, it would fall in the first second, sixteen feet; in the second, forty-eight; in the third, eighty, etc.

88. It has been determined by careful experiment that, at the latitude of New York, a body will fall, in a vacuum through 16.08 feet in one second, and thereby acquire a final velocity of 32.16 feet. This last value is called *the increment of velocity due to gravity*, and is generally represented by $g = 32.16$. The space passed over during the first second is $\frac{1}{2}g = 16.08$.*

89. The velocity increases every second by the quantity 32.16 feet. The velocity at the end of the first second is 32.16; at the end of the second, 64.32; at the end of the third, 96.48, and so on. Now, the total space fallen through at the end of the first second is 16.08 feet; at the end of the second, 64.32 feet; at the end of the third, 144.72 feet, etc. If we compare these two series we shall find that *the velocity varies as the square root of the height fallen through*; for

$$32.16 : 96.48 :: \sqrt{16.08} : \sqrt{144.72}.$$

This is an important law. The velocity which is acquired

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* We may employ formulæ to express these laws by representing the space passed over *during* any second by s; velocity by v; the total height of the fall at the end of any given second by S, and the number of seconds by t.

First law $s = \frac{1}{2}g\,(2t - 1)$.
Second law $v = tg$.
Third law $S = \frac{1}{2}gt^2$.

On combining these formulæ $v = \sqrt{2gS}$, $t = \sqrt{2S \div g}$, or $\sqrt{S \div 16.08}$, etc.

by a body falling through any given height may be found by multiplying the square root of the height by $\frac{1}{4}g$, or by 8.04. Thus, a velocity due to a fall of four seconds, or to a fall of $(4^2 \times 16.08) = 257.28$ feet, is $8.04\sqrt{257.28} = 128.64$ feet.

90. If a body be thrown upward, the direction of the body is opposite to that of gravity, and, consequently, its velocity will be diminished each second by the quantity $g = 32.16$. Hence, the time of ascent is the same as that of a falling body which attains a final velocity equal to the initial velocity of the ascending body. Further, if a body be projected upward, the height to which it ascends is such that when it falls again, the body will have acquired under gravity during its descent a velocity equal to that with which it started upward.

91. Examples of this law. Suppose an iron ball is thrown upward with a velocity of 32.16 feet per second. At the end of one second it will come to rest and begin to fall. It will have moved in this second with an average velocity of $(32.16 + 0) \div 2 = 16.08$ feet, and hence will rise to the height of 16.08 feet.

Now, suppose the initial velocity be doubled, or 64.32 feet. It will rise two seconds with the average velocity of $(64.32 + 0) \div 2 = 32.16$, and will describe during the two seconds $32.16 \times 2 = 64.32$ feet.

If the initial velocity be tripled, its average velocity will be $(96.48 + 0) \div 2 = 48.24$, and the total ascent $48.24 \times 3 = 144.62$ feet.

Hence, with a double velocity of projection it will rise four times as high, with a triple velocity, nine times as high, and so on. That is, the heights to which a body will rise are as the squares of the velocities of projection.

In these examples the force has been doing work, for it has carried the body through space in opposition to the constant force of gravity. Hence, the energy of the force is proportional to the square of the velocity. The energy is also proportional to the mass of the body; for it is evident that it requires twice the energy to raise two pounds that it does to raise one pound. Therefore, the energy is proportional to the mass multiplied by the square of the velocity.

To compute the work done by a projectile force in opposition to gravity, it is sufficient to multiply the weight of the body expressed in pounds by the number of feet through which it is lifted. The height to which the body will rise is equal to $v^2 \div 64.32$, or to the square of the velocity divided by $2g$. Hence, the work of the force, expressed in foot-pounds, equals $mv^2 \div 64.32$.

In general, the energy of a force is equal to one-half the product of the mass into the square of the velocity, or $E = \frac{1}{2}mv^2$.

The factor $\frac{1}{2}mv^2$ is also called *vis viva,* or *living force.* It expresses the work that a moving body can perform before it is brought to rest, if no additional force is added to it; as for instance, the power which different cannon balls would have to penetrate obstacles, like planks, clay, etc.

92. If a projectile be fired in a horizontal direction, its path will be due (1) to the force of the gunpowder, and (2) to the constant force of gravity. In Fig. 36, suppose the velocity due to the powder to remain uniform during four seconds, and to be represented by equal spaces

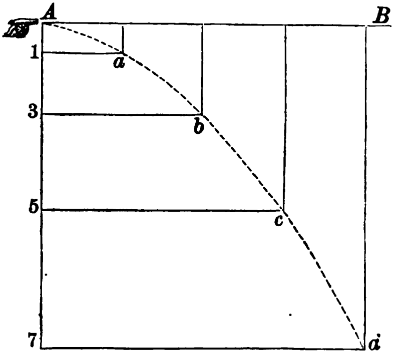

FIG. 36.

on the line AB, and represent the accelerating velocity due to gravity by the unequal spaces 1, 3, 5, 7. The resultant of these two forces will be the curve *Aabcd*, which is called a *parabola.*

93. Universal gravitation. Thus far we have considered gravity as acting only upon bodies near the earth's surface, and have found that for such bodies *gravitation is a constant force proportional to mass.* When we consider the earth's attraction upon remote bodies, as the moon, or the universal gravitation acting between the heavenly bodies, we must take into account not only (1) the mass of each body, but also (2) the *distance between the centers of gravity* of the two bodies. The law of gravitation, discovered in 1666 by Sir Isaac Newton, is usually stated as follows:

Every particle of matter attracts every other particle, with a force (1) *directly proportional to its mass*, and (2) *inversely proportional to the square of its distance.*

Whenever the distance between any two bodies is considerable, gravity must be considered as a variable force which diminishes as the square of the distance increases. Thus, suppose a body taken one thousand miles above the earth's surface, it is five thousand miles from its center. The force of gravity will, therefore, decrease in the ratio of $(\frac{4000}{5000})^2 = \frac{16}{25}$. At this distance a body will weigh $\frac{16}{25}$ of its surface weight, and during a fall of one second will acquire a velocity of $\frac{16}{25}$ of 32.16 feet = 20.6 feet per second. At the distance of the moon, which is about sixty times the earth's radius, the attraction of the earth becomes $(\frac{1}{60})^2 = \frac{1}{3600}$, and $g =$ .00892 feet. Hence, were the moon to fall toward the earth, it would pass in the first second over only .053 inch.

94. The earth's equatorial radius is 13¼ miles longer than the polar radius, and we should expect from this that the force of gravity would increase in going from the equator toward the poles. This oblateness of the earth causes a gain of $\frac{1}{590}$ part of the weight of a body. The rotation of the earth on its axis causes another gain of $\frac{1}{289}$ part. The sum of these is $\frac{1}{194}$, which is the gain in weight that a body would experience on being carried from the equator to the poles. Consequently, the increment of gravity will vary with the latitude, being at the equator 32.0934 feet; at London, 32.1912; at Spitzbergen, 32.2528.

RECAPITULATION.

Gravity is a constant force when mass alone is taken into account, but is a variable force when the distance between two bodies varies in a sensible ratio. It acts as a constant force on all bodies at the same place on the earth's surface and is a factor in the phenomena of pressure, of falling bodies, and of projectiles.

Its intensity may be measured:

(1) By the weight of bodies.

(2) By the increment of velocity of falling bodies.

(3) By the vibrations of a pendulum.

A force may be measured (1) by the momentum or the inertia of moving bodies. (2) By the energy, or the power of doing work.

PROBLEMS.

Suppose a body to fall freely in a vacuum:

1. How many feet will it fall during the fifth second? 1-4 The seventh? 201 The ninth? 2·/2

2. What will be its velocity at the end of the fifth second? The seventh? 224 The ninth?

3. How far will it have fallen at the end of the fifth second? The seventh? 78·1 The ninth?

4. How many seconds will be required for a fall of 402 feet? Of 578.28 feet? 6 What will be the final velocity attained in these cases? What is the ratio between these final velocities?

5. Suppose a body to be thrown upward with a velocity of 1029.12 feet per second, to what height will it rise? 5 How many seconds will elapse before it will come to rest? 32

CHAPTER VII.

THE PENDULUM.

95. If a heavy weight or bob, as *B*, Fig. 37, be suspended from a point, *A*, by means of a fine string, it will be at rest only when in the line of the vertical *A C*. If the bob be raised to *B*, it will tend to move through the curve *B C*, precisely as a ball would roll down an inclined plane of the same height, *H C*. The force of gravity will be partially resisted by the string, and the remaining component of gravity will force the ball in the line *B T*.

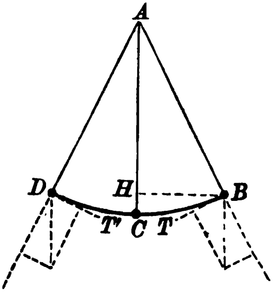

FIG. 37.

As the bob falls, it gradually gains in velocity, and, on falling the height *H C*, acquires sufficient momentum to carry it very nearly to *D*, an equal distance on the other side of the vertical. Thence it will return toward *B*, to repeat the vibrations until the resistance of the air shall bring it to rest.

This may be considered a *simple pendulum*, which, by theory, has its weight concentrated in a single vibrating particle. The motion of the pendulum from *B* to *D* or from *D* to *B* is called a vibration. The laws of the vibration of the pendulum may be found, experimentally, by using simple pendulums of different lengths and weights, as shown in Fig. 38.

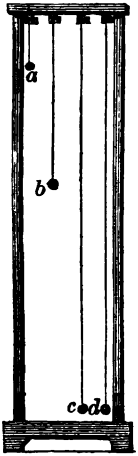

FIG. 38.

PHYS. 6.

96. The vibrations of a pendulum are caused by gravity alone; hence, the time of vibration will not vary with the quantity or quality of the weight suspended. If the ball *c* be of copper and *d* of wood they will vibrate in the same time. Neither will the time of vibration vary to a sensible amount, whether the arc through which the bob passes be large or small, because any increase in the length of the arc is so compensated by the increased velocity of the fall, that the same pendulum will describe an arc of five degrees in about the time required for an arc of five minutes. Hence:

97. The time of vibration is dependent only on the length of the pendulum. If we make one pendulum, as *a*, one foot long, and another, as *b*, four feet long, the first will vibrate in one-half the time of the other; and if a third pendulum, *c*, be nine feet long, the first will vibrate in one-third of its time; that is, *the times of vibration of any two pendulums are proportional to the square roots of their lengths;* and conversely, *the lengths of any two pendulums are proportional to the squares of their times of vibration.*

At New York, a pendulum beating seconds is 39.1 inches long; a half seconds pendulum is $39.1 \times (\frac{1}{2})^2 = 9.78$ inches; of one vibrating once in three-fourths of a second is $39.1 \times (\frac{3}{4})^2 = 22$ inches.

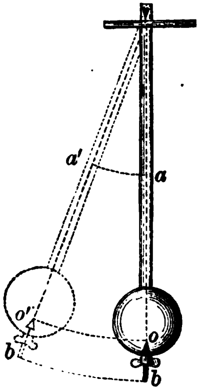

FIG. 39.

98. The compound pendulum consists of a heavy bob, suspended by an inflexible bar, from a fixed point, Fig. 39. In this, the mass of the bob and the weight of the bar are both to be regarded. In a rigid body, it is manifest that those particles nearest the point of suspension will tend to vibrate in the shortest time. Hence, a particle at *a* will accelerate a more distant particle at *b*, and the more distant particles will retard those that are nearer the point of suspension. There will, however, be one particle, as at *o*, which moves at the average rate of all, in which the tendency of the particles above it to accelerate its motion is exactly compensated by the tendency of the particles below it to retard its motion. This particle will, therefore, move as if it were vibrating alone, suspended by a thread which had no weight, thus fulfilling the conditions of a simple pendulum. The position of this particle is called the *center of oscillation.*

99. The length of a compound pendulum is the distance between the centers of suspension and oscillation. In a uniform bar, suspended from one end, the center of oscillation will lie two-thirds of the length of the bar from the center of suspension.

100. The centers of oscillation and suspension are mutually interchangeable. It is this fact which enables us to determine the length of a seconds pendulum with accuracy. We may obtain good results by the following simple apparatus, Fig. 40. Make of hard wood a slender bar sixty inches long. Mark the position of the center of gravity, which should be made to correspond very nearly with the center of the bar. About 39.1 ÷ 2 = 19.55 inches above and below this point insert two needles.

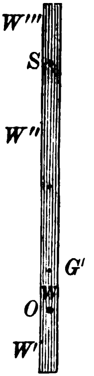

FIG. 40.

The bar, made to vibrate from either needle, will vibrate in about one second. If the vibrations from the two centers are not performed in the same time, the bar may be adjusted by elevating or depressing the center of gravity. This may be done by placing a coil of fine wire about the bar, where patient trial shall determine it is needed. When the times of vibration are the same from either point of suspension, the distance between them is the length of the pendulum. If the precise time of this vibration is known, as well as the length of the pendulum, the length of a seconds pendulum can be calculated.

101. Suppose that we have found, in this bar, that *S* is the center of suspension and *O* the center of oscillation, what effect will be produced on adding weights?

(1) All the matter of the pendulum may be considered as concentrated at *O*. Hence, if we add a weight, *W*, at this point no change will be made in the rate of vibration, although the bar will have a new center of gravity, as at *G′*.

(2) If the weight be applied below *O*, as at *W′*, the centers of gravity and oscillation will both be depressed, and the length of the pendulum increased.

(3) If the weight be applied between *S* and *O*, as at *W″*, its effect will be to raise the centers of gravity and oscillation, and to shorten the pendulum.

(4) If the weight be applied above *S*, as at *W‴*, it tends to retard the vibration of the bar, because the particles above *S* move in directions opposite to those below. The time of vibration is thereby lengthened, and, consequently, the center of oscillation lowered, while the center of gravity is raised.

(5) If sufficient addition be made above *S*, the center of gravity may be made to coincide with the center of suspension. The bar will then be in a state of neutral equilibrium, and if set in motion will tend to rotate continually.

(4 and 5) Now, as we can raise the center of gravity as near the center of suspension as we please without making them coincide, we may so lower the center of oscillation that it shall be *below the bar*. The bar may be made to

vibrate in two, three, or even five seconds, which correspond to the vibrations of pendulums whose lengths are 156.4, 351.9, and 977.5 inches. It is on this principle that the *metronome* is constructed.

102. **The principle of the pendulum** was discovered by Galileo in 1581, but it was first employed in clocks by Huyghens, in 1656. The utility of a pendulum, as a measure of time, depends upon the perfect equality in the times of its vibration. It is, therefore, essential that the distance between the centers of suspension and oscillation should be invariable. In ordinary clocks, heat tends to lengthen and cold to shorten the pendulum, and hence such clocks are apt to go too slow in summer and too fast in winter. Clocks are regulated by raising the bob to make the clock go faster, and by lowering the bob to make it go slower.

103. **Compensating pendulums** are those which are self-regulating. They are made of two substances in such proportions that the change in length of one upward is exactly compensated by an equal change of the other downward. The gridiron pendulum, Fig. 41, consists of a series of five steel bars, expanding downward, and a series of four brass bars expanding upward. In this the length of the steel bars is $\frac{100}{81}$ that of the brass. The seconds mercurial pendulum, Fig. 42, has at the end of a steel rod a cylinder containing a column of mercury 6.7 inches high.


FIG. 41.

104. The mode in which the pendulum is applied to clocks is shown in Fig. 42. The pendulum rod passing between the prongs of a fork, *f*, communicates

its motion to the rod, *r*, which oscillates on a horizontal axis, *a*. To this axis is fixed the *escapement*, *PP′*, terminated by two projections, or *pallets*, which work alternately in the teeth of the *scape wheel*, *S*. This wheel, acted on by the weight, *W*, through a train of wheels (not shown in the figure), tends to move in the direction of the arrow. If the pendulum is at rest, the wheel is held at rest by the pallet, *P′*, and with it all of the clock work.

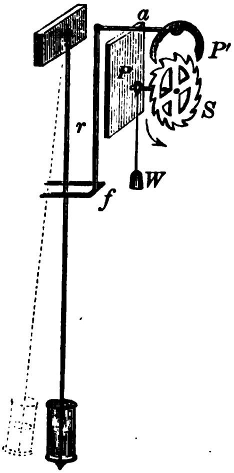

FIG. 42.

Now, if the pendulum be moved to the position shown by the dotted line, *P* is raised, and the wheel *escapes* from the pallet, and the weight causes the wheel to turn until its motion is arrested by the other pallet, *P′*, which has been brought in contact with another tooth of the wheel in consequence of the motion of the pendulum. In this manner the descent of the weight, and the consequent movement of the clock-work is regulated by the pendulum. The faces of the pallets are slightly inclined, so that each tooth of the wheel, on escaping, gives the escapement a slight impulse, which is communicated to the pendulum, and compensates for its loss of motion, due to friction and the resistance of the air.

105. Since the length of the seconds pendulum can be determined with great accuracy, we may use it as a means of determining the variation in the intensity of gravity on the earth's surface. The length of the seconds pendulum at the equator is 39.02167 inches; at New York, 39.10237 inches; at London, 39.13983 inches; at Spitzbergen, 39.21614 inches. The same pendulum would, therefore, vibrate in less time on being carried from the equator to the poles. Now, as the fall of the pendulum is due to gravity, the lengths of any two pendulums in different latitudes, which have the same time of vibration, are directly proportional to their increments of gravity. *

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* The time of vibration of a pendulum is expressed by the formula $t = 3.1416\sqrt{l \div g}$: if t be one second, then, at New York, $g = 9.87\,l$, or $g = 39.10237 \times 9.87 = 385.94$ inches. The fall of a body during the first second, *in vacuo* at New York, is one-half this quantity, or 192.97 inches.

RECAPITULATION.

The pendulum may be simple or compound.

The length of a pendulum is the distance between its centers of suspension and oscillation.

The time of one vibration depends,

(1) On the force of gravity.

(2) On the length of the pendulum.

(3) It is not sensibly influenced by the material of which it is made, nor by the arc through which it vibrates, excepting when these arcs are very unequal.

PROBLEMS.

1. What is the length of a pendulum making one vibration in four seconds? In one-fourth of a second? In eight seconds? In one-eighth of a second?

2. What will be the time of vibration of a pendulum thirteen feet long? Thirty inches long?

3. Suppose a seconds pendulum loses one minute a day, should it be lengthened or shortened? How much change is required?

CHAPTER VIII.

SIMPLE MACHINES.

106. A machine is an instrument by means of which a force, applied at a certain point, tends to produce motion at another point, more or less distant. The force employed in a machine is called the *power*. The resistance which is overcome by a machine at the point where the power acts, is called the *weight* or *load*.

107. Among the many advantages derived from the use of machines are:

(1) They enable us to utilize the products of nature. It is the knowledge of machinery that marks civilized life, since by it we have mills for weaving cloth, grinding flour, forging iron, etc.

(2) They enable us to employ other forces than our own, as the strength of animals, the forces of wind, water, and steam.

(3) They enable us to employ our full strength at one time. A person winding thread on a reel expends but a small portion of his strength; with suitable machinery he can turn many reels at the same time.

(4) They enable us to change the direction of our force. A sailor may hoist the sails of a ship while standing on deck, instead of pulling them up after he has climbed the mast.

(5) They enable us to perform work that we could not do with our unassisted strength. By using a crow-bar, a man may raise a large stone, which he could not stir with his hands.

108. No machine can create force. It is merely an inert instrument for the advantageous application of force. In fact, part of the force applied to machines is expended in overcoming friction, the resistance of the air, and in lifting the parts of the machine; hence, only a part of the force is effective in doing useful work. In the *theoretical* study of machines, these items are neglected, and it is generally assumed that no force is lost in the machine.

109. The work of the power is equal to the work of the load. If any machine enables us to lift a weight of ten pounds by the power of one pound, (1) the power must move ten times the space traversed by the load; (2) as the spaces are traversed in the same time, the power must move ten times as fast as the load. Conversely, if a power of ten pounds is required to move a weight of one pound, (1) the load will traverse ten times the space, and (2) with ten times the velocity of the power. The law of *virtual velocities* is an expression of these facts. It also receives a concise expression in the axioms,

> "What is gained in power is lost in velocity;
> What is gained in velocity is lost in power."

110. All machinery may be comprised in six elementary forms, called *simple machines*. These are (1) the lever, (2) the wheel and axle, (3) the pulley, (4) the inclined plane, (5) the wedge, (6) the screw. We shall study only the most important varieties of these.

111. A lever is an inflexible bar, moving freely about a fixed point, which is called a fulcrum. The *arms* of the lever are the parts into which the fulcrum divides it.

There are three classes of levers which are represented in Fig. 43. In levers of the first kind, the fulcrum is between the power and the load. In levers of the second kind, the load is between the power and the fulcrum. In levers of the third kind, the power is between the load and the fulcrum.

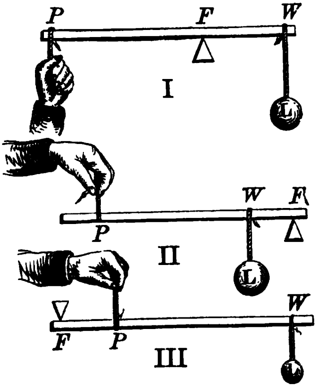

FIG. 43.

112. Familiar illustrations. A crow-bar is a lever of the first kind when we press one end *downward* to raise a load above a block used as a fulcrum, Fig. 44. It is a lever of the second kind, when one end rests on the ground as a fulcrum and we raise the other end *upward* to lift the load, Fig. 45. A fishing rod is a lever of the third kind; the fish being the load, the power is applied by one hand, while the other hand at the end of the rod acts as the fulcrum. The hinges of a door are its fulcra; the load is at the center of gravity of the door; in closing it, it is a lever of the second kind, when the hand is applied near the latch; but a lever of the third kind when the hand is near the hinges.

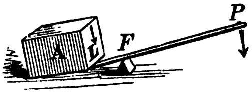

FIG. 44.

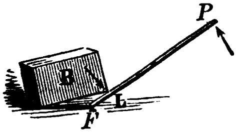

FIG. 45.

Since the work of the power is equal to the work of the load, the power multiplied by the vertical distance through which it passes equals the load multiplied by the vertical distance through which it passes. This law applies to all machines, but we can give it another expression, of greater convenience for each simple machine. Thus:

113. The law of the lever. *The product of the power mul-*

tiplied by its distance from the fulcrum is equal to the product of the load multiplied by its distance from the fulcrum.

That is, using the letters in Fig. 43:

$$P \times \overline{PF} = L \times \overline{WF}.$$

This law is called a *statical law*, because it expresses the relation of the power to the load when a machine is in exact equilibrium. To produce motion it is necessary that this equilibrium should not exist, which will be the case when one product exceeds the other. The machine will then move in the direction of the greater product.

Examples. In a lever of the first kind, sixteen inches long, with the fulcrum four inches from the load, and, therefore, twelve inches from the power, a power of one pound will balance a load of three pounds. Now, if an ounce be added to the power it will raise the load; if it is added to the load, the power will be raised.

In a lever of the second kind, sixteen inches long, with the load four inches from the fulcrum and the power sixteen inches, a power of one pound will balance a load of four pounds.

In a lever of the third kind, sixteen inches long, with the power four inches from the fulcrum, a power of four pounds will balance a load of one.

If we wish to prove these by actual experiments, we must first balance the lever by a sufficient counterpoise, before attaching the power and the load.

114. Levers of the first and second kinds are generally used to move heavy weights with small powers. Their efficiency may be increased (1) by increasing the power; (2) by increasing its relative distance from the fulcrum. Levers of the third kind are used when we wish to move small loads with great velocity by the use of great powers. We may also employ levers of the first kind for the same purpose.

115. When a beam rests on two props and supports a weight between them, the amount supported by either prop may be estimated by considering it as the power and the other prop as the fulcrum. If A and B carry a weight between them on a pole, each man will bear half the burden if the weight hangs from the middle of the pole. In all other cases, the load sustained by each increases as the distance between him and the load decreases. For example: if the weight is one-third the length of the pole from A, he will bear two-thirds of the burden and B one-third. Two horses attached to a wagon may be made to pull unequal loads by placing the bolt of the whipple-tree nearer the stronger horse.

FIG. 46.

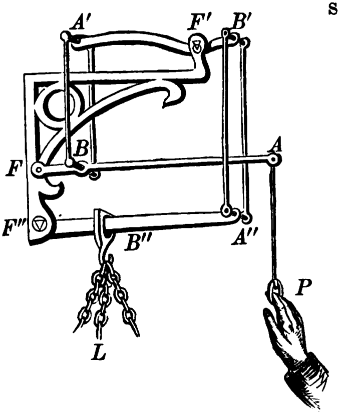

FIG. 47.

116. When a small force is required to sustain a considerable weight, and it is not convenient to use a long lever, a combination of levers, called a compound lever, may be employed.

A compound lever is shown in Fig. 47. *A F* is a lever of the second kind; the power, *P*, acting at *A* produces a downward force at *B* as many times greater than itself as the distance *A F* is greater than

BF. This effect is then transmitted as a power at A', which will tend to raise B' upward, with a force as many times greater than itself as $A'F'$ is greater than $F'B'$. Finally, the effect at B' will be a new power when transmitted to A'', and will tend to lift the load at B'', with another increase of effect. If these levers are so arranged that the power arm in each is ten times as long as the load arm, a power of one pound at P will balance a load of $10 \times 10 \times 10 =$ 1,000 pounds at L.

When a compound lever is at equilibrium, *the power multiplied by the continued product of the alternate arms, commencing with the power, equals the load multiplied by the continued product of the alternate arms, commencing with the load.*

117. The practical applications of the lever are very numerous. The balance is a lever of the first kind, having two equal arms. Delicate balances have a small needle attached to the center of motion, which oscillates before an index, n, to show very small deviations of the beam.

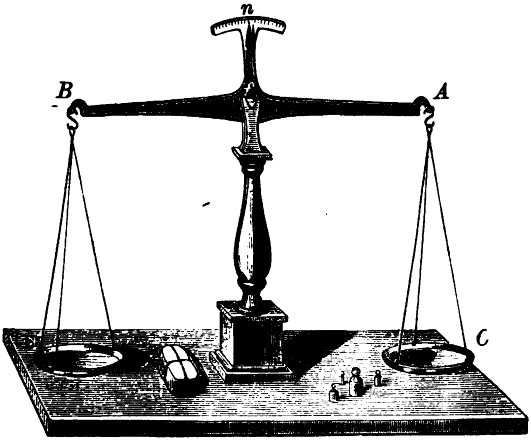

FIG. 48.

A balance is sensitive, when a very small difference between the weights causes a perceptible motion in the pointer. It must be in a state of stable equilibrium; that is, the center of gravity should be below the fulcrum, but not too far, because it will require too great a force to set it in motion. The apparatus of Fig. 31 well illustrates this; the horizontal needle will be the most sensitive to a small addition of weight, when the vertical needle is so placed that the center of gravity of the apparatus is a very little below the axis of suspension.

The arms of a balance must be equal in length, otherwise one will have a greater leverage than the other, and unequal weights will be required to produce equilibrium. To test this, place weights in each scale pan and bring the beam to a horizontal position. Now transfer the weights to the opposite scale pans. If the beam remains horizontal, the arms are equal.

118. Dishonest dealers are said to use balances with unequal arms, placing their merchandise when buying in the shorter arm, but when selling in the longer. The true weight of the merchandise is the square root of the product of the false weights. That is, if a body requires nine pounds to balance it from one side and four pounds from the other, the true weight is six pounds.*

119. The wheel and axle consists of a wheel and cylinder firmly united and free to revolve on a common axis. The power is applied at the circumference of the wheel and tends to move a load applied at the circumference of the cylinder or axle. This machine acts continuously as a lever

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*When a body whose true weight is w is in C, let it be balanced by x pounds in E. When in E, by y pounds in C, and let A and B be the lengths of the arms. Then,

$wA = xB$ and $wB = yA$. Multiplying these together $w^2AB = xyAB$. Dividing by AB, $w^2 = xy$. $w = \sqrt{xy}$.

of the first kind, the fulcrum being at *F*, the common center, the arms of the lever being *A F* and *F B*, the radii of the wheel and axle. Hence, *the power multiplied by the radius of the wheel equals the load multiplied by the radius of the axle.* That is, $P \times \overline{AF} = L \times \overline{BF}$.

Example. When the wheel is six feet in radius and the axle six inches, a power of one pound will balance a load of twelve pounds.

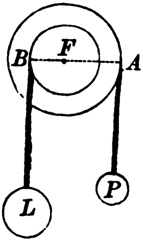

FIG. 49.

120. In the various forms of this machine, the load is generally attached to a rope wound round the axle; the power is applied in several different ways.

The form represented in Fig. 49 is that used in warehouses, in which the power is applied by means of a rope coiled on the wheel. When the rope on the wheel is unwound, that on the axle is wound up, and the load raised. The power may also be applied to pins projecting from the wheel, as in the steering apparatus on large vessels.

FIG. 50.

It is not necessary that the power be applied to a complete wheel, since a single spoke will answer. The *winch* of the common windlass, Fig. 50, is such a spoke for the application of the power. In the windlass used on ships, the winch is replaced by handspikes which fit into slots cut in the axle, and are shifted as occasion requires. The *capstan*, Fig. 51, is a vertical windlass, turned by men walking around it and pressing against handspikes inserted in the top or drum.

FIG. 51.

121. The power of this machine may be augmented on the principle of the compound lever, by combining several, so that the axle of the first may act on the wheel of the second, and so on. These are frequently connected by means of cogs, as in clock-work; or by means of endless bands of leather, as in turning lathes.

FIG. 52.

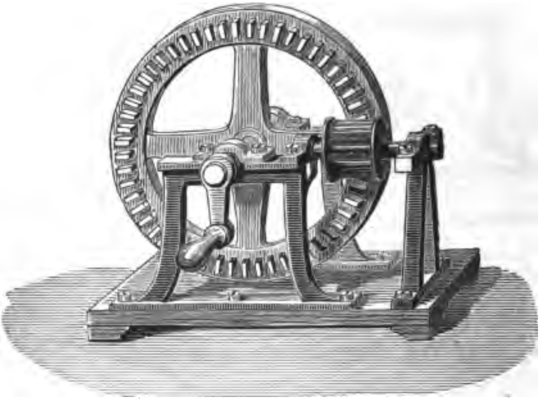

FIG. 53.

122. The pulley. Suppose a cord, fastened at one end to a hook, supports a load at the other end. The tension of the cord will be transmitted throughout its whole length, and exert a force on the hook equal to the weight of the load. If the cord be passed over the hook and one end held by the hand, the tension of the cord will be the same, and the hand must exert a force equal to the load. If we pull up the weight by the hand, we shall gain no mechanical advantage except a change in the direction in which the power acts. In fact there will be a loss, due to the friction of the cord upon the hook. We may diminish the friction by passing the cord over a wheel revolving on the hook as its axis, but can not lessen the tension of the cord. A *pulley* is a small grooved wheel revolving about an axis, and having a cord passing over its circumference. If the axis is fixed, the pulley is a *fixed pulley:* if the axis is movable, the pulley is a *movable pulley.*

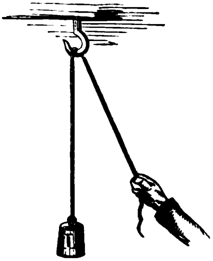

FIG. 54.

123. In the fixed pulley the power and load are equal. The advantage derived from its use is merely a change in the direction of the power. Thus, if a fixed pulley be attached to the rafters of a house, a man standing on the ground may raise loads to any floor of the building. As it is easier for him to pull the rope down than it would be to lift the weight directly upward, he can also afford to overcome the friction of the pulley. By the use of two fixed pulleys, as in Fig. 55, horizontal motion may be converted into vertical.

FIG. 55.

124. Movable pulley. If a cord be fastened at each end to a hook and a load hung by a ring in the middle of the cord, the weight of the load will be distributed; that is, each half of the cord will support but half the load. Therefore, if a fixed pulley take the place of one of the hooks, the power required to support the load will be one-half of the weight of the load. If it is desired to elevate the load, a movable pulley may be substituted for the ring in order to have less friction, as in Fig. 57.

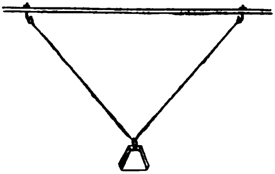
FIG. 56.

If one end of the cord be attached to the top of the movable pulley, as in Fig. 58, the tension due to the load will be distributed in three equal parts. Consequently the tension of the part of the cord to which the power is applied will be one-third of the load, and the combination will be in equilibrium when the power is one-third of the load. In the arrangement of Fig. 59, the power is one-fourth of the load.

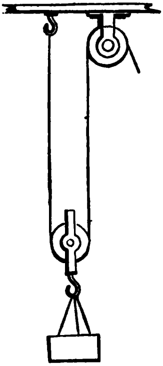
FIG. 57.

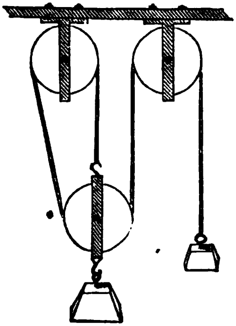
FIG. 58.

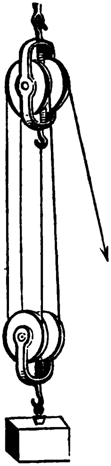
FIG. 59.

125. As fixed pulleys do not increase the power, the gain in the last three examples must be due to the distribution of the tension among the parts of the rope supporting the movable pulley. Hence, *the load equals the power multiplied* *by the number of parts of the cord engaged in supporting the movable pulley.**

126. The inclined plane is a hard, smooth, inflexible surface, inclined to the horizon. When a load is placed on a horizontal plane, the whole weight is supported by the plane: if the plane is tilted, a portion of its weight tends to make the load slide or roll down the plane. Thus in Figs. 60 and 61, the weight of the load lies in the direction of gravity, LG: this may be resolved into two components, one, LN, pressing upon the plane and perpendicular to it; the other, LE, which must be counterbalanced by the application of power, to prevent the load from sliding down the plane. The steeper the plane, the greater will be the power required. We shall consider two cases.

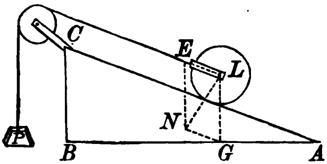

FIG. 60.

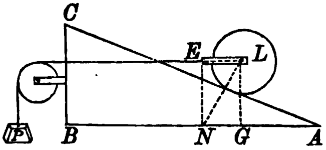

FIG. 61.

(1) When the power acts parallel with the plane, as in Fig. 60, LE represents the power required, and LG, or its equal, EN, the weight of the load. The triangles, LEN and ABC, are similar, and LE will bear the same relation to EN that BC does to AC; that is

Power is to load :: $LE : EN$, or :: BC to AC.

Hence: *the power equals the load multiplied by the ratio of the vertical height of the plane to its length.*

Thus, the power required to keep a barrel weighing two

---

* The law supposes that there is but one cord, and that its parts are parallel to each other.

hundred pounds on a plank twelve feet long, with one end on the ground and the other on a wagon three feet high, will be $200 \times \frac{3}{12} = 50$ pounds.

This is the most advantageous way of applying the power, because its whole effect is expended in raising the load.

(2) When the power acts parallel with the base, as in Fig. 61, a part of the power is expended in increasing the pressure on the plane, and we shall find,

Power is to load :: $LE : EN$, or :: $BC : AB$.

Hence: *the power equals the load multiplied by the ratio of the vertical height of the plane to its base.*

127. Familiar examples are found in roads, which are seldom perfectly level. On a level road, the power of a horse drawing a wagon is expended in overcoming friction. On a road rising one foot in twenty, the horse must lift one-twentieth of the load besides overcoming the friction. If we reckon friction at one-eighteenth of the weight of the wagon and its contents, the power necessary $(\frac{1}{20} + \frac{1}{18})$ will be almost double that required on a level road. Hence, in ascending mountains the road winds about so as to increase the length of the incline.

128. The wedge is a movable inclined plane. If, instead of moving the weight along the inclined plane, Fig. 61, the plane had been pushed under the load, the same advantage would have been gained. Therefore, since in the wedge, the power is always exerted parallel to the base, *the power is to the load as the height of the wedge is to the base.*

129. The double wedge, as AcA', is the form generally used. As each face meets half the resistance, the power is to the resistance as half the thickness of the wedge is to its length, Bc.

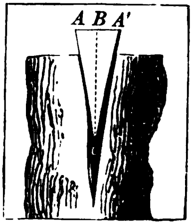

FIG. 62.

This law is of little practical use, beyond the general deduction that the efficiency of the power increases with the thinness of the wedge; because,

(1) The power is applied, not by a continuous force or pressure, but by percussion, and in such a form that we can not give it a numerical value.

(2) The surfaces to be separated generally assist the action of the wedge, by their elasticity at the moment of impact, and sometimes by the leverage of the faces to the cleft.

(3) The value of the wedge is often entirely dependent on friction, as is the case with nails, and the key-stones of arches.

130. **The wedge is used** where very great force is to be exerted through a small space. Masses of stone and timber are cleft by wedges. Ships are raised when on the stocks by wedges driven under their keels. Knives, awls, hatchets, chisels, and other cutting instruments, are wedges.

131. **The screw** is another variety of the inclined plane, as may be shown by winding a triangular piece of paper around a cylinder. The hypotenuse will form a spiral path exactly resembling the thread of a screw. The vertical distance, as *b c*, between two threads represents the height of the plane, and the circumference of the cylinder the base of the plane. The power acts parallel to the base, as in the second case of the inclined plane. Hence,

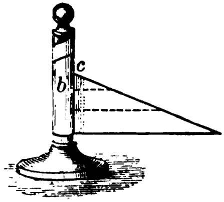

FIG. 63.

The power is to the load as the vertical distance between two adjoining threads is to the circumference of the screw.

132. **In actual practice,** the screw consists of two parts,

(1) a convex grooved cylinder, or *screw*, *S*, which turns within (2) a hollow cylinder or *nut*, *N*, whose concave surface is cut with a thread exactly corresponding to the threads of the screw. The power is employed either to turn the screw within an immovable nut, or to turn the nut about a fixed screw. In both cases, it is generally applied by means of a lever. This renders the contrivance a compound machine, whose advantage may be found by the following law:

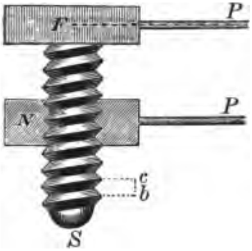

Fig. 64.

The power is to the load as the vertical distance between two adjoining threads is to the circumference described by the power.

Power is to load :: $bc : 2\pi\,\overline{FP}$, or :: $bc : 6.2832\ \overline{FP}$.

Example. If the threads of the screw are one inch apart, and the lever is four feet long, a power of five pounds will exert a pressure of $4 \times 12 \times 2 \times 3.1416 \times 5 = 1507.97$ pounds.

133. The screw is used for compressing cotton and hay, for expressing the juices of plants and fruits, for raising buildings, for propelling ships, and for many minor purposes.

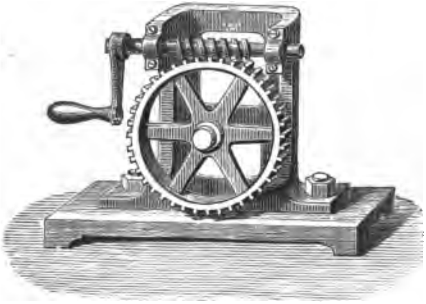
Fig. 65.

134. Compound machines are combinations of two or more simple machines. One of the most useful of these is the endless screw, Fig. 65; its thread works obliquely into the teeth of a wheel, which supplies the place of the nut. Cranes and derricks are combinations of pulleys with the wheel and axle. The crane shown in Fig. 66 has a wheel and axle at *G*, two fixed pulleys, *F* and *E*, and one movable pulley, *P*. The mechanical advantage of a compound machine is found by estimating the effect of the parts separately and then multiplying these together.

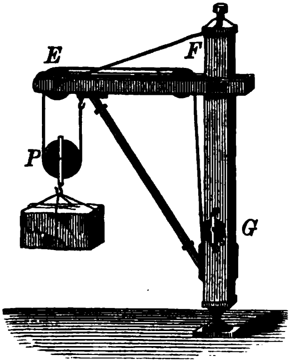

FIG. 66.

135. The human mechanism exhibits many examples of simple machines.

Thus, the nodding of the head illustrates a lever of the first kind, in which the load is the weight of the head; the fulcrum, the atlas bone; and the muscles of the neck, the power. When a man stands on his toes, the floor is the fulcrum; the power is applied at the heel by the tendon Achilles; and the weight of the body falls between the fulcrum and the power. This is a lever of the second kind. We employ a lever of the third kind in raising the fore-arm. The hand, and any thing that it contains, is the weight; the elbow-joint, the fulcrum; and the power is applied by a muscle attached to the fore-arm a little in front of the joint, Fig. 67. In biting by the front teeth, we employ a lever of the third kind. The force exerted by the muscles which raise the lower jaw is enormous. In man it can not be less than three hundred

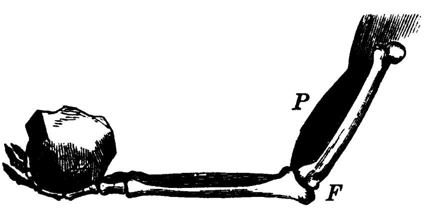

FIG. 67.

pounds, and in the tiger it must exceed two thousand pounds. The muscle which directs the eye downward and inward, passes through a cartilaginous pulley attached to the frontal bone. Some of the teeth are wedges, capable of cutting like chisels.

Throughout the entire frame we have surprising examples of economy of material to the end designed; combining lightness, force, firmness, elasticity, leverage, motion, resistance, security, and grace. These contrivances are so numerous, and so wonderfully constructed, that a volume would be insufficient to describe them.

RECAPITULATION.

Machines are simple or compound.

Simple machines employ	1. Leverage,	Lever, Wheel and axle.
	2. Tension of ropes,	Pulley.
	3. Inclined surfaces,	Inclined plane, Wedge, Screw.

Machines are compounded (1) by repeating the same simple machine, as the compound lever; (2) by uniting two or more simple machines, as the crane.

PROBLEMS.

1. Suppose a power of 50 pounds moves through a vertical distance of 10 feet, how high can it lift a load of 250 pounds? How great a load can it lift 100 feet high? In each case what will be the relative velocities of the power and the load?

2. A power of 75 pounds is applied at one end of a lever 12 feet long to move a load at the other end; what will be the load when the fulcrum is at the center of the lever? When the fulcrum is 3 feet from the load? 1 foot from the load?

3. When the same bar is employed as a lever of the second kind, what will be the load when it is sustained at the center? At 3 feet from the fulcrum? At 1 foot?

4. If, with the same bar, the load and the fulcrum be placed at the ends and the power applied between them, what will be the load when the power is at the center? At 3 feet from the fulcrum? At 1 foot?

5. If, with the same bar, a power of 30 pounds balances a load of 180 pounds, how far from the load will the fulcrum be when it is used as a lever of the first kind? As a lever of the second kind?

6. If A and B carry between them, on a pole 9 feet long, a load of 150 pounds, how much will A bear when the load is 3 feet from him? 6 feet?

7. In the compound lever, shown in Fig. 47, *A F* is 6 feet long, *A′ B′* 4 feet, *A″ F″* 5 feet, and the distances *F B*, *F′ B′*, *F″ B″*, each 1 foot, what is the relation between the power and the load? What load may be sustained by a power of 60 pounds?

8. In a false balance, a bundle weighs 16 pounds in one scale pan and 9 pounds in the other, what is the true weight? What is the relative length of the arms? Prove the answers obtained.

9. In a wheel and axle, the radius of the wheel is 10 feet and that of the axle 6 inches; required, the load that may be sustained by a power of 1 pound? By 100 pounds?

10. With the same machine, what will be the length of the rope unwound from the wheel, when the load has been lifted 10 feet?

11. A capstan has an axle one foot in diameter, and is furnished with 5 handspikes, each 6 feet long; how much power must be applied at each handspike to lift an anchor weighing 4,000 pounds?

12. In a wheel and axle, the axle is 8 inches in diameter, and is turned by a winch of 2 feet radius; what is the load that may be lifted by a power of 100 pounds? What is the power required for 100 pounds?

13. In a train of 3 wheels, the number of teeth in each wheel is 64, the number of leaves on each pinion 16: when a power of 10 pounds is applied at the circumference of the first wheel, what load will be sustained at the third pinion? 640 How many times must the first wheel revolve in order that the third pinion be turned around once? 16.

14. In a system of 2 movable pulleys, with a continuous cord, the power is 100 pounds; required, the load.

15. On a road rising 1 foot in 25, what power will be required to sustain a wagon weighing 1,000 pounds?

16. In a book-binder's press, the lever is 6 feet long, and the threads of the screw 0.5 inch apart; what pressure may be applied by a power of 100 pounds?

17. If 12 turns of a screw carry the head forward 1 inch, what power, applied to a lever 6 feet long, is required to exert a pressure of 2000 pounds?

18. In the crane, Fig. 66, the axle at *G* is 6 inches in diameter, and the winch 3 feet in radius, with one movable pulley; what will be the relation between the power and the load? The wheel and axle remaining the same, what advantage may be gained by the use of a system containing four movable pulleys?

CHAPTER IX.

FLUIDS AT REST.

136. Solids act in masses; if we move one end of a stick the whole stick will be moved, by reason of the coherence of its molecules. The molecules of fluids act independently of each other, and hence will move on the application of a very small force.

137. Liquids and gases are governed by very nearly the same laws. The principal difference between them arises from the fact that gases are easily reduced in volume by pressure, while liquids may be considered as *non-compressible fluids.* The pressure of one atmosphere causes in water a decrease of only 0.00005 part of its original volume, and in mercury only 0.000005 part. As soon as the pressure is removed both liquids and gases return to their original volume, showing that they are both *perfectly elastic.* The energy of the elasticity with which they resist a force that compresses them is exactly equal to the compressing force.

138. Solids transmit pressure only in the direction of the force acting upon them. *Liquids transmit pressure undiminished in every direction.* This fact may be demonstrated by experiment. Take a vessel of any shape, in whose sides are cylindrical apertures closed by movable pistons, whose areas are, respectively, 1, 2, 3, 4, and 5 square inches, and fill the vessel with water so that it shall be

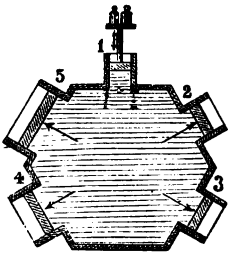

FIG. 68.

completely closed in on all sides. Suppose the water to have no weight and the pistons no friction, or, what amounts to the same thing, suppose the friction is equal to the weight of the water, then there will be no tendency to motion anywhere in the vessel. Now apply a pressure of one pound upon the piston whose area is one square inch. Each molecule beneath the piston will be slightly compressed, and develop a corresponding elastic force in each. Each one will then react upward against the piston, downward against the molecules beneath, and sideways against the adjoining molecules, or against the sides of the vessel. The next tier of molecules will transmit the pressure in the same way to a third tier, and they onward, until every molecule both receives and transmits an equal pressure. Therefore, each piston will be thrust outward with a force proportional to the number of molecules beneath it, and, as these are of the same size, the pressure on each piston will be proportional to its area. It will require a pressure of two pounds to keep a piston of two square inches in place; three pounds for one of three square inches, etc. Any portion of the sides of the vessel, or of any solid immersed in the fluid, will, in like manner, sustain a pressure *in proportion to its area.*

139. A liquid is not at rest unless its molecules are somehow restrained by a vessel or its equivalent. In an open vessel, the force of gravity tends to bring each molecule as near the earth's center as possible. This will only be the case when the surface is perpendicular to the force of gravity; for suppose the surface were curved, as in Fig. 69, then a particle at *M* would exert a pressure by reason of its weight. This would be transmitted downward and sideways; but, as there would be no equal pressure be-

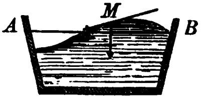

FIG. 69.

low A to counterbalance it, a part of its pressure would produce motion in the fluid, and would finally bring the surface to the common level, AB.

140. As two verticals, near each other, are sensibly parallel, any liquid surface between them is *level or horizontal.* As two verticals, drawn at distant points, incline toward each other, large surfaces of liquids are curved so as to correspond with the general form of the earth's surface.*

141. Water always seeks its lowest level. It is on this principle that water is conveyed from reservoirs through pipes to supply cities. The water rises in the pipes to the exact level of the reservoir; and would rise to the same level in fountains, were it not for the resistance of the air, and other impediments to motion. The spirit level, which is used to determine horizontal lines, operates on the same principle.

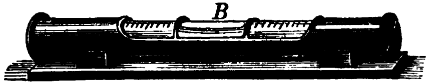

FIG. 70.

This consists of a closed glass tube, slightly curved, and nearly filled with some liquid not easily frozen. The tube is then so placed in a brass case that when the apparatus is perfectly horizontal, the small bubble of air, B, will lie exactly at the highest point.

142. Fluids exert pressure in consequence of gravity. Suppose the vessels, $A\,B\,C\,D$, to be filled with any liquid to the same level, CD, and consider each divided into an infinite number of horizontal strata, as indicated by the lines

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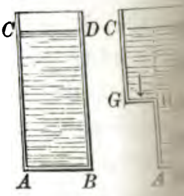
* The amount of curvature increases with the square of the distance, as shown by the following table:

Distance in miles......	1	2	3	4	5	6	7	8	9	10
Curvature in feet......	.667	2.67	6.	10.67	16.67	24.	32.67	42.67	54.	66.67.

of the diagram. Each stratum may then
a cylinder exerting a pressure on its bas
weight. By the law of fluid pressures, the weight of each stratum above will be transmitted undiminished to each stratum below in the ratio of their areas; therefore, the pressure sustained by any section, as AB, GL, GR, will be equal
column of the liquid whose base equ
section, and whose height equals its dep



143. The pressure exerted by a fl
to its depth. (1) The downward pres
illustrated by tying a piece of sheet ru
a long open tube. On pouring water i
ber will be distended in proportion
water. (2) The upward pressure of l
by thrusting
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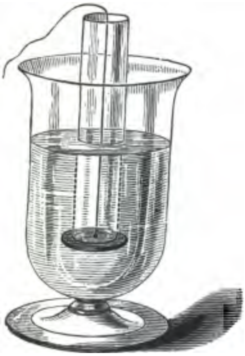


Fig. 72.

er face will be pressed upward by the CDN. The solid will, consequently, be a pressure which equals the difference of $MCDN - MABN = ABCD$. This is ht of a volume of the fluid equal to the d.

rce of gravity tends to bring the body e upward pressure of the fluid tends to will be to lessen the apparent weight of rare body, like cork, will rise to the sur- lisplace a volume of the fluid *equal to its* tached to a balance it will exert no pull, to have lost all its weight. (2) A dense sink deeper in the fluid, but if this is re- the pull will be less than its whole weight the volume of the fluid displaced; that is, a volume *equal to its own bulk*.

ciple was discovered by Archimedes, about ay be verified by hanging to one arm of a , and a solid cylinder, *B*, within the cup. Having d the balance by weights ale pan, immerse the solid, e equilibrium will be de- he solid loses a portion of be restored when the cup, ater.

d immersed in a fluid loses t equal to the weight of an fluid.

FIG. 79.

ow understand how the olids is found (read pages 13 and 14).

of the diagram. Each stratum may then be considered as a cylinder exerting a pressure on its base equal to its own weight. By the law of fluid pressures, the weight of each stratum above will be transmitted undiminished to each stratum below in the ratio of their areas; therefore, the pressure sustained by any section, as *A B*, *G L*, *G R*, will be equal to the weight of a column of the liquid whose base equals the area of the section, and whose height equals its depth.

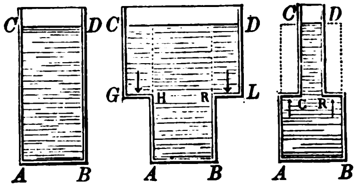


FIG. 71.

143. The pressure exerted by a fluid is proportional to its depth. (1) The downward pressure of liquids may be illustrated by tying a piece of sheet rubber over one end of a long open tube. On pouring water into the tube the rubber will be distended in proportion to the depth of the water. (2) The upward pressure of liquids is easily shown by thrusting the closed end of the tube into water, when the rubber will be driven into the tube further and further as the depth increases. It is generally demonstrated by taking an open tube, having disks of lead or leather closely fitting the lower end. Support the disk by a thread until the tube is plunged in a vessel of water. The disk will then be retained in its place by the upward pressure. If, now, the tube be carefully filled, the disk will not fall off until the weight of the interior column plus that of the disk exceeds the weight of the

FIG. 72.

exterior column. (3) The lateral pressure of liquids is shown by the velocity with which they flow from orifices at different depths. A fine illustration is represented in Fig. 73. It consists of a tall jar with a stop-cock near the base, and made to float on the surface of some liquid. If the jar be filled with water and the stop-cock closed, the lateral pressure at *L* and *L'* will be equal. Hence, the jar will remain at rest, because the pressures are equal; but on opening the cock, the pressure at *L* is removed, and the lateral pressure at *L'* will be effective in driving the float in the direction of the arrow, and opposite to the course of the stream.

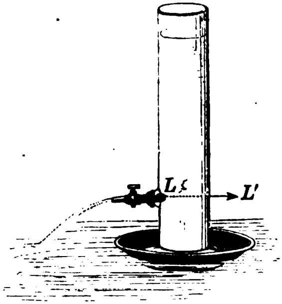


FIG. 73.

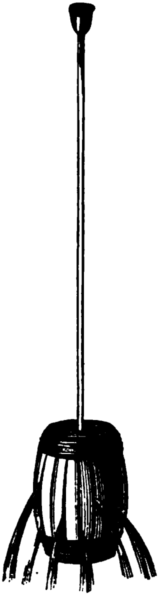


FIG. 74.

144. The pressure is independent of the quantity of the liquid. In 1647, Pascal fitted to the upper head of a small cask a tube about forty feet long. The cask being filled with water, he succeeded in bursting it by filling the tube. As an ounce of water will fill a tube forty feet long and $\frac{1}{15}$ of an inch in diameter, an ounce would have sufficed; for a tube $\frac{1}{15}$ of an inch in diameter has an area of only $\frac{1}{277}$ of a square inch, so that the ounce weight would multiply itself two hundred and seventy-seven times for each square inch on the vessel, which becomes a pressure of 17.31 pounds for each square inch. Either head of an eight gallon cask would have to sustain a pressure of about two thousand five hundred pounds, and the total pressure on the cask would have exceeded fifteen thousand pounds.

145. As fluid pressure is transmitted undiminished in all directions, it will not be affected by bends in the tube. The *hydrostatic bellows* consists of two boards, *A B*, united by stout leather, and a small tube, *c*, communicating with the interior. Water poured into the tube will lift the upper board, with a force proportioned to the height of water in the tube. Each foot in height represents a pressure of 0.4335 pounds to the square inch; therefore, if the upper board has an area of one hundred square inches, and the height of the tube is three feet, the weight capable of being supported on *A* will be .4335 × 100 × 3 = 130.05 pounds.

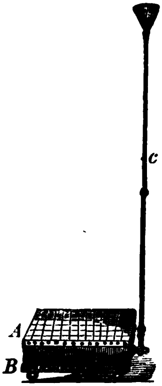


FIG. 75.

146. If *A* had been made to rise toward an immovable bar placed above it, any substance between the board and the bar would have been compressed with the force of 43.35 pounds for every foot in the height of the tube. By increasing the length of the tube, the pressure will soon become great enough to rupture the bellows. The same effect may be produced, if, instead of lengthening the tube, a piston is employed to force water down the tube. By the law of fluid pressures, a pressure equal to that upon the piston would be communicated to each equal area in the bellows.

147. Bramah's hydraulic press is constructed on this principle.

Within the collar of the iron cylinder, *B*, a cast-iron ram, *P*, works water-tight. The substance to be pressed is placed between the ram, *P*, and the immovable plate, *Q*. Water is brought by a force-pump into the small cylinder, *A*, and is thence driven by the piston, *r*, through the tube, *K*, into the larger cylinder. The advantage gained will be in proportion to the areas of the two cylinders. If the large cylinder is one hundred times the area of the small cylinder, one pound applied at the piston will produce a pressure of one hundred pounds on the ram. The efficiency of the press is further increased by the handle, *M*, a lever of the second class. If the distance from the fulcrum to the applied force is ten times the distance to the weight, a power of one hundred pounds will transmit one thousand pounds to the piston, and tend to raise the ram by a force of one hundred thousand pounds.

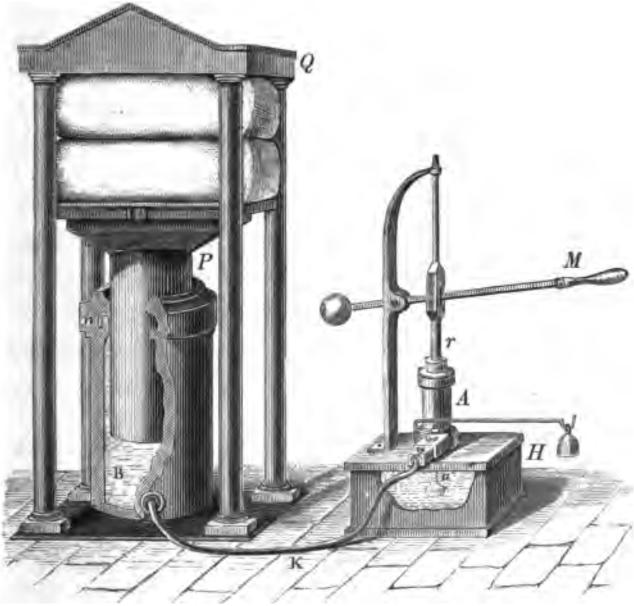


FIG. 76.

148. In this press very little power is lost by friction, and, practically, the advantage gained is limited only by the strength of the materials. Like all other machines, it is governed by the law of virtual velocities, and works very slowly. In the example supposed, one hundred parts of water driven out of the small cylinder would raise the ram but one part. The hydraulic press is used wherever great power is to be transmitted through small space, as in extracting oils from seeds and crude fats, and in pressing cotton for shipment. Two of these machines were employed to raise the immense tubes of the Britannia Bridge to their proper elevation. Such was the force employed to drive the water into the cylinder, that it was sufficient to raise a jet twenty thousand feet high, or over the peak of Chimborazo. With such pressures, the weight of the water in the smaller cylinder becomes inconsiderable.

149. The pressure is proportional to the density of the fluid. If mercury be poured into a U tube, so as just to fill the bend, and then water be poured into one arm of the tube, the mercury will be driven a little way into the other arm. Now, if we measure the height of the mercurial column above the lowest level of the water (represented in the figure by the dotted line), we shall find that it is $\frac{1}{13.6}$ as high as the column of water.

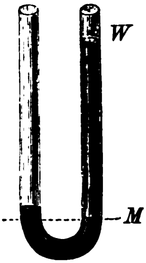


FIG. 77.

150. Principle of flotation. Suppose a solid, *A B C D*, to be immersed in water, every portion of its surface will undergo pressure. The horizontal pressures, on the sides of the body, will all be equal and opposite, and have no tendency to move the body in any direction. The upper face will be pressed downward by a liquid column,

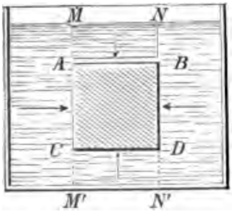


FIG. 78.

$MABN$, the lower face will be pressed upward by the liquid column, $MCDN$. The solid will, consequently, be urged upward by a pressure which equals the difference of these columns; $MCDN - MABN = ABCD$. This is equal to the weight of a volume of the fluid equal to the volume of the solid.

Now, as the force of gravity tends to bring the body lower, and as the upward pressure of the fluid tends to raise it, the effect will be to lessen the apparent weight of the body. (1) A rare body, like cork, will rise to the surface, and finally displace a volume of the fluid *equal to its own weight.* If attached to a balance it will exert no pull, and may be said to have lost all its weight. (2) A dense body will tend to sink deeper in the fluid, but if this is resisted by a string, the pull will be less than its whole weight by the weight of the volume of the fluid displaced; that is, by the weight of a volume *equal to its own bulk.*

151. This principle was discovered by Archimedes, about 230, B. C. It may be verified by hanging to one arm of a balance a cup, A, and a solid cylinder, B, which exactly fits within the cup. Having first counterpoised the balance by weights put in the other scale pan, immerse the solid, B, in water. The equilibrium will be destroyed, because the solid loses a portion of its weight, but will be restored when the cup, A, is filled with water.

Therefore, *a solid immersed in a fluid loses an amount of weight equal to the weight of an equal volume of the fluid.*

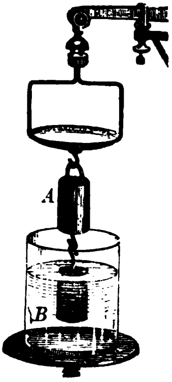


FIG. 79.

152. We can now understand how the specific gravity of solids is found (read pages 13 and 14).

We first weigh the body in air, then suspend it by a hair and weigh it in water. The difference of the two weights is the weight of an equal volume of water. Hence,

$$\frac{\textit{Weight of given substance in air}}{\textit{Loss of weight in water}} = \textit{Specific gravity.}$$

Thus, a mass of lead, weighing a pound in air, weighs 14.6 ounces in water. Its specific gravity is, therefore, $16 \div (16 - 14.6) = 11.4$.

153. When a solid is lighter than water, it is necessary to submerge it by attaching to it a heavy mass, whose weight in water and in air are known. The loss of the combined bodies is evidently the weight of water equal to their united volume. If the loss sustained by the heavy body alone is taken from this, the remainder will be the weight of water equal to the volume of the light body. The weight of the light body in air divided by this remainder, will give its specific gravity.

Thus, attach to a pound of lead two ounces of cork. The weight in water is 8.6 ounces. The loss of both bodies is $16 + 2 - 8.6 = 9.4$, but, as the the previous example shows, the lead loses 1.4 ounces, the weight of a volume of water equal to the cork is $9.4 - 1.4 = 8$ ounces. Therefore, the specific gravity of the cork is $2 \div 8 = .25$.

154. A floating body has a constant weight, but displaces a greater volume of light than of heavy liquids. Hence, if these relative volumes may be found, the specific gravity of any liquid may be found by dividing the volume which a floating body displaces in water, by the volume which it displaces in a given liquid. This is the principle of the *hydrometer.*

The hydrometer consists of a glass stem, near the bottom of which are blown two small bulbs. Some mercury or shot is placed in the lower bulb, to serve as ballast, and the point to which the instrument sinks in pure water is marked on the stem. It is then placed in a liquid whose specific gravity is known; the point to which it sinks is marked, and the intermediate space subdivided into equal spaces, called degrees. The value of these degrees in terms of specific gravity is then determined by a mathematical calculation. These instruments do not give accurate results, but are of convenience for rapid determinations.

Fig. 80.

A farmer roughly estimates the density of brine by noticing whether an egg or a sound potato will float in it.

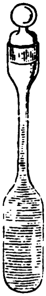


Fig. 81.

The specific gravity of liquids is accurately found by the *specific gravity bottle*, Fig. 81, by means of which we are enabled to weigh equal volumes of two liquids.

$$\frac{\textit{The weight of any given liquid}}{\textit{The weight of an equal volume of water}} = \textit{Specific gravity.}$$

155. The specific gravity of gases is found in the same way, only it is necessary to use very large flasks.

RECAPITULATION.

I. Liquids are both compressible and elastic.

II. They produce pressure by their weight, proportional to their depth, and transmit it as if it were an external pressure.

III. They transmit external pressure in every direction,

1. Undiminished.
2. Perpendicular to their surfaces.
3. Proportional to their areas.

IV. A liquid always seeks its lowest level.

V. The surface of a liquid at rest is horizontal.

VI. The upward pressure of a liquid upon a solid is equal to the weight of the fluid displaced.

1. A submerged solid loses weight equal to the weight of the fluid of the same volume.
2. A floating solid loses all its weight, and displaces a volume of the fluid equal to this weight.

VII. The standards for specific gravity are water for solids and liquids; and air for gases. The normal conditions are a temperature of 39.°1 F. for water and 32° F. for all other bodies, and a barometric pressure of 29.922 inches.

VIII. The specific gravity of a body is found by comparison with water and air.

1. By the relative weights of equal volumes.
2. By the relative volumes of equal weights.

PROBLEMS.

2,326

149,880

1. A reservoir is 120 feet long, 40 feet wide, and 20 feet deep; what is the weight of the water contained in it? What is the pressure on the bottom? On each side? The total pressure?

2. A mass of galena weighs 6 ounces in air and 4.8 ounces in water; what is its specific gravity?

3. The same mass attached to an ounce of cork weighs in water 2.7 ounces; what is the specific gravity of the cork?

4. A flask contains 900 grains of water, 800 grains of alcohol, or 1,350 grains of sulphuric acid; what is the specific gravity of the alcohol? Of the acid?

5. A boy's marble weighs in air 450 grains, in water 300 grains, in coal-oil 350 grains; required, the specific gravity of the marble and of the coal-oil.

6. If the upper board of the hydrostatic bellows has an area of 100 square inches, and a boy standing upon it raises water in the pipe to the height of 30 inches, what is the weight of the boy?

187,975 LBS

CHAPTER X.

FLUIDS IN MOTION.

156. We learned, in the preceding chapter, that the pressure of a fluid is proportional to its depth. Hence, if a vessel be filled with a liquid, and apertures *r*, *q*, *m*, *n*, *p*, be opened, the liquid will flow out with unequal velocities, being less for *r* than for any point beneath it, and equal for any two points at equal depth below the surface, as *p* and *v*. But the velocity does not increase in the simple ratio of the depth. The jet at *v* tends to rise to the level at *h*, and falls short of it only because of friction, the resistance of the air, and the weight of the particles falling back. If, then, the velocity at *v* is sufficient to carry the liquid through the vertical distance, *vh*, in opposition to gravity; *this velocity must be equal to that which a body would acquire in falling through the same space;* and this must be true for any

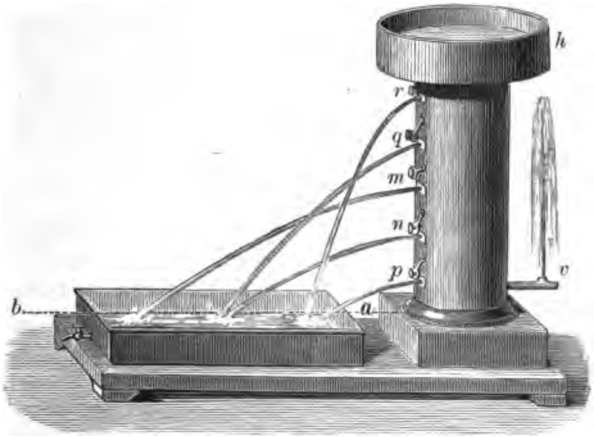


FIG. 82.

aperture. Hence (by page 60), the velocity with which a liquid escapes from an orifice increases with the square root of the depth below the surface.

157. The course of a stream spouting out in any other direction than the vertical, is that of a parabola. We can easily calculate the range of a horizontal jet. For example: if the jet, *q*, is four feet below the surface, the velocity due to the depth, *hq*, is sixteen feet per second. If its height above *ab*, the level on which it strikes, is nine feet, it will be three-fourths of a second in falling. As these two motions do not interfere with each other, the range will be found by multiplying the velocity by the time ($16 \times \frac{3}{4} = 12$). The range of a jet will be the greatest when it is midway between the surface and the level at which it strikes. Any orifice, as *n*, as far below the middle point as *q* is above it, will have an equal range with *q*, for although its velocity is greater, it has a less time to fall, and the products are the same in both cases. (The resistance of the air being removed.)

158. The flow of water in pipes is much retarded by friction and other causes, and, unless a large allowance is made for these, the quantity delivered will fall short of the estimate. Under ordinary circumstances, the diameter of the discharge pipe should be one-half greater than that required by theory.

159. Running water acts as a motive power (1) by its weight, (2) by the force of the current, or (3) by the combined effect of both. Water-wheels are either vertical or horizontal. In vertical wheel, the effective power of the stream is applied to buckets or boards fixed on the circumference. The wheel is connected with the machinery to be moved. There are three varieties of vertical wheels: (1) the overshot, (2) the undershot, and (3) the breast-wheel, which receive their names according as the water strikes near the top of the wheel, as in Fig. 83; or at the bottom, as in Fig. 84; or somewhere near the axis, as in Fig. 85.

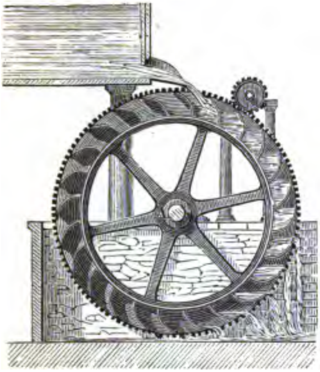


FIG. 83.

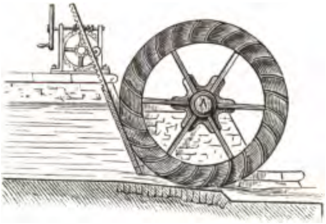


FIG. 84.

160. The availability of any wheel depends on the character of the fall. Undershot wheels are adapted to low falls or rapids with large supplies of water. Overshot wheels are used with falls not exceeding sixty feet in height, and are efficient even with small streams. Breast-wheels require a larger supply of water, but the fall is always less than their diameter.

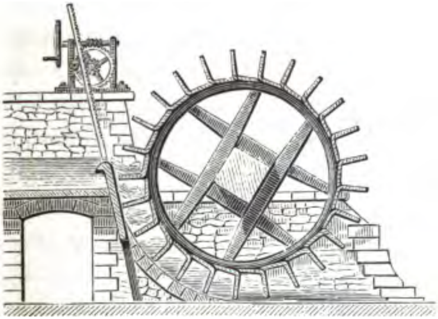


FIG. 85.

161. There are two forms of horizontal wheels; (1) the reaction, (2) the turbine.

The *reaction wheel* acts on the principle of unbalanced lateral pressure (page 95).

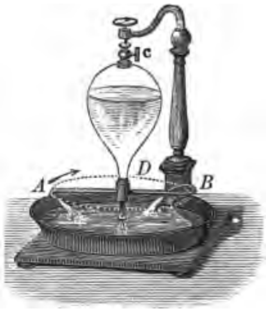


FIG. 86.

A vertical axis, CD, which revolves upon a pivot, terminates in in two horizontal pipes, A and B, whose extremities are curved in opposite directions. As the fluid escapes from the orifice in the ends of these pipes, the arms are driven around in opposite directions to the flow, and may be employed to communicate motion to machinery.

162. There are three classes of turbines, and many varieties of each class. One of the most efficient was invented in 1827, by M. Fourneyron. Fig. 87 shows a vertical, and Fig. 88, a horizontal section of this turbine.

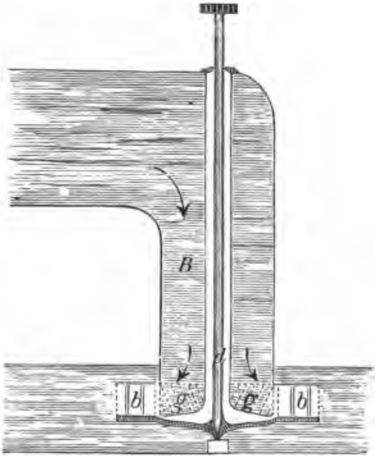


FIG. 87.

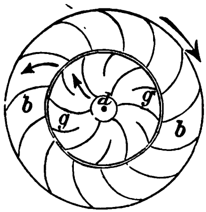


FIG. 88.

A column of water, confined in a cylinder, B, after descending in its vertical axis, rushes out at the bottom, through a great number of guides, g, so as to strike the curved buckets, b, of the wheel, and make it revolve. The buckets are so curved as (1) to receive the impulse of the water in the direction of its greatest efficiency; and then

(2) to permit its escape with the least loss of motion. The wheel is connected beneath the cylinder to the shaft, *d*, which passes upward through the center of the cylinder, and communicates its motion to the gearing at the upper end of the shaft. Turbines are applicable to falls of any height, from nine inches upward, and will utilize from .75 to .90 of the power of the water.

RECAPITULATION.

I. The velocity of a liquid jet is that which a body would acquire in falling through a space equal to its depth below the surface.

II. Running water exerts a power in proportion to its weight and the square of its velocity, diminished by the impediments to motion.

III. It acts as a motive power in water-wheels:

		Useful Effect.
1. Vertical	Undershot	.25
	Breast	.60
	Overshot	.75
2. Horizontal	Reaction	.40
	Turbine	.80

PROBLEMS.

1. A reservoir of water is 64 feet high; with what velocity will water flow from an orifice 16 feet below the surface? 25 feet? 32 feet? 64 feet? What are the ratios between these velocities? What will be the range of a stream escaping from an orifice at the center of the reservoir? 64 ft.

2. Suppose a pipe an inch in area was attached to each of these orifices, what would be the theoretical discharge of water per minute?

3. The source of the Mississippi is 1,572 feet above its mouth; if its flow were entirely unimpeded, what would be its final velocity?

CHAPTER XI.

THE PHENOMENA OF AERIFORM FLUIDS.

163. The atmosphere is mainly a mixture of two gases, oxygen and nitrogen. These constituents have never been obtained in a solid or a liquid state. Most gases have been condensed into liquids by the aid of pressure and of low temperature, and some so easily that they are frequently considered as a separate class under the name of *vapors*. Steam is the type of all vapors. Nevertheless, there is no difference between a vapor and a gas, except such as results from their specific properties, as density, odor, etc. Hence, whatever physical property may be established regarding atmospheric air, will be understood as applying to all bodies, so long as they are in the aëriform state.

164. Air has been proved to possess extension, impenetrability, compressibility, mobility, and inertia, which are essential properties of matter. Like all other fluids, it transmits pressure undiminished in every direction; but, as its compressibility far exceeds liquids like water, the effect of pressure is not felt as instantaneously at long distances as in the case of liquids.

165. The air is kept in its place about the earth by the joint action of the attraction of gravitation and the repulsive force which exists between its molecules. Consequently, the atmosphere, at its upper limit, must have a definite surface like the sea. At any point on the earth's surface, the air will exert, by reason of gravity, a pressure due to a line of molecules extending from that point to the upper limit of the atmosphere.

166. The pressure of the atmosphere may be illustrated by many simple experiments.

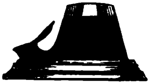


FIG. 89.

FIG. 90.

FIG. 91.

(1) In the *pneumatic inkstand*, Fig. 89, the *downward* pressure of the atmosphere on the liquid in the tube sustains the ink in the bottle. When the ink sinks down to the level of the neck, a bubble of air passes in and forces out a portion of the ink into the tube.

(2) Fill a tumbler with water, and, having placed a thick slip of paper over its mouth, press the paper down tightly with the hand, and invert the glass cautiously. The hand may now be removed, and the water will be supported in the glass by the *upward* pressure of the atmosphere on the paper, Fig. 90.

(3) Take a small open tube, or a *pipette*, Fig. 91, plunge it vertically in water until it is filled, then close the upper end with the finger and raise the tube. The water will not run out because the pressure of the air keeps it up. Remove the finger, so that the atmosphere may press above and below, and the water will fall by its own weight.

(4) Water will not flow out of a small tap in a tight barrel, because of the *lateral* pressure of the atmosphere. If this be counteracted by admitting air through an opening in the top, the water will run freely by its own weight.

No upper opening is required in beer barrels, because of the tension of the gases contained in the beer.

(5) A boy's *sucker* is made by attaching a stout string to the center of a small circular piece of thick leather. The leather is first soaked in water, and then pressed firmly against the smooth surface of a stone, so as to exclude all the air. The two surfaces are now held together by the force of fifteen pounds to the square inch, Fig. 92. On pulling the string, a vacuum is formed under a portion of the leather, and the weight of the atmosphere on its upper side is borne by the hand. The weight of the atmosphere is thereby removed from this portion of the stone, and, if it is not too heavy, the pressure of the atmosphere on its under side will raise it up.

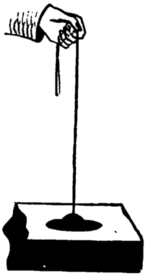


FIG. 92.

167. The barometer, described on page 20, is used for measuring atmospheric pressure. At the level of the sea, the mercurial column varies in height from twenty-eight to thirty-one inches, the average being, for London, 29.922 inches. This pressure will sustain a column of water 33.9 feet high.

168. Mercury is about eleven thousand times denser than the air at the level of the sea. If the air were everywhere of this density, the height of the atmosphere required to balance the barometric column would be 11000 × 29.922 inches, or twenty-seven thousand four hundred feet. The pressure of the air may, therefore, be reckoned as equal to a column 5.2 miles high, having throughout a density equal to that of air at the sea level.

We know that aëronauts have ascended seven miles. We know also that the air must become rarer as we ascend from the level of the sea, because the air at any level is compressed by the weight of the column above it. If a barometer were carried one thousand feet above the sea level, the column would descend about an inch. At the height of fifty miles, the mercurial column would be elevated about one-thousandth of an inch. This height, therefore, may be considered as the practical limit of the atmosphere.

Fig. 93 is an attempt to represent to the eye the decreasing pressure of the atmosphere.

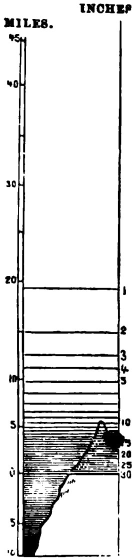


FIG. 93.

169. Heights are measured by the barometer, in accordance with the observed rate of the decrease in atmospheric pressure. Observations are taken at two stations at very nearly the same moment. The difference between the two barometric columns will represent the difference in the atmospheric columns above the two stations, from which the vertical distance between the stations may be calculated.

170. The atmosphere may be regarded as an aërial ocean, in whose lower depths we live. From the extreme mobility of its particles, it is never perfectly at rest, but moves in immense waves above our heads. When the crest of one of these waves is over the barometer, the column rises, and then again falls as the hollow of the wave succeeds. This will give rise to variations which are dependent on the season and even the hour of the day, but which succeed each other in periods which are very nearly regular.

171. The barometer is subject also to irregular variations, which are often coincident with the changes in the weather. The absolute height of the column varies with the altitude of the station, and affords, by itself, no indication of the weather; hence, the weather marks, "fair, rain, wind," on some barometers, are worthless. The barometer measures only the pressure of the atmosphere, and variations in its height indicate variations in this pressure, which, if they occur at irregular intervals, may be followed by changes in the weather.

Rules for predicting changes in the weather:

(1) The rising of the mercury indicates the approach of fair weather; the falling of the mercury indicates the approach of foul weather.

(2) A sudden and great fall indicates a violent storm.

(3) When the barometer changes slowly, a long continuance of the weather indicated may be expected.

(4) A sudden change of the barometer indicates that the change of weather will not be of long duration.

172. Thus far we have considered the air in the free state; let us see how it acts when confined. Bend the closed end of a barometer tube, as in Fig. 94, and pour in just enough mercury to fill the bend. The inclosed air is in its natural state, under the pressure of one atmosphere. If thirty inches of mercury be poured in the open arm, the confined air will be under the pressure of two atmospheres, one of mercury and the other of air, and will be reduced in volume one-half. If thirty inches more mercury be added, the pressure will be three atmospheres, and the volume will be reduced to one-third, and so on. Therefore: (1) *The volume of a given weight of air decreases as the pressure to which it is exposed increases.*

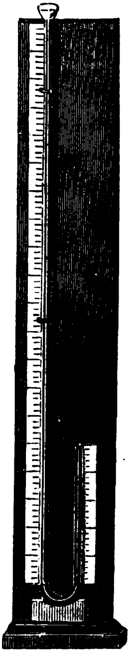


FIG. 94.

This statement is known as Mariotte's law, and is true for all gases within small limits of error. Now, as the volume decreases its density increases; therefore,

(2) *The density of a given weight of air is directly as the pressure to which it is subjected.*

Finally, as the pressure is always sustained by the elastic force, or tension, of the inclosed air,

(3) *The tension of a given weight of air is directly as the pressure to which it is subjected.*

Consequently,

(4) *The density and tension of a given weight of air will increase as its volume is decreased, and will decrease as its volume increases.*

173. Mariotte's law applies both to condensed and to rarified air. The proof for pressures less than one atmosphere may be made by filling a barometer tube to within four inches of the top with mercury, and then inverting it in a tall cistern of mercury, Fig. 95. When the tube is sunk until the level of the mercury is the same as in the cistern, the confined air will be under the pressure of one atmosphere. When the tube is raised, the pressure exerted on the air will be one atmosphere minus the weight of the mercury raised in the tube. If the column is raised fifteen inches, the air will have doubled its volume, and will have decreased one-half both in density and in tension.

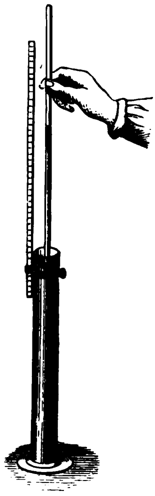


FIG. 95.

174. The tension of aëriform fluids is measured by *manometers* or *gauges*. One of the simplest forms is the closed manometer, Fig. 96. It consists of a U tube, closed at one end, and half filled with mercury. The closed end contains dry air. When the open end communicates freely with the atmosphere, the level of the mercury is the same in both parts of the tube, showing that the inclosed air is under a tension due to one atmosphere.

Now, if the open end is connected with vessels containing aëriform fluids whose tension is to be measured, as with steam in a boiler, the confined air will be reduced in volume to one-half, one-third, etc., according as the pressure increases to two, three, etc., atmospheres. Or, if the pressure is less than one atmosphere, the inclosed air will expand as the pressure decreases.

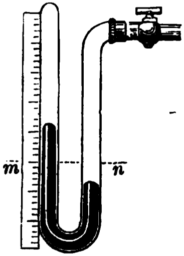


FIG. 96.

AIR-PUMPS.

175. An air-pump is an instrument for removing the air from a closed vessel.

Fig. 97 shows the Leslie air-pump, and Fig. 98 the same instrument in section. The receiver, *R*, is connected with the cylinder, *C*, by a long bent tube, terminating in a horizontal brass plate. The mouth of the receiver and the surface of the brass plate are carefully ground, so as to bring them in contact at every point. The edge of the receiver is smeared with grease, so as to render the connection as close as possible.

When the piston, *P*, is raised from the bottom of the cylinder, the external air closes the upper valve; the air in the receiver expands, opens the lower valve, and fills the cylinder. When the piston is depressed, the lower valve closes, and the air in the cylinder is forced through the upper valve out into the atmosphere. As the piston again rises the upper valve is closed, the lower valve opens, and the confined air expands into the cylinder. At every ascent and descent of the piston, a portion of air is removed from the receiver; and this process may be repeated until the tension of the air remaining is not sufficient to lift the lower valve. The receiver is then said to be exhausted.

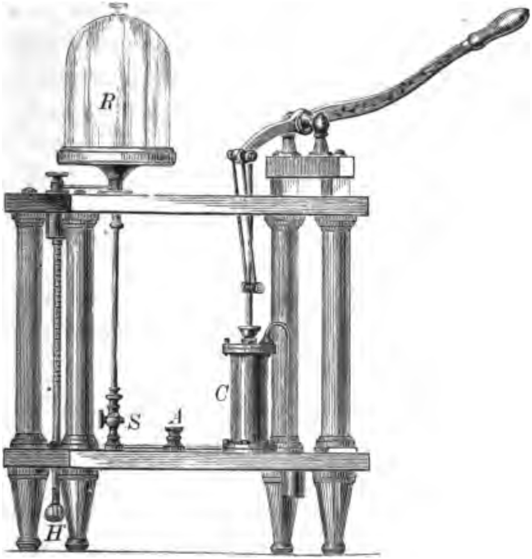


FIG. 97.

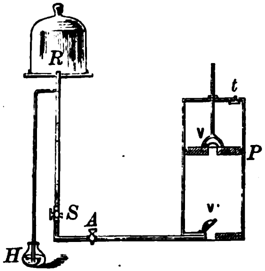


FIG. 98.

The tension of the air in the receiver is measured by a gauge, which consists of a bent tube, leading from the receiver to a vessel of mercury, *H.* The external air forces the mercury up the gauge, in proportion as the tension of the air in the tube is diminished. If the exhaustion were perfect, the mercury would rise to about thirty inches. The height of the gauge indicates the difference between the pressure of the atmosphere and the tension of the air in the receiver.

The air-pump is also provided with a stop-cock, *S*, to close the communication between the cylinder and receiver when required. The stopper, *A*, is used to admit the external air to the receiver. A third valve, *t*, is usually placed in the top of the cylinder to prevent the external air from pressing on the piston.

176. The air-pump may be used to perform a great variety of experiments, illustrating the properties of the air, only a few of which can here be given.

(1) *The presence of air* in bodies may be shown by placing a jar of well-water under the receiver. On working the pump, bubbles of air will be disengaged from the water. Having freed the water from air, fasten to the bottom of the jar bits of wood or other solids, and repeat the experiment. The formation of air bubbles will prove their porosity, and the presence of air in the pores.

(2) *Expansibility.* Tie the neck of a fresh, flaccid bladder and place it in the receiver. On exhausting the receiver, the bladder will dilate, because the air within it expands. On re-admitting air to the receiver, the air in the bladder resumes its former volume.

A withered apple, or a bunch of shriveled grapes will become plump in an exhausted receiver.

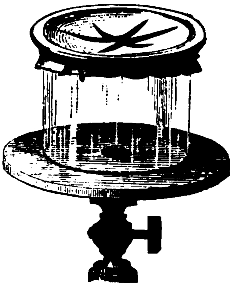


FIG. 99.

(3) *Pressure of the atmosphere.* Take a small open receiver, close the upper end tightly with a piece of moistened bladder, and suffer the

bladder to dry. On exhaustion, the external pressure will generally be sufficient to burst the bladder with a loud report. If the bladder is very stout, or the exhaustion incomplete, it may be necessary to weaken the strength of the membrane by puncturing it with the point of a pin.

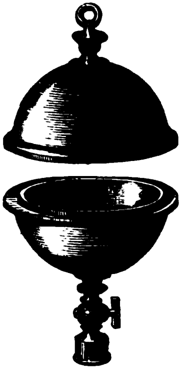


FIG. 100.

The Magdeburg hemispheres, Fig. 100, consist of two hollow brass hemispheres, which fit together air-tight. One of them may be connected with the air-pump by a tube and stop-cock arrangement. On exhausting the air from the interior, the two hemispheres will be held together with a force of fifteen pounds to the square inch. If their diameter is three inches, the area of the section will be seven inches, and the force which holds them together will be over one hundred pounds. As the restraining force is the same in every position in which they are held, *the pressure of the atmosphere is the same in every direction.*

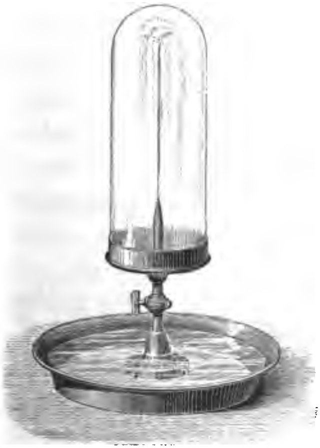


FIG. 101.

Fig. 101 represents a tall receiver, which terminates in a metallic cap, furnished with a stop-cock, a screw, and an interior jet pipe. Exhaust the air from the interior and close the stop-cock. Place the mouth of the tube under water and open the stop-cock. The pressure of the atmosphere will drive the water up the pipe, forming what is known as the *vacuum fountain.*

The weight lifter consists of a receiver, which is connected to the air-pump by an opening in the top. The lower end is closed by a piston or by a stout rubber bag. When the air is withdrawn from the receiver, the bag is forced upward, and carries with it weights attached below. If the receiver is five inches in diameter, nearly three hundred pounds will be lifted by *the upward pressure of the atmosphere*, if the vacuum is complete.

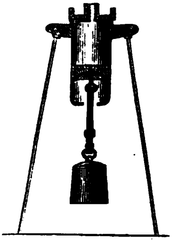


FIG. 102.

(4) When a heavy weight is thus sustained, the *elasticity of the air* may be shown, in a striking manner, by forcing down the load by the hand, and then releasing it. The weight will then oscillate up and down, as if on an elastic spring.

(5) *The weight of air* may be ascertained, by taking a vessel of known capacity and finding the difference of its weight when filled with dry air, and when exhausted of air. If the capacity of the vessel is one hundred cubic inches, the difference of its weight will be thirty-one grains. Therefore, the weight of one cubic inch of air is 0.31 grains.

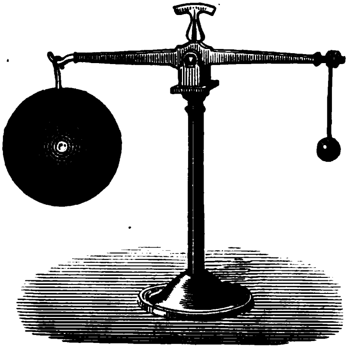


FIG. 103.

(6) *The buoyancy of air.* By the principle of Archimedes, a solid immersed in a fluid loses an amount of weight equal to the weight of an equal volume of the fluid. Hence, every substance weighs less in air than *in vacuo*.

Suspend to one arm of a balance a hollow globe, or a ball of cork, and counterpoise it with a lead weight. Now place the balance under a receiver and exhaust the air. The globe or the cork will fall, and thus seem to be heavier than the lead.

If a body is lighter than an equal volume of air, it will rise in it. Smoke rises in a chimney because air is rarified by heat. A soap-bubble, filled with warm air, rises because it weighs less than the air it displaces. If the soap-bubble is filled with hydrogen, it rises rapidly until it bursts.

Balloons are varnished silk bags, filled with hydrogen. The buoyant effort of the air in raising a balloon is equal to the difference between the weight of the gas used and the air displaced by it. A spherical balloon, forty feet in diameter, will displace two thousand five hundred pounds of air, but will contain less than two hundred pounds of hydrogen. The lifting force of such a quantity of gas is over a ton. It is, therefore, capable of lifting the weight of the balloon, the aëronaut, and a large quantity of sand used for ballast. If the aëronaut wishes to descend from a height, he allows some of the gas to escape, by opening a valve in the balloon. If he wishes to rise again, he throws out a portion of his ballast.

(7) That *air is necessary to combustion*, may be shown by placing a lighted candle in a receiver. On working the pump, the candle will grow dimmer, burn blue, and finally go out. The smoke of the candle will be seen to descend because there is nothing to sustain it.

(8) That *air is necessary to animal life*, may be shown by placing a bird or a mouse in a receiver. On exhausting the air, the animal will give evident signs of distress, and will soon die.

(9) The relations of air to sound and heat will be considered hereafter.

177. The body of a man of average size has a surface of about two thousand square inches. He, therefore, sustains, at the level of the sea, a pressure of thirty thousand pounds. It conveys a wrong notion to speak of this pressure as a load; on the contrary, the buoyant effort of the air lifts the man, and makes him press the ground more lightly than he would without it. The atmosphere acts on all sides of a body immersed in it, not as a weight, but as a crushing force. The reason why we do not feel this compressing force is because the pressure is transmitted throughout the body by the blood and other fluids of the body. Hence, when the atmosphere tends to squeeze in the sides of the blood-vessels, it is met by an equal outward pressure, caused by the pressure of the atmosphere on the other parts of the system.

We may become sensible of this outward pressure by placing the hand on a small open receiver and exhausting the air from beneath it. The external air now acts as a *load*, holding the hand firmly to the receiver. The blood, in the under surface of the hand, distends the vessels, and, if the skin has been punctured with a pin, the blood is forced out. Cupping-glasses are made to act on the same principle.

178. The condenser is an instrument for forcing a large amount of air into a closed vessel.

One of the best forms is shown in Fig. 104. It consists of a cylinder, *C*, in which a solid piston works air-tight. There are two valves in the cylinder, (1) the lateral valve, *a*, which opens from the outside, and (2) the lower valve, *b*, which opens from the inside. The receiver, *R*, may be connected by a screw to the cylinder, and may be opened or closed by means of stop-cocks arranged as in the figure.

In using this instrument, the condenser and receiver are connected and the piston driven down. This action condenses the air in the cylinder enough to close the lateral valve and open the lower. When the piston has reached its lowest point, all the air will be forced out of the cylinder into the receiver. The confined air will have its volume diminished and its tension increased. If the cylinder and receiver are of the same size, the condensed air will have a tension of two atmospheres. On raising the piston, the tension of the air in the receiver will close the lower valve, the external atmosphere will open the lateral valve, and again fill the cylinder.

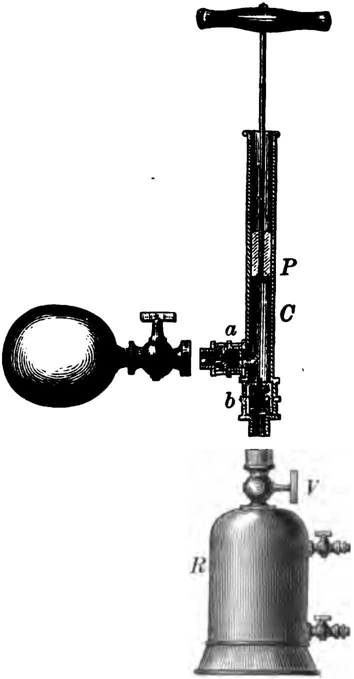


FIG. 104.

This operation may be repeated until the receiver is filled with air of the tension desired: When the receiver is thus charged, the stop-cock, *V*, is closed, and the cylinder is detached.

By bringing the lateral valve in communication with a reservoir containing any gas whatever, this gas will be withdrawn from the reservoir and forced into the receiver. In this manner liquids placed in the receiver may be charged with gases.

179. An air-gun consists of a charged receiver, properly connected to a gun-barrel. After fitting a bullet to the bottom of the barrel, a trigger turns the stop-cock, and the condensed air rushes out with great force. A boy's pop-gun also illustrates the tension of confined air.

A fountain can be arranged to play by condensed air. Before charging the receiver fill it partially with water, and connect to the stop-cock a tube reaching to the bottom of the receiver. When the air has been condensed and the stop-cock is opened, the air will force the water in a jet to a height proportional to the tension. The experiment may be varied by making the stream turn a horizontal tube, arranged on the principle of the reaction wheel, Fig. 105.

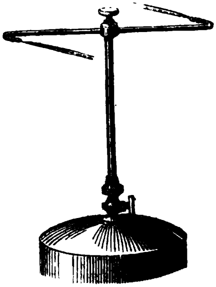


FIG. 105.

180. If we place one end of an open tube in water, and apply the mouth to the other end, we may cause the liquid to rise in the tube by suction. Correctly speaking, the effect of the suction is to diminish the pressure in the tube; the water is then forced up the tube by the pressure of the atmosphere on the surface of the water in the vessel.

The common suction, or lifting-pump, acts on the same principle. It consists of a barrel, *B*, similar to the cylinder of the air-pump, and, like it, fitted with a piston, *P*, working air-tight, and two valves, *U* and *e*, both opening upward. From the bottom of the barrel proceeds the suction-pipe, *C*, which dips below the surface of the water to be raised.

When the piston is worked, the air beneath it is rarefied more and more at each stroke; the pressure of the atmosphere causes the water to rise in the pipe and enter the cylinder through the lower valve. Now, on forcing down the piston, the lower valve, *e*, is closed, the water forces open the piston-valve, *U*, and rises above it. When the piston is again raised, the upper valve, *U*, is closed, and the water above it is *lifted* to the spout of the pump. At the same time, the atmospheric pressure on the water in the reservoir, causes more water to rise into the barrel under the piston.

181. The length of the suction-pipe can never exceed thirty-four feet, because the pressure of the atmosphere is capable of supporting a column of water only thirty-four feet high. Owing to variations in atmospheric pressure, and the imperfect mechanism of the pump, the limit, in practice, is less than twenty-eight feet. There is, however, no limit to the height through which water may be lifted after it has once passed above the piston. In deep wells, the working-barrel, containing the piston and both valves, is placed near the bottom. A long, vertical discharge-pipe, through which the piston-rod plays, connects the working-barrel to the surface of the ground. The atmospheric pressure forces the water from the well into the working-barrel; the force applied to the piston lifts the water from the working-barrel to the top of the discharge-pipe.


FIG. 106.

182. In the forcing-pump, the piston is made solid, and the upper valve, *u*, is placed in a lateral discharge-pipe, *d*, connected with the bottom of the barrel.

The lower valve and suction-pipe are the same as in the lifting-pump. When the piston is raised, the water passes up the suction-pipe through the lower valve, *e*, into the pump-barrel. On depressing the piston, the lower valve closes, and the water is forced through the upper valve, *u*, into the discharge-pipe. On again raising the piston, the upper valve closes, and prevents the water in the discharge-pipe from returning; the lower valve opens to admit more water into the barrel. At each depression of the piston, more water is driven into the discharge-pipe, until it is elevated to the required height.

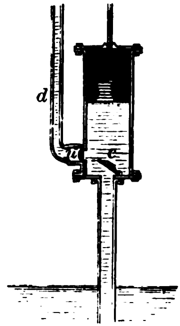


FIG. 107.

183. The water will be ejected from such a pump in successive impulses. When it is desired to make the stream continuous, an air-chamber is attached, as in Fig. 108. When the piston descends, it forces the water through the valve, *u*, into the air-chamber, *A*; the water partially fills the chamber, and thus compresses the air. The tension of the compressed air increases as its bulk is diminished, and soon becomes sufficient to force the water in the chamber out through the tube, *T*, in a constant stream.

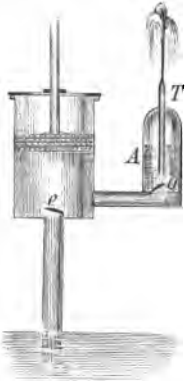


FIG. 108.

184. An ordinary fire-engine consists of two force-pumps, worked by long handles, called *brakes*, and having an air-chamber common to both. The piston of one barrel descends as the other ascends, by which means a continuous stream of water is forced into the air-chamber, and escapes through the discharging-pipe.

185. The siphon is employed for transferring liquids from a higher to a lower level. It consists of a bent tube with two unequal arms, Fig. 109. In using the siphon, the shorter arm is plunged in the liquid to be transferred. To begin the action, the air may be removed from the tube by suction at the lower end. The liquid will be forced up the shorter arm by the pressure of the atmosphere; it will then fill the tube and continue to flow through the siphon.

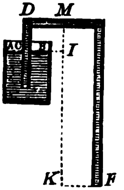


FIG. 109.

After the suction is stopped, the liquid is pressed up in the shorter arm by the weight of the atmosphere on the surface, *A B*, minus the weight of the liquid column, *M I*. So, also, the liquid in the longer arm is pressed upward by the weight of the atmosphere, minus the weight of the liquid column, *M K*. Hence, the liquid is urged in the direction, *C M F*, by a force equal to the excess of the weight of *M K* over that of *M I*. If *M K* and *M I* were equal, there could be no flow in either direction. The greater the difference in the length of the arms, the greater will be the velocity of the flow.

FIG. 110.

186. These facts may be prettily shown by the siphon fountain. Close the mouth of a tall flask, *R*, with a cork, and insert two glass tubes, as shown in Fig. 110. The shorter arm should be drawn out at the upper end to a very fine bore. On exhausting the air from the tube, the ordinary flow of the siphon will commence. If, now, the longer arm be lengthened, by attaching a rubber tube, the jet may be made to strike forcibly against the top of the flask. The force of the jet may be shown to be dependent on the difference in the length of the two arms.

FRICTION OF FLUIDS AGAINST EACH OTHER.

187. **The atomizing tube** is a contrivance for breaking up the particles of a liquid into spray. A common form is shown in Fig. 111. It consists of two open tubes, so inclined to each other that a jet of fluid driven through one shall issue over or near the mouth of the other. The blast tube, *A*, is usually contracted at its mouth, so as to increase the velocity of the stream. The lower end of the suction tube, *B*, is plunged in any liquid, as cologne.

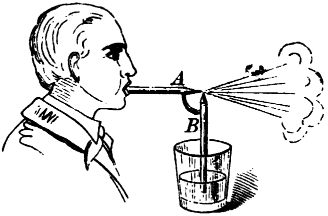


FIG. 111.

If a stream of air is driven forcibly through the blast tube, it will, on issuing from the mouth, drag the contiguous particles of air along with it, and thus produce a rarefaction behind it. As the air is rarefied in the suction tube, *B*, the atmospheric pressure on the liquid will force a column upward in the tube, and, if the tube be not too long, the particles will rise to the top. At this point, the jet of air will drag the liquid molecules along with it, and the two streams will be mingled in one of excessively fine spray.

The same principle is sometimes employed in producing a draft in chimneys and locomotives. In locomotives the waste steam is driven through a blast pipe in the smoke stack, and carries the smoke along with it, and thus increases the draft of the fire.

188. The pneumatic paradox affords another illustration of the same sort. It may be made by taking two small disks of card board, and fitting to one a small tube. Now, if the other disk is placed above the tube, and a pin passed through the center to keep it from sliding, it can not be blown off by any ordinary current of air driven through the tube. Because, as the air is driven between the disks, a rarefaction will be produced at the center of the upper disk; the air above it will crowd it toward the orifice and hold it the more firmly as the blast is made stronger. While the current of air is passing, the tube may be held in any position. The force requisite to blow away the upper disk must exceed the atmospheric pressure holding it down.

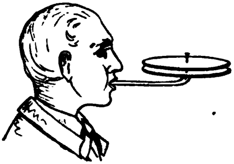


FIG. 112.

RECAPITULATION.

1. Aëriform fluids are governed by the same laws as liquids, except that, by reason of their compressibility, their volume is inversely, their density and tension directly, as the pressure to which they are subjected.

2. All gases, like air, may be shown to possess the universal properties of matter; but, except air, none are necessary to the support of animal life, and few are concerned in ordinary combustion.

3. The barometer measures the pressure of the atmosphere, and may be used:

(1.) To calculate the altitude of a place.

(2.) To predict changes in the weather.

4. The pressure of the atmosphere is employed in pumps and siphons.

5. The friction of fluids against each other is employed in blast-pipes.

CHAPTER XII.

THE MODES OF MOLECULAR MOTION.

189. The topics considered in the last eight chapters naturally fall into two groups. (1) Phenomena which relate to bodies in equilibrium; these belong to the science of *statics.* (2) Phenomena which relate to bodies in motion; these belong to the science of *dynamics.* Statics and dynamics taken together constitute the science of MECHANICS, which treats of bodies in equilibrium and in motion.

Now, it will be noticed that in these chapters we have studied the effect which force produces upon a body taken as a whole. It is true that the force of gravity acts upon every molecule of a body, but we have always assumed that the motion or rest of the body did not alter the relative position of these molecules. Thus, in falling bodies, and in the pendulum, we considered only the motion that was common to the entire mass. The molecules which made up the moving body did not change their relative positions, and were, therefore, at rest with respect to each other.

190. The following chapters relate to motion among the molecules of a body, but which involve the entire mass of the body. These molecular movements sometimes cause a visible change in the position of the body, but more frequently do not produce any motion in the body taken as a whole that we are able to detect by our senses. We know that these molecular motions exist by the results of the motion, just as we know that the hour-hand of a clock, or a rifle bullet, has moved by the result of the gross motion; for our senses do not enable us to detect very slow nor very swift motions. When a body expands by heat, we are convinced that the result is due somehow to a motion among the molecules of the body. It would be difficult to keep any body at the same temperature all the time; and if the temperature varies, the rate of molecular motion is increased or diminished, and the body is growing larger or smaller. It would be still more difficult to find a body that did not have some motion among its molecules due to the energy of heat, that is, that was in a state of absolute cold. Hence, on this consideration alone, it is probable that the molecules of even the most rigid bodies are constantly in motion even while the body, as a whole, appears to be in a state of rest.

191. A pendulum vibrates as a whole. The times of its vibrations are said to be isochronous; that is, they are performed in equal times. If an elastic body is bent, its molecules must have changed their relative positions, because the shape of the body is altered. If, now, it is let go, the molecules will tend to assume their original positions, and, by reason of their elastic force, a series of vibrations will follow, which are also isochronous. To show this, suspend a rubber tube from a hook, and stretch it taut by the hand. Now, if the cord be plucked at the center, it will vibrate in the dotted lines shown in the figure, and pass from *D* to *E* in precisely equal times, until it finally comes to rest. Such vibrations are called *transverse vibrations.* The greater the disturbing force, the greater will be the distance *E D.* This distance is called the *amplitude* of the vibration. The greater the amplitude, the greater will be the energy of the vibration, but the time required for a vibration is unchanged.

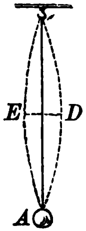


FIG. 113.

If, now, the cord be stretched by a weight, *A*, and the weight be pulled down and then suddenly let go, the cord will perform a series of *longitudinal vibrations*, which are also isochronous. That is, the weight, *A*, will oscillate alternately above and below its normal position, while the cord becomes alternately shorter and longer. So, if we twist the weight around, it will turn backward and forward in a series of isochronous *torsional vibrations.*

192. All elastic bodies may be thrown into alternating motions of some sort, which are due to the nature of the disturbing force and the elasticity of the body. If we consider the motion of only one particle, as *A* or *E*, these motions are called *vibrations* or *oscillations.* If we consider the motions of a line of particles, they are called *waves* or *undulations.*

193. How undulations are formed may be shown by stretching a heavy rubber cord from a fixed point, as *X*, by means of the hand at the other end, as at *A*. If the hand be jerked upward, an apparent movement will be transmitted along the cord like the waves on the sea. If the hand be jerked but once, its effect will be to produce the crest, *A E N;* the elastic force of the cord will cause the corresponding hollow, *N D O*. The curve, *A E N D O*, will advance along the cord, assuming successively the positions *I*, *II*, *III*, until it reaches the end, *X*, and then return in an inverted curve, *IV*, *V*, *VI*, to the hand. The curve, *A E N D O*, is called a *wave.*

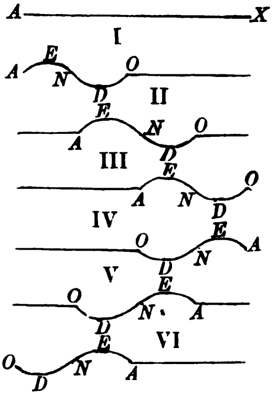


FIG. 114.

194. The particles of the cord appear to move from one end of the cord to the other. This, however, is impos sible; each particle has moved only up and down, and the wave is due to a series of particles which are passing in succession from the highest to the lowest point of the wave. Such a wave is called a *progressive undulation.*

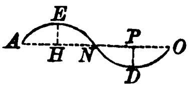


FIG. 115.

AO is the *length* of the wave.
HE is the *height* of the wave.
DP is the *depth* of the wave.
$HE + DP$ is the *amplitude* of the wave.
AEN is called the *phase of elevation* of the wave.
NDO is called the *phase of depression* of the wave.

If a pebble be dropped in a placid pool, progressive undulations will be formed. The waves will spread in widening circles around the pebble, and decrease in amplitude as they increase in diameter, until they finally become inappreciable. As in the case of the cord, the motion of each particle is only up and down, as is proved by the rise and fall of bodies floating upon the surface. A progressive undulation is, therefore, only an advancing form, and any apparent progression of the particles in the wave is merely an optical illusion.

195. The surface waves of fluids are propagated by gravity. All other waves are dependent, mainly, on the elastic force developed in a body by some disturbing force. Undulations may be confined to the body in which they are formed, or they may be formed in one body and transmitted through several others. So the vibrations of solids may cause waves to be transmitted to other solids, to the atmosphere, or to water. Any body through which waves are transmitted is called a *medium.*

196. Surface waves have a crest and hollow, or an up and down motion, but there are also waves in which the motion of the particle is in the same line as that of the direction in which the wave is transmitted. Thus, if the piston in the weight-lifter, Fig. 102, is pulled down and the pressure suddenly removed, the elasticity of the air will cause the piston to vibrate up and down. This must be due to the alternate condensation and rarefaction of the air above and below the piston. The undulations in aëriform bodies are chiefly due to similar *waves of condensation and rarefaction*, in which the same particle may be considered as moving backward and forward instead of up and down.

FIG. 116.

197. Let a soap-bubble containing a mixture of oxygen and hydrogen be exploded by the flame of a candle. The vapor formed by the union of these elements forms a sphere many times greater than the soap-bubble, and thus a rarefaction will be produced at the center of disturbance. The pressure of the surrounding air will then cause the vapor sphere to contract, its elasticity will again impel it outward, and thus it will continue to oscillate by alternate rarefaction and condensation for some time.

The surrounding particles of air will partake of these motions. When the vapor sphere expands, the shell of air inclosing it will be condensed, and again expand as the vapor contracts. This aërial shell will, in like manner, act upon a second aërial shell; it, in turn, upon a third, and so on.

These movements are analogous to the waves upon the surface of liquids, in that they increase in circumference from the center; only instead of a crest we have condensation, and, instead of a hollow, a rarefaction. While a surface wave consists of a crest and a hollow; an aërial wave consists of a condensation and a rarefaction. Fig. 116 is an attempt to represent to the eye four aërial waves: the darker parts represent condensations, the lighter the rarefactions.

198. Surface waves, starting from a center of disturbance, decrease in intensity, because, as the circles widen, there are more particles to be moved, and each will move with a less amplitude. Aërial waves form spherical surfaces, and, as they expand, the number of particles to be set in motion will increase as the squares of their radii; hence their intensity will decrease in the same ratio—or, *the intensity of an aërial wave diminishes as the square of the distance from the center of propagation increases.*

199. It will be easily understood that the greater the intensity of an aërial wave, the greater will be the amount of condensation and of rarefaction. The amplitude of an aërial wave is the space through which any particle passes from a state of condensation to a state of rarefaction, and hence the amplitude will increase with the intensity of the wave. On the other hand, the length of the wave will depend on the number of particles which constitute one condensation plus one rarefaction. Hence the amplitude of a vibration may be only a small fraction of an inch, while the length of an undulation may be many feet.

200. Suppose an impulse to be communicated through one thousand feet in one second by means of waves. This will express the velocity of the wave motion. Now, the greater the amplitude the greater will be the resistance to be overcome; the less the amplitude the less the resistance, and, hence, *all the waves will move over equal spaces with equal velocities.* The length of the wave depends on the rapidity with which the waves succeed each other; that is, on the rapidity of the vibrations or impulses which produce the waves. The more rapid the vibrations, the greater the number of waves and the shorter the wave length; the slower the vibrations, the smaller the number of waves and the greater the wave length. Hence we may determine a wave length by dividing its velocity of transmission by the number of vibrations performed in the same time.

RECAPITULATION.

There are two varieties of waves:

I. Waves of crests and hollows, in which the direction of displacement is perpendicular to that of transmission. This is exemplified by waves of water, the undulations of light and heat.

II. Waves of condensation and rarefaction, in which the direction of displacement coincides with that of transmission. The vibrations of musical instruments are transmitted through the air by waves of this sort to the ear. These are, therefore, called *sonorous waves.*

The intensity of a wave is dependent on the energy of the disturbing force. The initial amplitude is dependent on the intensity.

The velocity of a wave is the rapidity with which it is propagated in a medium.

The length of a wave is dependent both on the velocity and the number of vibrations in one second.

CHAPTER XIII.

ACOUSTICS, OR THE PHENOMENA OF SOUND.

201. **Three conditions** are necessary for the sensation of sound:

(1) Every species of sound may be traced to the vibrations of some elastic body.

When a tuning-fork sounds, its vibrations may be felt by placing one of its prongs lightly upon the teeth. If a knife-blade be placed against the edge of a bell that is ringing, it will be made to rattle. The tremors produced in the external air by the vibrations of an organ-pipe are distinctly perceptible. Bodies capable of producing sound are called *sonorous*.

(2) An elastic medium is requisite for the transmission of sound. The ordinary medium is the atmosphere.

The vibrations of sonorous bodies produce in the air, waves of condensation and rarefaction, which correspond in rapidity and amplitude to the rapidity and amplitude of the vibrations. These waves succeed each other in ever increasing spheres, until at last they reach the ear. Two or more media may be employed in transmitting the same sonorous wave; thus persons in a close room are sensible of distant sounds. In such a case, the undulations of the external air cause vibrations in the windows and walls, which produce corresponding undulations in the air within the room.

If a bell, kept in constant vibration by clock-work, is supported on a thick layer of loose cotton, under the receiver of an air-pump, the sound, at first distinct, grows more feeble as the air is exhausted, and finally ceases to be heard when a vacuum is obtained. Fig. 117. In like manner sound is quenched by the interposition of any body having feeble elasticity. Thus, a partition filled with sawdust, or covered by a thick carpet, will prevent the transmission of sound from one room to another.

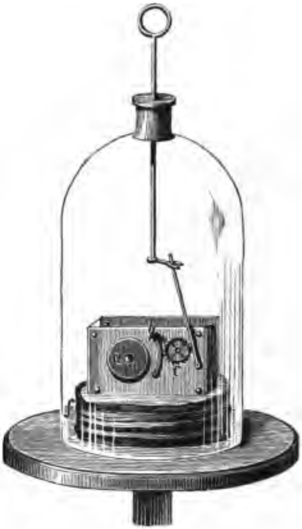


FIG. 117.

(3) The auditory nerve is necessary to the sensation of sound.

If the experimenter is deaf, or if a bell rings when there are no hearing organs capable of perceiving the vibrations, they exist merely as such, without producing sensation.

Nevertheless, in studying these vibrations it is convenient to disregard the sensation, and define sound as a mode of motion which is capable of affecting the auditory nerve.

202. A musical sound is produced by vibrations which succeed each other at short and equal intervals. If the vibrations are rapid, the ear recognizes the sound as high or acute; but, if slow, as low or grave.

These facts may be shown by pressing a card against a toothed wheel in motion. Fig. 118 represents Savart's wheel. If the card, *E*, strikes against less than 16 teeth per second, only a succession of taps will be heard. If the number exceeds 16 per second, the impulses blend together in a clear musical sound. As the velocity is increased, the sound is more and more acute. Therefore, *the pitch or tone depends on the rapidity of the vibrations.* Savart's wheel has at *H* an apparatus which indicates the number of revolutions in the toothed wheel by which we can easily calculate the number of vibrations per second that are required to produce any given tone. Sounds are *in unison* when the rates of vibration are the same. We may determine the rate of vibration in tuning-forks and other musical instruments by making the wheel sound in unison with them, and then noting the rapidity of the vibrations produced by it.

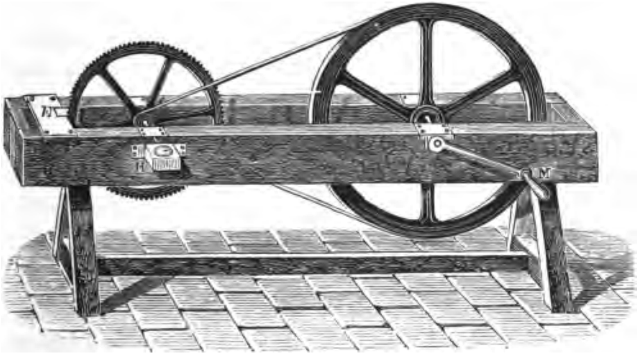


FIG. 118.

If the vibrations are less than 16 per second, the ear is affected by each impulse separately, and only a *noise*, or a succession of noises, is heard.

203. The quality of sound depends on the elasticity and form of the sounding body. Steel, glass, silver, brass, and cat-gut, are sonorous, because these substances are highly elastic, and possess sufficient strength for rapid vibrations. The fibers of wool and cotton are elastic, but are not sonorous, because their elasticity is so feeble that their vibrations are slow and inaudible. Hence, all elastic bodies are not sonorous, although all sonorous bodies are elastic.

204. If a tuning-fork be struck by a sharp blow, its sound will be at first loud, and then gradually die away.

The blow causes vibrations in its prongs that have considerable amplitude; the greater this amplitude, the greater will be the condensation which it produces in the aërial wave. As the amplitude decreases the condensation is less, until finally the condensation is not sufficient to affect the ear. Hence, *the intensity or loudness of the sound depends on the amplitude of the vibrations.* It must not be forgotten that the loudness has nothing to do with the pitch of a tone; thus, the same tuning-fork always vibrates with the same rapidity and yields the same tone, whether that tone be loud or soft.

The amplitude of sonorous waves rapidly decreases, because they are propagated in spherical surfaces; hence, *the intensity of sound varies inversely as the square of the distance of the sounding body.* A drum at a distance of one hundred feet sounds four times louder than at two hundred feet, and one hundred times louder than at one thousand feet.

205. When a string vibrates in free air, it emits but a feeble sound; but if it is fastened to a violin or a suitable sounding-box, the sound is louder. This arises from the fact that the thin plates of the box and the air within them vibrate in unison with the string, and the united effect is to produce a wave of greater intensity. We may illustrate this by holding a vibrating tuning-fork over the mouth of a tall jar, and carefully pouring water into the jar. Fig. 119. When it has reached a certain level, the sound of the fork will be greatly increased by the vibration of the column of air within the jar. The best effect will be produced when the length of the air column is such that a wave of condensation *or* of rarefaction will go down and back while the tuning-fork is making a single vibration. That is, the length of the column should be one-fourth of the length of the sonorous wave produced by the fork. We learn from these experiments that *sound is increased in intensity by the proximity of a resonant body.*

FIG. 119.

206. These experiments show that a vibrating body is capable of exciting undulations in bodies whose rate of vibration is the same as its own. When the voice utters a prolonged loud tone near a piano, that wire will be set in vibration whose sound is in unison with the voice. Such vibrations are termed *sympathetic.* Only that wire answers to the voice *that is capable of emitting the same tone when it is struck.*

207. The intensity of sound depends on the density of the medium in which it is generated. The experiment of the bell *in vacuo* shows that the more the air is rarefied, the weaker is the sound. On the tops of mountains the sound of a pistol resembles the report of a fire-cracker; while a whisper sounds painfully loud to the occupants of a diving-bell. The energy with which solids and liquids transmit sound exceeds that of the atmosphere. The scratch of a pin at the end of a long stick of timber is distinct to a person whose ear is at the other end.

208. The intensity of sound is weakened in passing from one medium to another. A noise made under water is feebly heard in the air, and *vice versa.* If the lungs are filled with hydrogen, the voice is weak and piping. The reason why sounds are more distinct by night than by day is because the air is more homogeneous. In the daytime the air contains layers of different densities, and the sound is weakened both as it enters and as it leaves one of these layers.

209. The distance at which sound is audible varies with the conditions that determine its intensity. Still air of great density and uniform temperature is favorable to the transmission of sound. In the Arctic regions, Lieutenant Foster conversed with a sailor at the distance of a mile and a quarter. The earth transmits sound further than air. The cannonading at Antwerp in 1832 was heard in the mines of Saxony, 320 miles distant.

210. The velocity of sound. Every one must have noticed that the flash of a distant gun is seen before the report is heard. If the distance and the time between the flash and the report are known, the velocity of sound may be computed. The velocity of sound in still air at 32° F. is 1090 feet per second.

211. The velocity varies with the temperature, increasing, as the temperature rises, at the rate of 1.12 feet for every degree Fahrenheit. At 60° F. sound has a velocity of 1121 feet per second.

212. These facts enable us to compute the distance of a sounding body when the time of transmission is known. Thus: suppose, on dropping a stone from a cliff, eight seconds elapse before the stone is heard to strike the base. A part of the time, x, was occupied by the falling body, the rest, $8 - x$, by the sound. By the law of falling bodies $x^2 \times 16\frac{1}{12}$ equals the height of the cliff; by the law of the transmission of sound $(8 - x)\ 1090$ also equals the height. Hence, $x^2 \times 16\frac{1}{12} = (8 - x)\ 1090$. $x = 7.23$; $8 - x = 0.77$. The height of the cliff is, therefore, 839.7 feet.

213. **All sounds are transmitted** with the same velocity in the same medium. If this were not true, the different notes simultaneously produced by the instruments of an orchestra would reach the ear of a distant auditor one after another, and so produce discord.

214. **The velocity of sound varies** with the medium. In gases denser than air, it moves with less velocity; and in those rarer, with greater velocity: in carbonic acid, the rate is 858 feet, and in hydrogen 4,164 feet per second. In solids and liquids, the velocity is greater than in air; in water, the rate per second is 4,700 feet; in lead, 4,030 feet; in steel and glass, 16,600 feet; in ash, 15,314 feet.

The difference of velocity in solids and in air may be demonstrated by placing the ear at one end of a long beam or wall, while an assistant strikes a blow at the other end. Two sounds will reach the ear, the first through the solid and the other through the air.

215. **If the sonorous wave** is not permitted to expand, its intensity can be maintained for a great distance. The speaking-tubes employed in large buildings for transmitting messages from one story to another illustrate this fact. The hearing trumpet concentrates sound, because the condensation and rarefaction of the sonorous wave which enters it is communicated to portions of air which are smaller and smaller, and thereby the intensity is increased.

215a. **Edison's phonograph** is an interesting proof that sounds are due to vibrations. It consists of an elastic plate, to the center of which a hard stylus is so attached that it plays above a sheet of tin-foil, which is made to cover a cylinder whose surface is cut into the form of a screw. On turning the cylinder, and at the same time speaking *at* the elastic plate, the stylus forms indentations in the tin-foil which correspond to the sounds uttered. After the tin-foil has been indented, if the cylinder is revolved as before, the sounds will be reproduced by the elastic membrane with greater or less fidelity.

SONOROUS WAVES.

216. Many sounds may be transmitted at the same time in the same medium without modifying each other. A cultivated ear can readily distinguish the sound of each different kind of instrument in a large orchestra. If, however, there are many instruments of the same kind perfectly in unison, their sounds will unite to produce a resultant wave of increased intensity. So, also, many feeble sounds, separately inaudible, may unite to produce a sort of murmur, as is exemplified by the rustle of leaves, or the hum of a whispering school.

217. If two sonorous waves of equal intensity combine, the effect may be either to increase or diminish their intensity. We can readily illustrate this effect by means of a long, narrow canal, with glass sides, partially filled with water. On tilting one end, a wave will pass to the other end, and be there reflected. If new waves are formed by fresh impulses, we may so time the motion that the direct and reflected waves may be made to meet at any phase of their undulation. If crest combine with crest and hollow with hollow, the amplitude of the resultant wave will be doubled; but if crest combine with hollow, both waves will disappear, and the surface become horizontal. This phenomenon is called the *interference of waves.*

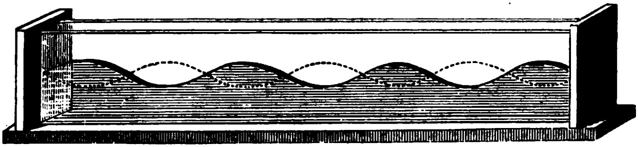


FIG. 120.

In like manner, if two sonorous waves of equal intensity meet in opposite phases, so that the condensation of one corresponds with the rarefaction of the other, both are destroyed, and silence results. The feeble sound of a tuning-fork, held in the hand, is partially due to the fact that the prongs are vibrating in opposite directions, and produce a partial interference of their waves. If a tuning-fork, when vibrating, is turned slowly around about a foot from the ear, four positions will be found in which the interference is total, and no sound is heard.

If two tuning-forks, vibrating respectively two hundred and fifty-five and two hundred and fifty-six times in a second, are sounded together, they will, at first, combine to produce a louder sound than either could alone, for both generate waves in which condensation corresponds with condensation, and rarefaction with rarefaction. At the one hundred and twenty-eighth vibration, one will have gained half a vibration on the other, and their phases are in complete opposition, and there will be no sound, because the condensation of one wave is neutralized by the rarefaction of the other. For the next half second, the interference is less and less, and at the end of the second they again combine. At every even number of half seconds the sound will be doubled in intensity, and at every odd number destroyed.

This alternate combination and interference is known to musicians by the name of *beats.* The number of beats in a second is always equal to the difference in the two rates of vibration. If the forks vibrate in unison no beats will be heard. If one vibrates two hundred and fifty and the other vibrates two hundred and fifty-six times in a second, the number of beats will be six.

218. **Echoes** are produced by the reflection of sound from distant surfaces.

Let a circular wave emanate from the center, *O,* and strike the plane surface, *S B,* with a velocity sufficient to have carried it in the next moment to $SP'B$. The particles in the perpendicular ray, OO', will first strike the surface, and will be reflected in the direction, $O'P$. When any diverging rays, as OD' and OI' reach the surface, they will be reflected on the other side of the perpendiculars, MK and $M'E$, in the lines, $O'D$ and $O'I$, making the angles of reflection equal to the angles of incidence. Now, as the velocities of the direct and the reflected waves are the same, the reflected wave will reach the points, DPI, in the same time that the direct wave would have reached $D'P'I'$, and the same is true of all intermediate points. Hence, the reflected wave proceeds as if from a center, O', on the opposite side of the surface, SB, and at a distance from the surface equal to that of the center, O, of the incident wave.

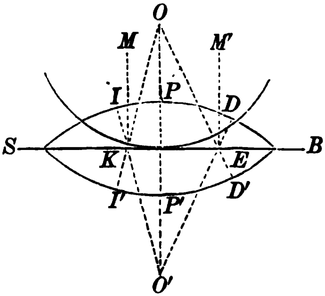


FIG. 121.

When the origin of the wave is far distant from the reflecting surface, the waves will be arcs of very large circles. In such cases, the diverging rays which fall upon a small surface will be nearly parallel. Parallel rays, incident upon a plane surface, will also be parallel after reflection.

Echo. The voice can not utter, nor the ear hear, more than five syllables in a second; therefore, a distinct echo of articulate sounds will require the reflecting surface to be at least $1090 \div (5 \times 2) = 109$ feet distant, as the sound has both to go from and return to the speaker. At a greater distance, two or more syllables may be perfectly repeated by the echo; but, at less distances, the direct and reflected waves will be more or less commingled, and the echo will not be distinct.

219. The increased intensity produced by the commingling of direct and reflected waves is termed *resonance.* Resonance is specially noticeable in empty rooms with bare, smooth walls. If the echoing walls are not distant more than thirty-five feet from the speaker, the reflected wave will reach the ear one-sixteenth of a second after the direct wave. This very short interval will not be noticed by the ear, and the voice will be strengthened without a loss of clearness. If the walls are at a greater distance the words are less distinct, unless the echoes are quenched by the furniture, or by the presence of an audience.

220. The echo may be heard when the direct sound is inaudible. Thus, if two concave mirrors are placed opposite to each other, the ticking of a watch placed in the focus of one mirror will be so reflected that it may be heard in the focus of the other, even when placed at a considerable distance. Fig. 122. The same effect may be produced in circular rooms. In such a chamber, a whisper at one focus will be heard at the other focus, although inaudible at any other place. Such whispering galleries are not uncommon. The dome of St. Paul's Cathedral, London, and of the Capitol at Washington, are fine examples.

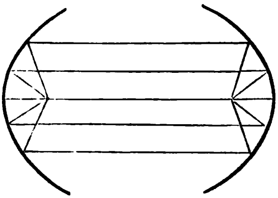


FIG. 122.

221. Sound may be bent out of its course or *refracted* in passing from one medium to another. The laws of refracted sound are the same as those of light, and will be studied hereafter.

RECAPITULATION.

1. The quality of sound depends on the elasticity and form of the sonorous body.

2. The pitch of sound depends on the rate of vibrations.

3. The intensity of sound increases: (1.) With the amplitude of the vibrations. (2.) With the density of the generating medium. (3.) By the proximity of a resonant body.

The intensity of sound decreases: (1.) As the square of the distance increases. (2.) In passing from one medium to another.
The intensity is maintained or strengthened by acoustic tubes.

4. The velocity of sound is not dependent on quality, pitch, or intensity, but varies with the elasticity and density of the medium.

5. Sonorous waves
  (1) may co-exist in the same medium.
  (2) may combine and interfere.
  (3) may be reflected or refracted.

MUSICAL SOUNDS.

222. The appreciation of musical sounds varies in different persons. Some can hardly distinguish variations in pitch, although they are sensible to variations in intensity. All ears are deaf to some vibrations. The gravest sound is produced by 16 vibrations per second, the highest sound by 38,000 vibrations per second; but there are many persons who can not hear very high notes like the note of a cricket, although they can distinguish very feeble sounds, as the lowest whisper.

223. More than 38,000 sound waves are possible, each one of which will, by itself, produce a pure tone. No ear is capable of recognizing, as distinct tones, one-hundredth part of these. Two tones, whose rates of vibration are nearly the same, can be distinguished from unison only by the formation of beats. If these beats are not readily perceptible, the ear recognizes the sound as the same.

224. Suppose a guitar string to be stretched across a sounding box, as in Fig. 123. When the whole length of the string vibrates, it produces a sound called the fundamental tone of the string. Suppose this tone to be that due to 128 vibrations in one second, as measured by Savart's wheel. If, now, the bridge, *B*, be placed at half the length of the string, it will make 256 vibrations per second, or twice as many as the fundamental. If the string be again halved, the number of vibrations will be again doubled, and so on.

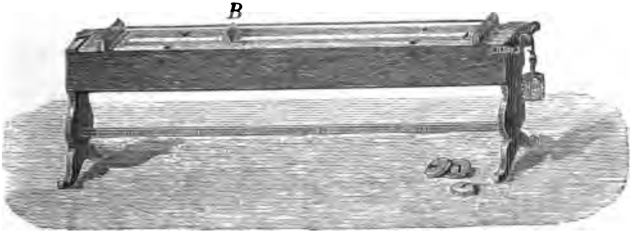


FIG. 123.

The ratio between any two tones is called an interval, and indicates how much one sound is higher than another. The interval 1 : 2 is called an *octave*, because, between any two tones bearing this ratio, other tones may be placed, so as to form, with the two extremes, a series of eight sounds having agreeable relations to each other.

225. These eight tones constitute the diatonic scale or *gamut*. They are designated by the first seven letters of the alphabet. If the length of the string which sounds the fundamental be assumed as 1, the relative length required to produce the other tones are:

Tones.	C	D	E	F	G	A	B	C
Relative length of cord. . . .	1	$\frac{8}{9}$	$\frac{4}{5}$	$\frac{3}{4}$	$\frac{2}{3}$	$\frac{3}{5}$	$\frac{8}{15}$	$\frac{1}{2}$
Relative number of vibrations.	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2

The laws which govern the vibrations of strings are:

(1) The number of vibrations per second is inversely proportional to the length of the string.

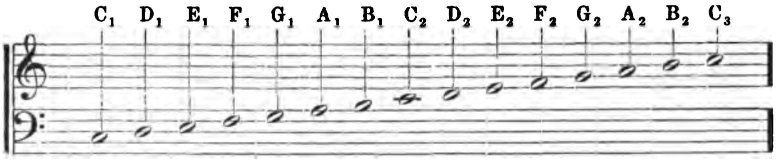
(2) The number of vibrations per second varies as the square root of the weight by which the string is stretched.

(3) The number of vibrations per second varies inversely as the square root of the weight of a given length of string.

All these laws are applied in the construction of stringed instruments. The high notes on a piano are produced by short, thin strings; the low notes by long heavy ones. The strings are brought to the proper pitch by tension, applied at the pegs.

226. Musicians have agreed to designate the tone due to 128 vibrations per second as *C*. It corresponds to *C* in the second space of the base clef. The number of vibrations corresponding to any other tone may be found by multiplying this number by the fractions $\frac{9}{8}$, $\frac{5}{4}$, etc., which express the relative number. The actual number employed by orchestras in different cities is not the same. For this reason a new scale of vibrations has been proposed, which give all the tones of the lower octave of the treble in whole numbers, C_2 being 264.

227. The length of a sonorous wave is found by dividing the velocity with which sound travels in a second by the number of vibrations per second. In air, at 60° F., the length of the wave, *C*, is $1{,}121 \div 128 = 8.7$ feet.

228. Musical intervals are named by the order of their position with respect to the fundamental, as seconds, thirds, fourths, etc. The interval of the fifth, as *C G* or $G\,D_2$, is expressed by the ratio 3 : 2. The following table gives a condensed summary of the relations of two octaves of the diatonic scale:

Name of interval	1st	2d	3d	4th	5th	6th	7th	8th	2d	3d	4th	5th	6th	7th	8th
Name of tone	Do	Re	Mi	Fa	Sol	La	Si	Do	Re	Mi	Fa	Sol	La	Si	Do
	C_1	D_1	E_1	F_1	G_1	A_1	B_1	C_2	D_2	E_2	F_2	G_2	A_2	B_2	C_3
Relative No. of vibrations .	1	$\frac{9}{8}$	$\frac{5}{4}$	$\frac{4}{3}$	$\frac{3}{2}$	$\frac{5}{3}$	$\frac{15}{8}$	2	$\frac{9}{4}$	$\frac{5}{2}$	$\frac{8}{3}$	3	$\frac{10}{3}$	$\frac{15}{4}$	4
Scale interval	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{16}{15}$	$\frac{9}{8}$	$\frac{10}{9}$	$\frac{9}{8}$	$\frac{16}{15}$	
Absolute No. of vibrations .	128	144	160	$170\frac{2}{3}$	192	$213\frac{1}{3}$	240	256	288	320	$341\frac{1}{3}$	384	$426\frac{2}{3}$	480	512
New scale of vibrations . .	132	$148\frac{1}{2}$	165	176	198	220	$247\frac{1}{2}$	264	297	330	352	396	440	495	528
Length of wave in feet . .	8.7	7.7	7	6.5	5.8	5.2	4.6	4.4	3.8	3.5	3.2	2.9	2.6	2.3	2.2

229. The pleasure derived from music depends on the frequent recurrence of vibrations in the same phase. *Melody* is due to a succession of simple tones having agreeable relations to each other. The *air* in a piece of music is an example of melody. A *chord* is due to the simultaneous production of two or more tones in agreeable relations to each other. A *harmony* is a melodious succession of chords. The air in music, with the accompaniment, constitutes a harmony.

FIG. 124.

Music is often composed and executed without any knowledge of sonorous waves, because the ear almost instinctively recognizes the combinations that are agreeable. When these combinations are analyzed, it is found that those are most agreeable whose vibrations bear simple relations to each other. If the ratio between any two sets of vibrations can be expressed by whole numbers less than six, the combination will be pleasant. Such are notes in unison, 1 : 1; then the chords of the octave, 1 : 2; then follow, in turn, the chords of the fifth, 2 : 3, the fourth, 3 : 4, and so on.

230. A string which vibrates transversely along its whole length can be made to vibrate in any number of segments by gently touching it at any aliquot part of its length, as one-half, one-third, etc., either at the moment the string is set in motion or after it has begun to vibrate. The touch quenches the vibration at the point, and the string divides into two, three, or more segments according to the distance of the point touched from the end. Now, not only will the vibration cease at the point touched, but also the string will be at rest between every two segments. If rings of paper are placed along the string they will collect at these points of rest, which are called *nodes*. Fig. 124.

FIG. 125.

It is impossible to sound the string as a whole without, at the same time, producing some vibrations of its aliquot parts. The string will, therefore, yield its fundamental tone strongly and some of its higher harmonics with less intensity. The same is true of other sounding bodies. This intermixture of tones gives each instrument a peculiar quality, called *timbre*, which enables us to distinguish one instrument from another, as a violin from a flute.

231. When plates are set in vibration nodal lines are formed. These may be rendered evident to the eye by covering the plate with fine sand. On quenching the vibration at any point, the sand will gather at the positions of rest and form beautiful symmetrical figures, as shown in Fig. 125.

If a thin goblet be partially filled with water, and then rubbed on the edge with a wet finger, the glass will emit a musical tone, and waves and nodal lines will be formed on the surface of the water.

232. In wind-instruments the sound is due only to the column of air which is confined in the tube. Fig. 126 represents an organ-pipe. When a blast of air is forced through the aperture, *l*, it strikes against the *lip*, *b*, which partially obstructs it and causes the air to issue from *b a* in an intermittent manner. In this way pulsations are produced, which cause alternate condensations and rarefactions within the tube, and a sonorous wave is the result.

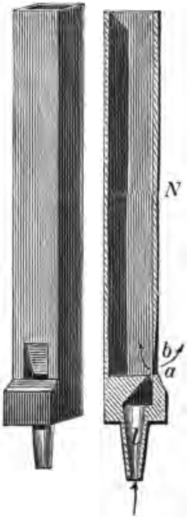


FIG. 126.

RECAPITULATION.

1. Any sonorous body gives its fundamental tone when it is vibrating throughout its whole length.

2. The diatonic scale contains eight tones of different intervals.

3. The relative number of vibrations in an octave is expressed by a simple series of ratios. The corresponding tones may be obtained by varying the length, tension, and weight of strings.

4. The pleasure derived from music is due to a succession of melodious or harmonious tones.

CHAPTER XIV.

OPTICS, OR THE PHENOMENA OF LIGHT.

233. Luminous bodies are those in which light originates; all others are non-luminous. Thus, the sun and burning bodies are luminous. Trees and stones are non-luminous, but while the sunlight falls upon them they give off part of the light which they receive, precisely as if they were luminous bodies.

234. Transparent bodies allow light to pass freely through them; as glass, water, air. Opaque bodies do not transmit light; as wood and the metals. Translucent bodies transmit light so imperfectly that objects can not be clearly seen through them; as ground glass or horn.

235. The sun and the fixed stars originate the light by which they shine; the planets and the moon shine by the light which they receive from the sun. (1) These are natural sources of light.

When any solid is sufficiently heated it emits light, and is said to become *incandescent.* The light varies with the intensity of the heat. At 977° F. bodies emit light of a dull red color; at 1,280° F. they are red-hot; at 2,000° F. orange; at 2,130° F. white hot, and above this temperature they are dazzling white. Hence, any source of intense heat will also be a source of light, if there are solid particles present which can be rendered incandescent.

(2) Chemical action is the principal source of artificial heat and of artificial light. When oxygen and hydrogen are burned together, a temperature of over 5,000° F. may

be attained. If the two gases alone are present the light is very feeble, because the product of combustion is aëriform, viz.: the vapor of water. If, however, a solid, as a bit of lime, is held in the flame, it becomes incandescent, and emits a light of great intensity. It is the so-called calcium or Drummond light.

The common illuminating agents, like oil, tallow, coal gas, etc., contain carbon and hydrogen. When these bodies are ignited, they are decomposed; the hydrogen burns with a pale flame; into this flame the solid carbon particles rise, become incandescent, and emit light. They then burn and pass into the air as carbonic acid.

Besides these sources of light may be mentioned (3) mechanical action, exemplified by the sparks of light emitted when flint and steel are struck violently together, (4) electricity, as in the glare of lightning, (5) and the phosphorescent light emitted by decaying wood, and by some insects.

236. The phenomena of light may be explained by the theory that it is due to very small waves of crests and hollows. The wave theory of light assumes (1) that matter of extreme rarity and elasticity, called the *luminiferous aether*, pervades all space, even the interstices between the molecules of every substance. (2) That the molecules of luminous bodies are in a state of very rapid vibration. (3) That the vibrations of every luminous point are communicated to the aether, and are then transmitted in all directions by spherical waves. (4) That these vibrations or waves constitute light.

237. The velocity of light was first ascertained by Roemer by means of the eclipses of the first moon of the planet Jupiter. This moon is observed to undergo eclipses by passing behind the body of the planet. Both the earth and Jupiter revolve about the sun, but in different periods;

consequently, they are sometimes on the same side of the sun, and sometimes on opposite sides. In the former case the earth is the whole diameter of its orbit, or about 183, 000,000 miles, nearer to Jupiter than in the latter. Now, as the moon of Jupiter has a uniform time of revolution about the planet, its times of eclipses should also be uniform if light passed instantaneously; but Roemer found that the eclipse of the moon is seen $16\frac{36}{60}$ minutes sooner when the earth is nearest to Jupiter than when it is furthest from him; therefore, the light must occupy this time in crossing the earth's orbit. The velocity is then about 185,500 miles in a second.

The velocity of light has since been calculated by direct experiment, and found to vary in different media; being in water 144,000 miles per second; in glass, 128,000 miles; in diamond, 77,000 miles.

238. Luminous bodies may be considered as a collection of luminous points. In the study of light it is convenient to assume, unless the contrary is stated, that the source of light is a luminous point. Suppose we had a very small bit of incandescent lime, it is evident that we could see it in all positions of the eye if there were no opaque body intervening; hence, *light radiates in all directions from a luminous point.*

A single line of light is called a *ray.* A collection of rays from the same source is called a pencil of light. The rays of light emanating from a point tend to separate from each other, and thus form *divergent pencils*; but, if the point is very distant, the rays that enter the eye will be sensibly parallel, and, hence, will form a pencil of parallel rays or *a beam of light.* Finally, we may so modify either divergent or parallel pencils that they will become a *convergent pencil,* that is, one whose rays are directed to a common point.

239. Light moves in straight lines through a homogeneous medium. A ray of sunlight admitted into a dark room is seen to be straight by illuminating the floating motes in its course. When an opaque body intervenes, the light is cut off, and a *shadow* is formed. If the source of light be a point, the shadow will be bounded by rays tangent to the opaque body. Generally speaking, the line that bounds the shadow is not clearly defined, because the luminous body has a sensible magnitude.

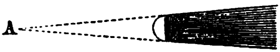


FIG. 127.

240. The intensity of the light varies inversely as the square of the distance from a luminous point. This is a property of all spherical waves, and may be shown experimentally for light by means of shadows.

A board having a surface one foot square placed one foot from a very small candle, will cast a shadow that will cover four square feet at double the distance, nine square feet at treble the distance, and so on. The areas increase as the square of the distance, and, consequently, the intensity of light on each square inch will decrease in proportion to the square of the distance from the luminous point.

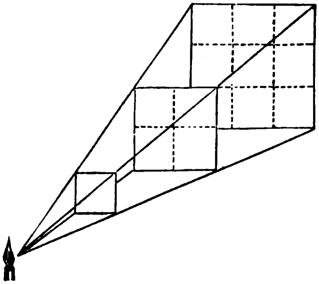


FIG. 128.

241. The relative intensities of two lights may be compared by an application of this law. Place an opaque rod before a vertical screen of white paper, and arrange the lights so that each shall cast a shadow of the rod on the screen. Now move one of the lights backward or forward until a position is obtained in which both shadows appear equally dark. If the shadows are equal, the amount of light falling on the screen from each source must be equal also, hence the relative intensities of the two lights are found by squaring the distance of each light from the screen. In such measurements, it is usual to select a candle of known weight as a standard unit, the other light is then spoken of as having as many "candle-power" as is expressed by the ratio found. The light which we receive from the sun is equal to that of 5,563 wax candles placed at the distance of one foot. The light of the full moon is 300,000 times less than that of the sun.

242. We should not forget that these laws apply strictly to luminous points. We can readily see that the illuminating effect takes into account also the size of the luminous body. Let us suppose, for example, that each portion of a broad gas jet shines with equal intensity. If we cover the jet with a tin shade having a narrow slit in its side, the illuminating effect of the jet will be decreased, although the intensity of the light which passes through the slit will not be altered. So, also, a bright coal-fire may have as great an illuminating effect as a gas jet, although with a less intensity.

243. When a pencil of light falls on any substance it is separated into parts. (1) Some of the light is always *absorbed.* (2) Some of the light is always *reflected.* (3) Some of the light may be *transmitted.* When the transmitted light is changed in direction it is said to be *refracted.*

Absorption. A very thin plate of glass is almost perfectly transparent, but if its thickness is increased, its transparency is diminished, and it may be made so thick as to transmit no light. On the other hand, gold may be made so thin that it will transmit light. The transmitted light has a violet-green color.

RECAPITULATION.

I. Bodies are classified with reference to light in regard—
  1. To the emission of rays:
    - Luminous.
    - Non-luminous.
  2. To the transmission of rays:
    - Transparent.
    - Translucent.
    - Opaque.

II. Light incident on a surface is:
  1. Absorbed.
  2. Reflected.
  3. Transmitted.

REFLECTION OF LIGHT, OR CATOPTRICS.

244. If a ray of light, as *I B*, falls on a plane surface, *A C*, a portion of it will be reflected or thrown back in the line, *R B*. Suppose a line, *P B*, to be drawn from the point of incidence, perpendicular to the reflecting surface, *A C*. It will form with the incident and reflected rays two angles, viz: *I B P*, called the *angle of incidence*, and *R B P*, called the *angle of reflection*, and in every case *the angle of incidence is equal to the angle of reflection.*

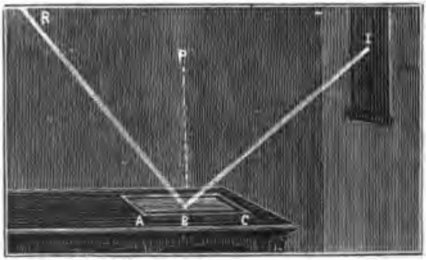


FIG. 129.

245. If a pencil of light falls on a perfectly plane surface, the reflected rays will proceed in the same direction, and the light is said to be *regularly reflected.* When a flat surface is examined by a microscope it is generally found to consist of a number of minute planes inclined to each other at all possible angles. Now, as each little plane has its own perpendicular, the light which falls on an uneven surface will be reflected in all directions, and is then said to be *irregularly reflected* or *diffused.*

246. Non-luminous bodies are rendered visible by light irregularly reflected. The light which they reflect renders them temporarily luminous. Those bodies which are not in the direct sunlight are illuminated by the diffused light reflected from surrounding objects. If a large portion of the incident light is reflected regularly, the eye may perceive an image of the body which *emits* the light. A good mirror gives a bright image of objects in front of it by reason of the light which it reflects regularly, but is itself seen by light irregularly reflected. A surface that reflected none of the incident rays irregularly would itself be invisible, and no substance is known that is perfectly reflecting, absorbing, or transparent.

247. Mirrors are either plane or curved. A looking-glass is an example of a plane mirror. The most common kinds of curved mirrors are those whose curvature is spherical. A *convex* spherical mirror is a portion of a spherical surface reflecting light from the outer face; a *concave* spherical mirror is a portion of a spherical surface reflecting light from the inner face.

The formation of images by mirrors may be determined by investigating the images due to a series of points on the object.

248. Plane mirrors. Let AB be an arrow in front of the plane mirror, MN. Fig. 130. The point, A, will emit a great number of rays. One pencil will be so reflected that it will appear to the eye to come from A'; a pencil from B will appear to come from B'; the pencils from intermediate points on the arrow from points between A' and B'. Hence, if an object be placed before a plane mirror, the image will be formed *behind* the mirror. Such an image has no real existence, and it is called a *virtual image*, because the rays only appear to come from the other side of the mirror.

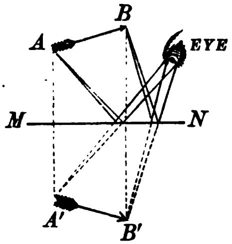


FIG. 130.

In plane mirrors, the image is the *same size* of the object, and appears *as far behind* the mirror as the object is in front.

249. If an object is inclined to the mirror, its image has an equal inclination; hence, the inclination between the object and the image is double that which each has to the mirror. For this reason, trees appear inverted by reflection from the surface of water.

If the object and mirror are parallel, there is a semi-inversion in one direction only. If a printed page is held before a plane mirror, the letters are reversed in a horizontal direction, or from right to left. If a person stands before a vertical mirror, the image of his right hand will be on the left side of the image.

Since the angles of incidence and reflection are equal, a person may see his entire image in a vertical mirror of half his length.

250. Multiple images are formed by mirrors inclined to each other. Two mirrors at right angles give three images. If the mirrors are inclined 60°, five images are produced. The number of images increases as the angle is reduced, and would be infinite when the mirrors are parallel, if the light were not gradually weakened at each successive reflection.

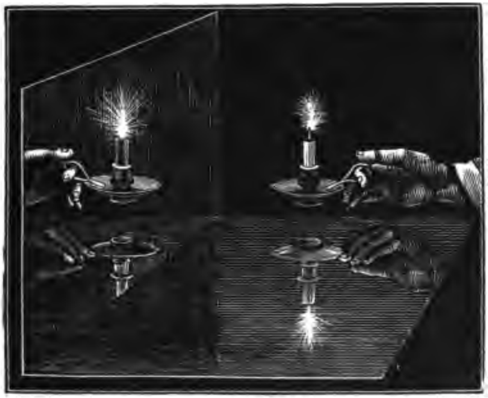


FIG. 131.

251. The kaleidoscope illustrates this property of inclined mirrors. It consists of a tube containing two or three long and narrow mirrors inclined to each other; one end of the tube is closed by ground glass, and the other by plane glass. Small colored objects, as bits of glass, are placed in a cell between the ground glass and another glass disk, leaving just room enough for the objects to tumble about as the tube is turned. On looking through the tube, the objects and their images are seen in beautiful forms.

252. Curved mirrors may be considered as made up of an infinite number of plane mirrors inclined to each other. Let TT''' be a section of a portion of a spherical mirror. C is called the *center of curvature.* The line, CC', which passes through the vertex of the mirror, is called the *principal axis* of the mirror;

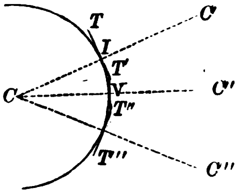


FIG. 132.

any other line, as $C C'$ or $C C'''$, which passes through the center of curvature, is called a *secondary axis*. Any radius, as $C I$, is perpendicular to the concave surface, and its prolongation, as $I C'$, is perpendicular to the concave surface; or, what is the same thing, these radial lines are perpendicular to the little planes, $T T'$, $T' T''$, of which we may consider the mirror to be composed.

253. In concave spherical mirrors the image formed on reflection varies with the distance of the object. The most important cases are the following:

(1) If a luminous point is at a very great distance, its rays will be sensibly parallel. Suppose the parallel rays $H B$, $G D$, $L A$, to fall upon the mirror. Any ray, as $H B$, will be reflected so that the angle $H B C$ is equal to the angle $C B F$. All the reflected rays will pass through the point, F, which lies on the principal axis, about half-way between the mirror and the center of curvature. This point is called the *principal focus* of the mirror.

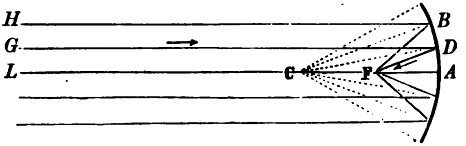


FIG. 133.

Now, as all the rays are reflected to one point, there will be a concentration of light at the focus, but no image will be formed. The converse is also true; if a bright point were placed at the focus, its reflected rays would be parallel, and not enough of them would enter the eye to form an image. Hence we may use concave mirrors to concentrate light to a focus, or, as in light-houses, to reflect the rays from a lamp placed in the focus in parallel rays.

(2) If the point is at a finite distance its rays will be divergent. Suppose *L* to be a point beyond the center of curvature, its rays will converge on reflection to a point *l*, between the principal focus and the center of curvature, and, conversely, rays diverging from *l* will converge on reflection to the point *L*. Points so related are called *conjugate foci*.

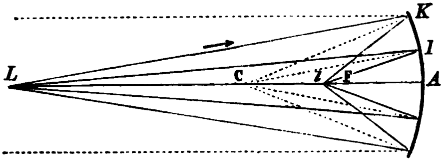


FIG. 134.

Now, suppose a candle to be placed at the same distance as *L*. The rays from the tip, *A*, will converge to some point, *a*, on the secondary axis, *A E*. The rays from *B* to some point, *b*, on the secondary axis, *B I*. Between these two extremes, the images of the other points will be formed; hence, *a b* is the complete image of *A B*. The image is *inverted*, *smaller* than the object, and lies *between* the center and the principal focus.

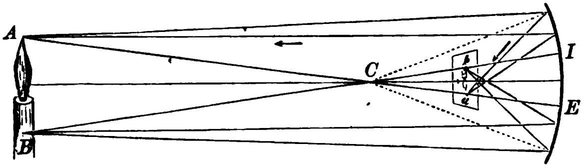


FIG. 135.

Reflecting telescopes are used to give a small but bright image of the heavenly bodies. These images are viewed after being enlarged by lenses. If a reflecting telescope is turned to the sun, the rays from any point on its surface will be parallel, but the rays from any two distant points, as the center and the edge, will not be parallel. Hence, an image of the sun will be formed very near the principal focus of the mirror.

Conversely, if the object were at ab the image would be at AB, *enlarged, beyond the center,* and *inverted,* with respect to the object. Both these images would be *real,* for either may be received on a screen.

254. (3) **When the object is between** the principal focus and the mirror, a virtual image is formed, which is *erect* and *enlarged.*

Let AB be an arrow nearer than the principal focus. Draw the axes, ca and cb. The pencil from A will appear to radiate from a in the same axis, likewise those from B as from b, and the entire image will lie between a and b. The image is enlarged, because the angle at which the lines from a and b enter the eye is greater than would be the lines proceeding directly from A and B. Fig. 136.

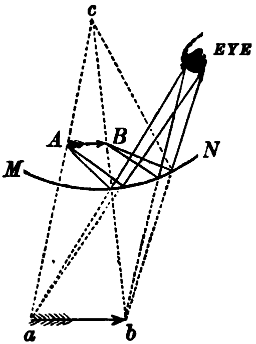


FIG. 136.

255. The visual angle is the angle contained between two lines drawn from the center of the eye to the extremities of an object. (1) For the same object, the angle decreases with the distance of the object; thus, if the same object, AB, is removed to $A'B'$, the visual angle decreases. Hence, if the size of an object is known, we may form some estimate of its distance by its visual angle, having learned by experience to associate together

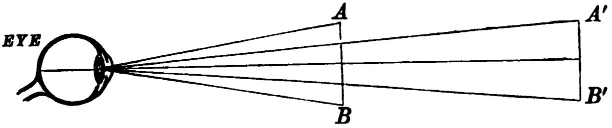


FIG. 137.

distance and angular size. (2) For the same distance, the visual angle increases with the size of the object. Hence, if in any way the visual angle of a known object is increased, it appears magnified, and if decreased, the object appears smaller. The magnifying power of a concave mirror is dependent, not on the area of its surface, but upon its radius of curvature.

256. In convex spherical mirrors the images are always *erect*, *virtual*, and *smaller* than the object. Thus, if *A B* be an object at any finite distance, the image of the point, *A*, will be somewhere on the axis, *A C*, and *B* on the axis, *B C*. The visual angle will be, in all cases, smaller than would the angle formed by the direct vision of the object *A B*. Fig. 138.

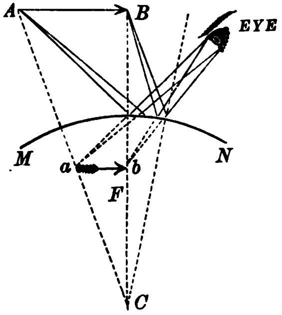


Fig. 138.

257. These laws are accurate when the mirror is a very small portion of a spherical surface. With a large portion, the reflected rays intersect each other, and their foci form curved lines, which are called *caustics by reflection*. Fig. 139. Thus the heart-shaped curve, formed by the reflection of a lighted candle from the concave surface of a tumbler containing milk, is a caustic.

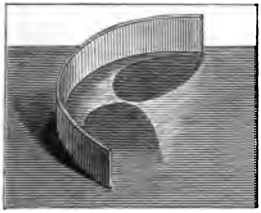


Fig. 139.

Parabolic mirrors are used for the lanterns of locomotives, because, if a luminous point is placed in the focus of a concave parabolic mirror, all the rays which strike the mirror will be reflected exactly parallel. The light thus reflected maintains its intensity for a great distance.

RECAPITULATION.

Mirrors are either plane or curved.

- Curved mirrors are . . . . .
  - Spherical
    - Convex.
    - Concave.
  - Conical
    - Paraboloid.
    - Ellipsoidal, etc.

THE REFRACTION OF LIGHT, OR DIOPTRICS.

258. When a pencil of light falls on a transparent body, (1) some of the rays are reflected, (2) some are absorbed, (3) some are transmitted. When a ray of light passes obliquely from one medium to another, it suffers a change in direction which is called *refraction.*

259. The actual occurrence of this change in direction may be shown by placing a coin in an empty cup in such a position that it is just out of sight; if, now, the cup be filled with water, the coin will become visible, although neither the eye nor the coin has changed its position. Thus, if *A B* be the surface of the water, the ray, *m E*, proceeding from the coin, appears to come to the eye in the line *m′ E.* That is, it suffers a refraction when it passes from the water into the air. Its actual course is the bent line *m I E.* Fig. 140.

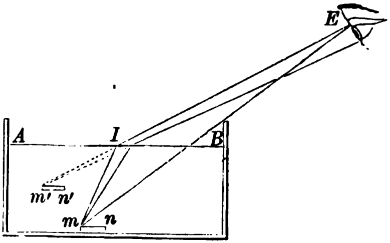


FIG. 140.

260. Suppose an incident ray of light, *A c*, (Fig. 141), moving in air, to meet the surface of water, *R S*, and let *c E* be the refracted ray. Draw *P F* perpendicular to the surface at the point of incidence, c; then AcP is the *angle of incidence*, and EcF is the *angle of refraction*. It lies between the perpendicular and the refracted ray. If the incident ray falls more obliquely, as ac, the angle of refraction, ecf, will become larger. In order to compare these angles, strike a circle with any convenient radius, as cR, and draw from the points, A, E, a, e, lines perpendicular to PF. These lines are called *sines*, and they are used to measure angles. AD and ad are sines of the angles of incidence; EF and ef are sines of the angles of refraction. Now, it is found that $AD \div EF = ad \div ef$, or, in other words, the ratio which exists between the sines of the angles of incidence and of refraction is constant for the same two media. This ratio is called the *index of refraction*; that is,

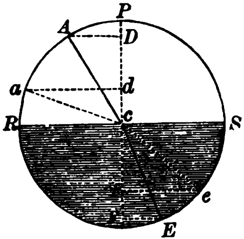


FIG. 141.

$$\text{the index of refraction} = \frac{\text{sine of the angle of incidence}}{\text{sine of the angle of refraction}}.$$

If light passes from air into water, the index of refraction is about $\frac{4}{3}$; when light passes from water into air, the index of refraction is the reciprocal of this fraction, or $\frac{3}{4}$.

261. The index of refraction varies with the media. The following table gives the indices of refraction when light passes from a vacuum into any of the substances named.

Table of Absolute Indices of Refraction.

Vacuum	1.0000	Ice	1.309
Air	1.0003	Water	1.336
Alcohol	1.374	Bisulphide of Carbon	1.768
Crown-glass	1.534	Flint-glass	1.830
Quartz Crystal	1.548	Diamond	2.439

From this table we can readily find the relative indices for any two of the substances named, by dividing the absolute index of one by the other; thus, when light passes from air into crown-glass, the index of refraction is $\frac{1.5340}{1.0003}$, or about $\frac{3}{2}$; from crown-glass into air it is $\frac{1.0003}{1.5340}$, or $\frac{2}{3}$.

In optics, the word *dense* signifies of great refractive power, and *rare*, of little refractive power—without reference to the specific gravity of the substance. The essential oils and alcohol are in this sense denser than water, although their specific gravity is less.

262. When a ray of light passes perpendicularly from one medium to another, it is not refracted. If, in the experiment, on p. 166, the eye is directly above the coin, the coin is seen in its true direction, but there is also a curious effect produced of making the coin appear nearer than it really is. This is due to the fact that the rays which reach the eye from the edge of the coin are not perpendicular to the surface of the water, and hence suffer a refraction.

When light passes obliquely from a rarer to a denser medium, it is refracted toward the perpendicular. When a star is near the horizon it appears to be higher than it really is, because, as its light passes through successive strata of the atmosphere, it is refracted more and more, and appears in the direction which the ray has when it enters the eye.

When light passes obliquely from a denser to a rarer medium, it is refracted from the perpendicular. In this case the angle of refraction is always greater than the angle of incidence.

Suppose light to pass from water into air. Fig. 142. As the angle of the incident rays $I\, I'\, I''$, etc., increases, the angle of the refracted ray, $R\, R^1\, R^2$, etc., also increases. There will be found some ray, as L, whose angle of refraction is a right angle, and the ray, if refracted, would coincide with the surface. If the incident angle is increased beyond this limit, say to *TON*, the ray can not suffer refraction, but will be *totally reflected* in the angle, *NOT'*.

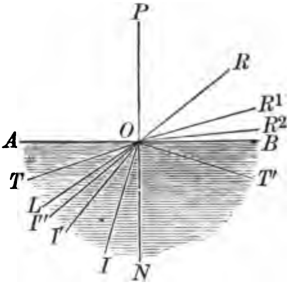


Fig. 142.

This result may be shown by filling a goblet with water, and placing in it a spoon. When the eye is a little below the surface of the water, it will see a bright image of the part of the spoon immersed, reflected from the surface of the water.

Refraction by Regular Surfaces.

263. If a transparent body is entirely surrounded by air, a ray of light, on entering it, will be refracted toward the perpendicular, and, on emerging from the body, will be refracted from the perpendicular.

(1) When the two surfaces of the medium are parallel, the incident and emergent rays are also parallel; because the ray is refracted an equal amount at each surface, and in the opposite direction. The two refractions do not cause any change in the general direction of the ray, but produce a slight lateral displacement, whose amount increases with the thickness of the medium and the obliquity of the incident ray. Fig. 143.

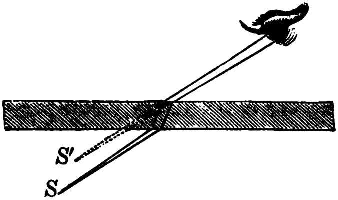


Fig. 143.

A pane of glass occasions no distortion of the objects seen through it when its sides are perfectly parallel; if they are not parallel, the objects will appear more or less distorted.

(2) A prism is a transparent medium having two plane surfaces not parallel. A prism may be a solid wedge of glass or crystal, or may consist of liquids inclosed in hollow prisms with sides of plane glass. The path of light through a prism is exhibited in Fig. 144. Suppose the light to come from O. As the incident ray, OD, enters the prism, it is refracted towards the perpendicular, PP', because it enters a denser medium, and will proceed in the line DK. On leaving the prism for a rarer medium, it will be refracted from the perpendicular, $P'P''$, and will emerge in the line KH. The light is thus twice refracted *toward the base of the prism*, and the eye which receives the emergent ray, KH, sees the object at O' nearer the summit of the prism than the real position of the point, O.

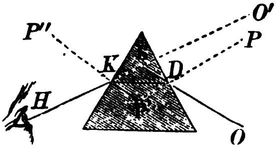


FIG. 144.

(3) A lens is a transparent medium, having at least one curved surface. The curved surface is usually spherical.

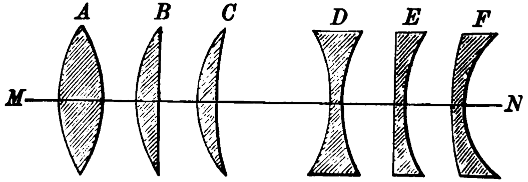


FIG. 145.

There are six varieties of spherical lenses, viz.: A is a *double convex*, B a *plano-convex*, C is a *meniscus*, concave on one side and convex on the other, the convex surface having the shorter radius. These three are thickest at the center, and are *converging lenses*. D is a *double concave*, E is a *plano-concave*, and F is a *concavo-convex*, the concave surface having the shorter radius. These three are thinnest at the center, and are *diverging lenses*. Fig. 145.

The line, *MN*, which passes through a lens perpendicular to both surfaces, is called the axis of the lens. The double convex lens may be regarded as a series of prisms whose bases are turned toward the axis, and the double concave lens as a series of prisms whose bases are turned away from the axis. If the sides of each prism are infinitely small, the series will form a spherical surface. Hence, as a prism refracts light toward its base, a convex lens will refract the light toward its axis, and tend to converge the rays; a concave lens will refract light away from its axis, or tend to disperse the rays. We shall study only the double convex and the double concave lenses, because the properties of these lenses are similar to the others of the same group.

264. If parallel rays fall upon a convex lens, the rays will converge to one point, which is called the *principal focus of the lens*. This focus is real, for all the rays of the sun may be collected at this point. The ordinary burning-glass is simply a large double convex lens. Fig. 146.

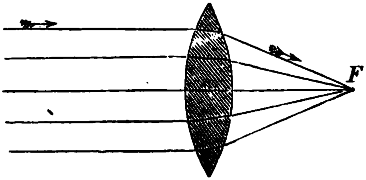


FIG. 146.

265. If the rays diverge from the principal focus they will be rendered parallel. A lamp so placed will illuminate objects at a great distance. Fig. 146.

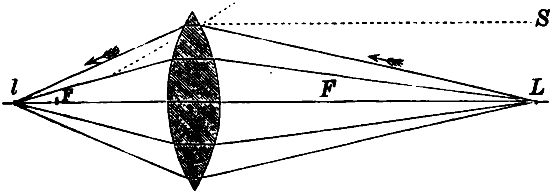


FIG. 147.

266. If the rays diverge from a point *beyond* the principal focus, as at *l*, they will converge on refraction to some point, as *L*, also at a greater distance than the principal focus; and conversely if they diverge from *L* they will converge at *l*. Both these foci are real; one is less than twice the principal focal distance and the other greater.

267. Real images are formed when the object is at a finite distance beyond the principal focus. Suppose *A B* to be at more than twice the principal focal distance. A ray diverging from *A* will converge on refraction at *a*; diverging from *B*, at *b*. Hence, the image of *A B* will be *ab*, *real*, *inverted* and *smaller* than its object. Conversely, if *ab* were a luminous object at less than twice the principal focal distance, but beyond the focus, its image would be *A B*, *real*, *inverted*, and *larger* than the object.

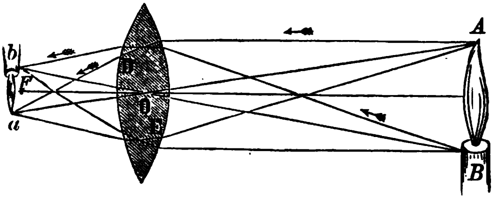


FIG. 148.

If the rays diverge from a point nearer the lens than the principal focal distance they will be less divergent on refraction, but will form no real focus, nor even be rendered parallel. Thus, the rays from *L* will appear to come from a *virtual focus* at *l*, which is on the same side of the lens as

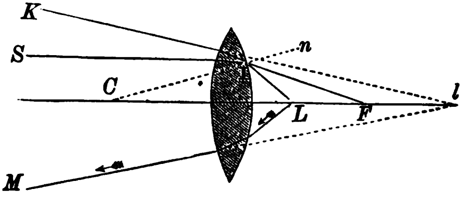


FIG. 149.

the luminous point. If a small object, as *A B*, (Fig. 150), were so placed, a virtual image would be formed at *a b*,

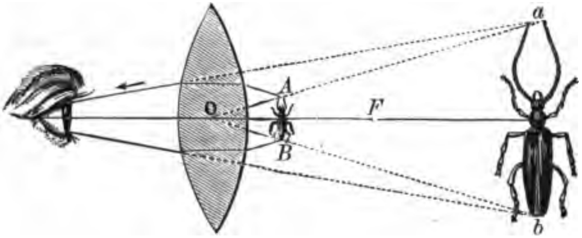


Fig. 150.

which would be *erect*, and *larger* than the object. This is the ordinary way of using a lens as a *magnifying glass*.

268. The foci of concave lenses are always virtual, and the images formed by them are also virtual. Let *A B* be an object in front of a concave lens. The rays from the point, *A*, will be so refracted as to appear to come from its virtual focus, *a*, and the rays from the point, *B*, will appear to diverge from its focus, *b*. Therefore, the eye sees at *a b* an image of *A B*, which is always *virtual*, *erect*, and *smaller* than the object.

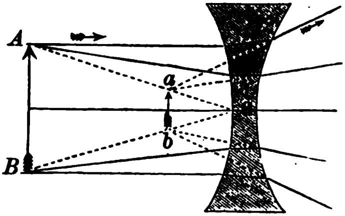


Fig. 151.

Fig. 152.

269. If a crystal of Iceland spar be placed upon an object, as in Fig. 152, a double image will be perceived.

This phenomenon is called *double refraction.* Most transparent bodies have the same property of refracting light in two separate pencils, but not to so great a degree.

These doubly refracted rays have properties which distinguish them from ordinary rays, and are said to be polarized. Light is also polarized by absorption, single refraction, and reflection. The subject of polarized light is so abstruse that it can not be taken up with profit in an elementary course. It must suffice us to say that when a ray has been polarized, it will neither be reflected, refracted, nor absorbed in precisely the same manner as common light, although the eye can not, unaided, distinguish one from the other.

RECAPITULATION.

I. Light is not refracted:

1. In passing through a uniform medium, nor
2. When passing perpendicularly from one medium to another.

II. Light is refracted in passing obliquely into a second medium:

1. Toward the perpendicular, when the second is the denser.
2. From the perpendicular, when the second is the rarer.

III. Lenses are either converging or diverging.

IV. The effects of concave mirrors and of convex lenses are similar: When the object is

1. Nearer than the principal focal distance,
   The image is virtual, erect, and magnified.
2. At the principal focus
   There is dispersion of light in parallel rays.
3. Beyond the principal focus, but less than twice its distance,
   The image is real, inverted, and magnified.
4. At twice the principal focal distance,
   The image is real, inverted, and of equal size.

5. At a finite distance, more than twice the principal focal distance,

The image is real, inverted, and diminished.

6. At an infinite distance,

There is concentration of light at the principal focus.

V. The effects of convex mirrors and of concave lenses are also similar, forming images which are always virtual, erect, and smaller than the object.

OPTICAL INSTRUMENTS, AND VISION.

270. If luminous rays are transmitted through a small aperture, and there received on a white screen, they form inverted images of external objects. The luminous rays proceed in straight lines; those from the top of the object, (Fig. 153), are received on the bottom of the screen, and those from the base of the object on the top of the screen. The rays of light must, therefore, cross each other without interfering. A darkened room so arranged is one form of the *camera obscura.*

FIG. 153.

The photographer's camera, Fig. 154, differs from this only in having a convex lens in the tube, *A*. The effect of the lens is to converge the rays so as to produce a small image of the object, which is, at the same time, clear and well defined.

FIG. 154.

271. The mechanical action of the eye is very similar to that of the photographer's camera. The human eye is very nearly spherical, and is about an inch in diameter. It consists essentially of (1) three enveloping coats and (2) three refracting bodies. Fig. 155 presents these parts in horizontal section.

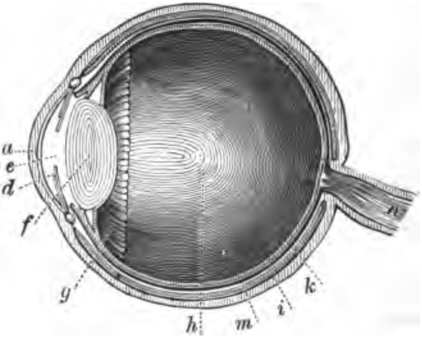


FIG. 155.

(1) The outer coat, or *white* of the eye, is a tough and opaque membrane called the *sclerotic*. In the front part of this, the transparent *cornea*, *a*, is set in like a watch-glass.

The middle coat, *k*, is the *choroid*, which consists of a membrane, abundantly supplied with blood-vessels, and covered, on its inner face, by a dark, velvety substance, called the *black pigment*.

The inner coat is the *retina*, *m*, which is mainly an expansion of the *optic nerve*, *n*, with the addition of terminal nerve elements for the perception of light, spread out in very fine net-work on the black pigment.

Near the junction of the cornea and sclerotic, the choroid becomes thicker, and terminates in the *ciliary processes*. To the outer portion of these is attached an opaque, contractile membrane, *d*, called the *iris*, because it is the colored portion of the eye. The iris is pierced by an aperture, called the *pupil*, through which the luminous rays pass to the bottom of the eye.

(2) Behind the iris, and supported by a suspensory ligament, attached to the ciliary muscle which proceeds from the ciliary processes, is the *crystalline lens*, *f*. This is a double convex lens, having its anterior face of less convexity than the posterior.

The portion of the eye, *e*, between the cornea and the crystalline, is filled with a thin liquid, called the *aqueous humor*.

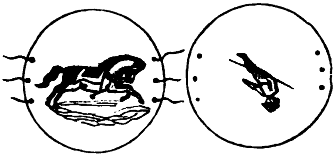
Behind the crystalline is the chamber, *h*, which is filled with a jelly-like liquid, called the *vitreous humor*. The humors and the crystalline are each surrounded by a delicate membrane, or *capsule*.

If a luminous point be placed before the eye, the central rays pass through the cornea and enter the aqueous humor. Of these rays, the more divergent are cut off by the iris, and only those that are nearly parallel are admitted through the pupil. These are transmitted through the crystalline and the vitreous humor, and finally fall upon the retina. The effect of these refracting bodies is to form at, or very near, the retina an image of the luminous point. The same being true of all diverging pencils proceeding from an object, there will be formed on the retina a small inverted image of the object.

272. The sensation of sight is due to the impression made by the image on the terminal percipient nerve elements of the retina, and thence conveyed by the optic nerve fibers to the brain. These nerve elements are contained in a layer next the black pigment, and consist of a great number of very minute bodies, arranged side by side, and resembling *rods* and *cones*, standing perpendicularly to the surface of the retina. It is supposed that the waves of light falling upon this layer of rods and cones produce vibrations, which are conducted by the nerve fibers in such a way to the brain that it is excited and acknowledges the reception of the luminous image on the retina.

273. The impression made on the retina is not instantaneous, and when once made continues, on the average, for nearly one-third of a second after the exciting cause has ceased to act. If, therefore, an ignited coal be whirled about rapidly, luminous rings are produced.

Many optical toys owe their effect to the duration of the impression on the retina. The Thaumatrope, Fig. 156, consists of a card which is made to revolve by means of strings attached to its sides. A horse may be so painted on one



G. 156.

side and a rider on the other, that a rapid revolution of the card will cause the rider to appear seated on the horse.

274. The accommodation of the eye to different distances is effected by the action of the ciliary muscle upon the crystalline lens. When the eye is turned toward a distant object, the muscle relaxes and the lens is flattened; but, for near objects, the muscle contracts and the lens becomes more convex. In this way the conjugate focus of the object is made always to fall upon the retina. The power of accommodation is very great, and is exerted unconsciously with marvelous rapidity. Nevertheless, there is, for all eyes, a certain distance at which the parts of an object, as the letters on this page, are seen most distinctly. This distance, which, for ordinary eyes, varies from five to ten inches, is called the *distance of distinct vision.*

275. Far-sighted eyes are those whose nearest point of distinct vision exceeds ten inches, and *near-sighted* eyes are those whose farthest point of distinct vision is a short distance, varying from three inches to twenty feet. For normal eyes, the farthest point of distinct vision is infinitely distant, the nearest point more than three inches.

276. An object will not appear distinct to the normal eye unless the rays which proceed from it enter the eye nearly parallel. This will be the case for a luminous point when it is distant more than eighteen inches. If a printed page be brought too close to the eye, the letters appear more or less blurred, because the rays are too divergent to focus on the retina. Now, place between the eye and the page a thin card in which a pin-hole has been pricked. The card will exclude the outer divergent rays, and the eye will be able to converge the few nearly parallel rays which pass through the pin-hole upon the retina, and thereby form a faint, but distinct, image. At the same time, the letters will appear magnified, because the visual angle is increased.

277. A convex lens placed a little nearer an object than its focal distance will converge all its rays upon the retina, thus preserving all the light while it magnifies the object by increasing its visual angle. With a powerful lens the object must be very near the lens, and, consequently, the *field of view* will be very small. The *magnifying glasses* used for viewing pictures magnify but little, because their radius of curvature is very large, but they afford a large field of view. *Pocket microscopes* usually contain two or three convex lenses, acting as a single thick lens. They seldom magnify more than five diameters.

278. The compound microscope consists of an object-glass, *M*, of short focus, and an eye-glass, *N*, of less magnifying power. The object, *A B*, is placed a little *beyond* the focus of the object-glass, and its real image, *a b*, inverted and magnified, is formed a little *within* the focus of the eye-glass. By this glass the real image is viewed as with a simple microscope, and, hence, forms another image, *a′ b′*, which is still more magnified, and is virtual. The advantage of this form of microscope is that a high magnifying power is obtained with a comparatively large field of view.

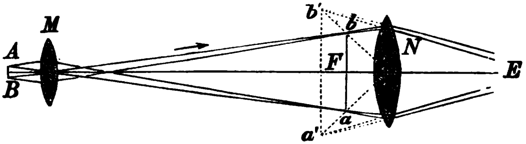


FIG. 157.

The difference between the simple and compound microscopes consists in this, that in the simple microscope the object is viewed directly, and in the compound microscope a real magnified image of the object is viewed with a common magnifier.

279. The telescope is used for viewing distant objects. In *refracting telescopes* a real image is formed by an object-glass of small convexity; in reflecting telescopes a real image is formed by a concave mirror; these images are, in both cases, very small, but very bright. They are then viewed by an eye-glass of high magnifying power.

280. The astronomical refracting telescope consists of the object-glass, *M*, and the eye-glass, *N*. Fig. 158. The object-glass forms an inverted image, *b a*, of a distant object, *A B*, in its principal focus, *F*. This image is then viewed by the eye-glass, *N*, which is so placed as to receive the image at a distance a little less than its own focal length. The image is inverted. This occasions little inconvenience in viewing heavenly bodies, but would be a serious defect if employed for terrestrial objects.

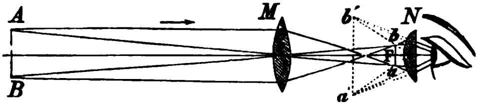


FIG. 158.

281. The terrestrial telescope has, therefore, two additional lenses for rendering the image erect. Fig. 159. The action of these glasses, *P* and *Q*, will be understood by tracing the rays from the luminous point, *A*. *P* renders them parallel, and gives them a new direction. *Q* converges them in the focus of the eye-glass, so as to form a real image which has the same position as the object. This second

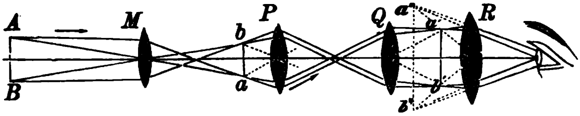


FIG. 159.

image is then viewed in the ordinary way by the eye-glass, *R*.

282. Reflecting telescopes have several different forms. Herschel's telescope is represented in Fig. 160. It consists

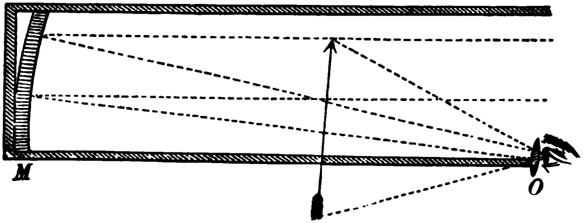


FIG. 160.

of a concave reflector, *M*, and a convex lens, *O*. The reflector is so inclined to the axis of the tube that the image of the star is formed near the side of the tube, in front of the eye-piece, *O*, and is then magnified by the lens and received by the eye.

Lord Rosse's telescope has a mirror six feet in diameter. The amount of available light received at the eye-piece exceeds 250,000 times as much light as commonly enters the eye. This enormous illuminating power enables the observer to use eye-glasses whose magnifying power is 6,000 diameters. This would render an object as large as the capitol at Washington visible at the distance of the moon.

Alvan Clarke, of Boston, has lately succeeded in making a refracting telescope for the Washington observatory, whose object-glass is 26 inches in diameter.

283. The magic lantern is an instrument by which translucent objects are magnified and thrown on a screen. Fig. 161. A lamp is placed in the common focus of a reflector, *MN*, and of a convex lens, *A*, so that a strong beam of light is thrown on the object which is inserted in the slit, *CD*. A magnifying lens at *B* forms an image of the object on the screen, *EF*. The objects are usually painted on glass, but the instrument may also be used to magnify any translucent object.

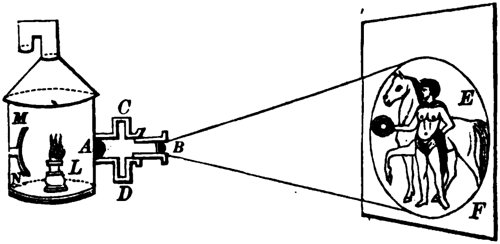


FIG. 161.

The *solar microscope* is essentially a magic lantern illuminated by the sun.

284. The stereoscope. If a solid object, as a die, be held a short distance before the eyes, each eye will see the object from a different point of view; and, consequently,

FIG. 162.

the two images formed on the retina will not be exactly alike. Fig. 162 represents a die as seen by the left and right eyes respectively. By the blending of these two images, the object appears solid. This effect will be produced in the engraving, if a card be held between the two figures, and they are steadily looked at for a few seconds, one by the right eye and the other by the left. The stereoscope, Fig. 163, is contrived to assist the eye in blending two slightly different pictures of the same object, taken from points of view related to each other in the same manner as the two eyes of the observer. These pictures are placed in the bottom of a box and viewed through two eye-pieces, which are segments cut from a double convex lens. A diaphragm, *D*, (Fig. 164), prevents each eye from seeing more than one picture. The rays of light from *A* after emerging from the lens, *M*, reach the eye as if they came from *C*, and the rays from the lens, *N*, also appear to come from *C*. Thus, the two pictures are blended in one, and appear to come from a solid object at *C*.

FIG. 163.

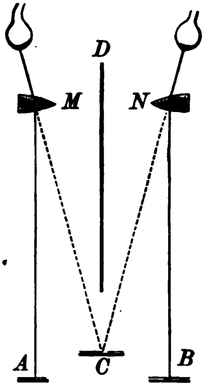


FIG. 164.

RECAPITULATION.

I. The human eye consists of	Enveloping coats.	Sclerotic. Choroid. Retina.
	Refracting bodies.	Aqueous humor Crystalline lens. Vitreous humor.

II. The sensation of sight is produced by luminous vibrations passing through the cornea, aqueous humor, pupil, crystalline lens, vitreous humor to the retina, and there exciting, in the layer of rods and cones, vibrations which are conveyed by the optic nerve fibers to the brain.

III. All optical instruments are combinations of either prisms, lenses, or mirrors.

IV. Microscopes are used for magnifying near objects.
Telescopes are used for magnifying distant objects.

V. Microscopes are simple, and compound.
Telescopes are refracting, and reflecting.

CHROMATICS, OR COLORS.

285. If a pencil of solar light be admitted into a darkened room through a very small aperture, it will form a round, white image of the sun, as represented at *K*, (Fig. 165). If, now, a prism be placed in the path of the pencil, it will form on a screen an elongated band of colors, which is called the *solar spectrum.* That is, the prism not merely refracts the rays, but refracts them unequally, and produces what is called the *dispersion of light.* Newton distinguished seven of these colors as *primary,* which are, beginning with the least refracted, *red, orange, yellow, green, blue, indigo, violet.*

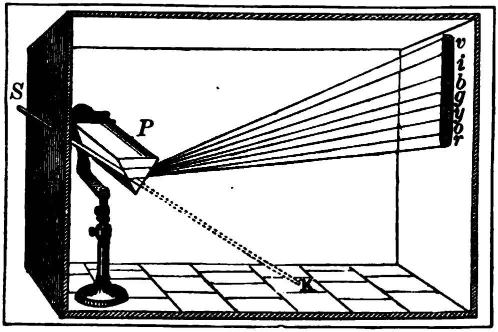


FIG. 165.

286. White solar light is, therefore, composed of different colored rays. An additional proof of this is found in the fact that, when all the colors of the spectrum are recombined, they will reproduce white light. Thus, if all the rays of the spectrum are received on a convex lens or on a concave mirror, a white image will be formed in the focus. If a circular card be painted with the seven colors and revolved rapidly, it will appear of a white color, more or less pure according as the colors on the card more or less exactly imitate those of the spectrum. Fig. 166.

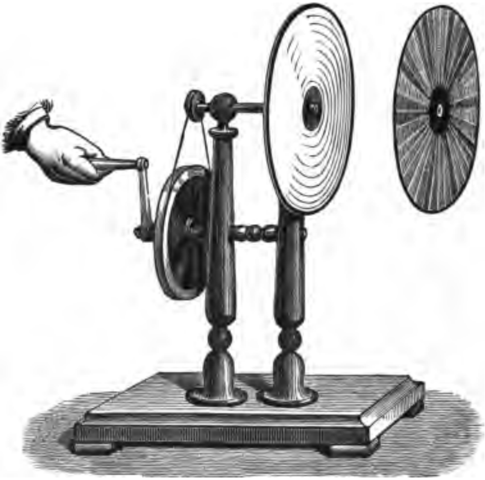


FIG. 166.

287. If the solar light be admitted through a very narrow slit and received on a good flint-glass prism, it will

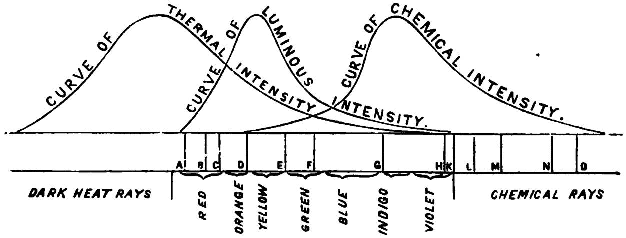


FIG. 167.

be found that the colors of the spectrum are not continuous, but that they are interrupted by numerous dark spaces, known as Fraunhofer's lines. On viewing the spectrum with a telescope two thousand of these lines are visible. Seven are more distinct than the rest, and are designated by the letters *B*, *C*, *D*, *E*, *F*, *G*, *H*, to serve as means of reference. Fig. 167.

288. The index of refraction for the different colors is fixed with precision by ascertaining the position of Fraunhofer's lines, *B*, *C*, etc. The table on p. 167 gives the index of refraction for the line *E* in the yellowish-green rays, which is assumed as the mean of all the rays. If similar prisms are made of different substances the mean refraction may be very nearly the same, and yet the spectra they furnish be of very unequal lengths. The *dispersive power* of a medium indicates the amount of separation it produces in the extreme rays compared with the amount of refraction in the mean rays.

Table of Dispersive Powers.

Bisulphide of Carbon	0.130	Crown-glass . . .	0.036
Flint-glass	0.052	Water	0.035
Diamond	0.038	Quartz crystal . .	0.026

289. If two prisms, exactly alike, are placed near each other, with their bases turned in a contrary direction, the one will exactly neutralize the other, and the light will emerge from the second as if from a medium with parallel faces. Now, suppose two unequal prisms, one of flint and the other of crown-glass, be placed together, as in Fig. 168. The dispersive power of flint-glass is almost double that of crown-glass, while

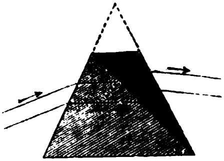


FIG. 168.

its refractive power is but little greater; hence, if the refracting angle of the former is made so much smaller than the latter that their dispersive powers are equal, only white light will emerge, but it will be refracted with about half the refracting power of a single prism of crown-glass.

An *achromatic lens* is made on the same principle by combining a double convex lens of crown-glass with a concavo-convex lens of flint-glass. Fig. 169. Such a lens transmits uncolored light. In any single lens, the image is fringed with colored rays, which are due to the dispersive power of the lens.


FIG. 169.

290. The spectra formed by artificial lights are usually wanting in several colors, but yield the remainder with the same refrangibility as the corresponding colors of the solar spectrum. An almost colorless flame may be produced by burning pure alcohol, or by burning gas in a Bunsen's burner. If a platinum wire be dipped in common salt, or in any sodium compound, and held in a colorless flame, the sodium will vaporize and emit a very pure yellow light. Lithium yields a pure red. Several other substances yield characteristic colored flames: thus, strontium gives a red color; potassium, purple; copper, green.

291. The spectroscope is an instrument used for analyzing flames. Fig. 170. The substance which colors the flame is placed on platinum wires in a Bunsen's burner at *E*, and vaporized. The light which it emits is received through a narrow slit in the end of the tube, *A*, where it is condensed by lenses and thrown on the prism, *P*. The *refracted* rays fall on the object-glass of a small telescope, *B*, and pass through it to the eye. The tube, *C*, is not necessary, but is added for the sake of convenience. It contains a transparent scale which is divided into equal parts. When a candle is placed in front of *C*, it casts a bright image of the scale on the prism, which is *reflected* into the tube, *B*,

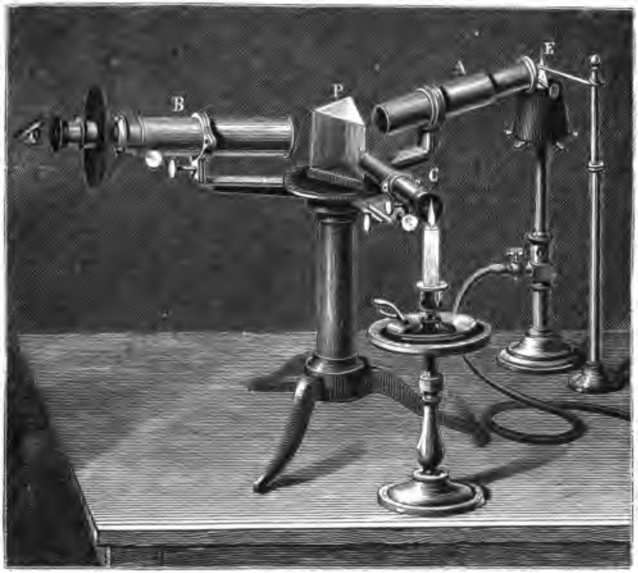


Fig. 170.

so that the observer sees at once the refracted rays and the lines of the scale to which they correspond.

Sodium gives a bright line, identical in refrangibility with the dark line, *D*, in the solar spectrum. Thallium gives a green line near the dark line, *E*. The light emitted by these substances is monochromatic; that is, of only one color. Potassium gives a red line near *A*, and a violet ray near *H*. Strontium gives several red lines between *B* and *D*, and a blue line between *F* and *G*. The light emitted by these substances is, therefore, not homogeneous, but contains two colors. Any substance which can be volatilized will furnish a spectrum of a few bright lines which have a constant degree of refrangibility. This is also true of incandescent gases: hydrogen yields three bright lines, which are identical in position with *C*, *F*, *G*. If several substances are mixed, each will give its own system of lines as if it were burned separately. This property has been turned to account in chemistry in detecting the presence of substances that are easily volatilized. For these bodies, it is an exceedingly sensitive test. It is, in fact, difficult to obtain a flame that does not show the presence of sodium, as $\frac{1}{180000000}$ of a grain of sodium will yield its yellow line. Since the year 1860 four new metals have been discovered by the aid of the spectroscope. Two of these, cæsium and rubidium, are widely distributed, being found in many mineral waters, and in the ashes of tobacco, but in such small quantities that the usual chemical tests failed to detect them.

292. If light, which would give a continuous spectrum, is passed through certain almost transparent and colorless solutions and then examined, dark lines are found, which are owing to the fact that the solution has absorbed some of the rays. Thus, solutions of didymium give two dark lines, one in the yellow and the other in the green. The gases also produce absorption bands; the vapors of iodine and bromine produce remarkable series of black bands. Even the atmosphere exerts an absorptive power, which is especially energetic when the sun is near the horizon. Some of Fraunhofer's lines are, undoubtedly, due to the air, but the larger portion must have another cause.

293. If two sodium flames are placed before the spectroscope, so that one must pass through the other, no spectrum is produced. In other words, sodium vapor absorbs the same rays that it emits. So, also, if the lime-light which gives a continuous spectrum is passed through a sodium flame, a dark line is found in the place where the yellow sodium ray should be, and the spectrum is said to be *reversed.* These phenomena are exhibited by so many substances that we may group the effects produced in two general statements.

(1) *Every substance, when rendered luminous, gives out rays of a definite degree of refrangibility.*

(2) *Every substance has the power of absorbing the same kind of rays that it emits.*

294. In view of these facts, Kirchhoff supposes (1) that the nucleus of the sun emits a continuous spectrum, containing rays of all degrees of refrangibility; (2) that the luminous atmosphere of the sun contains vapors of various elements, each of which would, by itself, give its system of bright lines; (3) that when the light from the nucleus is transmitted through this luminous atmosphere, the bright lines that would have been produced by the atmosphere are reversed; and (4) that Fraunhofer's lines are these reversed lines.

Since the bright lines of the elements coincide with very many of Fraunhofer's lines, it is fair to suppose that these elements exist in the sun. Iron gives four hundred bright lines which coincide with Fraunhofer's lines. Eighteen different metals give similar coincidences. Hence, we are led to suppose that the sun contains iron, manganese, nickel, calcium, copper, sodium, hydrogen, and some other elements. Hitherto no evidence has been given of the presence of gold, silver, mercury, and many other elements.

The fixed stars also show similar coincidences; thus Sirius and Aldebaran are thought to contain sodium, magnesium, and hydrogen. The comets and nebulæ give spectra with bright lines, which seem to show that these bodies are incandescent gases.

295. When a sunbeam falls on a film of oil floating on water, or on a soap-bubble, we notice a very brilliant display of colors. The light is reflected to our eyes both from the outer and inner surface of the film, and produces the phenomena of interference and combination. This is a confirmation of the wave theory of light. We may obtain similar phenomena in various ways. One of the simplest methods is the following: Press together a convex lens, *A B*, of long radius of curvature, upon a plate of plane glass, *D E*. If a beam of monochromatic light falls perpendicularly on the lens, a portion of it will be reflected from the convex surface, *A C B*, and another portion from the plane surface, *D E*. These two systems of waves will intersect in crests and hollows according as their paths differ by an even number of semi-undulations, or by an odd number. At a certain distance from *C*, as at *F*, the two waves will meet in opposite phases and destroy each other, and, hence there will be a black ring at *F*. At a greater distance, as at *G*, the waves will meet in the same phase and increase the amplitude of vibrations, and there will be a bright ring of the same color as the light. Other points will be found beyond *G*, in which the waves will meet in opposite or in similar phases, and, consequently, a series of black and colored rings will be found about the center, *C*.

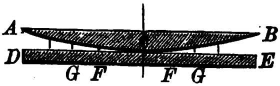


FIG. 171.

FIG. 172.

If the solar light be employed, each ring contains all the colors of the spectrum, because the colors have different refrangibilities, and the rings are not exactly superimposed.

296. These rings are known as Newton's rings. Now, as we can calculate exactly the distance between the two surfaces, we have a means of determining the wave length due to various colors. The following table has been constructed in accordance with these data:

Colors.	Lengths of waves in parts of an inch.	Number of waves in an inch.	Number of waves in a second.
Extreme red ...	.0000266	37640	442000000000000
Red...........	.0000256	39180	458000000000000
Orange	.0000240	41610	489000000000000
Yellow	.0000227	44000	517000000000000
Green..........	.0000211	47460	558000000000000
Blue	.0000196	51110	599000000000000
Indigo..........	.0000185	54070	634000000000000
Violet..........	.0000174	57490	675000000000000
Extreme violet .	.0000167	59750	702000000000000

297. **The color of light** is determined by the frequency of its vibration, or by the length of its wave. Light and sound are somewhat similar. We found that the low tones have a slow rate of vibration and a great wave length. So the luminous rays that are the least refracted are longer and slower than those that are more refracted. But the student will not fail to notice how very small and how very rapid are light waves when compared with sound waves.

298. **It is usual to classify** the properties of the spectrum in three groups: Luminous, Heating, and Chemical. Every ray possesses, it is probable, all of these properties, but not in equal intensity. Thus the maximum chemical effect is found in the rays of high refrangibility; the maximum heating effect in the rays of low refrangibility; the maximum luminous effect in the rays of nearly mean refrangibility, viz.: the yellow. The curves in Fig. 167, show the relative intensity of each property in a spectrum produced by flint-glass. It will be noticed that the spectrum

is drawn as if extending beyond the colored rays; that is to say, there are heat rays that the eye can not perceive because their rate of vibration is too slow, and there are chemical rays which it can not perceive because their rate of vibration is too great. These invisible rays do not differ in kind from the visible rays.

Some persons are color-blind, and can not distinguish colors at all, although in every other respect their sight is perfect. The most common defect of this sort is an inability to distinguish red colors. A person "red-blind" believes that ripe cherries are of the same color as the leaves which hang near them.

299. The natural color of a body is due to the power it has of extinguishing certain vibrations, and of reflecting or transmitting others. A red cloth reflects the red rays and absorbs the rest; red glass transmits only the red rays. A body that reflects all the rays of the solar spectrum is white; a body that reflects but very little light is black.

A curious experiment illustrates that the color of a body is not inherent. Darken a room, and then set on fire a cup of alcohol which has been saturated with common salt: every object will be illuminated by the yellow light of sodium, and appear of a yellow color. As this light falls on the faces of those near the cup, it gives them a ghastly appearance, which is quite wonderful to those who see the effect for the first time.

RECAPITULATION.

When solar light is examined with a prism, it is found to consist of seven primary colors, which are interrupted by dark lines.

Other luminous bodies yield spectra which resemble the solar spectrum in many particulars.

All spectra have luminous, thermal, and chemical properties, but not in equal intensity.

The spectrum analysis depends on the fact that every luminous body emits rays of definite refrangibility.

The dark lines are explained by the fact that every luminous body is capable of absorbing the rays which it emits.

Luminous vibrations may be made to combine and interfere by reflection and refraction.

Colors are dependent on the frequency of the luminous vibrations.

PROBLEMS.

1. It is calculated that the light from the polar star requires 3½ years to reach the earth; what is its distance? 20,486771,800,0

2. What are the relative intensities of two lights that cast equal shadows at distances from an opaque rod respectively 6 inches and 6 feet? 56 : 5/8 1

3. A wax candle is fixed at 10 inches from the opaque rod; what must be the distance of a gas-light from the same rod to cast an equal shadow when the gas burns with "12 candle power?" ~~7a ft.~~ 34.

4. What will be the index of refraction when light passes from crown-glass into bisulphide of carbon? When it passes in the other direction?

5. What will be the relative lengths of two solar spectra produced under the same circumstances by prisms of quartz and of bisulphide of carbon?

6. With red taken as unity, find the ratio between the relative number of vibrations in the colors of the spectrum, and compare with the relative number of sonorus waves in an octave. Will the comparison warrant any analogy between vibrations of light and of sound?

CHAPTER XV.

THE PHENOMENA OF HEAT, OR PYRONOMICS.

300. The phenomena of heat are so generally manifest that we have had frequent occasion to refer to them, and have explained the methods by which heat may be measured. It may be noticed that our sensations of warmth and cold are only relative, and are sometimes utterly untrustworthy as a means of measuring heat. If we place the right hand in iced water and the left in hot, and then transfer both to ordinary cistern water, the left hand will pronounce the cistern water cold and the right hand pronounce it warm. So, also, if we pass from the outer air of a winter's day into a heated room, our sensations may lead us to declare it overheated, even while the occupants of the room are somewhat chilly.

We have also noticed that one effect of heat is to render bodies incandescent, and that the solar rays have their maximum heating effect near the red rays. These phenomena, as well as others that we shall have occasion to study, so connect heat with light that we are almost justified in assuming that their phenomena are due to the same force. Both are certainly forms of energy by which molecules of matter are thrown into vibrations and give rise to waves of crests and hollows. They differ in the fact, that the eye recognizes as light only those waves which have certain limits of rapidity of motion, and which are, at best, very small, while waves of heat can be recognized that are, in comparison, large and of slow rate of motion; although it is not meant to be stated by this that heat waves may not also accompany, or be identical with, the most refrangible luminous waves.

Besides these phenomena, heat produces certain effects within the bodies upon which it acts, which we shall now proceed to consider.

301. **The first effect of heat** on any body, solid, liquid, or aëriform, that is not destroyed by it, is to expand it.

The expansion of gases may be shown by the air-thermometer. Fig. 173. This consists of a bulb of glass with a long stem, which dips into a colored fluid. If the bulb be warmed by the hand, the air inclosed will so expand that a portion will be expelled and rise in bubbles through the fluid. On cooling, that portion of the air which remains will contract to its former volume, and the fluid will rise to take the place of the air expelled.

On repeating this experiment with other gases, it will be found that *all aëriform bodies expand equally* and *regularly for equal successive increments of temperature.* The expansion is $\frac{1}{491}$ for each degree F., or $\frac{1}{273}$ for each degree C.

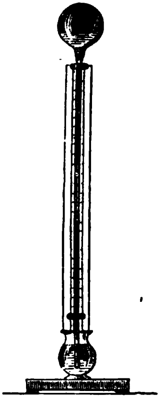


FIG. 173.

The expansion of liquids may be shown by a flask having a long narrow tube fitted to its neck by a cork. Fig. 174. If the flask be filled with alcohol and plunged in boiling water, the expansion of the alcohol will be shown by its rise in the tube. Coal oil expands more than alcohol, but most other liquids less, showing that *different liquids expand unequally* for the same increments of temperature. More accurate experiments show that each liquid also expands *irregularly.* On being raised from 32° F. to

FIG. 174.

212° F. alcohol expands $\frac{1}{9}$ of its volume, water about $\frac{1}{21}$, and mercury $\frac{1}{55}$.

The expansion of solids may be illustrated by the apparatus given in Fig. 5. These experiments show an increase in volume which is termed *cubical expansion.* In solids the expansion is sometimes measured in one direction only, and is then termed *linear expansion.*

Fig. 175 represents the *pyrometer*, an instrument which shows the linear expansion of solids, and which is sometimes used to measure very high temperatures. A metallic rod, *A*, fixed at one end, *B*, presses at the other end the short arm of the index, *K*. When the rod is heated it expands and drives the index along the scale.

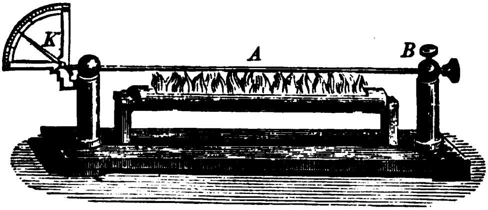


FIG. 175.

302. Different solids expand unequally for equal increments of temperature. If two thin bars of iron and brass are riveted together at different points along their whole length, and boiling water is poured on them, it will bend so that the brass will be on the convex side of the curve. If it is then plunged in cold water, it will curve in the opposite direction. The reason of this is, that the brass expands and contracts more than the iron, and the bar curves, so that the longest bar shall be on the convex side.

FIG. 176.

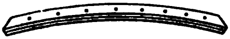


FIG. 177.

Table of Expansion from 32° F. to 212° F.

	Linear.	Cubical.		Linear.	Cubical.
Flint-glass .	$\frac{1}{1248}$	$\frac{1}{416}$	Brass	$\frac{1}{586}$	$\frac{1}{179}$
Platinum . .	$\frac{1}{1131}$	$\frac{1}{377}$	Silver	$\frac{1}{524}$	$\frac{1}{175}$
Steel	$\frac{1}{926}$	$\frac{1}{309}$	Tin	$\frac{1}{516}$	$\frac{1}{172}$
Iron	$\frac{1}{846}$	$\frac{1}{282}$	Zinc	$\frac{1}{340}$	$\frac{1}{118}$

The fractions in the above table of linear expansion show what proportion of its length a body will increase in being raised from 32° F. to 212° F. It will be noticed that the cubical expansion is expressed by a fraction three times as large. With very few exceptions, all bodies contract on cooling to their original dimensions.

303. **When water is heated** from 32° F. to 212° F. it expands .0466 of its volume; it is compressed by a pressure of one atmosphere .000044 of its volume. Therefore, it would require a pressure of over 1000 atmospheres to restore boiling water to its bulk when at the freezing point, or to prevent its expansion on being heated 180°. We see from this that the amount of force exerted in expansion or contraction by heat is enormous. The expansive force of water for each degree F. is nearly $\frac{1000}{180} = 6$ atmospheres, or 90 pounds per square inch.

A bar of wrought iron expands for each degree F. with a force of nearly two hundred pounds per square inch. Hence, it is often necessary to take into account the changes in length which are produced by variations in temperature. Iron beams built into masonry should be left free at one end.

We have an application of the same principle in the method by which tires are secured on wheels. The tire, made a little smaller than the wheel, is heated red-hot, and, while expanded, placed in position. On cooling, it not only secures itself on the rim, but holds all the other parts of the wheel in position.

Brittle substances, as glass or cast-iron, often crack when heated suddenly; because the outside is heated sooner than the inside, and thereby causes an unequal expansion. The thicker the plate, the greater the liability to fracture. A sudden cooling by producing an unequal contraction, has the same tendency to fracture.

304. Water presents an exception to the general law of expansion and contraction by heat. If a flask with a long and very slender neck, Fig. 174, be filled with boiling water and allowed to cool, the water will contract until it reaches the temperature of 39°.2 F. It then begins to expand, and continues to do so until it freezes. At 32° F. it occupies the same space that it did at 48° F. The *maximum density of water* is, therefore, attained at 39°.2 F., and above or below this temperature it expands.

This fact is of infinite importance in nature. In winter, the lakes and rivers cool until they attain their maximum density throughout. If the cooling proceeds further, expansion begins at the surface, and the lighter, though colder, particles float on the warmer particles below. Hence, the freezing takes place only at the surface.

At the moment of freezing, water, in becoming solid ice, undergoes a sudden increase of about ten per cent in volume. The ice, once formed, covers the water like a blanket, and renders the freezing process very slow. If the ice had a greater specific gravity than water, it would sink to the bottom, and in time our lakes would become solid.

305. The second effect of heat on a solid is to melt it. Some solids, as paper, wood, wool, do not melt, but are decomposed. The temperature at which any solid melts is invariable for the same substance, if the pressure is the same. This temperature is called the melting point.

Table of Melting Points, in Degrees Fahrenheit.

Mercury	— 37.9	Bismuth	512.
Bromine	+ 9.5	Lead	620.
Ice	32.	Zinc	680.
Phosphorus	111.5	Silver	1832.
Potassium	136.	Gold	2282.
Tin	451.	Wrought Iron	2912.

Certain bodies, as iron, platinum, glass, and wax, soften before they fuse and become plastic. It is in this plastic state that glass is worked and iron or platinum forged. The melting point of alloys is often lower than that of either of its components. Rose's metal, which consists of four parts of bismuth, one of lead, and one of tin, fuses at 201° F.

306. If a liquid is cooled sufficiently it generally solidifies at the melting point, but the freezing point may be lowered by various means.

If water is boiled to expel the air and then allowed to cool very slowly and without agitation, it sometimes reaches 10° F. before it freezes. When in this condition, any disturbance, as a jolt or the addition of a bit of ice, will cause immediate congelation throughout the entire mass. The temperature will rise to 32° F. In fine capillary tubes, water has been lowered to — 4° F. without solidifying. This probably explains why sap is not frozen in plants.

The presence of salts in solution lowers the freezing point of water. Saturated brine freezes at — 4° F. Sea-water freezes at 27°.4 F. In such cases, nearly pure ice is formed. The water appears to crystallize out, leaving the salt behind. Weak alcoholic mixtures, like wine and cider, may be concentrated by exposing them to cold and removing the layers of ice as they form.

307. Water expands with enormous force at the moment of freezing. Bomb-shells an inch thick, filled with water, have been burst by the freezing of the water. On a smaller scale, the fact is familiar to northern housekeepers in the breaking of utensils in which water has been allowed to freeze. Cast-iron, bismuth, antimony, and type-metal also expand on solidifying. These substances give sharp casts, because, when the metal sets, the expansion forces it into the minute lines of the mold. Most substances contract on solidifying. Coins of copper, silver, and gold are not cast, but stamped.

308. The third effect of heat is vaporization. Some solids, as iodine, arsenic, and camphor, vaporize without becoming liquids; but, generally, vapors are formed from liquids, as liquids are from solids. If the vaporization takes place quietly, it is termed *evaporation*; but, if the liquid is agitated by the formation of bubbles of its own vapor, the process is termed *boiling*.

309. The evaporation of water is going on constantly in nature, and is one of the means by which the earth is rendered fit for the maintenance of life. The principal circumstances which influence the evaporation of water are the following:

(1) *The temperature.* Evaporation may go on at very low temperatures. Snow and ice disappear from the ground even when there has been no thawing. Clothes are dried on a winter's day when the thermometer shows a temperature below freezing. Increase of temperature favors evaporation. In summer, the roads are soon dry after a shower, because the evaporation is rapid.

(2) *The amount of surface exposed;* because evaporation proceeds only from the surface.

(3) *The condition of the air.* The air can hold only a limited amount of aqueous vapor. At 32° F. one cubic foot of air can hold only 2.37 grains of aqueous vapor, which is $\frac{1}{236}$ part of its weight. For every increase of 20° F. the capacity of air for moisture is nearly doubled; at 52° F. it can absorb $\frac{1}{118}$ part of its weight; at 72° F. about $\frac{1}{59}$ part, and so on. When air contains as much moisture as it can hold, it is said to be *saturated*, and evaporation must cease. Therefore, evaporation is most rapid in dry air.

Now, if the air above a liquid is not changed, it becomes saturated. Hence, evaporation is more rapid in a breeze than in still air. For this reason a warm, sultry day is less favorable to evaporation than a cold day with a brisk wind.

310. Suppose air at 72° F. to be saturated with moisture, and then to cool gradually. As the temperature lowers, its capacity for moisture decreases, and a portion of the moisture present will be deposited as dew. If the temperature falls to 52° F. half of the original quantity will have been deposited. Now, suppose the air at 72° F. to have been nearly but not quite saturated; as the temperature is lowered, a point will be reached at which the air is saturated, and then a temperature at which the dew will begin to form. This last temperature is called the *dew-point.*

The dew-point may be determined with sufficient accuracy for ordinary purposes by placing ice in a tin cup containing water, and noting, by a thermometer, the temperature of the water when the dew begins to form on the outside of the vessel. The "sweating" of pitchers is an indication of rain, because it shows that the air is nearly saturated with moisture, which will fall if the temperature of the air is lowered below the dew-point.

Our comfort depends largely on the amount of moisture present in the atmosphere. If the air is saturated, the perspiration is not carried off from our bodies; if it is, at the same time, warm, we perspire more, and the air is said to be *sultry*. If the air is too dry, the moisture is carried off too rapidly from our lips and eyelids, and they become dry.

311. The temperature at which liquids boil is constant for the same substance, under like conditions. Several conditions influence the boiling point:

1. *The nature of the liquid.* The boiling point of several liquids under the pressure of one atmosphere is given below.

Table of Boiling Points.

Nitrous oxide .	— 157° F.	Bromine . .	145°.4 F.
Carbonic acid .	— 108.4	Alcohol . . .	173.1
Sulphurous acid	+ 17.6	Water . . .	212.
Ether	94.8	Mercury . . .	662.

2. *The adhesion of the liquid* to the vessel that contains it. Water sometimes boils in a glass vessel at 214° F.; especially is this apt to be the case if the water has been deprived of air by previous boiling.

3. *Salts in solution* increase the boiling point. A saturated solution of common salt boils at 227° F.; of calcium chloride at 355° F. Substances mechanically suspended, like sawdust, do not influence the boiling point. The steam which forms in the last two conditions assumes almost immediately the temperature of 212° F.

4. *Variations of pressure.* A liquid boils when the tension of its vapor is equal to the pressure which it supports. If a cup containing ether be placed under the receiver of an air-pump, the ether will boil when the receiver is partially exhausted. So, also, tepid water may easily be made to boil in an exhausted receiver.

The culinary paradox illustrates the same principle. A flask containing boiling water is tightly corked while the steam is escaping, and inverted. If, now, cold water be poured on the bottom of the flask, the boiling will be renewed. The reason of this is, the cold water condenses the steam above the water, produces a partial vacuum, and thus diminishes the pressure on the liquid.


FIG. 178.

The sirup of sugar and of vegetable extracts are concentrated in closed vessels, called vacuum pans. A powerful air-pump constantly removes the pressure from the pan, and, consequently, the evaporation proceeds at a temperature so low that it secures the sirup or the extract from injury by heat.

312. A variation of an inch in the barometric column makes a difference of about 2° F. in the boiling point of water. The atmospheric pressure is lowered on ascending mountains; hence, water boils at lower temperatures on mountains than at the sea level. A difference of 600 feet of ascent makes a variation of about 1° F. in the boiling point.

Under increased pressures the boiling point is raised. If water be placed in a small boiler, Fig. 179, furnished with a thermometer, a manometer, and a stop-cock, and boiled, it will be found that so long as the stop-cock is open the temperature of boiling will remain steadily at 212° F. On closing the cock the boiling point will rise, because the steam which continues to form increases in elastic force, and produces pressure on the water. When the manometer shows a pressure of thirty inches of mercury, the boiling point will equal 249°.5 F. This is the boiling point due to two atmospheres: one shown by the manometer; the other, the atmospheric pressure present before closing the cock.

If steam is formed in a boiler and then conducted through red-hot tubes, it follows the general law for expansion of gases, and is then called superheated steam. Such steam is applied to the rendering of fats.

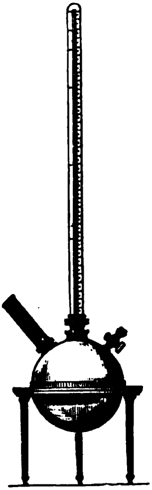


FIG. 179.

313. Every one must have noticed that when drops of water are thrown on a heated stove they roll about, becoming gradually smaller, and finally disappear in a sort of explosion. The explanation of this phenomenon is, that as soon as the drop reaches the surface a portion of it is converted into vapor, which supports the liquid and prevents it from touching the heated metal. The drop assumes what is called the *spheroidal state*, and evaporates at a temperature lower than its boiling point. If a copper flask be intensely heated, and a small quantity of water poured in, the water will assume the spheroidal condition, and, for a time, all will appear quiet. Fig. 180. Now cork the flask and remove the source of heat. When the flask has sufficiently cooled, the water will come in contact with its surface, and so much steam will be formed

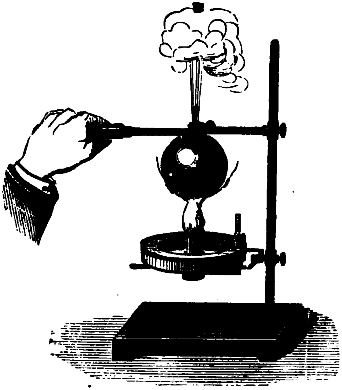


FIG. 180.

suddenly that the cork will be ejected with violence. It is probable that boiler explosions are sometimes caused in a similar manner.

There are some curious phenomena which are due to the spheroidal state. Thus, if sulphurous acid is thrown into a capsule heated white hot, it assumes a spheroidal state, and remains at a temperature of 13° F. Water thrown into it will instantly freeze. So, also, a hand moistened with water may be drawn without injury through molten iron as it runs from the furnace. The moisture forms a non-conducting envelope which sufficiently protects the hand during the short period of its immersion.

314. A saturated vapor condenses into a liquid at its boiling point. The process of distillation illustrates this fact. It is used to separate volatile liquids from mixtures. Fig. 181 represents a common still: the boiler, *a*, contains the liquid to be evaporated; the spiral tube, *d d*,

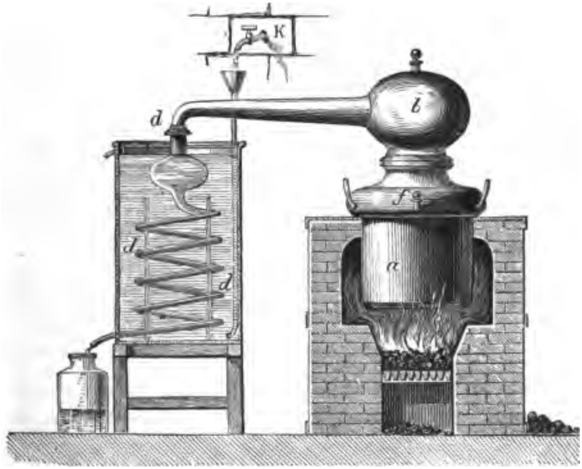


FIG. 181.

which is called a *worm*, receives the vapors from the boiler. The worm is kept cool by being surrounded with cold water, and the vapors condense within it and run into a suitable receptacle.

RECAPITULATION.

The effects of heat are:

1. The expansion and contraction of bodies.
2. The melting and solidifying of solids.
3. The vaporization and condensation of liquids.
4. The incandescence and cooling of solids.

SPECIFIC AND LATENT HEAT.

315. Let us now consider some facts relative to the amount of heat which is required to produce changes of temperature in known weights of different substances. We assume as a relative measure of the quantity of heat that may be gained or lost by a body the *thermal unit*, which is the amount of heat required to raise one pound of water from 32° F. to 33° F.

Suppose, now, that we have a uniform source of heat, as an alcohol lamp that consumes a pint of alcohol an hour, and suppose that in our experiments no heat is wasted in heating the apparatus, or the surrounding objects. If we employ this heat in warming different substances, we should find two sets of phenomena: those of *specific*, and of *latent heat*.

SPECIFIC HEAT. If one pound of water were raised from 32° F. to 33° F. in a given time, the same amount of heat would be competent to raise five pounds of sulphur or thirty pounds of mercury from 32° to 33° F., or would raise one pound of sulphur five degrees F. and one pound of mercury thirty degrees F. The heat required to raise one pound of any substance through 1° F., compared with the thermal unit, is called the *Specific Heat* of the substance.

316. **We may determine the specific heat** of bodies by reversing this experiment. Suppose equal weights of different bodies be heated to the same temperature in a bath of boiling water or oil, and then placed in cavities in a cake of ice. In comparison with water, sulphur will melt $\frac{1}{5}$, iron $\frac{1}{9}$, and mercury $\frac{1}{30}$ as much ice. These fractions express the specific heats of these substances, because the heat given out in cooling is precisely equivalent to that required to raise the same body through the same number of degrees.

317. **The specific heat of aëriform bodies** may be determined by passing a heated gas through the worm of a distilling apparatus, and noting the rise in temperature produced in the water when a given weight of gas has been cooled to a known temperature.

318. **The specific heat of a substance** increases slightly with a rise in the temperature, and is generally much greater in the liquid state than in either the solid or the aëriform condition. These facts are shown in the annexed tables.

Tables of Specific Heat.

	Between 32° F. and 212° F.	Between 32° F. and 572° F.
Mercury	.0330	.0350
Silver	.0557	.0611
Iron	.1098	.1218
Glass	.1770	.1900

	Aëriform.	Liquid.	Solid.
Water	.4805	1.0000	.5050
Bromine	.0555	.1060	.0843
Lead	....	.0482	.0314
Alcohol	.4534	.5050	....

	Equal volumes.	Equal weights.
Air	.2375	.2375
Oxygen	.2405	.2175
Hydrogen	.2539	3.4090
Turpentine	2.3776	.5061

319. With the exception of hydrogen, water possesses the highest specific heat known. The presence of large bodies of water has, for this reason, a marked effect on the climate, owing to the large amounts of heat which seas absorb and emit in accommodating themselves to changes in external temperatures. An oceanic climate is, therefore, more equable than an inland climate; its summers are cooler and its winters warmer.

On the islands of Lake Erie, water does not freeze until the water of the lake has cooled to 40° F., thus prolonging the season sufficiently to ripen grapes. A daily effect is witnessed in tropical islands in the land and sea-breezes. While the sun shines, the land becomes warmer than the ocean, and, by consequence, the air above the land becomes rarefied by the heat, and is displaced by the cold air which presses in from the ocean, and a *sea-breeze* is produced; in the night, the land is sooner cooled, the air above it becomes more dense and flows out to the ocean in a *land-breeze.*

LATENT HEAT. These facts show that different bodies require different quantities of heat in order to increase their temperature. Suppose, now, that we employ heat sufficient to melt them or to vaporize them. If a thermometer be placed in a basin filled with melting ice, it will remain at 32° F. until the whole is melted. The temperature will then rise to 212° F., and then again become constant until all the water is changed to steam. So, generally, *a body in the act of changing its state in melting or in vaporizing maintains a constant temperature.* Now, it is manifest that a considerable amount of heat is required to effect these changes, although it is not sensible to the thermometer. It performs work by overcoming the cohesion of the molecules, and disappears as heat. It is, however, capable of re-appearing as heat; for, when the vapors change to liquids or the liquids to solids, the force of cohesion performs work, and a corresponding amount of heat is given out. The heat which a body absorbs or gives out in changing its molecular condition is termed *latent heat.*

320. The latent heat of fusion may be determined by the method of mixtures. Suppose a pound of water at 212° F. be mixed with a pound of water at 32° F., it will give two pounds of water at $\frac{212° + 32°}{2} = 122°$ F.; but, if a pound of water at 212° F. be mixed with a pound of ice at 32° F., we shall have two pounds of water at 51° F. In this case the water has lost $212° - 51° = 161°$ F., while the ice has gained $51° - 32° = 19°$ F.; so that $161° - 19° = 142°$ F. have disappeared in changing ice to water; or, in other words, 142 thermal units are required to change a pound of ice into water.

Latent Heat of Fusion.

Water	142°.65 F.
Sulphur	16.85
Lead	9.65
Mercury	5.11

The latent heat of water is of the greatest value in nature, because (1) it retards the melting of snows. If it were not for this provision, the inhabitants of northern valleys would be subject to terrific inundations at every approach of spring. (2) The melting of ice withdraws heat from surrounding objects. Near the Great Lakes, the spring is so much retarded by the melting of the winter's ice that, generally, the buds of trees do not swell until the danger of late frosts is past. (3) The freezing of water mitigates the sudden setting in of frosts, as the very act of freezing liberates heat. Hence, it is a common remark that the weather moderates on a fall of snow.

321. Freezing mixtures depend on the latent heat which is absorbed in dissolving solids. If one part of common salt and two of snow are mixed together, the salt causes the snow to melt and the water dissolves the salt, so that both become liquid and absorb a large amount of heat from surrounding objects. The temperature may be lowered to —4° F. This is the mixture used in freezing ice-creams. If crystallized calcium chloride be mixed with snow, a cold of —50° F. may be produced. This is more than sufficient to freeze mercury.

322. The latent heat of vapors may be determined by distilling them and noting the rise of temperature caused in the water surrounding the worm on condensing a known weight of vapor. The following experiment is a convenient method of illustrating the latent heat of water.

Arrange a glass flask and beaker, as in Fig. 182. Pour one ounce of water at 32° F. into the flask, and $5\frac{1}{3}$ ounces at the same temperature into the beaker. Now, note (1) the time required to raise the water in the flask to boiling and that required to change the boiling water into steam. The latter will be $5\frac{1}{3}$ times longer than the former. (2) When the water in the flask has been expelled, that in the beaker will be raised to 212° F., showing that an ounce of steam is competent to raise 5⅓ ounces of water through 180° F. Therefore, the latent heat of steam is $180 \times 5\frac{1}{3} = 960°$.

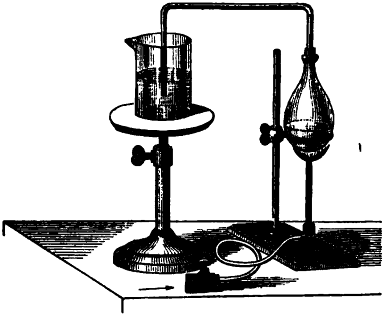


FIG. 182.

Latent Heat of Vapors.

Water	966°.6 F.	Ether	162°.8 F.
Alcohol	374.9	Bisulphide of Carbon	156.
Acetic acid . .	183.4	Bromine . . .	82.

323. When liquids are evaporated they absorb heat from surrounding objects and produce cold. A shower of rain cools the air by its evaporation. The more rapid the evaporation the greater will be the effect produced. Water may be frozen by its own evaporation, by placing a thin, shallow capsule, filled with water, over strong sulphuric acid, under the receiver of an air-pump. On rapidly exhausting the receiver, the sulphuric acid absorbs the aqueous vapor, and allows a very rapid evaporation of the water, which effects the freezing of a portion of it.

If a volatile liquid like ether or bisulphide of carbon be poured in a watch-glass which rests on a drop of water placed on a board, and a rapid current of air be blown over it, the cold produced by the evaporation will freeze the watch-glass to the board.

324. When vapors are condensed they give out their latent heat. Water may be boiled in a wooden tank by forcing steam into it. Buildings are warmed by the heat of steam generated in a boiler placed in the basement. To this end, the steam is conveyed to the several apartments by coils of iron pipes.

RECAPITULATION.

The measurement of heat may regard,

1. The relative intensity	Temperature.
2. The relative quantity	Specific heat.
3. The amount absorbed or emitted during molecular changes	Latent heat.

THE DISTRIBUTION OF HEAT.

325. The effects of heat thus far considered have reference only to the molecular motions which take place within a heated body; we are now to consider how heat may be transferred to other bodies. In the first place, we remark that no body is known to exist at a temperature of absolute zero; that is, at a temperature in which its molecules are absolutely at rest with respect to each other. Hence, all bodies possess some heat. In the second place, we notice that any body assumes, sooner or later, the temperature of surrounding bodies. Now, this can occur only by a continued exchange of molecular motions, by virtue of which every body emits thermal waves or vibrations of some degree of intensity, while, at the same time, it receives other thermal waves from surrounding bodies. If the sum of the motions received is less than that emitted, the body becomes colder; but, if greater, the body becomes warmer. If it receives back just as much heat as it gives out, it remains at a uniform temperature.

326. Heat may be transferred from one body to another in three ways:

1. By *conduction*, or from molecule to molecule.
2. By *convection*, or by molecules moving in currents.
3. By *radiation*, or by thermal undulations through space.

327. The conductibility of solids may be shown by equal-sized rods, along which a number of marbles are fastened, at equal distances, with wax. Fig. 183. If one end of the rod be in contact with a heated body, the marbles will drop off one after the other as the different sections of the rod attain the temperature of the fusing point of wax. Different substances will show different conducting power, but in all cases it will be found that the transference of heat by conduction is a process comparatively slow. Porous solids are poor conductors; liquids and gases almost non-conductors; many of the metals are good conductors.

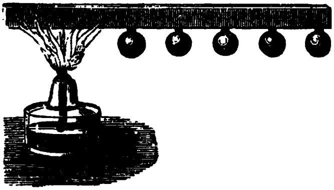


FIG. 183.

Relative Thermal Conductivity.

Silver	100.	Iron	11.9
Copper	73.6	Lead	8.5
Gold	53.2	Platinum	8.4
Brass	23.6	Bismuth	1.8

328. That liquids are poor conductors may be shown by passing the tube of an air-thermometer through a funnel, so that the bulb shall be just below the surface when the funnel is nearly filled with water. Fig. 184. Now, if ether be poured on the water and ignited, the thermometer will be but slightly affected.

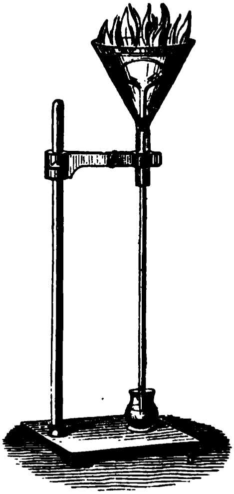


FIG. 184.

329. The conducting power of a body may be roughly estimated by the touch. An iron rod heated above 120° F. will burn the hand, because it conveys its heat rapidly to the skin, and if cooled below 0° F. it will blister the lips, because it conveys their heat away so rapidly. An oil-cloth feels warmer or cooler than a carpet in the same room according as their common temperature is greater or less than that of the skin. So, also, a person clad in woolen garments may enter an oven heated to 300° F. without inconvenience, because both his garments and the air are poor conductors.

Water is sooner heated in a tin cup than in one of porcelain, because the metal is a better conductor of heat. Porous bodies, like ashes and plaster of Paris, are such poor conductors that if the hand be protected by a thin layer of either, it may carry live coals without danger.

330. Non-conductors are used (1) to prevent the escape of heat, or (2) to exclude heat.

1. Double doors and windows, which inclose a layer of air, prevent the escape of heat from our apartments. Clothing prevents the escape of heat from our bodies. The conducting power of the ordinary materials used is in this order: linen, cotton, silk, wool, furs. Hence, with equal

texture, a woolen garment is warmer than one of silk, cotton, or linen.

2. Furnace men wear thick woolen garments to exclude heat, because that to which they are exposed is greater than the heat of their bodies. Ice may be kept from melting by wrapping about it a thick blanket. Ice-houses have double walls, inclosing a thick layer of straw, sawdust, or charcoal. Water-coolers are constructed in the same manner.

331. Convection. If heat be applied to the bottom of a flask of water, (Fig. 185), containing matter in suspension, as sawdust, up and down currents will be formed. The particles of the liquid which become heated expand and rise, because the colder and heavier particles descend and force them upward. This process of circulation among molecules is termed *convection.*

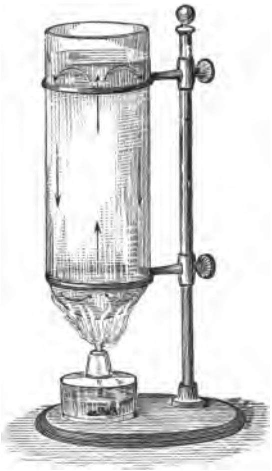


FIG. 185.

332. The convection of gases is more energetic than that of liquids, because their expansion by heat is much greater. If "touch-paper" containing potassium chlorate be burned in the vicinity of a heated body, the currents of air arising from it may be traced in the smoke. The air which thus rises is heated by convection.

333. In all cases of convection there must be two currents in opposite directions. If a lighted candle be held in the crack of a door which opens between two apartments of different temperatures, a current of warm air from the heated room will drive the flame outward, if held at the top of the door; and a current of cold air will drive the flame inward, if held at the bottom of the door.

The winds are primarily due to interchange of air between localities unequally heated. Only the lower current admits of being accurately traced, but we have ample evidence that there are also upper currents. It frequently happens that clouds are seen moving in different directions — the lower clouds in the direction of the surface-winds, and the upper clouds in the opposite direction.

334. The heat of the sun can not reach the earth by conduction nor by convection, since heat is propagated by either of these methods very slowly. In our study of the solar spectrum we learned that the least refracted end of the spectrum contained invisible rays which had the power of affecting the thermometer. These dark rays must reach us in the same way that light reaches us; that is, by thermal waves, which are transmitted by the aether and other media. Heated bodies have the same power of emitting thermal waves in all directions that luminous bodies have of emitting luminous waves. This emission of heat is termed *radiation*. The phenomena of radiant heat and light are, in all respects, similar; and, with the necessary change of terms, their laws are identical.

The laws of radiant heat are:

1. *Heat radiates in straight lines in all directions.*

2. *The intensity of radiant heat is inversely as the square of the distance from its source.*

3. *The intensity of radiant heat is proportional to the temperature of its source.*

335. Radiant heat, incident on a surface, may be (1) reflected, (2) refracted, (3) absorbed, or (4) transmitted.

336. Substances which reflect light well are also good reflectors of heat. The polished metals are all good reflectors of heat. Archimedes is said to have burned the Roman fleet at Syracuse by concentrating upon the ships the solar rays by means of concave mirrors.

337. **When a solar beam** is transmitted through a prism of rock-salt, and the spectrum is examined by a thermometer, we have the result sketched in Fig. 167, showing:

1. That the thermal spectrum extends through and beyond the visible spectrum. Thermal waves must, therefore, be of different refrangibility and wave length.

2. The maximum heating effect lies beyond the red, in rays of great wave length, but invisible to the eye.

The thermal waves which accompany light are called *luminous thermal waves*, and the dark rays are called *obscure thermal waves*. When a platinum wire is heated it emits, at first, only obscure rays; when it becomes incandescent, it not only emits luminous rays, but adds to the intensity of the obscure vibrations.

338. **Most transparent** bodies transmit the rays of heat from the sun as well as those of light, but will not equally transmit the thermal rays from artificial sources. Thus, the heat of the sun will readily pass through glass windows and warm a room, while the same thickness of glass would effectually shut off the heat of a fire. On the other hand, there are bodies that are opaque to light which transmit the dark rays of heat almost perfectly; such, for example, is a solution of iodine in bisulphide of carbon. A substance which transmits heat is called *diathermanous;* one that is opaque to heat is called *athermanous.* Rock-salt is one of the most diathermanous substances known. A lens made of rock-salt will so concentrate the obscure thermal rays that they may be made to melt and even ignite solid bodies.

The incident rays of heat which are not reflected or transmitted are absorbed. Only the rays which are absorbed have any effect in warming the body on which they fall. Dry air is almost perfectly diathermanous, but air containing moisture has far less power of transmitting luminous thermal rays, and is almost athermanous for obscure thermal rays. The solar rays pass with comparative ease to the earth, and are expended in warming its surface. The heated earth radiates only obscure rays, which are absorbed by the atmosphere, and, consequently, its rate of cooling is diminished. In central Asia the air is very dry, and the radiation from the earth is so rapid that the nights are very cold and the winters almost unendurable.

The hot-beds of gardeners act by economizing the heat of the sun. The solar rays pass freely through the glass and are absorbed by the earth and the plants. These emit only obscure rays, which can not escape through the glass. The air confined in the bed attains a temperature above that of the exterior atmosphere.

339. If a body is athermanous all the rays of heat which fall upon it that are not reflected are absorbed. Hence, bad reflectors are good absorbents and are readily warmed. As bodies must give out, in cooling, the heat which they have absorbed, so good absorbents are good radiators. The relation between the radiating, reflecting, and absorbent powers will be seen by the following table:

	Reflection.	Absorption.	Radiation.
Lamp-black	0	100	100
Indian ink	4	96	85
White lead	47	53	100
Isinglass	48	52	91
Gum lac	57	43	72
Polished metal	86	14	12

The radiating power of a body is dependent more on the nature of its surface than of its substance. If a tin canister have one of its sides coated with lamp-black, another with paper, a third scratched or tarnished, and the fourth polished, and be filled with boiling water, its sides will, of course, have the same temperature; but they will differently affect a thermometer placed in succession near each face, according to the difference in their radiating power.

Lamp-black has the highest emissive power known; the polished metals are the poorest radiators. Hence, a bright silver tea-pot filled with hot water will retain its temperature longer than one of earthenware.

340. Franklin found by placing pieces of cloth of the same texture, but of different colors, upon newly fallen snow, that the snow melted under the cloth with greater rapidity the darker the tint. This fact shows that, for solar rays, clothes of dark color are better absorbents and poorer reflectors than white. Other experiments show that this difference in the absorptive effect of colors entirely fails for heat from artificial sources. It so happens that many good reflectors are white, and many good absorbents and radiators are dark; but their respective powers are due rather to the molecular condition of their surfaces than to their colors.

Recapitulation.

Heat may be transferred by	Conduction. Convection. Radiation.
Radiant heat, incident on a body, may be	Reflected. Absorbed. Refracted. Transmitted.

THE SOURCES OF HEAT.

341. The sources of heat may be comprised in three classes: (1) physical, (2) chemical, (3) mechanical.

The principal physical sources are the sun and the fixed stars. It has been calculated that, if the earth had no atmosphere, the solar heat received by the earth in one year would melt a layer of ice, completely enveloping it, to the depth of one hundred feet. It has also been estimated that the earth receives from the fixed stars about four-fifths of this amount. These are the ultimate sources of most of the available heat of the globe. Were either of these cut off, the life of the globe would soon be destroyed.

342. When any two bodies unite in chemical combination heat is usually evolved. Combustion is the rapid combination of two or more substances, attended by the evolution of heat, and generally of light. If a grain of iodine be placed on a slip of phosphorus they will kindle into a flame, which will afterward be continued by the oxygen of the air.

343. Ordinary combustion is due to the union of the oxygen of the air with the carbon and hydrogen contained in the coals, oils, and gases of our fires and flames. The rusting of iron and the decay of wood, are examples of slow combustion with oxygen. A log of wood in decaying evolves the same amount of heat that it does in burning, although the combustion takes place so slowly that no increase in temperature is perceptible.

Animal heat is due to slow combustion. In respiration (1) oxygen passes by osmosis through the cell walls of the lungs, and is absorbed by the blood; (2) this blood is then carried to the capillaries of the different organs, where the oxygen unites with the carbon of the tissues and forms carbonic acid; (3) the blood then returns to the lungs charged with this carbonic acid; (4) the carbonic acid is then exhaled by osmosis, and a fresh supply of oxygen absorbed.

The supply of carbon in the tissues is maintained by the processes of digestion and nutrition. Thus, in one sense, our animal heat is maintained by the indirect combustion of food and air.

344. **The mechanical sources of heat** are percussion, compression, and friction. (1) If a nail be pounded on an anvil with rapid blows, it may be made red-hot by percussion. (2) The production of heat by the compression of gases may be shown by the pneumatic syringe, Fig. 186.

FIG. 186.

This instrument consists of a stout tube in which a piston works air-tight. To use it, a piece of tinder is placed on the bottom of the piston, which is then driven suddenly down the tube. The air in the tube is compressed, and liberates so much heat as to set fire to the tinder, which is seen to burn when the piston is withdrawn.

(3) The friction of two bodies always produces heat. It is the heat produced by friction that ignites the phosphorus on the end of a match, and that causes the axles of car-wheels to become hot. Savages procure fire by revolving the end of one piece of wood in the cavity of another.

An experimental demonstration of the same fact may be shown by attaching to a whirling table a brass tube filled with water, and corked. Fig. 187. If, when the tube is revolving rapidly, a clamp, *P*, of two pieces of oak is pressed against the tube, the heat evolved by the friction of the clamp will be sufficient to boil the water in a few minutes.

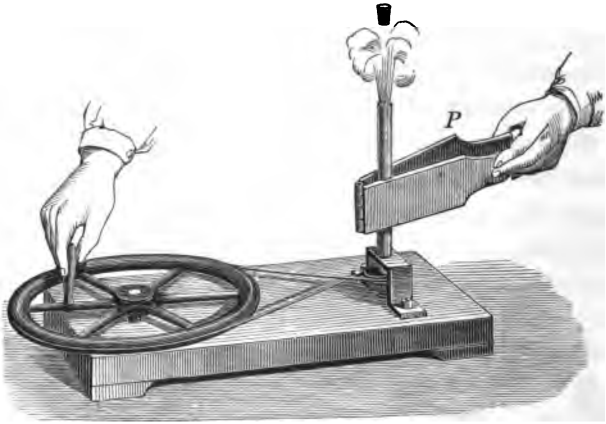


FIG. 187.

345. These facts are in accordance with the dynamical theory of heat, which assumes that heat is a kind of energy which produces molecular motion. In all cases of percussion, compression, and friction, a certain amount of mechanical energy is arrested, and its visible motion is destroyed. At the same time heat is *produced.* That is, *the energy of visible motion is transformed into the energy of molecular motion,* which is heat.

Conversely, *heat is consumed in effecting mechanical work.* Let a cylinder filled with compressed air be cooled to the temperature of surrounding bodies. Its elastic force is competent to perform mechanical work (1) by moving a piston, and (2) by displacing the air in front of the piston. If the air be allowed to expand so as to perform work, it will be, at the same time, chilled, because its molecular energy is transformed into the energy of visible motion.

346. There is a constant numerical relation between the energy of visible motion and the energy of molecular motion, which is known as *Joule's equivalent*, and is thus expressed: The amount of heat required to raise one pound of water 1° F. is competent to lift 772 pounds one foot high. The converse is also true; if 772 pounds be dropped one foot it will develop sufficient heat to raise one pound of water 1° F.

347. If we know the weight and velocity of any moving body, we can calculate the amount of heat which would be generated by suddenly stopping it. It has been calculated that if the earth were stopped in its orbit, it would develop heat equal to that derived from the combustion of fourteen equal-sized globes of coal. If, then, it should fall into the sun, it would generate by the collision heat equal to that evolved by the combustion of 5,600 equal worlds of solid carbon.

These considerations have led some philosophers to the conclusion that the solar heat is maintained by the falling of meteoric masses into the body of the sun. If the earth should strike the sun, the heat developed by the shock would be sufficient to equal the solar radiation for a century.

348. The dynamical theory of heat also explains the phenomena of expansion and of latent heat. Thus, when heat enters a body, its actual energy is employed (1) in increasing the intensity of molecular motion, which is shown by a rise in the temperature; (2) this also separates the molecules and produces expansion; (3) a sufficient heat melts or vaporizes the body. The latent heat required is the energy necessary to overcome cohesion; that is, it performs work in separating and re-arranging the position of the molecules. The latent heat which disappears is not lost, but has been employed in giving the molecules new positions. If the vapor returns to the liquid state, or a liquid to the solid state, an equal amount of heat will be given out, because interior work has been performed by cohesion, which draws the molecules closer together, and is transformed into sensible heat.

We may roughly compare latent heat with mechanical energy. If I throw a stone to a roof sixteen feet high, I shall need to give to it a velocity of thirty-two feet per second. While the stone rests on the roof it produces only pressure, but it is evident that should it fall, it will again attain a velocity of thirty-two feet per second before it strikes the ground. Therefore, the stone, while on the roof, has a *possible energy* due to its position. So, also, if I melt a body I shall require to expend a certain amount of sensible heat; but, in so doing, I shall confer upon the molecules a possible or potential *energy of position*, which will be again transformed into the sensible energy of heat when the melted body solidifies.

349. Force may be changed but not annihilated. The sun is the ultimate source of the available forms of energy with which we are surrounded. Let us consider a few of the ways by which sunshine may be transmuted and preserved.

1. The mechanical energy of the winds, of falling water, and of running streams, is due to the joint action of gravitation and of the solar heat. A part of this energy may be made to re-appear as heat by friction. Thus, a large room has been warmed by the friction of two plates, made to revolve by machinery driven by a fall of water.

2. Plants grow by reason of the light and heat of the sunshine, and accumulate a supply of fuel and of food.

(*a*.) Wood and mineral coal are, therefore, transmuted sunshine. In combustion, the heat re-appears as heat, or it may be applied as a moving force for engines.

(*b.*) Food is transmuted by animals into animal heat and muscular energy, or stored up as flesh. Beef and mutton are, therefore, due to solar rays twice transmuted.

RECAPITULATION.

The sources of heat are—

1. Physical	The sun. The fixed stars.
2. Chemical	Combustion.
3. Mechanical	Compression. Percussion. Friction.

PROBLEMS.

1. How much will a railway track 100 miles long expand on being heated from 32° F. to 96° F.?

2. How many thermal units are required to raise 80 pounds of water from 32° F. to 212° F.? Suppose a pound of coal, if economically burned, to have this thermal power, how many pounds of mercury can it raise through the same temperature?

3. How many pounds of ice at 32° F. would the same fuel melt? How many pounds of water at 212° F. would it change into steam?

4. From the table on page 199 calculate the relative lengths of silver and platinum which should be taken to construct a gridiron pendulum.

CHAPTER XVI.

ELECTRICITY.

350. One of the earliest physical facts recorded in the history of science, is that when amber is rubbed with silk, it acquires the property of attracting to itself light bodies, and then of repelling them. Within the past century, philosophers have found that these are but particular manifestations of a force which is constantly evoked in all kinds of molecular changes, and whose phenomena are among the most wonderful in nature. This force is *electricity*. It is convenient to study its phenomena under three divisions: (1) Magnetism, (2) Statical Electricity, (3) Dynamical Electricity.

THE PHENOMENA OF MAGNETISM.

351. It has long been known that a certain ore of iron, called the loadstone, has the property of attracting iron filings. Because this ore was first found near Magnesia, a city of Asia Minor, loadstones are called *natural magnets.* Bars of hardened steel may be converted into *artificial magnets* far more powerful than natural magnets.

352. If a magnet be rolled in iron filings, the filings will cling to it, but especially at the ends. Fig. 188. These ends are termed the *poles* of the magnet. The force residing in a magnet is called *magnetism.*


FIG. 188.

If a sheet of stiff paper be laid upon a bar magnet, and iron filings be sifted evenly upon the paper, the particles of iron will arrange themselves in curved lines about the poles. Fig. 189. If a magnetic bar or needle be poised at its center so that it will swing freely, one end will point toward the north and the other toward the south; hence, one end is called the south and the other the north pole of the magnet.

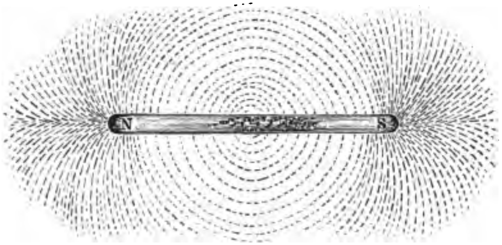


FIG. 189.

353. Either pole will equally attract iron filings; but if two magnets are brought near each other, it will be found that the north pole of one will attract the south pole of the other. If, however, two similar poles are brought near each other, a repulsion takes place. Fig. 190. Hence, this law: *Like poles repel and unlike poles attract each other.*

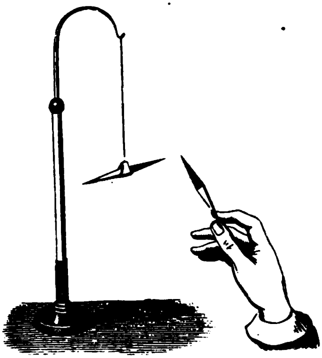


FIG. 190.

354. If a long steel needle be magnetized, the center will exhibit no magnetic force and is said to be *neutral.* If the needle be broken, each half will be found to be a magnet with two equal and opposite poles. If this division be continued, no portion can be obtained so small that it will not be a perfect magnet. We, therefore, conclude that every magnet is a collection of polarized particles having their similar poles turned in the same direction.

We may represent this state of polarity in a magnet by Fig. 191, in which the alternate black and white spaces

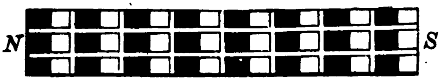


FIG. 191.

represent the polarity of each particle. All the north poles are disposed in one direction (the black spaces) and all the south poles (the white spaces) in the opposite. The opposite polarities balance each other at the center, which thus remains neutral, but are strongly manifested at the ends.

355. If a rod of soft iron, *Fe*, Fig. 192, be brought near one of the poles of a magnet, *M*, the two ends of the

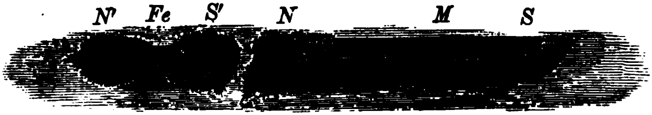


FIG. 192.

rod will also be able to attract iron filings. The rod becomes a *temporary magnet*, but it will lose its magnetic properties soon after it is taken away from the presence of the magnet. The influence by virtue of which a magnet can develop magnetism in iron is called *induction*. We may suppose that, in its ordinary state, the molecules of the iron rod are all indued with magnetism, but that they are so arranged that the opposite forces neutralize each other; and that the presence of the magnet in some way so modifies the surrounding region that the molecules of the iron assume the polarized state of the magnet as represented in Fig. 191. The inductive force is greatest when the magnet is in contact with the iron. If a steel bar be in contact with a magnet, its particles become polarized very slowly; but when once acquired, its magnetism is *permanent.* Magnetism may be sooner induced in steel by rubbing it with one of the poles of a magnet. In this way the ordinary magnetic needles are prepared, but the more powerful magnets are produced by means of the voltaic current, as will be described hereafter. It is important to notice that in induction there is no *transfer* of any force, but merely a development of polarity among the particles of the body acted upon.

A magnetic battery consists of a number of magnets joined together with their similar poles in contact. The common form is that of a horse-shoe. Fig. 193. When a magnet exerts its inductive power on a piece of soft iron, its own magnetic intensity is temporarily increased. For this reason the magnet is provided with a *keeper* or *armature, K,* of soft iron.

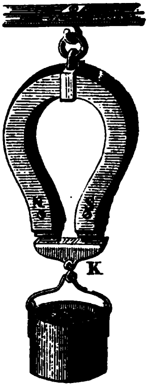


FIG. 193.

356. Iron, steel, nickel, and cobalt are the only substances in which magnetism can be developed by ordinary induction. Manganese and a few other substances are also attracted by very powerful magnets. All these are called magnetic substances. If a magnetic substance is suspended by a string between the poles of a horse-shoe magnet it will take a position in the direction of the line which joins the two poles of the magnet.

On the other hand, there are a great number of substances which, if similarly suspended, will assume a position at right angles to the line joining the poles, as if repelled by them. Such substances are called *diamagnetic.* Among diamagnetic substances are phosphorus, bismuth, antimony. The diamagnetism is not permanent.

357. The earth acts as a magnet. The magnetic needle, which is of almost priceless value to mariners, points toward the magnetic poles of the earth. These magnetic poles are near, but do not coincide with the geographical poles of the earth. Hence, the needle will point in a due north and south line only when the magnetic meridian coincides with the geographical meridian. This is very nearly the case at Cleveland, O., but in New York the needle points west of north and in Chicago east of north. Moreover, the magnetic poles are slowly shifting their position westward, so that the magnetic meridian does not remain constant. The deviation of the needle from the geographical meridian is called the *declination of the needle.*

RECAPITULATION.

Magnets are . .	Natural or artificial.	
	Permanent or temporary.	
Substances . . .	Attracted by magnets are . .	Magnetic.
	Repelled by magnets are . .	Diamagnetic.

THE PHENOMENA OF STATICAL ELECTRICITY.

358. An electric pendulum is a pith ball attached, by a silk thread, to a glass support. If a stick of sealing-wax be rubbed with dry flannel and brought near the pith ball, Fig. 194, the latter is instantly attracted, but is soon repelled. If, now, a warm glass rod be rubbed with a silk handkerchief and presented to the ball, the same phenomena of attraction and repulsion will be observed.

It will now be found that when the ball has been repelled by the glass, it will be attracted by the wax; and when again repelled by the wax, it will be attracted by the glass. If the glass and wax be placed on opposite sides of the ball, it will vibrate between them by the alternate attraction and repulsion of each. It is, therefore, evident that the glass and wax manifest similar and yet opposed properties. These properties, thus excited by friction, are due to electricity.

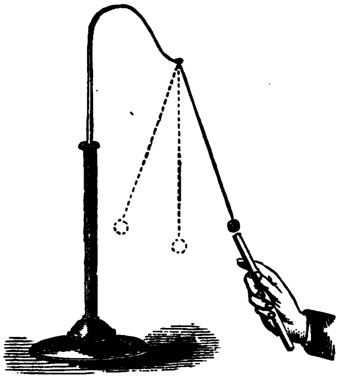


FIG. 194.

359. Electricity is a force which becomes manifest by its peculiar phenomena of attraction and repulsion. It is now regarded as a mode of molecular motion which is always manifested in two opposite or polarized states. That developed on the glass is called positive, (+), and that on the wax, negative electricity, (—).

Formerly, electricity was supposed to be due to the presence or absence of a single electrical fluid, or to the presence of two electrical fluids. There is, however, no evidence of the existence of any electrical fluid. Nevertheless, many of the terms of the fluid theory are still in common use, and are convenient for describing most electrical phenomena, although the meaning attached to them is taken in a sense different from that originally intended.

360. In the preceding experiment we suppose that the wax became negatively electrified by friction, and, on contact, transferred a portion of this force to the ball. The ball thereby became electrified or *charged* with negative electricity and the two bodies separated. On bringing the charged ball near the positively electrified glass the two were attracted, because of their different electrical states. The glass then communicated enough of positive electricity to neutralize the negative electricity of the ball, and, also, to render it positively charged. The ball was then repelled by the glass and attracted by the wax, and so on through a series of attractions and repulsions. From these experiments we derive the following law: *Two bodies charged with like electricities repel each other; two bodies charged with opposite electricities attract each other.*

361. Electricity is transmitted from one body to another with different degrees of rapidity. Those substances that transmit electricity readily are called *conductors;* those that do not, are called non-conductors or *insulators.* In the following list the substances named are arranged in the order of their conducting power. Those midway in the list may be termed semi-conductors or semi-insulators.

Conductors.

1. The metals,
2. Charcoal,
3. Graphite,
4. Acids,
5. Water,
6. Linen,

Semi-conductors.

7. Ether,
8. Dry wood,
9. Paper,
10. Dry ice,
11. Caoutchouc,
12. Air and gases,

Semi-insulators.

13. Furs,
14. Silk,
15. Glass,
16. Wax,
17. Shellac,
18. Ebonite.

Insulators.

362. In order that a charged body may retain its electrical force, it must either be a non-conductor, or be *insulated* by being supported on non-conductors. The most common insulators are made of glass. Baked wood covered with shellac varnish will answer very well. Dry air is necessary for insulation. In a damp room a film of moisture gathers upon the apparatus and forms a conducting surface.

363. Electricity is produced whenever two dissimilar substances are rubbed together. The reason why it is not more frequently manifest is because it is carried off as fast as it is developed. When the electrical force is sufficient to force its way through a bad conductor a *spark* may be produced. In dry, frosty weather, a person, by shuffling about a warm, carpeted room, may develop electricity sufficient to emit a spark from his finger capable of igniting a jet of gas.

364. Both kinds of electricity are always simultaneously produced. If two insulated disks of dry wood, one covered with shellac and the other with silk, are rubbed together and separated, the shellac will manifest positive and the silk, negative electricity. Any substance in the following list, when rubbed by any one succeeding it, becomes positively electrified, and by any one preceding it, negatively electrified:

+ Cat's-fur, flannel, smooth glass, cotton, paper, silk, the hand, sealing-wax, rough glass, sulphur, ebonite, —.

Thus paper becomes positively electrified when rubbed with silk and negatively electrified when rubbed with flannel.

365. The electricity which is produced by friction is called frictional electricity. There are, however, other modes of producing the same electrical phenomena. It is also called *statical electricity,* because it may be retained for a time upon an insulated body.

An electroscope is an instrument used to detect the presence and determine the kind of electricity in any body.

The simplest is some form of the electric pendulum. The gold-leaf electroscope, Fig. 195, consists of two strips of gold-leaf, suspended in a glass vessel by means of a metallic rod which terminates in a knob or a plate. Within the vessel are two metallic posts connected with the ground, which serve to remove an excessive charge from the leaves.

If the knob be touched with an electrified glass rod, the leaves will diverge, because they become charged with positive electricity. If, now, any electrified body be brought near the knob, the kind of electricity in the body may be determined by its influence on the gold-leaves; for, if the electricity be positive, the leaves will diverge farther, but, if negative, they will collapse.

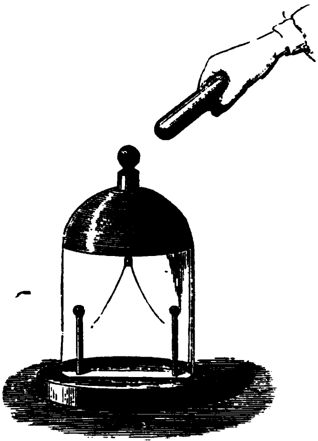


FIG. 195.

366. Electrified bodies influence bodies at a distance in a manner similar to the action of a magnet on magnetic substances. This influence is called *electrical induction;* and the resulting effect, *induced electricity.*

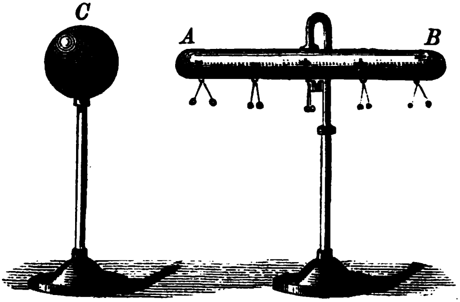


FIG. 196.

Let $A\,B$ be a conductor of brass, insulated on a glass pillar and furnished with a number of pith ball electroscopes. If this is brought near an electrified body, C, but not so near as to receive a spark from it, the balls will diverge as shown in Fig. 196. By means of the gold-leaf electroscope we may ascertain that the nearer end, *A*, of the conductor contains electricity opposite to that of the electrified body, *C*, and the further end, *B*, the same kind. If *C* be positively charged, its effect will be to repel the positive electricity toward the end, *B*, and to attract negative electricity to the end, *A*.

367. **The two electrical forces may be separated** by induction. Suppose the conductor, *A B*, to be made of three parts, each insulated and movable, and while the whole is under the influence of a positively electrified body, let the central portion be removed. (1) This part will either yield no spark or a very feeble positive one. (2) The portion, *B*, may be discharged by bringing the hand near it, yielding a spark of positive electricity. Its electricity is, therefore, *free* to diffuse itself. (3) So long as *A* and *C* remain near each other neither will be completely discharged on touching it separately, because their mutual attractions tend to retain their opposite electricities. Electrical forces in this condition are said to be *bound* or *disguised.* If the two are separated, *A* will yield negative and *C* positive electricity. If communication is made between them, both will be discharged by the union of their opposite forces.

If the cylinder, *A B*, while near the positive ball, *C*, be touched by the hand, the pith balls at *A* will diverge further—those at *B* will *collapse.* As the hand and body are conductors, the positive electricity will be repelled to the earth. The negative can not escape being bound by the attraction of the positive ball, *C*. On the contrary, it will increase, because the inductive force of *C* was previously opposed by the positive electricity accumulated in the end, *B*. If the hand be *first* removed from the cylinder and *then* the inducing body, the cylinder will remain negatively charged.

Therefore, a body may be charged by induction, or by conduction. In conduction there is a transfer of either force from an electrified body to another body. In induction there is no transfer of force; but an excited body induces both kinds of electricity in an insulated body, which remains charged with the opposite electricity if uninsulated, for a time, in the presence of the excited body.

368. The electrophorus, Fig. 197, consists (1) of a cake of resinous matter, *R*, resting on a conducting plate of tin, and (2) a movable metallic cover, *T*, provided with an insulating handle, *G*. If the resinous cake be beaten with cat's fur it becomes charged with negative electricity. If, now, the cover be placed on the cake, its condition is that of an insulated conductor in the presence of an electrified body. Its lower surface becomes positive and its upper negative by induction. The cake does not discharge itself into the cover, because (1) of the inequalities of its surface and (2) because of its non-conducting power.

FIG. 197.

If the cover be uninsulated for a moment by touching it with the finger, the negative force passes to the ground, while the positive is held bound by the negative electricity of the resin. Now, if the finger be first removed, and then the cover raised by its insulating handle, *G*, its positive electricity diffuses itself over its surface, and the cover will yield a positive spark when it is brought near a conductor.

As the cake acts only by induction, when once charged it retains its electricity for a long time, and may be made to induce any number of successive charges in the disk.

369. To explain the action of induction we may suppose that whenever a body is electrified, the molecules of the surrounding medium become polarized. Thus, if *C* represent a charged body, the adjacent molecules of air, as *a, b, c, d,* will become polarized. Fig. 198. The molecules of any insulated conductor, as *A B*, within their influence will also become polarized; but as they are conductors they will discharge their electrical forces one into the other, and thereby the cylinder itself will become polarized, as if it were a huge molecule.

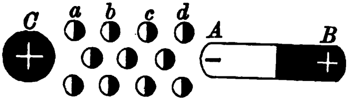


FIG. 198.

370. Induction takes place in most, if not all, electrical phenomena.

I. *In attraction.* The pith ball of the electrical pendulum is first polarized, like the cylinder, *A B*, Fig. 198. The side next the excited glass rod becomes negative by induction, and as soon as the attraction of the opposite electrical forces becomes greater than the repulsion of the positive electricity on the further side of the ball, the ball flies to the rod.

II. *In charging.* In Figs. 196, 198, suppose *C* positively charged to be brought toward *A B*. The polarization of *A B* will rise higher and higher in proportion as *C* comes nearer. When *C* is near enough, *A B* will become charged with positive electricity either by spark or by contact. The most probable explanation of this is, that at a high state of polarization the adjoining particles discharge their electrical forces into each other. By the spark or by contact, an equal amount of the two electricities combine and become neutral, and the cylinder becomes charged, not by receiving more positive electricity, but by discharging its negative.

III. *In discharging.* If, now, the hand be brought near the positively charged conductor, the electricity of the hand is polarized. Its positive electricity passes to the ground, and its negative to the fingers. At contact, the negative of the hand and the positive of the cylinder combine, and the molecules of the cylinder become neutral or unpolarized.

371. **The molecules of conductors** are easily polarized and discharged: the molecules of insulators require a greater force to effect polarization and discharge. Magnetic and electrical induction are similar. The induction of magnetism in soft iron is rapid but temporary; that of steel is slower but permanent. In magnetic induction, however, the two forces can not be separated. In electrical induction, a body may be charged positively or negatively; but this can be effected and maintained only when it is surrounded by insulating molecules in which the opposite force is induced. Hence, the two forces are always present, and electricity, like magnetism, is a polar force.

372. **Electricity is found only on the surface** of an insulated body. Let a brass ball be suspended by a silk thread and be closely covered by two hemispheres of brass. Fig. 199. Now, if a charge be communicated to the apparatus, and then the hemispheres be withdrawn, the elec-

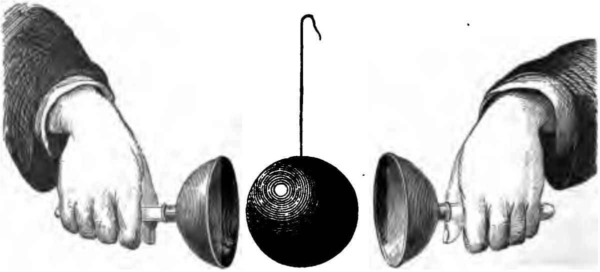


FIG. 199.

tricity will be found only on the hemispheres. This is a consequence of the repulsion of like electricities. Another result is that the charge tends to escape from bodies; hence,

373. **The charge will be distributed uniformly** only on spherical surfaces. On cylindrical surfaces, the charge will be accumulated at the ends. If the ends are mere points, there will be so great an increase of electrical intensity that the body will be discharged with great facility and generally without the passage of a spark. Hence, if we wish to avoid this, the ends of cylinders should be rounded, and no sharp edges nor points, should be attached to the apparatus.

374. **The terms quantity and intensity** will be understood by reference to the similar use of the same words with respect to heat; thus, the heat of molten iron is intense, but a hogshead of boiling water contains a greater quantity of heat than a pound of molten iron. In one case, each particle is in very rapid vibration: in the other, very many particles are in vibration, and the sum of all the vibrations is the quantity. *Electrical intensity* has reference to the amount of force lodged in each particle. *Electrical quantity* has reference both to the number of particles affected and to the force lodged in each. There are both quantity and intensity in every electrified body, but the charge may be characterized by the predominance of either quality. The intensity is measured by its power to effect discharge through bad conductors; thus, a long spark is evidence of great intensity. In statical electricity, the quantity is always small, though its intensity is sometimes enormous.

ELECTRICAL APPARATUS.

375. **There are many forms** of electrical machines. Fig. 200 represents Winter's plate machine, which is one of

the best. This consists of a circular plate of glass, mounted on a glass axis which is supported by two posts of dry wood and made to revolve by a winch. Friction is applied to the glass plate by two rubbers, *R*, made of stuffed leather, and coated with an amalgam of mercury, tin, and zinc. The rubbers are kept in place by clamps attached to an insulated brass ball, *N*, called the *negative* conductor. Attached to the rubber are two wings of silk, *S*, to prevent the electricity from escaping into the air.

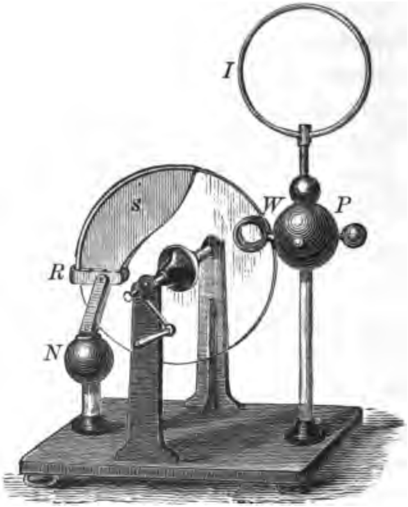


FIG. 200.

The plate also passes between two wooden rings, *W*, which are attached to an insulated brass ball, *P*, known as the *prime conductor*. On the side of the wooden rings, next to the glass plate, are two rows of brass points, which are connected by tin strips to the prime conductor.

On turning the plate, the friction of the rubbers develops both electricities—the negative on the rubbers, the positive on the glass. The negative electricity passes to the negative conductor. The positive electricity is carried on the glass between the wooden rings, and here acts by induction on the prime conductor, attracting its negative electricity. This negative electricity collects on the points inside of the rings, *W*, and finally attains sufficient intensity to pass through the intervening air and unite with the positive electricity on the glass. The glass plate thereby becomes neutral as at first. The prime conductor, having given off its negative electricity in the manner described on page 239, remains charged with positive electricity.

376. **If both conductors were insulated,** this action would soon cease, because the positive electricity of the prime conductor would act inductively on the negative of the other conductor, and thus only a feeble charge would be possible. If either conductor be uninsulated, its electric intensity will become zero, and thereby leave the electric force on the other conductor free. Hence, (1) when the rubbers are connected by a brass chain to the ground, positive electricity accumulates on the prime conductor. (2) When the brass chain connects the prime conductor to the ground, negative electricity accumulates on the negative conductor. If the hand is brought near either conductor, when charged, it is discharged by a spark.

The length of the spark is wonderfully increased by the addition of a large wooden ring, *I*. An iron wire forms the core of this ring, and is connected with the prime conductor. Without the ring, which may be removed at the pleasure of the operator, the machine will give a spark two inches in length; with the ring, sparks may be obtained six or seven times as long, but proportionally less frequent. The quantity of electricity is, in both cases, the same, the ring acting only by induction, and preventing discharge until electricity of high tension is attained.

There are several varieties of the frictional machine, some with plates, others with cylinders, but the action of all is the same.

377. **There are other machines** which act only by the induction of a charged surface. Among these are the electrophorus, and Holtz's machine, which may be briefly characterized as a revolving electrophorus.

378. **There is a limit** to the accumulation of electricity on any surface. But, if two conducting surfaces are separated by an insulating medium, the intensity will be increased by the mutual inducing action of the two surfaces. Any arrangement of this sort is said to act as a *condenser*.

379. **The Leyden jar** is the most convenient form of the condenser. This consists of a glass bottle, coated both on the inner and outer surface with tin-foil to within three inches of the neck. The mouth is closed with a plug of varnished wood, through which passes a brass wire surmounted by a knob and reaching to the inner coating. If the jar be held near a machine in action, sparks will pass to the interior of the jar, but after awhile this will cease, and the jar is then said to be charged. Fig. 201.

FIG. 201.

To discharge the jar, the inner and outer coatings must be brought in connection. This may be done by placing one hand on the outer coating and bringing the other hand near the knob. A brilliant spark will then pass from the knob, and the experimenter receives a peculiar twitching sensation called the *electric shock*. The discharge may also be effected by means of a discharging rod, which consists of a jointed wire terminating in brass knobs. See J in Fig. 213.

If the outer coating be insulated, the jar will receive little or no charge. But if the finger be then brought near the outer coating, for every positive spark that passes into the jar, an equal spark of the same kind will pass from the outer coating to the finger.

380. The action of the jar may be explained as follows: When the positive spark passes to the interior of the jar, the molecules of the glass become polarized, as shown in Fig. 202. If the jar be insulated, but little charge can be received because of the repulsion of the positive electricity which accumulates on the outer surface. If, now, the outer coating be connected with the ground, the positive electricity escapes from it, and, consequently, the outer layer becomes charged with negative electricity, as represented in Fig. 203.

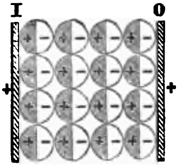


FIG. 202.

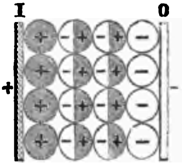


FIG. 203.

The outer surface is, therefore, charged by induction. The two surfaces have very nearly equal charges of opposite electricities which are held mutually bound, so that neither can be discharged separately. The amount of charge which a jar may receive is in proportion to the facility it offers for induction. The thinner the glass, the better; but if too thin, the polarization may rise high enough to cause a discharge through the glass, thereby perforating it.

The charge is, therefore, dependent rather on the glass than on the coatings. This is shown by means of a jar with movable coatings. (Fig. 204.) If the parts be put in place and the jar charged, the coatings may be removed and discharged. On again replacing the parts, a charge may be received almost as strong as if the coatings had not been removed. Hence, the principal office of the coatings is that of a conductor, to connect the polarized molecules of the glass. Another evidence of this is that the glass cup, *B*, may be charged separately by rotating its inner surface on the knob of the prime conductor, and, then, if the two coatings are applied, the whole combination will be discharged by a single spark.

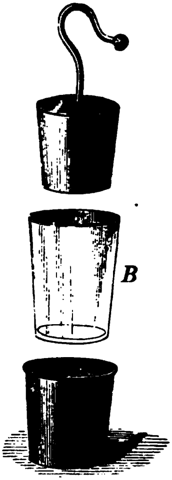


FIG. 204.

381. If a series of jars be insulated except the last, as in Fig. 205, all may be charged simultaneously. The electricity repelled from the first, charges the second, and so on. Each may then be discharged separately. Or all the similar coatings may be connected to form an *electrical battery*, as represented in Fig. 213, and discharged by a single spark.

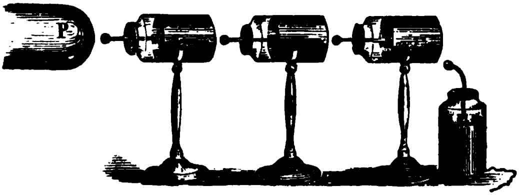


FIG. 205.

ELECTRICAL PHENOMENA.

382. The laws and phenomena of electricity may be illustrated by a great number of experiments.

1. *Repulsion.* If a person stands on a stool supported by glass legs and touches the prime conductor, he becomes, in fact, a part of it; and sparks may be drawn from him with the same effect as from the cylinder. His hair, if dry and loose, will stand out in a fantastic manner, because the separate hairs are charged with the same electrical force.

2. *Attraction.* If, now, a bystander bring his hand over the electrified person, the hairs will converge toward it. Negative electricity is induced in the hand, and the two bodies oppositely electrified attract each other.

3. *Attraction and repulsion.* The electrical chimes, Fig. 206, consist of two bells in metallic connection with the machine, and of a third bell, insulated by a silk thread from the machine, but connected with the ground. Between the bells are small brass balls suspended by silk threads. On working the machine, the outer bells are positively electrified, and induce negative electricity in the middle bell. The balls are alternately attracted and repelled by the outer and inner bells, and thus a constant ringing is kept up.

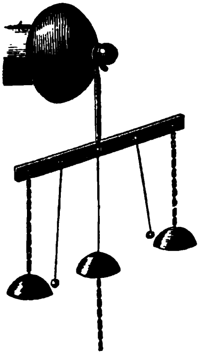


FIG. 206.

The electrical hail is exhibited by means of two metal plates, one connected with the ground and the other with the machine, as in Fig. 207. Light pith balls or grotesque figures placed between the plates when the machine is in action rise and fall in an irregular manner.

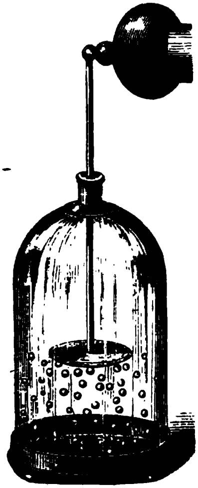


FIG. 207.

383. The kinds of electrical discharge are three: (1) *conductive*, as when the electricity passes through a good conductor without light; (2) *disruptive*, as effected through a bad conductor and attended with light; (3) *convective*, which is effected by particles of matter passing away from a charged surface.

The electrical hail is an example of convective discharge, but usually it is effected by the movements of particles of air passing away from a point on a charged surface. Quite a current of air may be detected by persons standing near such a point. The face feels as if a cobweb were drawn over it. The electric whirl consists of a number of such points suspended on a pivot. Fig. 208. The reaction of the current of air is sufficient to turn the wheel rapidly about.

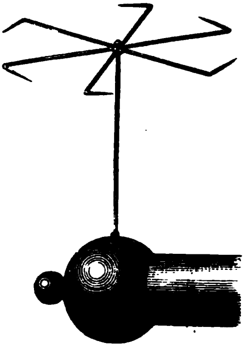


FIG. 208.

384. Flames act as points. If a candle be held near a charged conductor, the flame will be repelled, as shown in Fig. 209, and sometimes extinguished. If the candle be placed on the conductor and a point turned toward it, the flame will be driven in the contrary direction. This is due to the current of air which sets out from the point which has become negatively electrified by induction.

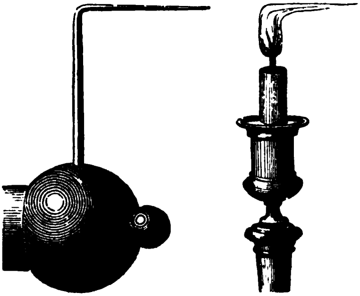


FIG. 209.

385. Luminous effects. If a discharge be passed through an interrupted conductor, a succession of sparks will be obtained, which, when exhibited in a darkened room, yield a brilliant display. The luminous tube may be used for this purpose. Fig. 210. It consists of a glass tube on which are pasted in a spiral form bits of tin-foil.

FIG. 210.

FIG. 211.

When the discharge passes off from the thin edge of a plate, a number of feeble sparks are obtained, which assume the form of a *brush*.

If the discharge is effected in rarefied gases the effect is very beautiful. For this experiment a receiver called the aurora tube is used. Fig. 211. In rarefied air the light has a bluish color; in nitrogen, more of a purple; in hydrogen, a fine crimson.

386. The duration of the spark is less than one-millionth part of a second. If Newton's wheel, Fig. 166, be set in very rapid rotation in a dark room and be illuminated by an electric spark, the wheel will appear stationary.

387. The velocity of the discharge in copper wire is estimated at 288,000 miles in a second. This was measured by transmitting the discharge of a Leyden jar through a very long copper wire. The circuit was broken at three points, one at the middle of the wire and one near each coating. In this way three sparks were formed, which, to the eye, seemed instantaneous. When they were viewed by means of a revolving mirror, they presented the appearance of three arcs of equal length, the middle one rather behind the others, as in Fig. 212. The velocity with which the mirror revolved was known, and from this the retardation was calculated which gave the velocity of transmission. The velocity is found to vary both with the nature of the conducting medium and the intensity of the charge.


FIG. 212.

388. Calorific effects. Any combustible substance, as ether, is readily inflamed by the spark. Very thin wires may be melted by a discharge from a Leyden battery. Fig. 213. Those wires are heated most, which are the worst conductors. In using this battery the apparatus, *U*, on the right of the figure, is convenient. It consists of three glass posts, two of which carry jointed rods, while the center bears on its top a glass plate. A thin gold wire, *a b*, supported on this by a paper card, *c*, is instantly volatilized by a powerful discharge.

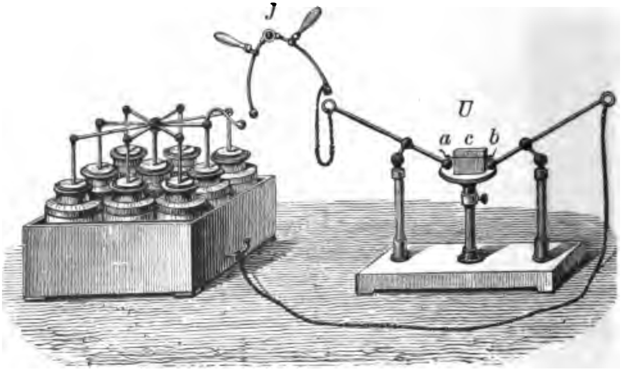


FIG. 213.

Chemical effects. The peculiar odor which always accompanies the electrical discharge is due to the formation of ozone, an allotropic modification of the oxygen of the air.

A succession of sparks passed through ammonia decomposes it. The spark may also effect chemical combination.

Thus, if two volumes of hydrogen and one of oxygen be mixed in the electrical pistol, Fig. 214, a single spark will cause them to combine with a loud explosion.

FIG. 214.

389. The mechanical effects are shown when a discharge passes through a poor conductor. If a discharge is passed through a card of thick paper, a burr will be produced in both directions. A glass plate may be perforated by a moderately strong charge. The mechanical effects of lightning are well known. It rends and tears every obstacle which hinders its free transmission, with amazing force. The noise which accompanies the spark is due to the sudden expansion of the surrounding air, followed by a sudden collapse, thereby producing a sonorous wave of condensation and rarefaction.

390. Physiological effects. Quite a number of persons may receive the electric spark simultaneously. For this purpose, all must join hands, the first touching the knob of a Leyden jar, and the last the outside.

Electricity has also been found of service in the treatment of some diseases. For this purpose, as well as for producing chemical decomposition and magnetic effects, which require quantity rather than intensity, some form of dynamical electricity is generally employed.

ATMOSPHERIC ELECTRICITY.

Franklin demonstrated, in 1752, that a flash of lightning is simply an enormous spark of electricity. He raised a silk kite at the approach of a storm, and as soon as the rain had wetted his hempen kite string, thereby rendering it a good conductor, he succeeded in drawing sparks from a key hung on the string and in charging a Leyden jar.

391. The principal source of atmospheric electricity is supposed to be the evaporation and subsequent condensation of water. A cloud becomes positively electrified by the accumulation of the electricity which, before its formation, was disseminated through its particles. It is probable that negative clouds are mostly due to the inductive action of other positively charged clouds.

The earth beneath a cloud is subject to the same inductive action and becomes, by consequence, charged with electricity opposite to that of the cloud.

392. A flash of lightning is produced when the air between two adjacent bodies oppositely charged becomes highly polarized. The light is due to the intense heat of the discharge which renders the particles of the air incandescent. *The thunder* is due to the violent commotion produced in the air by its sudden expansion along the path of the flash, and is prolonged by echoes.

Heat lightning is the name applied to bright flashes of light observed in the horizon on summer evenings. This is generally due to the reflection by the atmosphere of ordinary lightning so distant that the thunder is inaudible.

393. Lightning conductors are metallic rods used to protect buildings from the effects of lightning. (1.) They offer to the discharge the line of smallest resistance. Hence, the rod should be a good conductor, continuous from top to bottom, and should terminate in earth which is permanently moist. (2.) They may prevent the discharge. If the rods are tipped with points, the discharge may be effected silently and the polarization of the air particles never rise high enough to produce the flash.

394. There are other phenomena of atmospheric electricity among which may be mentioned the *Aurora Borealis*, or northern lights, and St. Elmo's fire. It has been noticed that during the auroras the telegraph lines have been disturbed so as to prevent sending intelligible dispatches, and, also, that telegraphs may be worked without the aid of a battery when the auroras are very bright, as was the case in 1869.

RECAPITULATION.

I. The phenomena of statical electricity are:

1. Excitation
   - By friction.
   - By other molecular disturbances.
2. Attraction of bodies charged with unlike electricities.
3. Repulsion of bodies charged with like electricities.
4. Distribution
   - On the surface of insulated conductors.
   - Accumulated at pointed extremities.
5. Transference
   - By conduction
     - Readily in conductors.
     - Slowly in insulators.
   - By convection in moving particles.
   - By disruption
     - Spark.
     - Brush.
6. Induction . . By a charged body on insulating matter.

II. The effects of statical electricity are:

1. Mechanical . By producing fracture.
2. Luminous . In the electric spark.
3. Calorific . . By evolving heat.
4. Chemical .
   - By effecting combination.
   - By decomposing compounds.
5. Physiological . In producing electric shocks.

Dynamical Electricity.

395. All chemical actions are attended with the development of electrical force. This force is identical with that produced by friction; but because its discharge is continuous that department of electrical science which treats of electricity produced by chemical action is called *dynamical electricity*. It is also called *Galvanism* and *Voltaic electricity* in honor of Galvani and Volta, who were among the first to study its phenomena.

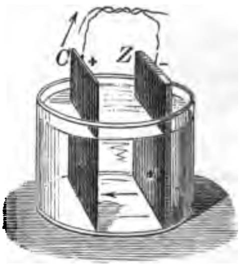


FIG. 215.

The fundamental phenomena of dynamical electricity may be exhibited by means of the simple Voltaic element. Fig. 215. This usually consists of a glass vessel containing a plate of amalgamated* zinc and a plate of copper, partially immersed in water to which a little sulphuric acid has been added. A chemical action takes place, by which (1) the water is decomposed; its hydrogen is liberated and its oxygen combines with the zinc to form zinc oxide. With water alone this action is very feeble, because the zinc oxide soon forms a coating on the zinc plate, which does not dissolve in water. (2) The sulphuric acid prevents the formation of this coating. This it does by uniting with the oxide to form zinc sulphate, which readily dissolves in the liquid and leaves the plate clean. The copper is not chemically acted upon and serves merely as a conductor of the electricity.

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*To amalgamate zinc, it is first cleaned by immersion in dilute sulphuric acid and then mercury is rubbed over its surface.

As soon as the plates are immersed, there is a slight disengagement of hydrogen and both plates become feebly charged with electricity. If the plates are kept from touching, no further action will be perceived. The whole arrangement is in a polarized condition, which may be represented by Fig. 216, in which the positive molecules are shaded. The outer end of the zinc is negative, and the portion in contact with the liquid is positive. The negative molecules of the liquid are turned toward the zinc and the positive toward the copper plate. The copper thus becomes polarized in a sense opposite to that of the zinc.

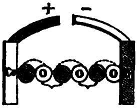

FIG. 216.

If, now, the plates are brought in contact either directly or by means of a metallic wire, a discharge will take place through the whole combination or *circuit.* At the same time, the chemical action increases and gives rise to a series of charges and discharges in such rapid succession, that the discharge appears continuous and the circuit is said to be traversed by an *electrical current.* The current continues so long as the contact is maintained, but ceases when the plates are disconnected. The operation of connecting the plates is called *closing the circuit,* and the separating of them is called *breaking the circuit.*

396. It is to be noted that when the circuit is closed, the hydrogen rises only from the surface of the copper. In explanation of this, it is supposed that when the oxygen and zinc combine, a molecule of hydrogen is set free, and unites with the oppositely electrified oxygen in the neighboring molecule of water, and displaces its hydrogen. This molecule of hydrogen is transferred to the adjacent molecule of water, and, in like manner, the same transference takes place throughout the whole series until the hydrogen of the molecule of water next to the copper is displaced. This hydrogen can not combine with the copper, but discharges its free positive electricity into it and escapes in a gaseous state.

Each successive transfer of the hydrogen may be assumed to be accompanied by a separation and recombination of the opposite electricities. The current itself must be considered as due to a constant series of polarization and discharge among all the molecules of the Voltaic element, both liquid and solid, by reason of which there is a transmission of both electrical forces throughout the circuit, the positive going one way and the negative the other.

To avoid confusion, only the direction of the positive current is usually given in speaking of the current. The direction of the positive current (1) within the liquid is from the zinc to the copper, and (2) without the liquid, from the copper to the zinc.

397. The current always sets out from the metal most easily acted upon by the liquid, which is therefore called the *generating* or *positive plate.* The other metal is called the *conducting* or *negative plate.* In most Voltaic elements, the liquid used is dilute sulphuric acid; that is, acid to which has been added from ten to twenty times its bulk of water. The electric deportment of several substances with reference to this acid is given in the following *Electro-motive series:*

+ Zinc. Lead. Iron. Nickel. Bismuth. Antimony. Copper. Silver. Platinum —.

In this list, the metals named are positive with reference to those that follow them, and are negative with reference to those that precede.

Poles. The current passes without the liquid, from the negative plate back to the positive plate; hence, if the connecting wire be cut, the positive electricity will tend to accumulate at the end of the wire attached to the negative or copper plate and the negative electricity to the positive or zinc plate. These ends are called the *poles* or *electrodes* of the circuit. In most combinations, zinc is used for the positive plate; the wire attached to it is called the negative pole or electrode. The wire attached to the negative plate is the positive electrode or pole.

398. **The electro-motive force,** or that which causes or tends to cause a transfer of electricity, is dependent on the relation which the metals bear to the liquid. It is greater the farther apart the metals are in the series. Dilute sulphuric acid acts upon copper when taken by itself; hence, it tends to produce on the copper plate a current acting contrary to that developed on the zinc. The electro-motive force of the Voltaic element is, therefore, due to the difference of these two opposing forces. Now, as dilute sulphuric acid does not act upon platinum at all, a stronger current may be established between zinc and platinum than between any other two metals in the series.

399. **The quantity of electricity** produced by a Voltaic element is proportional to the chemical activity. The work which the current can do is, therefore, proportional to the amount of zinc consumed in a given time. The quantity is at all times enormous. It has been calculated that an element which might be contained in a lady's thimble is capable of evolving a greater quantity of electricity than the largest electrical machine ever constructed.

400. **The intensity of the current** depends both on the electro-motive force and the resistance which is to be overcome. The greater the electro-motive force, the greater will be the intensity; the greater the resistance, the less will be the intensity. This relation, then, may be expressed by Ohm's law:

$$\text{Intensity of current} = \frac{\text{Electro-motive force}}{\text{resistance.}}.$$

401. The resistance is inversely as the conducting power of the substance through which the current passes. The conducting power of different substances of equal dimensions is shown relatively by the following table:

Solids.		**Liquids.**	
Silver	100.	Mercury	1.6
Copper	99.9	Dilute sulphuric acid	.00009907
Zinc	29.	Strong nitric acid	.00008868
Platinum	18.	Common salt, saturated solution	.00003152
Iron	16.8	Sulphate of copper " "	.00000542
Carbon	.04	Distilled water	.00000001

It is manifest that the resistance will increase with the length of the conductor, and also that it will decrease as the area of its cross section increases. Hence, the shorter and thicker the connecting wire, the less will be the resistance. So, also, the nearer the plates are together and the larger their area, the less will be the resistance offered to the current by the liquid layer between them.

The table shows that the resistances offered by liquids are enormous when compared with solids. Hence, the resistance caused by the liquid between the plates is far greater than in a short conducting wire. When the conducting wires are very long, as in telegraphs, the external resistance may exceed the internal.

402. A Voltaic Battery consists of several Voltaic ele-

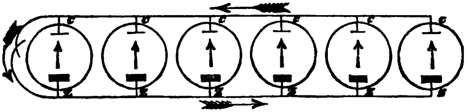

FIG. 217.

ments so connected that the current has the same direction in all. The efficiency of the battery will vary with the manner of grouping the elements. For the sake of illustration, take six elements, each containing a square inch of zinc, separated from a copper plate by a liquid layer an inch in thickness. If all the similar plates are connected, as represented in Fig. 217, the effect will be the same as that of a single element having a zinc plate of six square inches, one inch distant from the copper plate. Either arrangement is called a *simple* Voltaic circuit.

In the *compound* Voltaic circuit the positive plate of each element is connected with the negative plate of the adjoining element, as shown in Fig. 218.

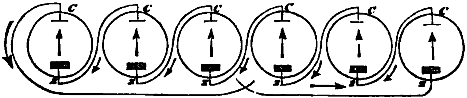

FIG. 218.

The simple circuit is sometimes called a *quantity* battery. It is used when the external resistance is very small. It is adapted for producing thermal effects, such as melting wires. The compound circuit is sometimes called an *intensity* battery. It is used when the external resistance is very great. It is adapted for telegraphs, for the electric light, and for producing chemical decomposition.

403. Numerous batteries have been constructed on the principle of the Voltaic element already described, but most of them have gone out of use, because of the rapid enfeeblement of the current.

This may occur (1) from the gradual consumption of the acid and the zinc, and (2) from *local action.* By local action is meant the production of small closed circuits on the positive plate, which are due to impurities on the zinc plate. This is remedied by amalgamating the zinc. (3) Besides these defects, the older batteries were liable to what is called the *galvanic polarization of the plate.* In the action of the simple element, the hydrogen is apparently evolved from the copper. In the process of time, the copper becomes coated with a layer of positive hydrogen, which, of itself, would weaken the current, but which acts the more injuriously because it reduces the zinc sulphate, and thereby forms a layer of metallic zinc on the copper.

404. **Constant batteries** obviate this last defect by preventing the permanent deposition of the hydrogen on the negative plate. There are over fifty forms of constant batteries; among the best of them are the following two-fluid batteries:

Grove's battery consists of (1) a glass cup containing a hollow cylindrical zinc plate and weak sulphuric acid; (2) of a porous cup made of unglazed earthenware, containing strong nitric acid and a strip of platinum. The porous cup and its contents are placed inside the zinc cylinder. Fig. 219.

FIG. 219.

The hydrogen which is liberated by the action of the zinc passes by osmosis through the porous cup, and on meeting the nitric acid unites with a part of its oxygen to form water, and reduces the acid to nitric oxide. This oxide is either dissolved in the liquid or escapes in red fumes.

FIG. 220.

Bunsen's battery (Fig. 220) is simply a large Grove's battery in which the platinum slip is replaced by a carbon cylinder. The chemical action is the same as the preceding, but as the elements are larger, for the same amount of zinc consumed, Bunsen's battery gives a greater quantity of electricity, but less intensity, than Grove's.

In this form the nitric acid is sometimes advantageously replaced by a mixture of one part of potassium bichromate, two of sulphuric acid, and ten of water.

Daniell's battery (Fig. 224) may readily be constructed by the student by placing within the porous cup a zinc plate and dilute sulphuric acid, and in the outer vessel a thin roll of copper with a saturated solution of sulphate of copper. The hydrogen, liberated by the action of the zinc, enters the solution of the sulphate of copper and reduces it, forming (1) metallic copper, which is deposited on the negative plate; and (2) sulphuric acid, which passes by osmosis into the porous cup, and replaces the acid which was neutralized by the zinc.

RECAPITULATION.

I. A Voltaic element may consist of,

1. Two metals and one fluid . . . . Voltaic.
2. Two metals and two fluids . . . { Grove's. Bunsen's. Daniell's.

II. The Voltaic current is due,

1. To the polarization of the metallic and liquid particles, composing the circuit.
2. To the contact of two dissimilar metals.
3. To a chemical action on one metal.
4. To a transfer of the fluid molecules.

III. The Voltaic current depends,

1. On the electro-motive force.
2. On the chemical action.
3. On the resistance, both internal and external.

IV. The Voltaic circuit may be . . . { Simple. Compound.

THE PHENOMENA OF DYNAMICAL ELECTRICITY.

405. The effects of the current are manifested either (1) within its path, or (2) external to its path. The former will be first considered.

Physiological effects. The science of dynamical electricity is said to owe its origin to an experiment of Galvani in 1790, which may be repeated in the following manner:

Let a strip of zinc be passed below the crural nerve of a frog, recently killed, and a copper wire be made to touch the muscles of the legs, as shown in Fig. 221. Each time the ends of the metals are brought together at *A*, the legs are thrown out in the direction of the dotted lines. The same convulsive movements take place when one pole of a battery touches the nerve and the other the muscles. The muscles contract as often as the circuit is opened and closed, but remain quiet when the current is passing. Hence, the more frequently and abruptly the circuit is broken and closed, the greater will be the physiological effect.

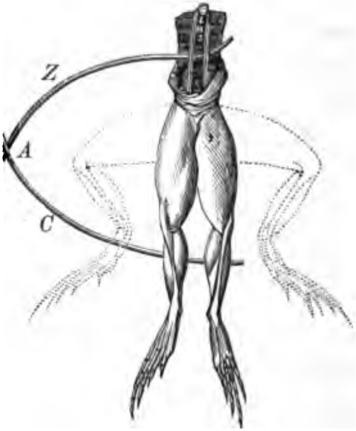

FIG. 221.

If the electrodes of a strong compound circuit be grasped with the hands, previously moistened, a shock will be experienced; but, unless the number of elements is considerable, the sensation is hardly perceptible. The nerves of the palate and of sight are easily affected. If a strip of zinc be placed above the tongue and a strip of silver between the gums and the cheek, as often as the metals are made to touch, a peculiar taste will be experienced, and a flash of light will seem to pass before the eye.

406. *Calorific effects.* If a current be passed through a thin metallic wire, the wire will be heated in proportion to the quantity of electricity and the resistance offered by the wire. The wire may become incandescent, may fuse, or even be dissipated in vapor. With the same current, the worst conductors will be the most readily heated. Thus, if a suitable current be passed through a chain made of alternate links of platinum and silver, it may render the platinum incandescent, while the silver remains dark.

On the same principle, if a platinum wire be interposed in any part of the circuit, it may be made to ignite gunpowder. This has been turned to account in blasting rocks and exploding torpedoes.

407. *Luminous effects.* No spark is obtained unless the poles are brought in contact, or nearly so. With a moderately strong battery, sparks may be obtained at the moment the circuit is broken and closed. A most brilliant *electric light* is obtained by connecting the terminal wires with carbon points, as shown in Fig. 222. The carbon points are first brought in contact, and the heat developed is such as to render their ends incandescent. They may then be removed to a short distance without interrupting the current, which forces its way through the air and produces a luminous arc of great intensity. With 48 Bunsen's elements, the arc is about one-fourth of an inch long. The light is of

FIG. 222.

far greater intensity than that obtained by the oxyhydrogen blow-pipe, being equal to that of 572 wax candles. With 600 elements, the arc is nearly eight inches long, and may be said to rival the brilliancy of the sun.

The light is not due to combustion, but to the transference of the intensely heated particles of carbon from the positive to the negative electrode. In consequence of this, the positive electrode gradually wears away and the negative electrode receives a deposit. The effect of this is to increase the distance between the electrodes; and, hence, some arrangement is necessary to bring them together in proportion as the distance alters. This may be done by the hand, or more conveniently by clock-work.

The electric light is admirably adapted for illumination in theaters and lecture-rooms, but is not well adapted for general purposes of illumination. Besides the cost of its production and the skill required in its management, the very intensity of the light is a source of difficulty, as it acts injuriously on the eye and throws shadows into too strong relief.

The most refractory substances, as platinum, quartz, and lime, when introduced into the arc are fused. The color of the light varies with the substances placed between the terminals. Gold emits a bluish light; silver, an emerald-green; lead, a purple, etc.

408. *Chemical effects.* If a chemical compound, in a liquid state, be made to form a part of the external voltaic circuit, a series of decompositions will take place like those already described as occurring within the simple voltaic element. This process is called *electrolysis.*

Fig. 223 represents a convenient apparatus to show the decomposition of water. It consists of a glass vessel, through the bottom of which are passed two wires terminating in platinum electrodes. The vessel being filled with acidulated water, two glass tubes also filled with water are inverted over the electrodes, and the outer wires are connected with a battery. Five of Grove's elements will cause a rapid decomposition of the water; bubbles of gas will collect in the tube above each pole. Hydrogen rises from the negative pole and oxygen from the positive. The volume of the hydrogen liberated is double that of the oxygen.

As the gases evolved are in proportion to the amount of zinc consumed, a modification of this apparatus, called a voltameter, is used to measure the strength of a battery.

FIG. 223.

409. The decompositions of other compounds may be effected by a similar apparatus. If the electrodes are plunged in solutions of binary compounds, like chloride of copper, iodide of potassium, cyanide of silver, the metals collect at the negative pole and the non-metals at the positive. On the principle that bodies dissimilarly charged attract each other, the metals are called electro-positive substances and the non-metals electro-negative.

410. Ternary salts are also decomposed by the current, the metal going to the negative pole, and the acid, on the body which is chemically equivalent to it, going to the positive.

Ordinarily, a single voltaic element will suffice for the decomposition of a salt. The condition in which the metal is deposited on the negative electrode, depends somewhat on the strength of the current. When the action is rapid, most metals are deposited as loose, flocculent powders; but if it is slow, copper, silver, gold, and some others are deposited in firm, coherent layers, which exactly fit the surface of the electrode.

411. Electro-metallurgy is the art of depositing the metals from solutions of their salts by means of the electric current. The solution is decomposed in the manner just described, and the pure metal is deposited on the negative electrode. This may consist of any article whatever that has a conducting surface. If the material is non-conducting, the surface may be rendered conducting by covering it with finely powered graphite. The positive electrode, *C*, Fig. 224, should be a plate of the same metal as that to be deposited—in order that the acid which is liberated may dissolve it, and thus maintain the strength of the solution.

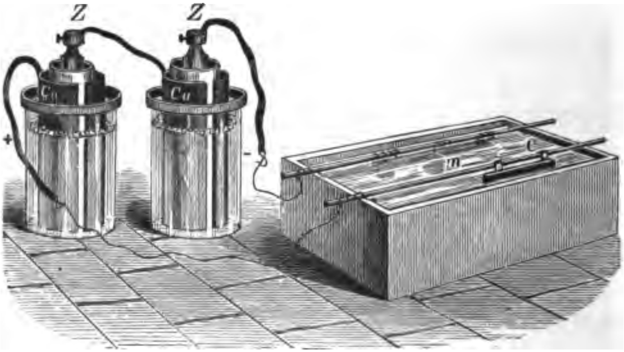

FIG. 224.

412. The processes of electro-metallurgy may be arranged in two divisions: (1) those in which the deposit remains permanently fixed on the electrode, and (2) those in which the deposit is intended to be removed. The first may be represented by *electroplating* and the second by *electrotyping*.

The apparatus employed in electroplating is represented in Fig. 224. The bath consists of a weak solution of cyanide of silver. The articles to be silvered are first carefully cleaned, then attached to the negative pole of the battery and immersed in the bath. A coating of pure silver begins to form at once, and may be obtained of any thickness desired. When the articles are first taken from the bath, their surfaces appear dull and white. The metallic luster of silver is then communicated to them by burnishing.

By a similar process articles may be electro-gilded, or coated with other metals, as copper and nickel.

413. In electrotyping, it is usual (1) to form a mold of the object to be copied, and then (2) to deposit within this a coating of some metal sufficiently thick to be stripped off whole. Thus, suppose we desire to copy a medal in copper. The medal is first rubbed over with graphite and the excess of graphite blown off; (2) an impression of the medal is taken in wax and the wax coated with graphite, as before; (3) a copper wire is now thrust through the wax and made to connect with the layer of graphite; finally, (4), the wax mold is made the negative electrode in a bath of sulphate of copper. A tough coat of copper will gradually be deposited on the surface of the graphite, and, after a day or two, will be sufficiently thick to be removed. The plates from which this book was printed were electrotyped in this way.

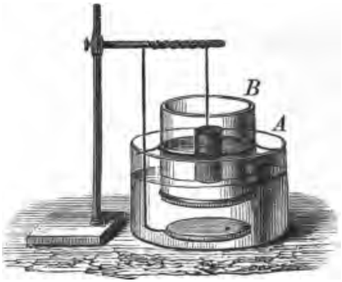

FIG. 225.

The student may easily copy small articles like coins and seals by the simple means shown in Fig. 225. *A* is a glass vessel containing a saturated solution of sulphate of copper. *B* is a lamp-chimney closed below with a piece of bladder, and containing very dilute sulphuric acid. The apparatus is completed by putting a roll of amalgamated zinc in the sulphuric acid, and connecting it by a wire to the object to be copied which is laid below the bladder. The connecting wire and any part of the object which it is not desired to copy must be carefully coated with wax or a resin varnish.

RECAPITULATION.

The effects of the current within its path are:

1. Physiological . . .	Applied in some diseases.
2. Calorific	Applied in firing mines.
3. Luminous	Applied in the electric light.
4. Chemical	Applied in electro-metallurgy.

PHENOMENA EXTERNAL TO THE PATH OF THE CURRENT.

414. The voltaic current also acts inductively upon conductors external to its path, and thereby causes phenomena which closely ally its action to magnetism. These phenomena may be grouped in two divisions:

1. *Electro-magnetism* considers the phenomena in which magnetic attraction and repulsion are caused by the voltaic current.

2. *Electro-dynamic induction* considers the production of other currents in the vicinity of closed circuits.

Conversely, permanent magnets act inductively on conducting wires, and thereby give rise to electrical currents without the aid of a battery.

(3) *Magneto-electricity* considers the production of electrical currents by means of permanent magnets.

ELECTRO-MAGNETISM.

415. Oersted discovered, in 1819, that a magnetic needle held in the vicinity of a voltaic current tends to place itself at right angles to the conducting wire.

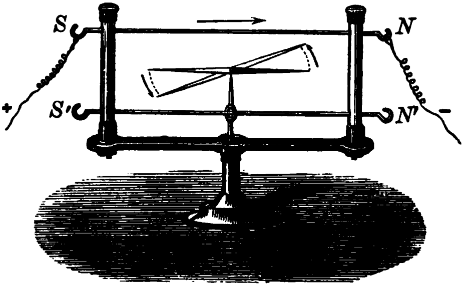

FIG. 226.

To repeat his experiment, a magnetic needle is allowed to assume its natural position, pointing north and south. If, now, the wire conducting a voltaic current be held parallel to the needle, the needle will be deflected. Fig. 226.

The direction in which the needle should turn may be remembered by the following rule: *Suppose a diminutive figure of a man to be so placed in the circuit that the current shall enter by his feet and leave by his head: then if his face be turned toward the needle, its north pole will be deflected toward his left.*

In accordance with this rule, if the current passes above the needle and goes from south to north, the north pole of the needle will turn toward the west. It will also turn westward, if the current passes below the needle from north to south. Hence, if the wires NS, $N'S'$ be joined so that the current shall pass around the needle, the deflecting power will be doubled. By coiling insulated wire many times around the needle the deflecting power is so increased that it may be used to detect the presence of very weak currents, to determine their direction, and even to measure their intensity. An instrument constructed on this principle is called a *galvanometer*.

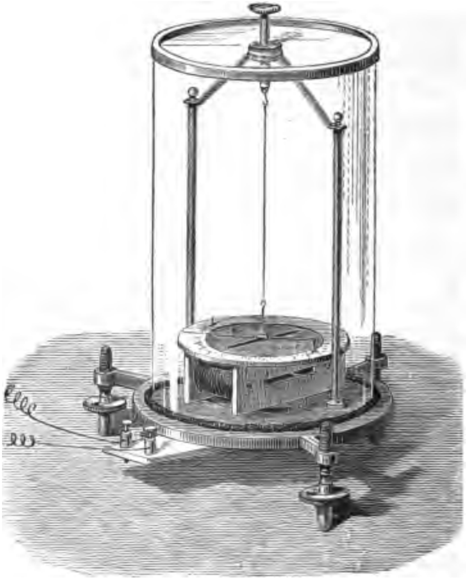

FIG. 227.

The *Astatic galvanometer*, represented in Fig. 227, derives its name from the fact that it employs two magnetic needles fastened to the same axis of suspension, but with their poles reversed. The directive force of the earth on the needles is nearly or quite neutralized.

416. If the conducting wire be movable, we may obtain results the converse of the preceding; that is, a straight conducting wire will tend to place itself at right angles to a magnet held in its vicinity.

De La Rive's floating battery (Fig. 228) enables us to verify this fact. It consists of a small voltaic element which is floated in acidulated water by means of a cork. The conducting wire may be made straight or coiled. The spiral coil shown in the figure is called a *helix.* An elongated helix with its conducting wire returned through the axis of the coil is a *solenoid.* Fig. 229.

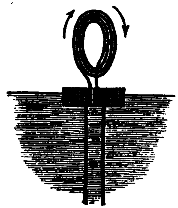

FIG. 228.

417. When the current is passing through the wire it exhibits all the properties of a magnet.

1. If a permanent magnet is held near the floating helix, one face of the coil will be attracted by the north pole of the magnet and the other repelled.

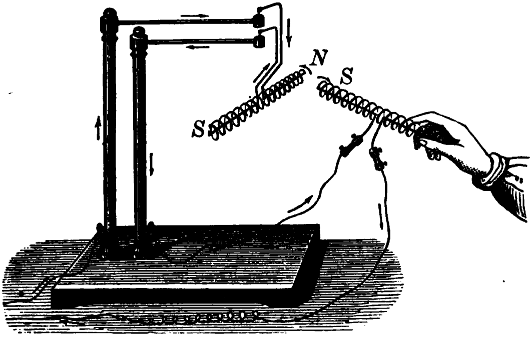

FIG. 229.

2. Each side of the helix will attract iron filings.

3. The axis of the helix will point north and south.

4. If two solenoids (Fig. 229) are brought near each other, their similar ends will repel each other; their dissimilar ends will attract each other.

5. If the conducting wire of a floating battery be straight, and a wire from another circuit be placed parallel to it—(1) *The wires will be mutually attracted if the currents pass in the same direction, but* (2) *will be repelled if the currents pass in opposite directions.*

418. The voltaic current may also induce magnetism in magnetic substances. If a bar of soft iron, *NS*, be placed in the axis of a helix, the bar will be instantly magnetized on closing the circuit. Fig. 230. If the helix is held vertically the bar will not fall out. If the bar be pulled down a little way and then let go, it will spring back to its former position. It will also attract bits of iron to itself, and act in every respect like a magnet. When the circuit is broken it loses its magnetism almost instantly.

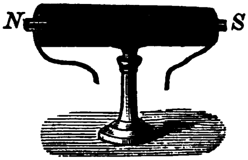

FIG. 230.

A pleasing modification of the same experiment may be had by passing the ends of two semicircular pieces of soft iron within a helix, as shown in Fig. 231. On closing the circuit, they will adhere with considerable force.

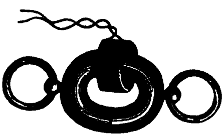

FIG. 231.

419. Electro-magnets are bars of soft iron which become magnets under the influence of the voltaic current. Electro-magnets of surprising power have been made by bending bars of soft iron in the form of a horse-shoe, and surrounding each leg with many turns of insulated copper wire. Fig. 232.

When a strong current is passing, the magnetism induced is far greater than is possible in a permanent magnet. Electro-magnets have been made that were capable of sustaining nearly two tons.

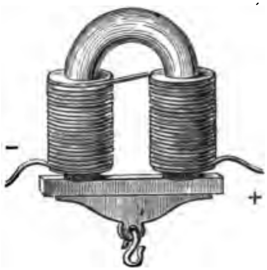

FIG. 232.

Permanent magnets. When the current is broken, the magnetism ceases instantly if the iron is quite pure; but, otherwise, traces of the magnetism will remain for some time. A steel bar placed in the helix (Fig. 230) will become permanently magnetized.

420. An excellent method of making permanent magnets is shown in Fig. 233. The steel horse-shoe is applied to an electro-magnet and a piece of soft iron is drawn in the direction of the arrow beyond the curve, and is then replaced and the process frequently repeated. Both magnets are then turned over without separating them, and the other side treated in the same way.

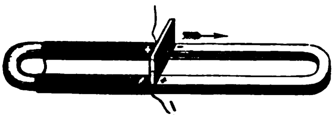

FIG. 233.

421. Various machines have been devised in the hope of employing the prodigious force of electro-magnets. The electric telegraph is by far the most important application of electricity. Every electric telegraph consists essentially of four parts: (1) a voltaic battery for generating a current; (2) a circuit consisting of an insulated metallic connection between two places; (3) a *key*, which is an instrument for sending signals from one station; (4) an instrument for receiving signals at the other station.

1. Any constant battery may be used for generating elec-

tricity. In this country, some modification of Daniell's battery is generally used.

2. The two stations must be connected by at least one insulated wire. Generally this is done by passing galvanized iron wire over glass insulators attached to a series of tall wooden posts.

At the station which sends the dispatch, the line is connected with the positive pole of the battery, but as the current will not pass unless the two poles of the battery are connected, it is also necessary to have a second conductor returning in the opposite direction to the negative pole of the battery.

In 1837, Steinheil discovered that the earth might be used for the return conductor. To effect this, large metallic plates are buried in the ground at each station, and are connected at the sending station with the negative pole of the battery and at the receiving station with the line wire. The earth really dissipates the electricity, but the effect is the same as if it were an infinitely large return conductor offering an infinitely small resistance.

422. Morse's telegraph, which is more extensively used than any other, requires at least two distinct parts, the *signal key* and the *receiver*. Beside these, a third part, called a *relay*, is necessary on long circuits as adjunct to the receiver. These parts are all shown in Fig. 236. If messages are to be received and answered, each station will require a full set of apparatus.

The signal key is used for breaking and closing the circuit at the transmitting station. It usually consists of a brass lever, *ad*, which works on an axis, *K*, supported on an insulated base. The middle of the lever is always in connection with the line wire. At the ends are two metallic points by which the line wire may be brought in connection either with the receiver or with the positive pole of a battery.

(1) When the lever is left to itself, a spring, *n*, forces the end, *a*, down, so that a receiver at *R'* (not drawn in the figure) is in condition to receive a dispatch from a distant station. (2) When a dispatch is to be sent, the end, *d*, is depressed by applying the finger to an ebonite button, *f*. The current passes from the battery up the point *d*, through the lever to *K*, along the wire to the receiving instrument, or relay, at the distant station, and thence returns by the earth, making the circuit complete. When the finger is removed, the current ceases, and hence the operator can close the circuit for a longer or shorter time, at his pleasure, by depressing or elevating the point *d*.

423. The receiver, Fig. 234, consists (1) of an electro-magnet whose helices form part of the line circuit, and (2) a lever which is worked by the joint action of the electro-magnet and an adjustable spring, *S*.

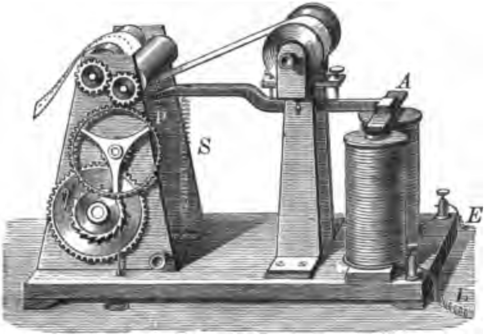

FIG. 234.

One end of the coil, *L*, is connected with the line wire from the sending station, and the other, *E*, with the earth. When the circuit is closed, the electro-magnet draws down the armature *A*, which is so attached to a horizontal lever that when the end *A* is depressed, the other end, *P*, is forced up. This end carries a steel point, or style, which writes the signals.

For this purpose, a narrow slip of paper is drawn by clock-work between the style and a revolving cylinder, and is indented by the pressure of the style. When the circuit is broken, the style is pulled down by the spring, and the paper is left blank. Hence, by varying the time of contact at the sending station, a series of signals consisting of dots and lines is produced at the receiving station.

The following is the modified Morse's alphabet:

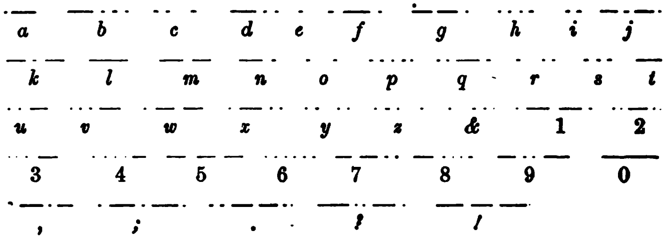

FIG. 235.

424. The clicking sound of the armature and the style indicates to the ear the same distinction of long and short signals that are indicated to the eye upon the paper. A skillful operator seldom looks at the paper when he is receiving a message. In most cases, the paper and clock-work are dispensed with, and the dispatch is read only by sound.

The relay. The intensity of the current is so weakened after it has traversed a few miles, that the recording instrument can be worked directly by the line current only on short circuits. In circuits exceeding fifty miles, the actual receiving instrument is the *relay.* This is simply an electro-magnet whose only duty is to open and close a local circuit in which the recording instrument is included.

The manner in which this is done will be rendered evident by an inspection of Fig. 236. The line current passes from the positive pole of the battery, *B*, through the key and the line wire to the relay, thence around the helices of the relay and down to the earth plate, *X*. The earth connection is then said to return the current to the ground plate, *X′*, and thus finally completes the circuit to the negative pole of the battery.

Each time the line current passes into the relay, the electro-magnet attracts its armature, *A*, which is fixed at the bottom of a vertical lever, *L*. At the same moment, the upper end of the lever strikes against the screw, *P′*. At this instant, a current from a local battery, *B′*, enters at the axis of the lever, ascends to the screw, *P′*, thence passes to the electro-magnet of the recording instrument, and finally returns to the local battery from which it started. When the line current ceases, the lever is drawn back by the spring *S′*, and the local circuit is broken. By this means, the local current is made to act in unison with the line current, and may be used either to print a legible dispatch or to transmit a fresh current to a station further on.

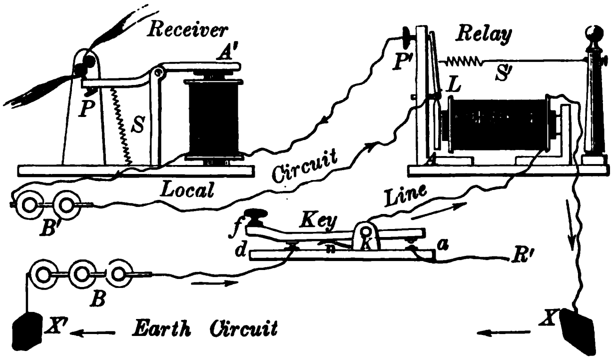

FIG. 236.

425. The electrical fire-alarms, now extensively used in large cities for indicating the localities of fires, are modifications of the Morse instrument. The properties of the electro-magnet have also been practically applied to various purposes. Among these are electric pendulums, electric clocks, and chronographs. The chronograph is an instrument for recording the time at which any phenomenon occurs. Several forms of this instrument have been devised which have been used to register automatically the fluctuations of barometers, thermometers, and the winds.

426. Hitherto the attempts to use the electro-magnet as a motive power have not been altogether successful. Nevertheless, small electro-magnetic machines have been employed in cases where economy is of less consequence than convenience and facility of application, as in running sewing machines. We can not hope that they will ever be able to compete with steam-engines in point of economy.

427. There are various other forms of the telegraph, among which Wheatstone's needle telegraph is the most important. Its receiving instrument consists essentially of a delicate galvanometer. A modification of this instrument is used with the Atlantic submarine cable.

CURRENT INDUCTION.

428. The phenomena of electro-dynamic induction may be shown by the apparatus represented in Fig. 237. Let P be a helix of insulated wire through which a *primary current* is passing from the battery; and I a second helix connected with the galvanometer. When the primary current is brought near I, a *secondary* or *induced current* will be set up in I and will cause the deflection of the needle in the galvanometer.

If the two helices are kept in the same relative position, the induced current soon ceases, and the needle returns to its old position. It will, however, be again set in motion if the primary current is in any way changed; that is, if the coil be removed, or if the current be broken or increased in strength.

An induced current is, therefore, but momentary in its action; but, nevertheless, it has all the properties of the primary current. For instance, it may induce other currents on adjacent circuits, and give rise to induced currents of the third, fourth, and even the seventh, order.

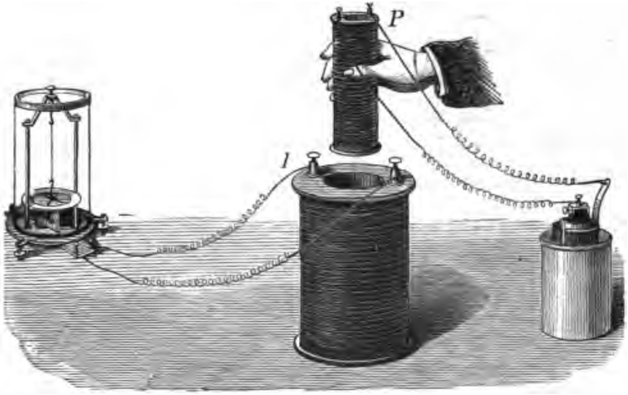

FIG. 237.

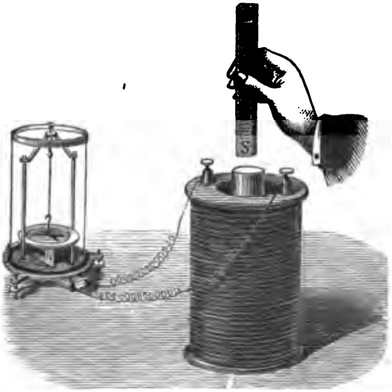

FIG. 238.

429. Magneto-electrical induction is like the preceding, except that it is caused by a permanent magnet. If in Fig. 238 we place a bar of soft iron within the helix, and bring above it a strong permanent magnet instead of the primary coil, *P*, we shall obtain almost identical effects. The core of soft iron becomes magnetized by induction, and induces an electrical current in the helix, which in turn deflects the needle in the galvanometer. This is as should be expected, since we have learned that the coil, *P*, during the passage of the current, is essentially a magnet.

430. The magneto-electrical machine is constructed on this principle. Fig. 239.

This consists of a permanent magnet, *A B*, in front of which two helices of insulated copper wire are made to revolve on an axis, *f*, by means of a winch. The cores of the helices are made of two pieces of soft iron joined by an armature, *t t′*. The same wire is coiled about the two cores, but in different directions, in order that the currents induced by the opposite magnetic poles should be in the

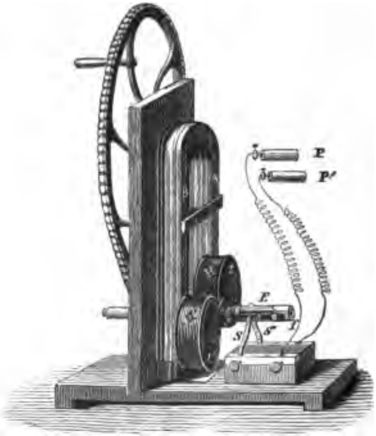

FIG. 239.

same direction. The two ends of the wire terminate in two metallic plates insulated from the axis and from each other by ivory, and are alternately connected by the springs, *S S′*. On turning the wheel, a current of electricity is induced in the coil each time the core is brought before the magnet. It, therefore, gives rise to a rapid succession of momentary currents.

431. **This instrument** is capable of producing sparks, decomposing water, igniting wires, and other effects of dynamical electricity. If a break piece, not shown in the figure, be added, an extra current of great tension will be produced. If the handles, *P P′*, be grasped with the hands slightly moistened, the muscles contract with such force that they no longer obey the will, and the handles can not be dropped. From its convenience, this apparatus is generally used for applying the effects of induced currents in therapeutical operations.

432. **Other magneto-electrical machines** constructed on the same principle, are in extensive use for all of the practical applications of electricity. The smaller are employed in fire-alarm signals, in calling attention on telephone circuits, and other simple forms of telegraphing. The larger, which are frequently driven by steam-power, and use indifferently both permanent and electro-magnets, are often of remarkable power. These are in use for electroplating and for the production of intense heat and light.

Machines, which are substantially that of Fig. 239 repeated several times, have been invented by Z. T. Gramme and by C. E. Brush, and have attracted much notice by reason of their compactness and efficiency. The *Brush machine* is used for illuminating purposes. The inventor has devised a plan by which he has been enabled to produce economically fifty electric arcs (§ 407) of 2000 candle power each on the same circuit. Other inventors have endeavored to attain the same effect by rendering platinum or carbon incandescent, but hitherto without great success.

433. The Telephone is an instrument used for transmitting sound-waves to a great distance. So perfect are some of these instruments that conversation has been carried on distinctly between stations 250 miles apart; and so convenient are they, that they are rapidly superseding short telegraphic lines, and are already in common use in all of the large cities.

Two instruments are always employed: (1) the *transmitter*, from the sending station, applied to the mouth of the sender; (2) the *receiver*, at the distant station, applied to the ear of the person who receives the message. These two instruments are connected by a wire.

The telephone was foreshadowed in a toy known as "The Lovers' Telegraph." The instruments used are two hollow cylinders of tin. One end of each is open, and over the other end is stretched a piece of bladder, to serve as a vibrating membrane; the two membranes are connected by a string fastened to the center of each. When in use (1) the connecting string is stretched taut; (2) the sender of the message speaks into the open end of his cylinder. He thereby excites vibrations in the tense membrane which correspond to waves of condensation and rarefaction produced by his voice. (3) These vibrations are transmitted as sound-waves through the taut string to the membrane of the receiving instrument. (4) This membrane is thrown into vibrations exactly similar to those of the transmitting membrane, and (5) thereby waves of condensation and rarefaction, are excited in the receiving cylinder, which reproduce the speech, etc., of the sender so as to render it distinctly audible to a person whose ear is applied at the open end of the receiving instrument. This toy has been so perfected that speech can be transmitted by it over two miles of straight wire, and it is practically used to connect workshops, etc., with the sales-rooms in manufactories.

The *Bell Telephone*, shown in Fig. 240, has for its vibrating membrane a thin iron plate, *E*, which is free to move above but not quite touching a permanent magnet, *A*. Around one end of the magnet is a coil of fine wire, *B*, which is connected with the binding posts, *DD*. One of the posts, *D*, is connected by a wire to the earth: the other post, by a wire to the distant station. The plate, *E*, is held in its place by a cup-shaped cover, to which the mouth is applied in sending, or the ear in receiving, the message. A sound made in front of the plate, *E*, produces: (1) Waves of condensation and rarefaction, which cause movements in the plate to and from the magnet, *A*. (2) Every such movement produces a disturbance in the magnetic field, by means of which induced currents will be set up in the coil (§§ 428, 429). (3) This induced current, propagated through the connecting wire, sets up vibrations in the plate of the receiving instrument. These vibrations are similar to those which caused them, and hence (4) excite in the air sound-waves, which reproduce the original sounds in pitch, quality, and even timbre, so faithfully that the characteristic tones of a speaker are easily recognized. No battery is used on short lines. On long lines, however, the sound transmitted is too feeble to be audible, and is, besides, liable to become confused by stronger currents in adjacent wires. To obviate these difficulties on

FIG. 240.

long lines, a battery is used; the Bell telephone is employed only as a receiving instrument; the transmitter resembles one of the two following instruments.

434. The Microphone is an instrument capable of transmitting distinctly very feeble sounds.

Hughes's Microphone, Fig. 241, consists essentially of two carbon sockets, *S* and *S′*, each of which is connected with one of the wires in a galvanic circuit, and of a carbon spindle, *C*, placed vertically so as to rest in the lower socket and play loosely in the upper. Now, if while the current is passing, a noise be made in front of the spindle *C*, it will so jar the spindle as to produce a greater or less surface contact between the ends of the spindle and its sockets. In consequence of this, the current transmitted by the battery will vary in like proportion. These variations will represent the sound-waves, and may be made to reproduce audible sounds if a receiving instrument such as a Bell's telephone be interposed in the circuit. Since the spindle is set in motion by very feeble sounds, such as the ticking of a watch, it receives the original impulse strongly, and also impresses the receiving instrument strongly, and, it is said, that when a powerful battery is used the intensity of the sound is increased.

FIG. 241.

Fig. 242 shows the interior of the *Blake Transmitting Telephone*, which is extensively used to send audible messages.

It contains a diaphragm which vibrates in answer to the voice against a small platinum disk, which is thereby forced against a movable carbon cylinder, *C*. The disk and carbon are connected with a battery, and the current will not pass except when these are in contact. The amount of surface contact between them will of course vary with the condensation and rarefaction of the sound-waves, and consequently there will be a variation in the resistance of the primary circuit which may be reproduced as sound-waves in a distant telephone receiver. The receiving telephone is placed in connection with an induction coil, *I*, and is worked by the secondary current. Each station has a call, arranged on the principle of fire alarms.

FIG. 242.

435. The Photophone, or Light Sounder, is the last invention of Mr. A. G. Bell. In this instrument sound-waves are made to strike upon the back of a flexible mirror, which is thereby thrown into vibrations. Upon the face of this mirror a beam of light is projected which is reflected to a distant point in undulations which correspond to the vibrations of the mirror. At the distant station the reflected beam is received upon a concave mirror, and by it concentrated upon a plate of amorphous selenium. Now, amorphous selenium has its conducting power for electricity curiously increased by exposure to light, and this property is utilized in the photophone. The plate of selenium is connected with a battery and with a telephone. By this arrangement the luminous undulations produced by the sound are reconverted into sounds at the distant station. Messages have been conveyed by this instrument when the mirrors were 800 feet apart, and it is possible that, when perfected, it will be of great use in military operations.

436. Induction coils are instruments which employ both electric and magnetic induction. One form, in which the helices are separable, is shown in Fig. 243.

The primary coil, *P*, of coarse insulated copper wire, is connected by the screw cups + and — with the battery. *I* is the secondary coil of fine, insulated copper wire to which the handles are attached. *M* is a bundle of iron wires, which are sufficiently insulated from each other by the rust that soon gathers on them. The primary current is made to open and close by its own action. This is effected by a small electro-magnet, *B*, the spring of whose armature is made to open and close the circuit.

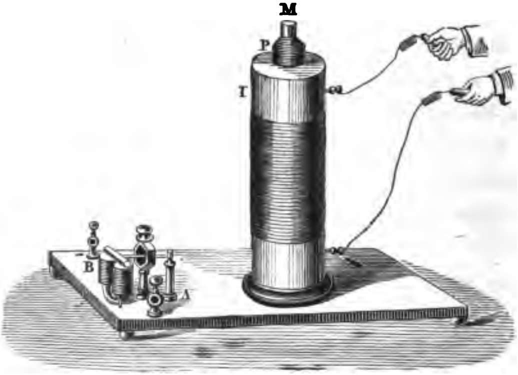

FIG. 248.

As soon as the coil of *B* receives the current, the armature is drawn down and the circuit is broken. This releases the armature, and the circuit is again closed. At every interruption of the primary current the iron wires become magnetized and demagnetized, and act inductively on the secondary coil. The primary current also acts inductively on the secondary coil, and by this joint action the intensity of the induced currents becomes much increased, and may even become of so high tension as to produce all the effects of statical electricity.

437. Ruhmkorff's coil is made on the same principle. The secondary helix contains from three to thirty miles of fine copper wire carefully insulated. With three Bunsen's elements and a large coil, the induced current becomes of amazing intensity. Some of the effects of the coil are as follows:

1. *Physiological.* The shocks are so violent that incautious experimenters have been prostrated by them.

2. *Calorific.* Fine iron wires brought between the ends of the induced wire are melted and vaporized.

3. *Luminous.* Sparks have been obtained nineteen inches in length. When the discharge is passed into rarefied gases the phenomena of auroral light is produced in a most beautiful and varied manner. These experiments are performed in sealed glass tubes, known as Geisler's tubes, one of which is shown in Fig. 244. The color of the light varies with the vapor inclosed in the tube, and is frequently arranged in bands giving the appearance of stratified light.

FIG. 244.

4. *Mechanical.* Plates of glass over an inch in thickness may be pierced by the discharge.

5. *Leyden jars* may be charged and discharged with an almost continuous spark of great brilliancy.

THERMO-ELECTRICITY.

438. If any two metals are soldered together and heated at their junction, an electrical current is evolved. On the other hand, if their junction be cooled, an electrical current in the opposite direction will be produced. These currents are called thermo-electric currents, but they differ in no respect from those already studied.

The direction of the current will depend on the metals which are associated together. The following thermo-electric series is so arranged that if any two of the substances named are soldered together, and heated at the soldering, the current will pass from the first named to that succeeding it.

+ Bismuth. Cobalt. Nickel. Lead. Tin. Copper. Platinum. Silver. Zinc. Iron. Antimony. Selenium. −

The most efficient electro-thermal couple is said to be formed of artificial sulphide of copper and metallic copper. Fig. 245. The usual combination is bars of antimony and bismuth. Fig. 246 shows a section of a thermal battery made up of these metals. The greater the number of pairs the greater will be the force of the current. Although the electro-motive force of a thermal battery is always low, it may be used to obtain the same results as the voltaic battery.

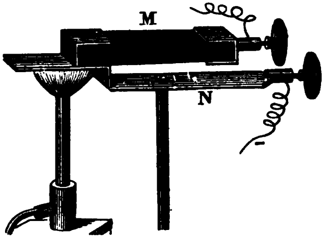

FIG. 245.

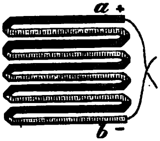

FIG. 246.

In combining the bars, it is necessary to join both ends of all the bars except the two extremes. Hence, the effect of the current will be due to the difference of temperature in the two ends. This fact is utilized in the thermo-multiplier, shown at *T* in Fig. 247. It consists of thirty pairs of bismuth and antimony, inclosed in a non-conducting frame, and connected with a galvanometer which has only a few turns of moderately thick wire. The slightest difference in the temperature of the two ends of the thermo-multiplier will instantly be manifested by the deflection of the needle of the galvanometer. The apparatus is used in all delicate investigations on the subject of radiant heat.

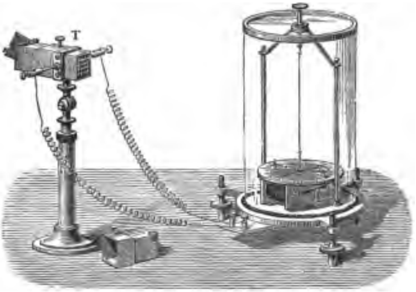

FIG. 247.

ANIMAL ELECTRICITY.

We have already learned that electricity produces peculiar phenomena in living animals, and that one of the most sensitive galvanoscopes may be had in the legs of a recently killed frog. Matteuci has reversed this last experiment, and has succeeded in evolving a current by means of a battery formed of the muscles of frogs.

439. **Several species of fish** have the power of giving, when touched, shocks like those of the Leyden jar. Among these are the torpedo, the gymnotus, and the silurus. Each of these fish has special organs for the production of electricity. This electrical apparatus is under the control of the animal, and may be made to serve as a means of offense and defense.

APPENDIX.

440. **The advances in Physical Science** during the past fifty years have been marvelous. Some of its departments, like Sound, have been greatly enlarged; some, like

Heat, have been reconstructed; some, like Electricity, are almost entirely of recent development.

Among the most interesting of these advances is the theory which relates to the *constitution of matter*. Reasoning from the well known properties of gases—(1) their diffusion, which clearly necessitates motion among their molecules; (2) their expansion by heat, which must also be a result of molecular motion; (3) their elastic force, which increases with the work they have to do, another function implying motion—the *dynamical theory of gases* has been satisfactorily established.

By the terms of this theory, any gas is made up of an enormous number of molecules which are moving in all directions with great velocity. Any single molecule will move for a while in a free path with uniform velocity. When it encounters another molecule, both are brought to rest and then recede from each other: the direction of the path may be changed, but no velocity of motion is lost, because these molecules are perfectly elastic. If the molecule strikes against the side of a vessel which contains it, the same result to the molecule follows. Thus all the molecules in an enclosed space are moving about, sometimes in a free path, sometimes colliding, sometimes at rest, but so that the total energy of the entire system remains the same. The average motion of any molecule will be the average of the entire system. Subjecting these hypotheses to a rigid mathematical analysis, several remarkable conclusions are established:

(1) This theory of gases is in direct accord with Mariotte's law (Art. 172) and with all other known laws of gases; (2) Equal volumes of all gases, under like conditions, contain an equal number of molecules; and (3) The mass of any molecule and its velocity may be measured numerically.

Among the results attained are these: Under the normal pressure and temperature, a cubic centimeter of any gas contains $(19 \times 10^{18}) = 19.000,000,000,000,000,000$ molecules. A hydrogen molecule has an average velocity of 1859 meters per second; the length of its mean free path is 965 ten billionths of a meter ($\frac{965}{10^{10}}$; its number of collisions per second, 17,750,000,000; its diameter is about 6 ten billionths of a meter; and its mass, 46 ten million, million, million millionths of a gramme $= \frac{46}{10^{25}}$.

In a solid, the molecules have simply a vibratory motion. In liquids, the molecules move about, but no molecule can be said to have a free path. In gases the free path is many times the diameter of their molecule. As the density of the gas increases, the free path diminishes; conversely, if the density decreases, the length of the free path increases; and in a space greatly rarefied it is several thousand times longer than at the normal pressure.

441. Professor Crookes maintains that there is a fourth state of matter, exceedingly attenuated, which he calls **radiant matter**, and has devised a series of apparatus to sustain his views.

One form is the *Radiometer.* Fig. 248. This is a small receiver nearly exhausted of air, having within it four light vanes blackened on one side and delicately poised so as to revolve freely on a slender glass axis. When the radiometer is placed in the sunlight the vanes begin to revolve, and cease when removed from the light. At first he thought that the vanes turned because of the impact of light, but soon it was demonstrated that the vanes moved by impact of the molecules which still remained in the receiver upon the vanes. The reason why the impact is directed upon the

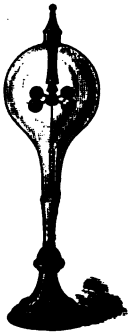

FIG. 248.

disks, is that they become slightly warmed by the heat rays accompanying the luminous rays; that thereby the molecules in front of them are warmed, and, reacting from the glass sides of the receiver, cause the vanes to turn. The experiment is, in fact, a confirmation of the dynamical theory of gases.

RECAPITULATION.

The science of electricity includes the phenomena of,

1. Electricity that may be insulated	Statical.
2. Electricity continually discharged in currents.	Dynamical.

Dynamical electricity investigates the phenomena,

I. Within the path of the current:

1. Due to chemical action	Galvanism.
2. Due to heat.	Thermo-electricity.
3. Due to vital action	Animal electricity.
4. Due to magnetic currents	Magnetism.

II. External to the path of the current:

1. Inducing magnetism in iron and steel	Electro-magnetism.
2. Inducing currents in adjacent circuits	Electro-dynamics.

III. Of currents induced by permanent magnets	Magneto-electricity.

Direct and induced currents are applied:

1. For physiological and therapeutical purposes.
2. For evolving intense light and heat.
3. For effecting chemical changes.
4. For making permanent and temporary magnets.
5. In the Telegraph, Telephone, etc.

THE END.

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