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*ECLECTIC EDUCATIONAL SERIES.*

# THE ELEMENTS

OF

# NATURAL PHILOSOPHY,

BY

SIDNEY A. NORTON, A. M.

*Three Hundred and Fifty Illustrations.*

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# PREFACE.

THIS work is the result of many years' experience in teaching the science of Physics. In its preparation, the author has endeavored to keep constantly in mind that its value must depend on its availability as a text-book. Accordingly he has made such a selection of the facts and principles embraced in the wide range of Natural Philosophy as, in his judgment, is best suited to the requirements of the pupil.

While due attention has been given to the recent progress in Physics, including the latest methods and inventions, it has not been forgotten that all facts are equally fresh to the tyro, although all are not of equal importance, as regards either their fitness for developing the theory of the science, or their application to the practical affairs of life. For this reason, nothing has been introduced for the sake of its novelty; nor have cardinal principles been omitted, because a former generation of pupils has studied them.

It has been an object of careful thought to present the science, in all its departments, in a manner at once systematic and symmetrical. Of course, no pretense is made of exhausting the subject, but it is hoped that the student will find in this treatise all that is necessary for his purposes. While fully impressed that "there is no royal road *to science*," the author has yet endeavored to make the labor of the student as attractive and invigorating as possible. To this end, the subject has been treated not merely as a science to be learned, but also as a means of educational discipline: the topics are considered in their logical order, methodically developed, thoroughly illustrated and enforced.

No pains have been spared to secure clearness of expression, precision in definitions, and accuracy in the statement of facts. The manuscript was read by Prof. Charles H. Smith, the proof sheets by Mr. H. H. Vail, and to these gentlemen the author returns his sincere thanks. Should any errors have escaped their notice, the author will thank any of his readers who will have the kindness to inform the publishers of such as he may find.

The problems are placed in the appendix for greater convenience. If properly used, they will serve not only to test the knowledge acquired by the student, but also to lead him to think on the nature of the laws and principles required for their correct solution.

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NOTE.—The following table has been prepared for the convenience of schools in which the time allotted to the study of Natural Philosophy is not sufficient for the mastery of the entire work. The topics indicated fill about eighty pages. The omission of these will give the student a **shorter course**, which is still complete in itself.

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# NATURAL PHILOSOPHY.

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## CHAPTER I.

### INTRODUCTION.

1. **Matter** is any thing that possesses extension and impenetrability; as earth, water, air. The different kinds of matter are called substances.

2. **Force** is that which causes any change in the form or condition of matter; as heat, electricity. We know very little of the ultimate nature of matter and force, because it is difficult to conceive of either alone. All the phenomena of the visible universe are caused by the action of force upon matter.

3. **A body** is any separate portion of matter, whether large or small; as a cannon, a cannon ball. Every body is considered as made up of very small particles, called *molecules*, each of which is supposed to contain two or more still smaller particles, called *atoms*. It is also supposed that these atoms do not touch each other, but are retained side by side by means of certain forces known as *molecular attractions*. The firmness of their union is modified by the presence of an opposing force called *molecular repulsion*. Heat is the principal, if not the only, repellant force in Nature.

**4. With respect to the coherence** of its molecules, a body is said to be in one of three states: 1. *solid;* 2. *liquid;* 3. *aëriform,* or *gaseous.*

1. A body is in the solid state when the relative position of its molecules can not be changed without the expenditure of considerable force; as ice, marble, iron. Bodies in this state are called *Solids,* and retain whatever shape has been given them by nature or art.

2. A body is in the liquid state when the relative position of its molecules is easily changed; as water, oil, wine. Bodies in this state are called *Liquids,* and assume with readiness the shape of any vessel into which they may be poured.

3. A body is in the aëriform or gaseous state when its molecules tend to separate and occupy a greater volume; as steam, air, oxygen. Bodies in this state are called *Aëriform Bodies, Gases,* or *Vapors.*

The term *fluid* is applied to both liquid and aëriform bodies; as water, steam. The same substance may, at different times, be in either of these three states, according to the relations which exist between the molecular attractions and repulsions. Thus, by a moderate change in the temperature, water may be made to pass through the solid, liquid, and aëriform states; as ice, water, steam. So, also, many metals may be easily melted, and then changed into vapors.

**5. The number of distinct substances** is almost infinite; but every body consists, either (1.) of a single element, or, (2.) of several elements combined. With respect to the number of elements it contains, a body is said to be either (1.) simple or (2.) compound.

1. A simple substance contains but one element; as iron, gold, diamond.

2. A compound substance contains two or more elements; as water, oil, alum.

There are sixty-six elements now recognized, but a more rigorous analysis may either increase or diminish this number. Very few elements are found native: by far the greater number are derived from their combinations. Only eighteen or twenty may be obtained in any considerable quantity. The rest appear to play a subordinate part in the structure of our globe, and are known only to chemists.

6. **Forces** are either *Attractive* or *Repellent* according as they cause the particles of matter (1.) to approach, or, (2.) to recede from each other. Force may act either (1.) only upon the molecules of matter and at distances which are inappreciable to our senses, or, (2.) also upon bodies taken as a whole, and at any distance, whether small or great. The forces of the first class are called the *Molecular Forces*, and are severally named (1.) cohesion, (2.) adhesion, (3.) affinity. Those of the second class are (1.) gravitation, (2.) light, (3.) heat, which always acts as a repellant force, (4.) electricity, which is both an attractive and repellent force.

The forces of affinity, electricity, heat, and light, are so closely allied that many philosophers consider them as modifications of the same force, in the same sense that magnetism is a modification of electricity. We know that the action of either of these forces may induce the action of any other of them; thus the action of affinity may induce heat, then light, as is shown by the burning of a candle. For this reason, they are called the *correlative forces*. Heat, light, and electricity are sometimes termed the imponderable agents, from an erroneous notion that they are matter without weight.

7. All these are the forces of inanimate nature. Plants and animals live and move by virtue of higher *vital forces*, which control and modify all other forces in an entirely inexplicable manner.

The forces already named are the only ones of which we have any knowledge. They produce, by their action on matter, secondary forces, which are employed by man in machines. Thus the molecular forces give strength and elasticity to springs. Heat develops the elastic force of steam, and, acting in conjunction with gravitation, raises winds which cause the waves of the seas. Gravitation is made serviceable to man in the force of running water, and in machinery moved by weights. The muscular strength of men and animals is the result of many forces, as heat, cohesion, affinity, modified by the vital forces.

8. **The changes** to which all bodies are liable may be reduced to two classes: (1.) those by which the substance is not altered so as to lose its identity, and (2.) those by which its identity is entirely lost. Thus (1.) a mass of iron may be hurled from a cannon, or wrought into nails, or beaten into a plowshare, or, by contact with a magnet, become endowed with the property of attracting iron filings, but, notwithstanding these changes of position, shape, and size, or even properties, we still recognize it as iron.

So water may be converted into ice or steam and yet preserve its identity, for if the ice be melted or the steam condensed, the fluid water re-appears with its characteristic properties. So, also, if a bit of hard rubber or sealing-wax be rubbed with a silk handkerchief, it will become endowed with the property of attracting and then repelling small pieces of paper or pith, although we can not perceive any change in the structure of either. Such changes are called *physical changes.* The agencies by which they are produced are the *physical forces,* of which the principal are gravitation, cohesion, and the secondary forces.

(2.) On the other hand, if the iron be exposed to moist air it crumbles to a red powder; if it be placed in weak sulphuric acid, it is converted into a green, crystalline solid. If steam be passed over red hot iron, it yields a combustible gas (hydrogen). If sealing-wax is burned, it passes away into colorless gases which can never again be united to form wax. Such changes are called *chemical changes,* and the agencies by which they are caused are called *chemical forces.* The principal chemical force is affinity.

Light, heat, and electricity, in their action on matter generally produce physical changes, but they sometimes assist in producing chemical change, or they are evoked by the action of chemical affinity: thus, if we heat a strip of zinc, it increases in size, then melts, and, finally, if no air is present, passes away in a state of vapor: but, on cooling, the vapor first becomes liquid, then solid, and, at last, contracts to its original dimensions, showing that all these changes are physical. On the other hand, if zinc is strongly heated in the air, it burns away to a soft and bulky powder sometimes used as a white paint. This permanent change is due to chemical affinity, assisted by heat.

**9. Two classes of properties** correspond to these two classes of changes. (1.) Those which a substance may exhibit without undergoing any change itself, or causing any essential change in other bodies, are called *physical properties.* (2.) Those which relate to the permanent change which a substance may experience itself, or effect in other substances, are called *chemical properties*: thus, among the physical properties of iodine are its luster, weight, its purple vapor, etc.; among its chemical properties are its power of turning starch blue, of setting fire to phosphorus, of combining with other elements, etc.

**10.** The changes, forces, and properties relating to matter may thus be classified in two distinct groups. The study of the laws and phenomena which severally relate to each group has given rise to two distinct sciences, (1.) Natural Philosophy, or Physics, and (2.) Chemistry.

CHEMISTRY considers those phenomena in which the substances acted upon suffer a loss of identity.

NATURAL PHILOSOPHY, or PHYSICS, considers those phenomena in which the substances acted upon do not suffer a loss of identity.

**11. The laws and phenomena** which belong to the domain of natural philosophy are so varied and numerous that it has been found necessary to divide them into several branches of study; each of which is of sufficient importance to merit the name of a distinct science. It will be found convenient to make an arbitrary division of Natural Philosophy into Physics and Chemical Physics.

**12.** PHYSICS considers the forces whose phenomena are never attended by chemical changes. It includes three branches:

(1.) Somatology, which treats of the properties of matter.
(2.) Mechanics, which treats of equilibrium and motion.
(3.) Acoustics, which treats of sound.

CHEMICAL PHYSICS considers the forces whose phenomena are sometimes attended by chemical changes. It also includes three branches:

(1.) Pyronomics, which treats of heat.
(2.) Optics, which treats of light.
(3.) Electricity, which treats of electrical forces.

Some of these branches are again subdivided, as will be seen hereafter. The mechanics of the heavenly bodies constitutes the science of astronomy.

### 13. Recapitulation.

Bodies are classified:

| | |
|---|---|
| I. With regard to state. | Solid; as ice.<br>Liquid; as water.<br>Aëriform; as steam. |
| II. With regard to composition. | Simple; as oxygen.<br>Compound; as water. |

Sciences which treat of the action of force upon inanimate matter are:

| | | |
|---|---|---|
| Natural Philosophy, which includes | Physics. | Somatology.<br>Mechanics.<br>Acoustics. |
| | Chemical Physics. | Pyronomics.<br>Optics.<br>Electricity. |

Chemistry, which treats of Chemical Affinity.

Forces in their action upon matter are either attractive or repellant.

I.

| | | |
|---|---|---|
| Act only on molecules. | Molecular. | Cohesion.<br>Adhesion.<br>Affinity. |

| | | |
|---|---|---|
| Act also upon bodies. | General. | Electricity.<br>Heat.<br>Light. |
| | Universal. | Gravitation. |

II.

| | | |
|---|---|---|
| Never cause loss of identity. | Physical. | Gravitation.<br>Cohesion.<br>Adhesion. |
| Sometimes attend loss of identity. | Chemico-Physical. | Light.<br>Heat.<br>Electricity. |
| Always cause loss of identity. | Chemical. | Affinity. |

## CHAPTER II.

### SOMATOLOGY.

**14.** By studying the properties of iron, it is found that they may be divided into two classes: one class includes properties which it possesses in common with all other substances; the other class includes properties which are peculiar to iron, and which distinguish it from all other kinds of matter.

Thus, (1.) a mass of iron occupies a certain portion of space to the exclusion of all other bodies; that is, it possesses extension and impenetrability; it also has weight: but every other substance, whether solid, liquid, or aëriform, possesses extension, impenetrability, and weight. Properties which belong to all bodies are called *universal properties.*

(2.) Besides these, iron is endowed with other properties peculiar to itself. Thus, iron not only possesses extension, but has a peculiar crystalline form; it not only possesses weight, but every piece of iron weighs 7.8 times as much as an equal *bulk of water;* it has a certain hardness, strength, flexibility, and a familiar luster. Properties which are peculiar to a substance, and serve to characterize it, are called *specific properties.*

**15.** The **Universal Properties** of matter are (1.) extension, (2.) impenetrability, (3.) weight, (4.) mobility, (5.) inertia, (6.) divisibility, (7.) porosity, (8.) compressibility, (9.) expansibility, (10.) indestructibility, (11.) elasticity.

The first two of these may be termed the essential properties of matter, since they serve to define it. The last nine may be conceived of as not applying to atoms, but only to bodies, and hence may be termed general properties.

The most important **Specific Properties** are (1.) elasticity, (2.) tenacity, (3.) hardness, (4.) brittleness, (5.) ductility, (6.) malleability. Besides these might be named others, as color, transparency, taste, odor, as well as the relations which bodies bear to heat, sound, and electricity.

### THE UNIVERSAL PROPERTIES OF MATTER.

**16. Extension or Magnitude** is that property by virtue of which a body occupies a certain space.

Extension has three dimensions—length, breadth, and thickness. No one can conceive of a body which does not possess all these. As a necessary consequence, every body has a certain shape or figure. The figure of solids is permanent; the figure of fluids varies with the shape of the vessel which contains them. The amount of space that a body occupies is termed its *Volume* or *Bulk.*

**17.** For the purpose of measuring length, England and the United States have adopted an arbitrary unit called the Yard, with its multiples and divisions, rods, inches, etc. The unit adopted by France is the metre, which is the forty millionth part of a meridian of our globe, and is equal to 39.3685 inches used in the U. S. coast survey.

All the French measures increase and 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 ($\frac{1}{100}$), mille ($\frac{1}{1000}$) are used. A decimetre is drawn on the margin in comparison with a scale of inches. It will be seen that one inch is a trifle longer than 25 millimetres.

The units of surface and volume, derived from the linear unit, are called the square inch, cubic inch, etc. The wine gallon of the United States contains 231 cubic inches. The English imperial gallon contains 277.274 cubic inches.

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

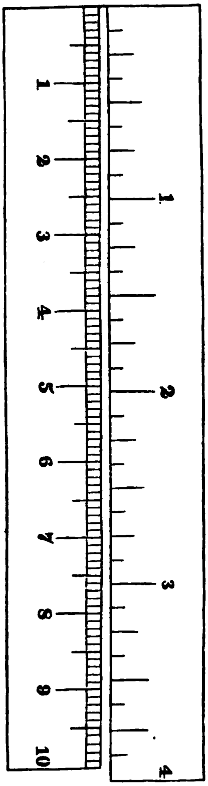

Fig. 1.

**18. Weight** is due to the force of gravitation, by virtue of which every particle of matter attracts every other particle toward itself. A falling body is drawn by the attraction of all the particles of the earth toward the center of the globe; but, when the body is not free to fall, the force which the earth's attraction exerts upon it is expended in pressure against its support. This pressure is called *absolute weight.* Hence, weight is the measure of the earth's attraction, and must vary as the attraction varies. This definition limits weight to bodies on the earth, but, as the attraction of gravitation is universal, a body would possess weight if removed to any of the heavenly bodies.

**19. 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.*

| | | | |
|---|---|---|---|
| Hydrogen | 0.005592 | Potassium | 53. |
| Nitrogen | 0.07841 | Wrought Iron | 480. |
| Air | 0.080728 | Copper | 556. |
| Oxygen | 0.089256 | Lead | 712. |
| Water | 62.418 | Gold | 1224. |
| Mercury | 848.75 | Platinum | 1373. |

**20. Impenetrability** is that property by virtue of which two bodies can not occupy the same portion of space at the same time.

When a solid is immersed in a fluid, it displaces a quantity of fluid equal to its own volume. Thus, if a pebble be dropped into a tumbler full of water, enough water will overflow to equal the size of the pebble. Even a needle will displace its own bulk, for, although no one may be able to detect any change of level on the addition of a single needle, if many needles are dropped into the tumbler, the water will overflow as before. 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 enter the tube because of the impenetrability of the air enclosed in the tube; but, when the thumb is removed, the air will be expelled, and the water will rise to the level of that in the vessel.

**21.** This property belongs to all bodies, solid, liquid, and gaseous, though there are some apparent exceptions.

Thus, in the last example, the water will rise a little way in the tube; but this occurs because the air is compressible. A nail may be driven into a board without increasing its size, but this is effected by separating the fibers of the wood and crowding them together to make room for the harder body. If a long and slender test tube be half filled with water, and strong alcohol be poured in carefully so as not to mix the liquids until the tube is quite full, and then the liquids be thoroughly shaken together, the mixture will no longer fill the tube. The reason for this is not that the particles of water and alcohol penetrate each other, but that the smaller particles occupy a portion of the space between the particles of the other.

Space utterly devoid of matter is termed a vacuum.

22. **Mobility** is that property by virtue of which the position of a body in space may be changed on the application of sufficient force. A body in the act of changing its place is said to be in motion. Rest implies permanence of position.

The motion or rest of a body is determined by its relation to some given point; but, as this point may itself be fixed or moving, motion or rest is either (1.) absolute or (2.) relative.

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

Absolute rest is permanence in place with reference to a fixed point: relative rest is permanence in place with regard to a point in motion.

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

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

24. **The rate of motion** of a body is termed its velocity. It may be found by dividing the space by the time. The formula

$$[1.] \quad v = s \div t$$

expresses the relation between space, time, and velocity, and may be used to find the third quantity when the other two are known. From the formula given, other formulæ may be obtained; thus, from [1.] we find $s = vt$ and $t = s \div v$.

### *Table of Velocities.*

| | Feet per second. | Miles per hour. | | Miles per second. |
|---|---|---|---|---|
| Man walking........ | 4.4 | 3 | Swiftest railway train..... | 0.02 |
| Man running......... | 14.66 | 10 | Initial velocity of a cannon ball.................... | 0.44 |
| Swift trotting horse | 40. | 27 | The earth in its orbit..... | 18.97 |
| A moderate wind... | 10.26 | 7 | A point on the Equator | 0.29 |
| A storm................ | 73.33 | 50 | Light........................ | 185500. |
| A rifle ball .......... | 1466.66 | 1000 | Electricity..................... | 288000. |
| Sound.................. | 1118.6 | 762 | | |

**25. Inertia** is that property by virtue of which a body tends to retain its present state, whether of motion or rest.

This is a purely negative property of matter, and implies that motion and rest are equally natural to a body. A body dropped from a balloon in mid air falls because of the earth's attraction. A bullet fired in the air does not stop because the explosive force of the powder will carry it no further, but because other forces bring it to rest.

**26.** Many common phenomena may be explained by the inertia of matter. If a boy wishes to leap a broad ditch, he starts with a run, that the inertia of his body may be added to the muscular effort of leaping. With the same velocity, the inertia increases with the weight of the body. A small boy in running will easily "dodge" a larger, because the heavier boy will be unable to change his course at once.

If a person descends carelessly from a car in motion, the upper part of the body retains its onward motion, while the feet are prevented from doing so by the friction of the ground, and he is thrown forward. So a person standing in a wagon partakes of its condition of motion or rest. If it is suddenly started from a state of rest, his feet are drawn along by the friction against the bottom, before the head can acquire the motion, and the person falls backward. If the carriage is suddenly stopped when in rapid motion, the person is thrown forward.

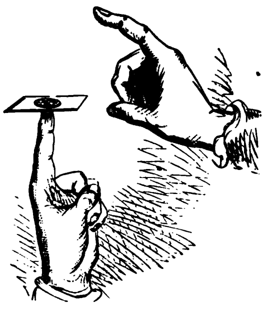

FIG. 2.

If a card is balanced on the top of one of the fingers of the left hand and a penny placed on it, a sudden blow given by the nail of the middle finger of the right hand, will drive the card away and leave the penny on the finger. In this case the friction of the card against the penny will tend to carry it along with it, but the motion communicated will be so small that the coin will be moved but little. This experiment has been explained by saying that the inertia of the coin retains it in its place; but it really moves a little, as may be ascertained by placing the card and penny on the edge of a smooth table, and striking away the card as before.

The inertia of the air may be proved by the resistance it offers to a body moving through it. Thus, if we endeavor to carry an open umbrella, with the concave side forward, we shall need to employ considerable force to overcome the resistance of the air. Wind is only air in motion. If air had no inertia, it would not require force to set it in motion nor to stop it.

**27. Divisibility** is that property by virtue of which a body may be divided into distinct parts.

A geometrical magnitude, as a line, may be supposed to be divided into an infinite number of parts. Let A B be the line to be divided. Draw D B and A C at right angles to it at its extremities and lay off, on A C, A 2, 2 3, 3 4, etc., each equal to D B, join D with each point, then D 2 will cut off one-half of A B, D 3 will cut off one-third of A B, D 4 one-fourth, etc. Now as the line A C may be taken of infinite length, there is no limit to the number of equal parts which may be taken on it; consequently there is no limit to the number of parts into which A B may be divided.

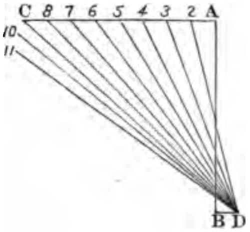

FIG. 3.

**28. The practical division of matter** by mechanical means is subject to limitation, but wonderfully minute particles may be obtained by repeated subdivisions.

Gold may be hammered so thin that fifteen hundred leaves, placed one upon another, will not equal the thickness of a single leaf of ordinary foolscap. The gilt wire used in embroidery has a surface of gold even thinner than this. It has been calculated that its thickness does not exceed one twenty-five millionth of an inch: if this calculation is correct, then, by the aid of a microscope, a particle of gold may be distinguished which *does not* weigh one two-million-millionth part of a grain. The microscope has proved the existence of animals not larger than the particle of gold just mentioned, yet as these animals are furnished with organs of nutrition and locomotion, as well as the larger animals, their several parts must be inconceivably small. Blood is composed of a colorless liquid in which float red, flattened globules, so small that there are over a million of them in a single drop.

29. **The wonderful divisibility** of matter in solution may be readily shown by a few simple experiments.

If a drop of nitric acid is allowed to remain for a few moments on a copper coin, it will dissolve an almost imperceptible amount of copper. Wash the coin in a tumbler full of water; the water will hardly be tinged in color. Now add some strong ammonia, and the liquid will be changed to a beautiful blue, showing the presence of copper in every drop of the solution. It has been estimated that a single grain of copper may thus be divided into one hundred million parts. *

30. The film of a soap bubble before bursting is less than one millionth of an inch in thickness; but, as this film possesses all the properties of water, a molecule of water can not be more than a millionth of an inch in diameter. Odors demonstrate the presence of particles whose size and weight must be infinitesimal. A single grain of musk will diffuse a perceptible odor through a large room for years, without appreciably losing in weight.

31. **Certain facts in chemistry** have led to the belief that there is a limit to the divisibility of matter, and that there are particles called *Atoms*, incapable of further subdivision. By the conditions of this hypothesis:

32. **An Atom** is a particle of matter infinitely hard, infinitely small, and possessing a definite size, shape, and weight.

Nothing is known of the ultimate structure of atoms, but it has

---

* The same facts may be shown by taking a tumbler of water and adding a drop of each of the following solutions:

1. Sulphate of iron and ferrocyanide of potassium.
2. Acetate of lead and sulphuric acid.
3. *Boiled starch* and tincture of iodine.

been conjectured that they are spheroidal in shape, that some are larger and some heavier than others. That they are spheroidal in shape is a conclusion attained from the porosity of bodies. That they vary in size has been deduced from the fact that hydrogen will escape from a closely packed piston which retains oxygen and nitrogen. That they vary in weight seems probable, from the fact that the elements unite in a definite and invariable ratio to form chemical compounds. Thus, if the atom of hydrogen is assumed as unity, the atoms of the other elements will weigh respectively: oxygen, 16; sodium, 23; iron, 56; silver, 108; lead, 207, etc.

**33. Porosity** is that property by which spaces exist between the molecules of a body.

Pores are of two kinds, (1.) Physical Pores, which are so small that the surrounding molecules are at insensible distances from each other; (2.) Sensible Pores, which are actual cavities or cells that may be discerned by the eye or by the microscope; as the cells in bread and in sponges.

**34.** In common language, a porous body is one that contains sensible pores. The porosity of some woods is evident to the eye. The microscope reveals the presence of many thousand pores in every square inch of skin on the human hand. Many of the phenomena of the organic world are due to the existence of sensible pores.

The presence of sensible pores is turned to practical use in filtering. A piece of unsized paper is folded in a conical shape and inserted in a funnel. Liquids, containing suspended matters, having been poured into this, pass through clear, leaving the solid particles behind. A milk strainer acts on the same principle.

**35. The term porosity,** as applied in the study of Natural Philosophy, generally relates to physical pores. All bodies possess these pores, and it is supposed that their atoms do not touch each other. All bodies, with one apparent exception, expand by heat. This is not due to any change in the size of the atoms, but to the increase of the spaces between them. Iron and lead are made smaller by hammering, because the atoms are driven closer together.

**Water** *may be shown to possess* pores by dissolving sugar in a cup

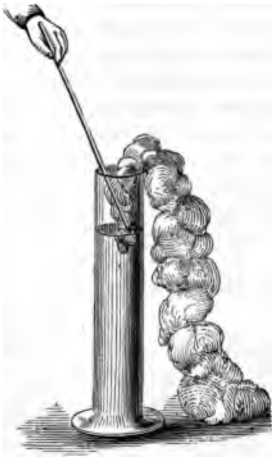

FIG. 4.

full of hot water; two or three spoonfuls may be added before the cup overflows. If a jar be filled with alcohol to a certain height, a large quantity of cotton may be forced into it without raising the level. Fig. 4. Gases are so porous that, if a vessel be filled with air, another gas may be introduced, and will fill the vessel as though the air were not there. The explanation of these experiments must be that the atoms of sugar and water, alcohol and cotton, or the two gases, are mutually arranged between the pores.

**36. Bodies vary greatly** with respect to the pores they contain. Those that have many and large pores are called rare bodies; those that have small pores are called dense bodies. Fig. 5 shows the size of one grain of air, of water, and of platinum.

The term mass is used to denote the amount of matter contained in a body. If gravity were invariable, the terms *mass* and *absolute weight*

SPHERE OF AIR WEIGHING ONE GRAIN.

FIG. 5.

might be used interchangeably, as mass is the amount of matter in a body, and weight is the pressure exerted by it in consequence of gravity. The terms are not identical, as a little reflection will show. An iron ball will contain the same amount of matter or mass in every conceivable place, but if it weighs one hundred and ninety-four pounds at the equator it will weigh one hundred and ninety-five pounds at the poles, because, as will be shown hereafter, the force of gravity varies in different places.

The mass of a body contained in a unit of volume is its *density;* the weight of the same unit is its *specific weight.* Hence, mass and density are invariable terms.

**37. Specific gravity** is the relative weight of any body compared with that of an equal volume of water or of air.

Air is the standard of comparison for all gases and vapors, and water is the standard for both solids and liquids. The specific gravity of air being unity, that of chlorine is 2.47, of water, 773. The specific gravity of water being unity, that of air is .0013, of platinum, 21.5. In other words, specific gravity is the ratio which shows how many times heavier a body is than an equal bulk of air or of water, as a cube of platinum is 21.5 heavier than an equal bulk of water.

Although the terms density and specific gravity involve different quantities, they are used interchangeably without sensible error. For, since the weights of the water or air and the body to be compared are ascertained in the same place, they will be alike influenced by gravity, and the specific gravity will be an invariable quantity.

**38. The specific weight** of any body is equal to the product of its specific gravity multiplied by the weight of the unit of water, or of air, as the case may require: thus, for liquids and solids:

$$[2.]\quad \text{Sp. W.} = 998.7 \text{ oz.} \times \text{Sp. Gr.}$$

Since the weight of a cubic foot of water is nearly 1,000 ounces, that of the same bulk of any solid or liquid is nearly as many thousand ounces as are denoted by its specific gravity.

The mass of any body is equal to the product of its density and volume; its absolute weight is equal to the product of its specific weight and volume.

Therefore for cubic feet of either liquids or solids

[3.] $W = V \times \text{Sp. W.} = V \times \text{Sp. Gr.} \times 62.42$ lbs.

Thus the weight of a cubic yard of lead is

$27 \times 11.35 \times 62.42 = 19{,}128$ pounds.

For aëriform bodies whose volume is stated in cubic inches,

[4.] $W = V \times \text{Sp. Gr.} \times 0.31$ grains.

Thus the weight of a gallon of chlorine is

$231 \times 2.47 \times 0.31 = 176.87$ grains.

**39. The method of finding specific gravity** will be given in its proper place. As there will be frequent occasion to refer to specific gravity, a table of the most important substances is inserted at this point:

*Specific Gravities Compared.*

| | 32° F. | 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 |

One cubic inch of air at 60° F. weighs 0.30954 grains.
One cubic inch of water at 60° F. weighs 252.456 grains.

*Specific Gravity of the same Body in different States.*

| | Air = 1. | Water = 1. | |
|---|---|---|---|
| | Gases. | Liquid. | Solid. |
| Ammonia | 0.596 | 0.731 | Heavier than in the liquid state. |
| Carbonic acid | 1.529 | 0.83 | |
| Chlorine | 2.47 | 1.33 | |
| Sulphurous acid | 2.247 | 1.38 | |
| | As Vapors. | | |
| Alcohol | 1.613 | 0.792 | |
| Ether | 2.589 | 0.715 | |
| Water | 0.622 | 1. | 0.93 |
| Mercury | 6.976 | 13.596 | 13.596 |
| Iodine | 8.716 | | 4.948 |
| Sulphur | 2.230 | | 2.086 |

### *Table of Specific Gravities.*

| GASES. | |
|---|---|
| Air | 1. |
| Hydrogen | .069 |
| Nitrogen | .972 |
| Oxygen | 1.106 |

| LIQUIDS. | |
|---|---|
| Water, distilled | 1. |
| Sea water | 1.026 |
| Olive oil | 0.915 |
| Sulphuric acid | 1.84 |
| Saturated brine | 1.205 |

| SOLIDS. | |
|---|---|
| Cork | 0.24 |
| White oak | 0.86 |
| Ebony | 1.331 |
| Glass | 3. |
| Potassium | 0.86 |
| Platinum | 21.53 |
| Gold | 19.26 |
| Silver | 10.5 |
| Copper | 8.83 |
| Iron | 7.788 |
| Lead | 11.35 |
| Iron pyrites | 5. |

**40. Compressibility** is that property by virtue of which the volume of a body may be diminished.

This is a consequence of porosity. Rare bodies are much more compressible than dense bodies. Gases may be made to occupy a hundred times less space than they do under ordinary circumstances. Many gases, under great pressure, become liquids; others, as oxygen, nitrogen, and air, seem to have no limit to their compressibility. Liquids possess this property in so limited a degree that they were once supposed to be incompressible. Solids are all compressible.

**41. Expansibility** is the converse of the preceding. The volume of all bodies, except clay, is increased by heat. With equal increments of heat, gases expand most, liquids next, and solids least.

FIG. 6.

When a diving-bell is sunk in the sea, the water compresses the air and rises within the bell to a certain height, although it can not fill the bell because the air is impenetrable, When the bell is raised, the air expands and recovers its former volume. If a flask is *nearly filled* with water and then inverted in a basin, a little air will be inclosed at the top of the flask. If the flask is warmed, the air expands and expels a portion of the water. On cooling the flask, the air resumes its former bulk.

**42. Various units** have been adopted for the measurement of intensity of pressure. Thus, pressure may be estimated at so many pounds to the square inch, or to the square foot. The pressure of one atmosphere is a unit in very common use. The atmosphere presses on every square inch of all surfaces at the level of the sea with a force of about fifteen pounds, hence all other pressures may be taken as so many times greater or less than this, or, as so many atmospheres.

*Units of Pressure.*

| | Pounds on each square inch. | Pounds on each square foot. | In atmospheres. |
|---|---|---|---|
| Water, 1 foot deep, at 39°.2 F.... | 0.4335 | 62.425 | 0.0295 |
| Water, 1 foot deep, at 62° F...... | 0.4330 | 62.355 | 0.0294 |
| 30 inches mercury, at 62° F....... | 14.7225 | 2120. | 1. |
| 1 inch mercury, at 32° F........... | 0.4912 | 70.73 | 0.0334 |
| 1 foot of air, at 32°................... | 0.0006 | 0.0807 | 0.00004 |
| 1 pound to the square inch. = | 2.3 ft. water. | 2 in. mercury. | 0.068 |

**43. Indestructibility** is that property by virtue of which a substance resists annihilation.

Whatever changes man may impose upon matter, it still continues in some form, and may at any time be recognized as matter. Thus, all the changes described in (8.) caused no loss in the substances acted upon. Wood, in burning, passes away in smoke, leaving only a small proportion of ashes; yet the ashes and the smoke contain all the matter of the wood.

## SPECIFIC PROPERTIES OF MATTER.

**44. Most of the specific properties** of matter are dependent on the molecular attractions, affinity, cohesion, and adhesion, modified by the molecular repulsion of heat and, perhaps, of electricity.

**45. Affinity** is that force which causes the atoms of unlike substances to unite and thus form new bodies.

For example, when a nail is exposed to moist air, the iron combines with the oxygen of the moisture and forms a coating of rust, which is an oxide of iron.

**46. Adhesion** is the force which causes the molecules of different kinds of matter to cling together.

Thus, adhesion causes the dust to cling to every thing it falls upon, chalk to cling to black-boards, mud to clothing, dew drops to leaves, and icicles to eave-troughs. Under the name of *Friction*, it diminishes the work of moving forces, (1.) by stiffening the joints of machines, and (2.) by increasing the resistance to be overcome. Friction often acts as a mechanical advantage, as in preventing our feet from slipping when standing or walking, in retaining nails and screws in their sockets, and in enabling locomotives to ascend gradients.

**47. The force of adhesion** gives value to the cements. No better proof can be desired that adhesion is not the same for all substances, than the great variety of cements employed for different materials; thus, glue is used for wood, the gum resins for glass, mortars for brick, etc. The adhesion of good glue and of the best hydraulic cements is about five hundred pounds to the square inch, that of ordinary mortars is much less.

**48. Cohesion** is the force which causes like molecules to unite in one mass. This force retains the particles of a cannon ball or of a lump of ice in a single piece. It is strongly exerted in solids, less strongly in liquids, and is entirely absent in aëriform bodies.

**Liquids.** In large masses of liquids the force of cohesion is overcome by the force of gravity, which tends to bring all their molecules to the same level; in very small masses the cohesive force is the stronger, and causes them to assume a spheroidal *form*.

This is shown in drops of dew, in globules of mercury, and in small drops of water rolling upon a dusty table. The same fact is exemplified in the following pretty experiment: fill a tall wine-glass half full of water and carefully pour upon the water an equal quantity of alcohol so as not to mix the two liquids, then drop a very little olive oil through the alcohol; it will assume the shape of a spheroid and rest in the middle of the glass. The experiment may be made more striking by pouring into a clear glass bottle half full of a saturated solution of sulphate of zinc, some distilled water, and dropping through the water a little bisulphide of carbon, colored by iodine. The spheroid may be made larger than the neck of the bottle.

**Solids.** When the cohesion of solids has been once destroyed it is often difficult to cause the particles to reunite.

Broken metallic castings may be remelted, and made to cohere in the same or a different form on cooling. Particles of loose sand jammed forcibly together, as, for instance, by a cannon ball, will cohere like stone. In like manner broken ice can be cemented together in one transparent mass by pressure. Two dull leaden bullets will not unite because the surface is covered by the oxide; but if each be cleanly cut by a sharp knife so as to present a smooth and bright surface, they will unite on being pressed tightly together, with a slight twisting motion. Two plates of polished glass will cohere, under pressure, so forcibly that they may be worked as a single piece. The slightest film of paper or even dust is sufficient to prevent this action.

**49. 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. They differ from each other in this, that adhesion acts between unlike particles, and cohesion between like particles.

Heat generally increases the force of affinity, but it tends to weaken the force of cohesion. It is probable that all solids may be converted to liquids, and even to vapors, by sufficient heat, and that all gases and liquids may be changed to solids by a sufficient reduction of temperature, assisted by pressure, although there are many solids that have not been liquefied, and many gases that have hitherto resisted all endeavors to change their state.

**50. The cohesion of the particles** of a solid may be estimated by the kind and amount of resistance which its particles offer to a strain tending to rend them. The force which causes the strain may be applied

I. In the direction of the length of the body:

(1.) By a direct *thrust*, as when a weight, resting on a column, tends to crush it.

(2.) By a *pull*, as when a weight, stretching a string, tends to tear it in pieces.

II. Transversely, or across the length:

(3.) By *bending*, as when a bow is strained and tends to break.

(4.) By *twisting*, when the strain tends to wrench the particles asunder.

III. A body may be subjected to several strains at the same time.

**51.** These relations are made more evident by the following table:

| Direction of force. | Kind of stress. | Kind of strain. | Kind of fracture. |
|---|---|---|---|
| I. Longitudinal. | (1.) Thrust. | Compression. | Crushing. |
| | (2.) Pull. | Stretching. | Tearing. |
| II. Transverse. | (3.) Bending. | Bending. | Breaking. |
| | (4.) Twisting. | Torsion. | Wrenching. |
| III. Combined. | (5.) Distortion. | Detrusive. | Shearing. |

**52. Experience teaches** that the effect produced by any strain will vary greatly with the material on which it acts, as well as with the intensity of the force. Thus, a sufficient force will cause fracture in any solid; a less force may produce a permanent or a transient change in its shape.

**53. Elasticity** is the property by virtue of which bodies altered in form or volume by any external force, resume their original shape, when that force has ceased to act.

The change of form or volume is due to the strain, which *compresses*, *stretches*, bends, or twists the body. The energy with which the particles resume their original position, is due to their elastic force. Up to a certain limit, which varies with the substance, the elastic force is exactly equal to the stress, and the elasticity is therefore perfect. Beyond that limit, brittle bodies break; the molecules of most other solids are forced into new relations with each other, by which the bodies assume a permanent change, or *set*, with new relations to elasticity 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.

The elasticity developed by pressure belongs, in some degree, to all bodies, whether solid, liquid, or gaseous, and is, therefore, a general property of matter. The other forms of elasticity belong only to solids.

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

The air near the earth's surface is compressed by all the air above it. If a portion of the air is confined in the receiver of an air pump, and the pressure removed by working the pump, the elastic force of the air remaining, though lessened by every stroke, is always sufficient to fill the receiver. From their perfect elasticity under increased and diminished pressure, aëriform bodies have received the name of elastic fluids.

**55. Liquids** are sometimes called the non-elastic fluids, but the name is applied erroneously, from a mistaken notion of their incompressibility. Whenever the force that compresses them is removed, they immediately regain their original volume; therefore, *all fluids are perfectly elastic.*

**56. Solids** possess this property in different degrees. India rubber, ivory, glass, and marble have **considerable** *elasticity; lead,* clay, and fats have very little.

**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 smeared 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 the experiment, it will be seen that the size of the spot on the table and on the ball increases with the height from which it falls. From this experiment it appears (1.) that, at the moment of shock, the ball was compressed, (2.) that its rebound was caused by the effort to regain its original shape, and (3.) that its elastic force increases with the strain.**

**57. The elasticity of traction** is shown by the strings of musical instruments, which are made more or less tense, by stretching, at the will of the performer.

**58. Flexibility** should not be confounded with elasticity. A wire of soft iron is very flexible, though but slightly elastic. A steel sword blade has been bent double and on the removal of the force, has straightened itself perfectly, showing that it is both flexible and elastic. Threads of glass are even more elastic than steel, though not as flexible.

**59. The elasticity of torsion** is manifested in the tendency that twisted yarns and strings have to untwist.

**60. The practical applications** of the elasticity of bodies are innumerable. The elasticity of aëriform bodies is turned to account in foot balls, air cushions, springs, etc.

The elasticity of solids is applied in the springs used in watches, clocks, carriages, bows, balances, etc. The value of corks is due, in great measure, to their elasticity.

**61. The ultimate strength** is the cohesion with which a body resists a stress tending to produce fracture. The *proof strength* equals the greatest strain that may be borne with safety; it varies from one-tenth to two-thirds of the ultimate strength. The kind of strength which a body manifests in any instance, is called its resistance to the strain employed; as resistance to compression, etc., except that:

The resistance which bodies offer to forces tending to pull **their particles** *apart is called Tenacity.*

**62. All kinds of strength** increase, to a greater or less degree, with the area of the cross section of the body, and all, except tenacity, decrease when the length is increased. The only effect of increase of length upon tenacity is that the weight of the body is added to its load. The annexed table shows the comparative strain, expressed in pounds avoirdupois, that may be borne by rods not exceeding a foot in length and whose cross section is one square inch. The first column shows the force required by theory to double the length of the bars, a thing impossible to be done, except in the case of india rubber.

### 63. Table.

| Materials. | Modulus of elasticity. | Resistance to fracture. | | | |
|---|---|---|---|---|---|
| | | By crushing. | Tenacity. | By breaking. | By wrench'g. |
| Ash | 1600000 | 9000 | 17000 | 168 | 1460 |
| Oak | 1750000 | 10000 | 19800 | 245 | 2350 |
| Pine | 1460000 | 6200 | 12000 | 160 | 1540 |
| Iron, cast | 22900000 | 112000 | 29000 | 980 | |
| Iron, bar | 29000000 | 40000 | 70000 | 700 | |
| Steel | 42000000 | 295000 | 130000 | 1918 | |
| Copper | 18240000 | 117000 | 36000 | | |
| Lead | 720000 | 7700 | 3300 | | |

**64.** From this table, it will be seen that the greatest strength of materials, except of wrought iron and timber, lies in their power to resist compression. The values given in the table can not be regarded as absolutely accurate, inasmuch as it is extremely difficult to obtain specimens for experiment which shall exactly represent the strength of the material, and also because slight imperfections and impurities of the material produce marked change in the result. The following deductions from many experiments are, however, of general application:

**65. The strength of a fabric** depends not only (1.) on *the nature* of the materials, as has been shown; but, also, (2.) on the distribution of the strain, and (3.) on the mode in which the materials are arranged.

The long continued action of a small strain will often produce fracture in a bar that would originally have resisted a much greater force for a short time. Every strain that exceeds the limit of elasticity tends to weaken the substance, until at last it yields readily. A continual jarring or pounding so alters the molecular condition of iron, that after a while it becomes extremely brittle; for this reason axles in carriages and railway cars should be subjected to frequent tests. A sudden shock causes a greater strain than a continued force of equal amount. A horizontal beam, supported at both ends, will sustain twice the force, when distributed throughout its length, that it will when concentrated at the center.

**66.** It has been demonstrated that the most advantageous form for iron beams is one which has its greatest depth at the center, and a cross section resembling Fig. 8. Of two rectangular beams, having the same area, that which has the greatest depth will be the stronger: for this reason, beams and rafters are placed so as to receive the stress on their edges.

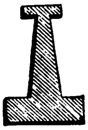

FIG. 8.

The most economical arrangement of a given mass of material is that of a hollow tube. This arrangement is seen in the bones of animals, stalks of grain, and quills of birds. A hollow cylinder may be made of twice the strength of a solid cylinder containing an equal weight of the same material. An easy illustration of this fact may be had by resting the ends of a flat sheet of paper on supports and ascertaining the force necessary to break it down; and then repeating the test after having coiled the paper into a tube.

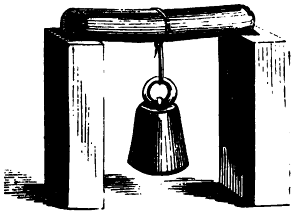

FIG. 9.

**67.** A hollow rectangular tube, whose height considerably exceeds its breadth, is stronger than a round tube of the same mass. This form is applied in the Victoria bridge, at Montreal, and in the Great Eastern steamship.

The center tube of the Victoria bridge is three hundred and thirty feet long, sixteen feet broad, and nearly twenty-two feet high. It is made of boiler iron, about one half inch in thickness, and strongly braced with lateral irons. The ordinary pressure of a railway train passing through it is scarcely noticeable.

**68. The tenacity of a substance** is increased by drawing it into the form of a wire. Hence, cables made of fine iron wire twisted together, are far stronger than chains of equal weight, and are now coming into general use. There are many suspension bridges in this country and in Europe made of wire cables. The suspension bridge across the Ohio river at Cincinnati, has a span of one thousand feet.

**69. If wood were as durable** as iron, its lightness would make its use preferable in all cases where tenacity is required. Thus, pine, which has nearly half the tenacity, has only one tenth the weight of cast iron; so that, for equal weights, pine has more than four times the tenacity of cast iron.

It would be impossible to build such roofs and bridges of iron as have been built of timber, because the strength of the material would not be sufficient to support its own weight. It is evident that the effective strength of any fabric is merely that which is not employed in supporting itself, and that when a certain size is passed, every additional part only adds to the load without increasing the strength, and thus weakens the whole. For this reason many inventions, that appear faultless in model, fail when made of full size.

**70.** There is therefore a limit of magnitude which no structure, natural or artificial, can surpass, so long as their materials are unchanged. Thus, insects are proportionally stronger than mammals, the smaller quadrupeds are capable of feats of strength and agility impossible to the larger. Whales would be incapable of motion if their enormous weight were not sustained by the buoyancy of the ocean.

71. **The hardness** of a body is measured by the readiness with which it is worn or scratched by another substance.

For the purpose of determining the relative hardness of minerals, the following arbitrary scale has been adopted, in which any substance is scratched by those below it:

*Scale of Hardness of Minerals.*

1. Talc, G.fr.st
2. Gypsum,
2.5 Mica,
3. Calc-spar, C.Car
4. Fluor spar,
5. Apatite, C Phosph.
5.5 Scapolite,
6. Feldspar,
7. Quartz,
8. Topaz,
9. Sapphire,
10. Diamond.

**72.** A body which neither scratches nor is scratched by any given mineral of the table, is said to be of the degree of hardness represented by that mineral. Thus, there are fifty-three minerals whose hardness is 4, or equal to fluor spar. The diamond can be cut only by means of its own powder; talc, or soapstone, is easily cut with the thumb nail. Few of the metals are as hard as glass; some, as lead and potassium, are very soft, and mercury is a fluid, from which it appears that hardness bears no relation to the density of a body. As a general thing, metals are softer than their alloys.

**73. Brittleness** is the property which renders a body capable of being easily broken or pulverized. Thus, hard bodies are generally brittle, and so too are most elastic bodies, when the limit of elasticity has been exceeded.

**74. Ductility** is the property by virtue of which a body may be drawn into wire. Platinum has been drawn into wire $\frac{1}{30000}$ of an inch in diameter.

**75. Malleability** is the property by virtue of which bodies may be rolled or hammered into sheets. Gold leaf may be made less than $\frac{1}{282000}$ of an inch thick.

Most metals are both malleable and ductile, though not in equal degrees. Antimony, bismuth, and some others, have neither property.

**76.** Some metals are most readily malleable under the hammer and others under rollers. Elevation in temperature is generally attended with an increase of malleability and ductility; copper, and its alloys, and lead being the prominent exceptions. Iron and glass are very malleable and ductile at a red heat. Zinc can be rolled with best success at a temperature between 226° F. and 300° F. Although the tenacity, ductility, and malleability of metals are alike dependent on the force of cohesion, yet the same metal does not always manifest the same relative degree of each, as may be seen by the following table:

| Tenacity. | Ductility. | Malleability. | |
|---|---|---|---|
| | | Under the hammer. | Under rollers. |
| 1. Iron, | Platinum, | Lead, | Gold, |
| 2. Copper, | Silver, | Tin, | Silver, |
| 3. Platinum, | Iron, | Gold, | Copper, |
| 4. Silver, | Copper, | Zinc, | Tin, |
| 5. Zinc, | Gold, | Silver, | Lead, |
| 6. Gold, | Zinc, | Copper, | Zinc, |
| 7. Lead, | Tin, | Platinum, | Platinum, |
| 8. Tin. | Lead. | Iron. | Iron. |

**77. Some of the effects** of heat upon cohesion have already been noticed. Among the permanent changes produced by heat are:

(1.) HARDENING. Many substances, if suddenly cooled after having been strongly heated, become harder, more brittle, and more elastic than before. If steel is raised to a white heat and then plunged into a bath of cold water or mercury, it is rendered almost as hard as the diamond, very elastic, and so brittle that it is suitable only for the dies used in coining and engraving, and for the hardest files.

(2.) SOFTENING. Metals and glass are annealed by being slowly cooled from a high temperature. Annealing generally increases the flexibility, softness, and ductility of bodies. When metals have become brittle through excess of strain in rolling, wire drawing, twisting, hammering, or other mechanical means, their properties may be restored by annealing.

(3.) TEMPERING. Steel is wrought into any form required in the arts when it is in its softened condition. It is then strongly heated and suddenly cooled, but, as this hardening process renders it too brittle for ordinary purposes, something of its elasticity is sacrificed, and a portion of its hardness removed by reheating the steel to a lower temperature and then cooling it gradually. This process of annealing is called *drawing the temper*, or tempering. The temper required depends on the use to which the steel is to be applied, and may be regulated by varying the temperature of the second heating; the higher the heat, the softer will be the steel.

If a steel knitting needle be hardened, then brightened and reheated, the film of oxide on its surface becomes, at a temperature of 428° F., of a light straw color, then through intermediate hues to violet yellow (509° F.), blue (560° F.); at 977° F. the steel passes to a red heat. These colors guide the workman in the effects he wishes to produce. Light yellow indicates the heat required for surgical instruments, in which a keen edge is required; a deeper yellow, fine cutlery; violet is the tint for table knives, requiring flexibility more than a hard but brittle edge; blue for springs, sword blades, and other flexible instruments.

**78.** The effect of rapid or slow cooling of glass is about the same as in steel. Melted glass dropped into water solidifies into the curious toy known as Prince Rupert's drops. 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 with considerable violence. This brittleness is prevented in glass utensils by careful annealing. As soon as glass vessels are blown they are placed in a long furnace, in which the heat, at first very great, gradually

FIG. 10.

diminishes from one end to the other. Through this furnace they are slowly drawn, and thereby are cooled so gradually and equably that their molecules assume the most stable position with regard to each other, and all are alike affected by any shock.

Heat produces on copper and bronze, effects precisely the reverse of those manifested by steel. When they are cooled slowly they become hard and brittle, but when cooled rapidly, soft and malleable.

### 79. Recapitulation.

Properties of matter:

| | | |
|---|---|---|
| Universal. | Essential. | Extension,<br>Impenetrability. |
| | General. | Weight,<br>Mobility,<br>Inertia,<br>Divisibility,<br>Porosity,<br>Compressibility,<br>Expansibility,<br>Indestructibility,<br>Elasticity. |
| Specific. | Involving strain of particles. | Elasticity,<br>Tenacity. |
| | Involving permanent displacement of particles. | Hardness,<br>Brittleness,<br>Ductility,<br>Malleability. |

### PHENOMENA CONNECTED WITH ADHESION.

**80. Two facts** relating to the force of adhesion have already been noticed: (1.) that it exists only between unlike molecules; (2.) that it varies with the kind and the state of matter. To these may be added, (3.) that it increases with the number of molecules in contact. As only the exterior particles of solids can be brought in contact with others, this statement, when applied to solids at rest, becomes,

*Adhesion increases with the extent of surface.*

**81.** With regard to the second fact, it is evident that, as there are only three states of matter, all the possible varieties of adhesion must fall into some one of their combinations, taken two and two. It will be convenient to indicate these by Roman numerals, thus:

| | | |
|---|---|---|
| I. | IV. | VII. |
| Solids to solids. | Solids to gases. | Liquids to gases. |
| II. | V. | VIII. |
| Solids to liquids. | Gases to solids. | Gases to liquids. |
| III. | VI. | IX. |
| Liquids to solids. | Liquids to liquids. | Gases to gases. |

**82. The adhesion of solids to solids** has found sufficient illustration in cements and in friction (46, 47). As all attractions are mutual, it is hardly necessary to make any distinction between the three pairs connected by braces, except it be for the purpose of giving prominence to either body in any special case. Thus, when lycopodium or powdered resin is strewn in patches on a board, and water is sprinkled upon it, (II) the drops that fall on the powder attract the particles to themselves and roll about in globules, covered by the adherent solid; (III) the drops that strike the clean surface of the board adhere to it and flatten. Either case illustrates the adhesion between the solid and the liquid.

Some of the nine varieties of adhesion, given in the table above, have received specific names, and are of sufficient importance to merit separate treatment: others are unimportant in every respect.

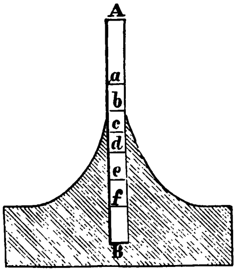

Fig. 11.

**83. Capillary action.** If a clean glass plate is placed vertically in a basin of water, the liquid will rise on each side to the height of nearly one-sixth of an inch. In this case, it is evident that the force of adhesion between the liquid and the solid (III) is greater than the cohesion of the liquid molecules. An inspection of the diagram shows that any particle of the glass near the normal surface of the liquid can have no influence in producing this elevation. A particle at *d*, or *e* will attract the upper portion of the liquid down with as much force as it tends to raise the molecules beneath it. It follows, therefore, that the whole weight of the liquid column must be supported by the narrow line of solid particles, *b c*, near the top. To these particles the nearest molecules of the water adhere, and support, by their cohesion, the second line of molecules of water; these, in turn, support other molecules, and so on until the weight of the column equals the cohesion of the upper line to the second.

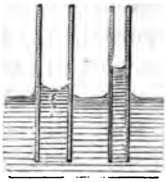

FIG. 12.

**84.** A second plate of glass will support an equal weight of the liquid; therefore, if a second plate be placed parallel to the first, the weight of the water supported will be double that of a single plate. If the plates are brought so near each other that both plates may act on the same molecules of the liquid, the water will rise between the plates. The nearer the plates the higher will be the column of water. Two plates, one hundredth of an inch apart, will support a column of water two inches high.

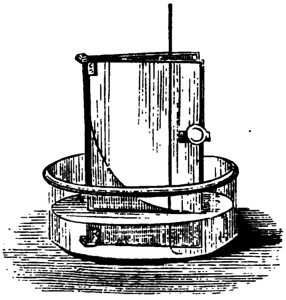

FIG. 13.

**85.** If the two plates are inclined toward each other, and are in contact at one vertical edge, the water will rise between them to heights varying inversely as the distance between the plates. The outline of the surface thus formed has been designated the ***equilateral hyperbola.***

**86.** Finally, if the molecules of the liquid are attracted in all directions, as they would be if a tube were substituted for the glass plate, the liquid will rise to twice the height produced by two plates separated by an interval equal to the diameter of the tube. A tube, one hundredth of an inch in diameter, will support a column of water four inches high.

**87. Because these phenomena** are best exhibited in tubes whose internal diameters are so small as to resemble hairs, *that variety of adhesion which causes liquids to rise on solids is termed Capillary Attraction.*

The height to which a liquid will rise, varies with the nature of both the liquid and the solid; thus, in the same glass tube, a solution of carbonate of ammonia will rise a little higher than water; nitric acid three-fourths, and alcohol a little more than one-half as high as water. On the other hand, mercury will not wet glass, although it rises freely on lead, zinc, and some other metals. In fact, it may be demonstrated that liquids will not rise on solids unless the adhesive force is more than half the cohesive force. Therefore, although mercury is attracted by glass, yet as this attraction is less than twice the attraction between the molecules of the mercury, the phenomena manifested when glass is placed in mercury are directly opposite to those already described as taking place between glass and water. The most satisfactory experiments to illustrate capillary action, are conducted in glass tubes of the shape represented in Fig. 14, which any one can readily make for himself. Water poured into A assumes a concave surface in both branches, and rises in the smaller branch *above* the level of the larger. Mer-

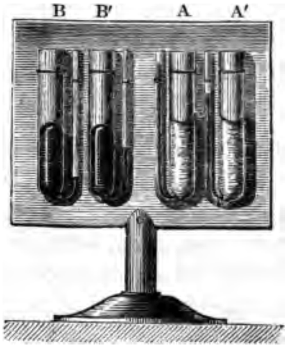

Fig. 14.

cury, poured into B, assumes a convex surface in both branches, and is depressed in the smaller branch. In a greased tube, water is depressed. A needle, slightly greased, will float on water, because, not being wet by the liquid, it produces a depression, in which it is supported.

**88.** From these general facts it is easy to deduce the following laws of capillary action, when applied to small tubes:

1. Liquids ascend in tubes when they wet them, and are depressed when they do not.

2. The ascent and depression increase as the diameters of the tubes decrease.

3. The ascent and depression vary with the nature of the substances used.

**89. Familiar illustrations of capillary attraction** are seen in the action of the wicks of lamps and candles. If one end of a towel is plunged in a basin of water and the other end is left hanging over the edge, the whole will become wet. Blotting paper is useful because it readily draws ink into its pores: the pores of letter paper are closed by sizing. In France, dry wooden wedges are driven into holes drilled in rocks, and then wet with water; the fibers of the wood, by absorbing the water, expand with so much force as to split the rocks. Water can not be poured out of a full tumbler without running down on the outside of the glass, because of the capillary attraction.

**90.** Capillary action is of immense importance in the operations of nature. It draws the water necessary to the support of vegetation to the surface of the ground, in the droughts of summer. It is one of the principal causes of the ascent of sap in plants, and plays an essential part in the circulation of the liquids in animal tissues.

**91. Solution.** If a lump of sugar is dipped in water, the *liquid will rise* by capillary attraction until the whole mass is moistened. If sufficient water be present, the adhesion of the solid to the liquid (II) will be sufficient to overcome the cohesion of the solid, so that it will entirely disappear in the liquid, thereby forming a *solution*. Each drop of the solution has the sweetness of the sugar and the fluidity of the water, thus showing that the adhesion is perfect, because it is shared by every molecule. When the adhesive force of each molecule has reached its limit, no more of the solid will dissolve, and the solution is then said to be *saturated*.

**92. The solvent powers** of liquids vary exceedingly. An ounce of cold water can dissolve hardly a grain of sulphate of lime, although it readily dissolves one thousand grains of sugar. Many substances that do not form solutions with water are readily dissolved by other liquids. Water is the best general solvent; alcohol is the proper solvent for resins; ether and benzine, for fats; bisulphide of carbon, for sulphur and phosphorus; mercury, for lead and some other metals.

The solvent powers of every liquid are limited, both as respects the number of substances soluble in it, and the amount of any one necessary to complete saturation. As a general thing, however, when a liquid has been fully saturated with one solid, it is still capable of dissolving others.

When a solid disappears in an acid, as copper in nitric acid, the action is twofold; first, a chemical action, by which the solid and liquid unite to form a substance different from either, as nitrate of copper; second, a simple solution, by which the compound thus formed is dissolved in the liquid.

**93. The adhesion of gases to liquids** (VIII) is illustrated by the solution of gases in water and other liquids. Water dissolves all gases; but in proportions varying (1.) with the nature of the gas, (2.) the temperature, and (3.) the pressure. The following table shows the solubility of several of the gases in water or in alcohol, in open vessels and at the freezing *point:*

### *Solubility of Gases.*

| | Volumes of gas absorbed by one volume of water, | of alcohol. |
|---|---|---|
| Nitrogen | 0.0204 | 0.1263 |
| Oxygen | 0.0411 | 0.2840 |
| Carbonic acid | 1.7967 | 4.3295 |
| Sulphurous acid | 68.8610 | 328.6200 |
| Hydrochloric acid | 506. | |
| Ammonia | 1049.7 | |

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, and place the mouth of the tube in water. After a little time the water will absorb so much of the ammonia as to leave a partial vacuum in the bottle; the external pressure of the atmosphere will then drive the liquid up the tube, forming a fountain of greater or less force, proportioned to the size of the upper diameter of the tube.

FIG. 15.

**94. The weight of any gas** absorbed by a liquid, increases directly with the pressure; that is, if the pressure is doubled or tripled, the weight of the gas absorbed will be doubled or tripled. It will be shown hereafter that the effect of pressure on a gas is to diminish its volume and increase its density, in proportion to the pressure. For this reason, the volume of the gas absorbed is the same for all pressures. If the pressure is removed, the gas, by virtue of its elastic force, resumes its original density, and escapes with effervescence. The soda water of the confectioner is water charged with carbonic acid, absorbed under pressure.

**95. The adhesion of gases to solids** (V) is governed by nearly the same laws as the adhesion of liquids to solids (III), with this important difference, that gases are very compressible. When water is heated in glass vessels, the *air may be* seen to leave the water and collect in bubbles on the side of the vessel, where they often remain for some time. Porous solids, as meerschaum, plaster of Paris, freshly burned charcoal, and metals in the state of fine powder often absorb large amounts of gases. The following table exhibits the number of volumes of several of the gases absorbed by one volume of charcoal and of meerschaum:

*Absorption of Gases.*

| | Charcoal. | Meerschaum. |
|---|---|---|
| Nitrogen | 7.2 | 1.6 |
| Oxygen | 9.2 | 1.49 |
| Carbonic acid | 35. | 5.26 |
| Ammonia | 90. | 15. |

**96.** A piece of freshly burned charcoal, exposed to the atmosphere for a few days, will often increase one-fifth in weight. This phenomenon can be explained only 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 two hundred and fifty times its volume of oxygen. When iron, reduced by hydrogen, is poured from the reduction tube, it condenses the oxygen of the air so rapidly that the iron becomes ignited.

**97. The absorptive power** of freshly burned charcoal is of great economic value. The variety known as bone black is used for clarifying sugars.

The brown sirups are filtered through a layer of this charcoal twelve or fourteen feet in thickness, and are thus obtained perfectly clear; all the coloring matters, whether solid or liquid, being absorbed. Porter, filtered through animal charcoal, loses much of its bitterness, and all of its gases. All varieties of charcoal are efficacious in destroying noxious effluvia, not by preventing decay, but by absorbing the gaseous products of decomposition.

**98. Vesicular condition.** In clouds and fogs the moisture is in the liquid state, and is supported above the earth by the adhesion of liquids to gases (VII).

It has been supposed that each drop of water forms a vesicle or bladder, by inclosing a molecule of air. The hollow vesicle exposes a larger surface than a solid drop of the same size, and continues to float until the drops become heavy enough to overcome the adhesion of the air, when they fall as mist or rain.

99. **The mechanical transportation** of dust, snow, and other light bodies by the winds, is due to the adhesion of solids to gases (IV). Although this appears to be a trivial matter, yet, if this action is continued for a long series of years, it affects great physical changes, as is seen in the dunes of France and England, and in the ever shifting sands of the deserts of Africa.

## DIFFUSION OF FLUIDS.

100. The adhesion of liquids to liquids (VI), and of gases to gases (IX), affords phenomena so similar that they may be considered together under the general theme of diffusion of fluids.

The adhesion of some liquids, as oil and water, is so feeble that they can not be made to unite permanently by any amount of stirring and shaking. On the other hand, most liquids will mix readily with each other, though in various proportions; some, as water and alcohol or glycerine, are miscible in all proportions; others may be mixed only to a limited extent. Thus, if water and ether are shaken together, and then allowed to stand, they will, in a great measure separate, each liquid dissolving about one tenth of the other. In like manner, if two gases which do not act chemically upon each other, are placed in the same vessel, they will form a permanent mixture.

101. **The tendency of fluids** to mix with each other is termed *Diffusion*. Diffusion may take place without mechanical action, and even in apparent opposition to the attraction of gravitation.

Thus, if a tall jar is partially filled with a solution of blue litmus, and sulphuric acid is poured carefully through a long funnel, *reaching to the bottom* of the jar, the line of separation between the two fluids will be at first distinctly marked. This will soon disappear; the acid will gradually 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. The experiment may be repeated with almost any two liquids of different specific gravities, as alcohol and water, alcohol and turpentine, or the saturated solution of any salt and pure water. It is advisable to color one of the liquids with a little cochineal or alkanet root. The rate of diffusion will be found to vary with the nature of the substances used, and is uniform only in dilute solutions.

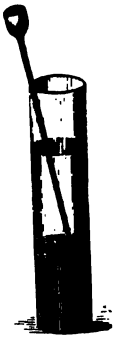

FIG. 16.

**102. The diffusion of gases** may be illustrated by an apparatus consisting of two bottles, connected by a long glass tube.

Fill the upper with the lighter gas, as hydrogen, and the lower with a heavier, as chlorine. In the course of two or three hours the two will mix perfectly and permanently. The green color of the chlorine enables us to trace its gradual ascent. This experiment should be performed only in diffused daylight, or in a darkened room, to avoid an explosion. The experiment may be modified by filling two jars over a pneumatic trough, one half full of hydrogen, the other half full of air, so that the water shall stand at the same level in both. If, now, we pass a few drops of ether into each jar, the same quantity of ether will evaporate in both, and ultimately cause the same depression of water level, but the diffusion will be much more rapid in the hydrogen.

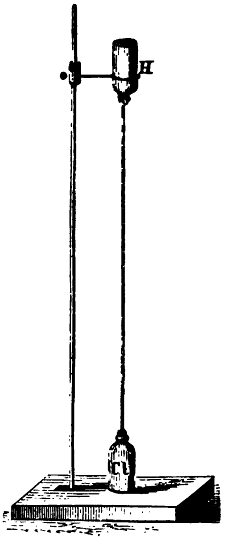

FIG. 17.

**103.** 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, were it* not for this beneficent law of nature. The noxious products of combustion and decay would then be found at the surface of the earth, and would produce the most disastrous consequences. As it is, they are rapidly diluted when formed, and soon are so perfectly disseminated through the atmosphere, that the most accurate chemical analysis fails to find any essential difference in the air of mountain, plain, or valley.

**104. Osmose.** The diffusion of fluids may take place when they are separated by a porous partition or septum. Inasmuch as the phenomena are greatly modified by the presence of the septum, the diffusion of fluids through septa has been termed *osmose*.

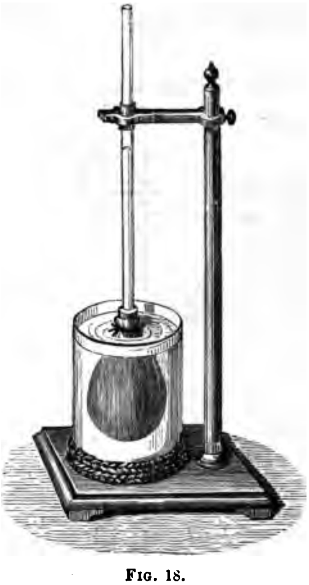

FIG. 18.

Tie a long glass tube to the mouth of a membranous bag or a bladder. Fill the bag with strong brine, 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 liquid which was in the interior. Hence, a current has been produced in two directions. The one passing to the liquid which increases in volume is called *endosmose*, the other is called *exosmose*. The rate of diffusion, and the volume of water diffused, is greater in osmose than in simple diffusion.

The cause of osmose has not been clearly explained, but the conditions of its action seem to be:

1. That the liquids be capable of mixing.
2. That the septum have a greater adhesion for one liquid than the other.

Experiments in osmose may be conducted by using, instead of the bag in Fig. 18, an inverted funnel, having its mouth closed by a strip of any animal membrane, or by parchment paper.

**105. Dialysis** is the application of osmose to the separation of the constituents of a liquid. Alcohol, hydrochloric acid, and substances capable of forming crystals, when in a state of solution, readily pass through septa. On the other hand, gelatine, gum arabic, and other substances that do not crystallize, do not exhibit this property. Hence, if a solution contain crystallizable and gelatinous substances, the former will suffer osmosis, and the latter will remain above the septum.

**106. The osmose of gases** may be shown by a striking experiment:

Take a glass funnel with a long delivery tube. Close its mouth by 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, and to dry thoroughly. Now attach the open end to a flask containing water and fitted with a jet pipe extending beneath the water, as in Fig. 19, and invert over the septum a jar filled with hydrogen. The endosmose of the hydrogen will be so rapid as to force out the water from the jet tube in a miniature fountain. Remove the jar, and air will bubble through the water, showing the escape of the hydrogen through the septum.

Fig. 19.

India rubber balloons, filled with hydrogen, soon become flaccid, from the escape of the hydrogen into the air.

**107.** Although the nature of osmose can not be satisfactorily determined, it is manifest, from the porous nature of vegetable and animal membranes, that it must play an important part in the operations of life. We know that poisons may be absorbed through the skin. 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.

### 108. Recapitulation.

The varieties of adhesion are:

| | | |
|---|---|---|
| I. | Solids to solids | Cements,<br>Friction. |
| III. | Liquids to solids | Capillarity,<br>Filtration. |
| II. | Solids to liquids | Solution of solids. |
| VIII. | Gases to liquids | Solution of gases. |
| V. | Gases to solids | Absorption of gases. |
| VII. | Liquids to gases | Vesicular condition. |
| IV. | Solids to gases | Sand hills. |
| VI. | Liquids to liquids | Diffusion of liquids. |
| IX. | Gases to gases | Diffusion of gases. |
| | Osmose | Diffusion through septa. |

# CHAPTER III.

## MECHANICS.

**109.** It has been shown that motion is caused by the action of force upon matter; but we can readily conceive that two or more forces may so act upon a body that their effects will mutually counteract each other, and that no motion will ensue. In this case, the forces are said to be in *equilibrium*, and the body is said to be at *rest.*

**110. Mechanics** is the science which treats of equilibrium and motion. That part of it which relates to equilibrium is called *Statics*, and that which relates to motion is called *Dynamics.* In the present treatise, no attempt will be made to separate statical and dynamical propositions, as the study of either presupposes the student to have some knowledge of the other. As a general rule, the facts in dynamics will be considered last.

**111.** Inasmuch as mechanics relates to all bodies, whether solid, liquid, or aëriform, it has been found convenient to divide the science into three divisions:

1. The mechanics of solids, called *statics* and *dynamics.*
2. The mechanics of liquids, called *hydrostatics* and *hydrodynamics.*
3. The mechanics of gases, called *pneumatics*, or *aërostatics*, and *aërodynamics.*

### GENERAL STATICS AND DYNAMICS.

**112. The forces considered in mechanics** may be reduced to gravity, elasticity, and muscular strength.

If a force acts but for an instant, it is called an *impulsive force.* If its action is continued, it is called an incessant, or *continuous force.* A continuous force may be regarded as a series of impulsive forces, acting in exceedingly brief but equal units of time. If the impulses are equal in intensity, it is called a *constant force;* but if their intensity changes, it is called a *variable force.*

**113.** Since motion is produced by the action of force upon matter, it must vary with the kind of force producing it. An impulsive force produces *uniform motion*—a continuous force acting alone produces *varied motion.*

I. UNIFORM MOTION is that in which equal spaces are described in equal times. A body once set in motion, would, by virtue of its inertia, continue moving in a straight line with uniform velocity forever, were there no opposing forces. But as every moving body meets with resistances, such as gravity and friction, it must soon be brought to rest unless impelled by a continuous force.

Continuous forces may produce uniform motion when the successive impulses are exactly equal to the resistance. Thus, a railway train moves with uniform velocity when the friction and the resistance of the air have increased so as to be in equilibrium with the motive power of the engine.

Thus, also, the earth revolves on its axis in exactly uniform motion. The time of one revolution is divided into 86,400 equal parts, one of which is called a second, and constitutes the *unit of time.*

*The velocity of a body* is the space described in a unit of time.

II. VARIED MOTION is that in which unequal spaces are described in equal successive units of time. If a body describes a greater space in each successive moment, the motion is *accelerated;* but if the space is less, the motion is *retarded.*

A constant force acting alone upon a body will produce *uniformly accelerated motion.*

A falling body may be taken as an example of this kind of motion. The moment it is unsupported, gravity causes it to descend, and if this force, and all opposing forces, were then annihilated, it would fall with uniform motion; but gravity continues to act with new impulses at each moment, and thus forces the body downward faster and faster. This illustration is not perfect, because the resistance of the air increases as the square of the velocity of the body, and, if the body continues long in falling, will at last produce uniform motion.

A constant force opposing the previous motion of a body produces *uniformly retarded motion.* Thus, when a body is thrown vertically upward, gravity retards its motion every instant and will finally bring it to rest.

*The velocity in uniformly varied motion, at any moment, is the space a body would describe, by virtue of its inertia, in the next subsequent unit of time, were all forces acting upon it to cease.*

**114. Momentum.** When a body is in motion, the effect may be measured by the time that would be required to stop the motion by a pressure of uniform intensity. This pressure, multiplied by the time through which it acts, is equal to the mass of the body multiplied by its velocity. This last product is the *momentum* of a body, or, as it is sometimes called, its *quantity of motion.*

Of two equal masses, that which has the greater velocity will have the greater momentum; of two unequal masses, having the same velocity, the heavier mass will have the greater momentum. The momentum is, therefore, dependent on the weight and the velocity, and may be estimated by the following rule: the momentum is equal to the weight multiplied by the velocity.

$$[5.] \quad M = W \times V.$$

The momentum of a thirty pound cannon ball, moving with a velocity of one thousand feet per second, is equal to thirty thousand pounds—that is, it is equal to the momentum of a body weighing thirty thousand pounds and moving one foot per second. From these considerations it is evident that the momentum of a large body moving slowly may be no greater than that of a small body moving rapidly. Thus, the momentum of an enormous but slow sailing ship may be no greater than that of a swift steam tug. The momenta of very large masses, as icebergs, are irresistible by any human power, even though their *motion be so slow* as to be almost imperceptible.

## LAWS OF MOTION.

**115.** The deductions in mechanics are based upon three axioms, known as Newton's laws of motion.

First Law.—*Every body continues in a state of rest, or of uniform motion in a straight line, unless acted on by some external force.*

This is called the law of inertia, because it depends on that property of matter. It is difficult to furnish examples which will perfectly illustrate this law, because all bodies on the earth are constantly acted on by one or more external forces. The following are given as approximate illustrations:

That a body can not set itself in motion is evident from our experience. Mountain cliffs remain for ages, until worn away by winds, rain, frost, or other agencies.

That a body tends to move in a straight line may be seen by rolling a ball along the ground, or on the floor, or on a smooth sheet of ice; the fewer the obstacles in the way, the more direct will be its course. The same experiment shows that the fewer the obstacles, the more uniform will be the rate of motion, and the longer will it continue in motion.

**116.** Whatever tends to oppose or retard motion is called the *Resistance.* The resistances which a moving body encounters are, mainly, gravity, friction, and the resistance of the medium surrounding it, as air or water.

There are some apparent exceptions to the law of inertia. A heavy ring may be so struck by the hand that it will proceed a little distance, on a level surface, and then return to the hand. In this case, the hand not merely gives the ring an impulse forward, but imparts a rotary motion in the opposite direction. The rotary motion soon destroys the impulse forward, and causes the body to change its direction.

**117.** Second law.—*Motion, or a change of motion, is proportional to the force impressed, and is in the direction of the line in which that force acts.*

In order to comprehend the action of a force, three things must be known: (1.) its intensity, (2.) its direction, (3.) *its point of* application.

1. The *intensity* of a force is the energy with which it acts. This may be expressed in pounds, and may be represented by a straight line. Thus if we represent a force of one pound by a line an inch long, any multiple of the force will be expressed by a line of corresponding length.

2. The *direction* of a force is the line along which it acts.

3. The *point of application* of a force is the point upon which it exerts its action.

**118. If a given force** generates a given motion, a double force will generate double the motion. It must not be supposed that twice the velocity will actually be realized. Thus, if an engine can propel a steamboat ten miles an hour, two engines of the same power will not double its speed, because the resistance of the water increases as the square of the velocity.

**119.** A body may be acted upon by a single force, or by several forces at the same time. By the terms of the second law, each will produce the same effect as if it acted alone. Motions are, therefore, classified, with reference to the number of forces employed, as simple and compound.

**120. Simple motion** is produced by the action of a single force.

**Compound motion** is produced by the joint action of two or more forces. The following are selected from the many cases that may occur:

CASE I. If several forces act upon the same point in the same direction, their effect will equal their sum.

Thus, if a carriage be drawn by two horses, one exerting a force of two hundred pounds, and the other three hundred pounds, then their combined effect will be the same as that of a single horse pulling with a force of five hundred pounds.

A single force that represents the effect of several forces acting together, is called their *resultant*. The forces which combine to *make up the* resultant are called its components.

When these forces produce motion, the sum of the velocities of the components will equal the velocity of the resultant. Thus, if a boat, impelled on quiet water by oars at a rate of four miles an hour, enters a river, flowing in the same direction at a rate of three miles an hour, the speed of the boat will become seven miles an hour.

**121.** Case II. If two forces act upon the same point in opposite directions, their resultant equals their difference.

If the carriage be drawn forward with a force of three hundred pounds and backward with a force of two hundred pounds, an effect of one hundred pounds will remain in the direction of the greater force. If, in the previous example, the boat proceed up the river against the current, it will have a velocity of one mile per hour in the original direction.

**122.** Case III. If two forces which act upon the same point are represented in intensity and direction by the adjacent sides of a parallelogram, the diagonal will represent their resultant in intensity and direction.

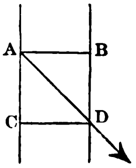

Fig. 20.

Suppose a boat to be rowed at the rate of four miles an hour, in the direction A B, across a stream running at three miles an hour, in the direction A C. The boat will move in the direction A D, the resultant of these components, at the rate of five miles an hour.

This proposition is called the parallelogram of forces, and the operation of finding the resultant when the components are given is called the *composition of forces.* When the forces are at right angles to each other, the finding of the resultant is an easy geometrical problem of finding the hypotenuse when the two sides are given. Many familiar natural phenomena may be explained by this principle.

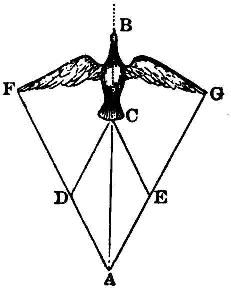

Fig. 21.

A bird, in flying, beats the air with wings *inclined toward* each other. The resistance of the air is perpendicular to their surfaces. Draw A F and A G perpendicular to each wing, and lay off on them A E and A D, to represent the force of each wing. Now complete the parallelogram A E C D, and draw its diagonal A C. This will be the resultant of the two forces, and the bird will move as if impelled by the single force A C.

A bullet dropped from the topmast of a ship in rapid motion, will strike the deck precisely where it would have fallen had the vessel been at rest. The reason of this is, that the ball, which falls by the action of gravity, also partakes of the motion of the vessel, which carries it forward as fast as the ship moves.

**123.** Conversely, when the resultant of two forces is given, the components equivalent to it may be found. This operation is called the *resolution of forces.*

Represent any force, equal in intensity to ten, by the line A C. On this line an infinite number of parallelograms, A B C B′, A D C D′, A E C E′, may be constructed, any two adjacent sides of which may be considered as the components of A C. Thus, if A B be drawn equal in intensity to eight, A B′ at right angles to it will equal 6.

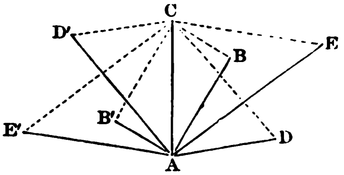

FIG. 22.

FIG. 23.

As an illustration, take the sailing of a sloop under a wind oblique to the course of the *boat. Represent* the course of the wind by the line V *m*. 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 useful component impels the sloop on its course.

**124.** CASE IV. When more than two forces act upon the same point, the final resultant may be found by combining any two for the first resultant, then a third force with the first resultant, then a fourth force with the second resultant, and so on, until all the forces have been combined.

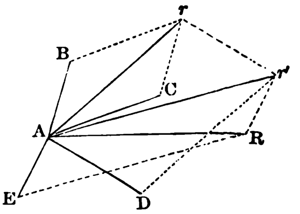

FIG. 24.

Thus, in Fig. 24, A *r* is the resultant of A B and A C; A *r'* the resultant of A *r* and A D; A R the resultant of A *r'* and A E, and, consequently the resultant of the four forces, A B, A C, A D, and A E.

**125.** CASE V. When two parallel forces act upon a line, B C, their resultant will also be parallel, and will have its point of application at a distance from either force, inversely proportional to its intensity. If the forces lie in the same direction, the resultant will equal their sum, as in the case of horses attached to the same whippletree. If the forces F and F' lie in opposite directions, as in Fig. 25, the resultant F—F' will equal their difference, and lie in the direction of the greater force.

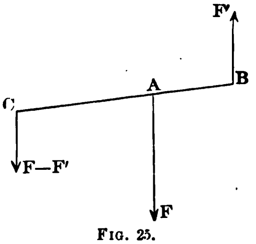

FIG. 25.

When opposite parallel forces are equal, they produce no progressive motion, but cause the body on which they act to revolve about a point midway between the two forces. Such a system is called a *couvle*.

By the application of these principles, an approximate answer may be obtained for problems whose accurate solution requires the higher mathematics. Thus, suppose a known vertical force, acting upon the point L, to be resisted by two forces, acting on each side of it, at angles respectively forty and thirty degrees, and suppose the value of these components to be required. Represent these forces by the lines L G, L N, L E, and set off on L G the value of the vertical force, in any convenient unit, as one inch, or one foot. Through G, draw lines so as to complete the parallelogram. The sides of the parallelogram L N and L E will be the forces required, and their lengths, measured by a scale of equal parts, will give their ratio to each other, and to the known force L G. This is the *method by construction*. In the case supposed L G = 1, L E = 0.67, L N = 0.52, an answer correct to two places of decimals. Conversely, had L E and L N been known, their resultant, L G, equals the force necessary to counteract them, or 1.00.

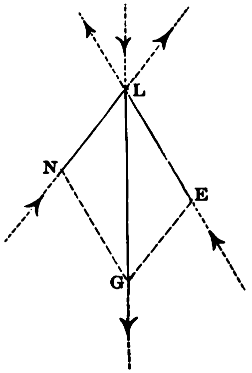

FIG. 26.

126. THIRD LAW.—*Action and reaction are always equal, and are in opposite directions.*

A weight, suspended from a hook, is retained in its place because the hook reacts with a force equal to the pull of the weight. When a ball is fired from a cannon, the cannon recoils with a momentum equal to that of the ball, but the backward motion is much less because of the greater weight of the cannon. A rocket rises from the reaction of the air against its expanding gases. 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. When a pugilist strikes his antagonist, his fist sustains as great a shock as it gives, but is usually less sensitive to injury than the part on which it strikes.

127. **When a moving body encounters another,** the effects of action and reaction are modified by elasticity, and other circumstances. The reaction of solids may be shown by balls of different material and size, hung from a frame, so that their diameters shall lie in the same straight line.

128. **Non-elastic solids.** If two balls, of soft wax or clay, be suspended, and one be let fall upon the other at

rest, the first will communicate a part of its momentum to the second, and both will move forward with the original momentum. The velocity of the two will be diminished in proportion as their combined weight exceeds that of the falling ball.

If both are dropped toward each other, they will come to rest, on striking, if their momenta are equal. This will be the case if equal balls are dropped with equal velocities. If their momenta are unequal, they will move, after collision, in the direction of the greater, and with a momentum equal to the difference of the original momenta.

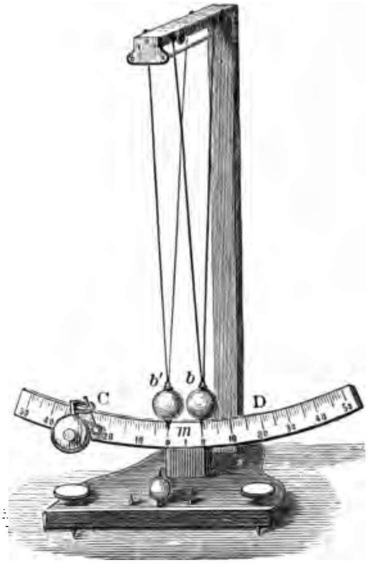

FIG. 27.

**129. Elastic bodies.** In perfectly elastic bodies, the force of elasticity is exactly equal to that of compression, and in such bodies the effect of reaction is of the same kind as that of action.

Suspend two equal ivory balls from the frame in Fig. 27. If *b* falls upon *b′*, it 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. By the same process of reasoning, *b′* will acquire all the velocity of *b*, and would rise as far as *b* fell, were it not for the want of perfect elasticity.

If the two balls are dropped with unequal velocity, in the same direction, each will move, after collision, with the previous velocity of the other body. For, as before, *b′* gains what *b* loses.

If the balls collide from opposite directions, each will rebound with the previous velocity of the other body.

**130. Bodies striking a fixed plane.** Let a ball be thrown in the direction I N, upon a hard and smooth plane A B, and suppose both bodies to be perfectly elastic. The force of the collision at N, may be resolved into two components; the one, N D, perpendicular to A B, which represents the elastic force, tending to urge the ball in the line N P, and the other component, N E, parallel to A B, representing its velocity in the direction of the plane. Complete the parallelogram, N E R G, its diagonal, N R, will represent the direction the ball will take after impact. A careful measurement will show that the angle, I N P, is equal to the angle P N R.

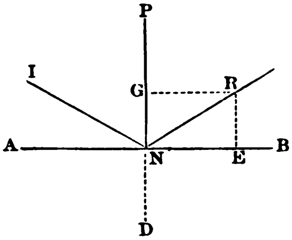

FIG. 28.

The angle, I N P, formed by the direction of the incident body and the perpendicular, is called the *angle of incidence*, and the angle, P N R, formed by the perpendicular and the direction of the body after reflection, is called the *angle of reflection.* Their equality is expressed by the following law: *The angle of incidence is always equal to the angle of reflection.*

This law applies exactly to the reflection of sound, light, and heat, and of perfectly elastic bodies.

If either body is imperfectly elastic, the component, N G, will be proportionally smaller; hence, the body will proceed, after reflection, in a line nearer the plane than N R, and the angle of reflection will be greater than the angle of incidence.

These facts may be readily exemplified by bounding balls of different elasticities, as rubber, ivory, marble, clay, putty, etc., upon a hard floor, and are well shown in the game of billiards.

**131. Reaction in soft bodies.** In the previous cases, the reaction has been supposed to be instantaneous, but if the reaction is gradual, its destructive effect will be less.

Thus, if a man leaps from a height into deep water, the particles of the water separate, and, though the reaction is the same as though he alighted on a solid plane, it is diffused through a sufficient interval of time to become comparatively harmless. In like manner stones may be caught in the hand with impunity, if the hand is allowed for a time to partake of the motion of the stone.

**132. Even soft bodies** require some time for the displacement of their particles. If the surface of water be struck sharply by the open palm, the blow is resisted almost as well as by solids. This power of resistance for the moment is exemplified by the sport of "skipping stones" along the surface of smooth water. Leaden bullets will become flattened if fired obliquely upon water.

**133. Diffused action.** If a blow be struck on a large body, the effect on each particle will be inversely proportional to the mass. Thus, if an anvil be laid on the chest of a man, he may receive a heavy blow on it without detriment, because the blow is first diffused through the anvil, and then deadened by the expanded lungs of the man.

**134. Striking force.** In these examples, bodies have been considered as under the influence of momentum, which expresses the *intensity* of the moving force. The *energy* of a force is its power to perform work, that is to overcome resistance through a certain space. This is called the *vis viva,* or striking force.

Thus, the momenta of two balls, weighing five and ten pounds, will be the same if the lighter ball moves with twice the velocity of the heavier; but if both strike a clay bank, the swifter ball will penetrate twice as far as the other, or perform double the work. This difference is due to their striking force.

**135. Either momentum or vis viva** may be taken as the measure of a force. The *momentum* represents the amount of pressure which, if applied to a moving body for one second, will bring the body to rest. With a given mass, the momentum is proportional to the velocity of the body. The *vis viva* represents the energy required to keep a body in motion with a constant velocity. Suppose a locomotive to double its velocity: it encounters twice as many points of resistance, and strikes each of these with double velocity; hence, to maintain a double velocity, its energy of motion must be increased four times. If it trebles its velocity, its energy must be increased nine times, etc. That is, with a given mass the *vis viva* is proportional to the square of the velocity. The work which a moving body can do through a certain space before it is brought to rest is the measure of its energy at any moment. Its average velocity will be only one-half of the initial velocity, and, hence, *The* vis viva *equals one-half of the product of the mass multiplied by the square of the velocity.*

$$[6.]\quad \mathfrak{F} = \frac{MV^2}{2}.$$

**136. Destructive effects of collision.** When railway trains come in collision, the engines are shattered by their striking force, while the momentum of the trains following each has been known to pile thirty cars one above another. The collision between two ships of equal size is the same as if either, at rest, had been struck by the other with twice the velocity. When a large ship runs down a small vessel, it suffers little injury, because of its stronger build and greater mass. Even light and soft bodies, as air and water, have tremendous power when moving rapidly, as in hurricanes and storms.

### CENTER OF GRAVITY.

**137. A body, unsupported, falls** to the ground; and, if supported, exerts a certain pressure, called its weight. These are but special examples of a force, of whose nature nothing is certainly known, which acts upon all particles of matter in the universe, and constantly tends to make them approach each other. Newton has shown that the motions of all the heavenly bodies are due to this force, which he called *Universal Gravitation.* As applied to bodies on or near the earth, it is called *Terrestrial Gravitation,* or simply *Gravity.*

**138.** It will be shown (213) that gravity acts with equal intensity upon the particles of all bodies, however they may differ in form, size, or state. The direction and point of application of gravity will now be considered.

**The direction of gravity.** Weights dropped at different places on the earth's surface will fall toward a point at, or near, the earth's center. Hence, the direction of the force of gravity may be considered, without sensible error, as the line joining the point of application and the earth's center. This direction may readily be found, at any place, by a plumb line, which consists of a heavy weight suspended by a light and flexible string. If a plummit hangs so that the weight dips in a vessel of water, the line and the surface of the water will be at right angles to each other. 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 two plumb lines are placed near each other, their lines of direction will be sensibly parallel, because their lengths are inconsiderable in comparison with the radius of the earth. Hence, the directions of the force of gravity on particles near each other are parallel. In Fig. 29, vertical lines on the earth are designated by V, and horizontal lines by H.

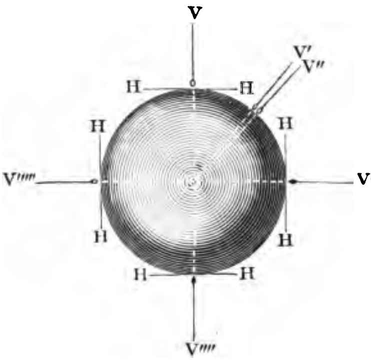

FIG. 29.

**139. The point of application of gravity.** As gravity acts in a vertical direction upon each particle of a body, its effect on the body, taken as a coherent mass, will be the same as the resultant of an infinite number of equal and parallel forces. When the form and dimensions of a body are known, this resultant may readily be calculated by Case V (125), but in all cases it may be determined by experiment.

Let A B be any body; represent the force of gravity on each point by the dotted vertical lines, and their resultant, G E, by the arrow. Then, if any point, as C, in the direction of this resultant be supported, the body will remain at rest, and all the forces will be expended in pressure on the fixed point C. If, now, we suspend the body by a string in the direction of the line D E, it will still remain at rest, because the line is the prolongation of the direction of the resultant.

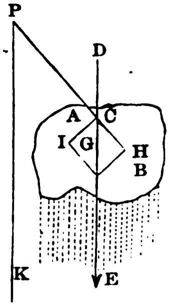

FIG. 30.

If, however, we were to attach the string to a point at P, outside of the direction D E, the body would not remain at rest. The resultant, acting at C, will be decomposed into two parts, the first acting in the line C H, representing the weight supported by the point P, and the second acting in the direction C I, which would move the body toward the vertical, P K. Therefore, a body supported by a fixed point, can not remain at rest unless the direction of the resultant of gravity passes through that point.

Now suspend the body at another point, as Z, the direction will change its position; but whatever be the number of directions thus found, they will all intersect in a common point, as G.

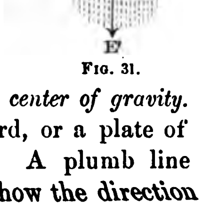

FIG. 31.

**140. The common point of intersection** of the resultants of the forces of gravity in all positions of the body is called the *center of gravity.* This center may readily be found in a board, or a plate of lead, by suspending it at various points. A plumb line attached to each point of suspension, will show the direction of the resultants.

The center of gravity may be regarded as the point of application of the force of gravity on all the particles of a body, since it is the only point common to all the resultants. Hence, in calculations, *the weight of a body may be considered as concentrated in the center of gravity.* The vertical line passing through the center of gravity is called *the line of direction.*

When the center of gravity is supported, the body will remain at rest, because any resultant will be supported when this point is supported. Therefore, *the center of gravity is the point about which all parts of a body balance.*

**141. In bodies of uniform density** the center of gravity will coincide with the center of the figure. When such a body is symmetrical, the determination of the center of gravity becomes a simple geometrical problem. Thus, the center of gravity will lie:

1. In a straight line, at its center.
2. In a circle, at the intersection of any two diameters.
3. In a parallelogram, at the intersection of its diagonals.
4. In a triangle, at the intersection of the lines drawn from the vertices of the angles to the middle point of the side opposite, and at a distance from any such middle point equal to one-third of the length of the given line.
5. In a sphere, at its center.
6. In a cylinder, at the center of its axis.
7. In a parallelopipedon, at the intersection of its diagonals.
8. In a pyramid, on its axis, one-fourth of its length from the base.

These results may be verified by balancing bodies, of the figures described, at the points designated. For the first four, figures may be made of thin sheets of pasteboard, wood, or metal; for the remainder, the solids may be made of light wood, hard soap, etc.

When the figure is irregular, the center of gravity may be determined by suspending it so that it will move freely from any two points, not lying in the same line of direction, as described in (139). The intersection of the two lines of direction will be the center of gravity sought.

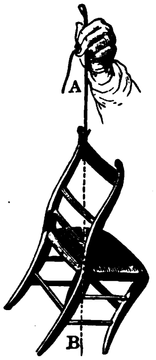

FIG. 32.

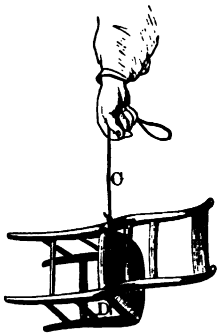

FIG. 33.

**142. The center of gravity** may lie entirely outside of the body, as will be its position in a ring, a hollow box, or ball, or cask, yet even in this case its properties will be the same as if included in the mass of the body.

**143. When two bodies are connected** so as to form a rigid mass, the center of gravity will be at a distance from either body, inversely as their weights. In Fig. 34, if the weights are equal, they will be balanced at the middle point of the bar connecting them; if A is the heavier, the center of gravity will lie nearer it. Thus, if A weighs four pounds and B one pound, the center of gravity will lie four times nearer A than B. When more than two bodies are connected, the center of gravity of the compound body is found by taking them successively in pairs, in the manner described for finding the resultant of several forces. (124.)

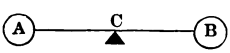

FIG. 34.

When a body is not of uniform density throughout, the determination of the center of gravity is similar to that of two bodies connected.

**144. Equilibrium of heavy bodies.** Although a body will remain in a state of rest when its center of gravity is supported, yet, as the center of gravity always tends toward the lowest possible position, the equilibrium of a body supported on a fixed point, will depend on the relative position of that point to the center of gravity. There will thus be three states of equilibrium: (1.) stable, (2.) unstable, (3.) neutral.

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 pendulum oscillates about its position of stable equilibrium, and will finally come to rest in that position.

2. A BODY IS IN UNSTABLE EQUILIBRIUM when it tends to depart farther 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, for the center of gravity will then be higher than in any adjacent position, and when removed from the vertical above the point of support, will not stop until it has gained the lowest possible position. This is illustrated in balancing a pencil by its point on the tip of the finger. Once balanced, it will remain in equilibrium until it is disturbed, but the least displacement will throw the line of direction beyond the point of support, and the pencil will fall. If, now, we attach a couple of knives on each side of the pencil, like the balls in Fig. 35, the center of gravity of the compound body will be below the point of support, and the body will be in stable equilibrium.

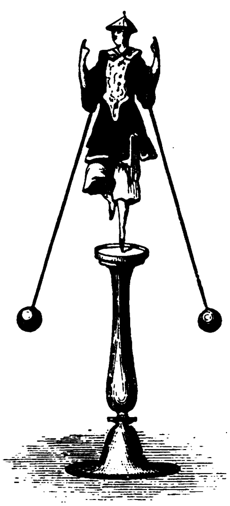

FIG. 35.

The conversion of unstable into stable equilibrium, may be illustrated by suspending a pail from the end of a stick lying on the edge of the table—Fig. 36. Now place a second stick, E G, with one end against the corner of the pail, and with the other end in a notch cut in the horizontal stick C D. By this contrivance, the center of gravity is brought under the edge of the table, and the whole will therefore be in stable eqilibrium. The pail may now be filled with water without changing the equilibrium.

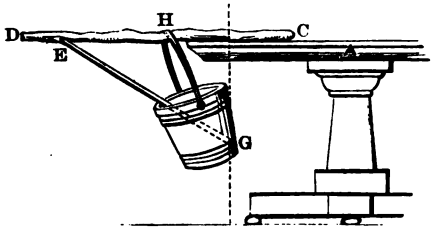

FIG. 36.

3. 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 wagon wheel is suspended on its axle. A perfect sphere, resting on a horizontal plane, is in neutral equilibrium, because its center of gravity is neither raised nor lowered in any adjacent position. The following figure represents three cones: A in stable, B in unstable, and C in neutral equilibrium. The position of the center of gravity is indicated by *g*.

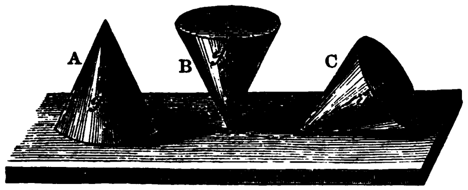

FIG. 37.

**145. The relation** which the center of gravity bears to equilibrium, may be shown by the following simple contrivance.

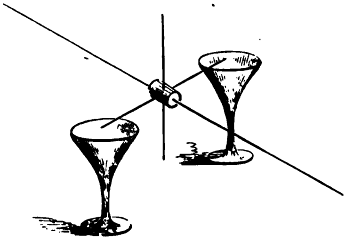

FIG. 38.

Thrust two half knitting needles and one whole one through a cork, at right angles to each other, and support the apparatus on two wine glasses, by one of the shorter needles. By pushing the vertical needle up or down, the center of gravity can be altered at pleasure, and the apparatus brought into either stable or unstable equilibrium. In performing this experiment, the student should carefully notice the position of the center of gravity, when the apparatus best exhibits the state of stable equilibrium, for this is the position required in a good balance.

**146.** This experiment shows that the preceding distinctions apply to bodies resting on two or more fixed points. The pressure on these points is manifestly equal to the resultant in the line of direction. Thus, a book is in stable equilibrium when resting on its side, and in unstable equilibrium when standing on its edge.

When a body, supported on two points, is in equilibrium, the line of direction will pass through the line connecting the points of support. Thus, a man standing on stilts is in a state of unstable equilibrium. So, also, is a man walking on a tight rope. The latter uses a long pole, which he elevates or depresses, 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.

**147. The stability of bodies.** When a body has but one point of support, or rests upon a line, it is easily moved from the vertical, and can not be said to possess *stability.* This property depends on the relation which the center of gravity bears to at least three points, not in the same straight line, which constitute the base of the body. The base of a body supported on legs, as a table, is the polygon formed by lines connecting the bottom of the legs.

A body resting on a base is stable, when the line of *direction* falls within the base. The stability of such bodies may be estimated by the force required to overturn them. If its position can be changed without raising the center of gravity, the slightest force would be competent to move it, if friction did not oppose. If its position can not be changed without raising the center of gravity, then the force required to move it must be sufficient to raise the entire body to the same height that the center of gravity would be elevated. To illustrate this, let the diagrams, Fig. 39, represent sections drawn through the center of gravity of different solids, and denote their centers of gravity by G. To turn either of these bodies over the edge E, the center of gravity must pass through the arc G T, and be raised through the height H T. A careful inspection of these figures will lead to the following deductions:

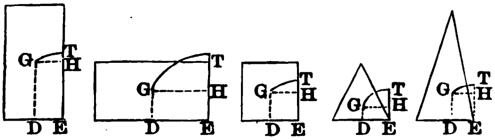

Fig. 39.

The distance, H T, increases as the ratio of the height to the base decreases: therefore, (1.) the stability of bodies of the same height and similar figure is increased by widening the base.

The distance, H T, increases in proportion as the center of gravity is lowered: therefore, (2.) the stability of bodies is increased by bringing the center of gravity to the lowest possible position.

As a corollary to this; (3.) of bodies having the same height and base, but of dissimilar figures, the pyramid is the most stable.

Now, if the similar sections, in Fig. 40, inclined more or less from the perpendicular, be compared, it will be seen, (4.) that the stability of bodies is greatest when the line of direction passes through the center of the base.

So long as the line of direction, G D, falls within the base, the body will stand, but its stability will be less in proportion as its distance from the center of the base increases, until the line of direction falls exactly through the edge, E. In this position the body is in a state of unstable equilibrium, and will be overturned by the slightest force. Finally, (5.) when the line of direction falls without the base, the center of gravity will be unsupported, and the body will fall.

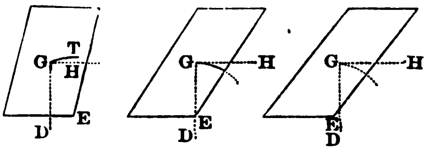

FIG. 40.

**148. A sphere remains at rest** on a horizontal plane, because the line of direction passes through the point of support, but if the plane be inclined, the line of direction will fall without the base, and the sphere will roll downward. So, any body on an inclined plane, will not slide down the plane, until the line of direction has fallen so far forward as to overcome the friction of the plane.

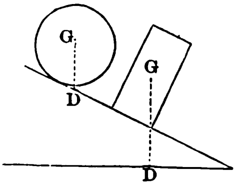

FIG. 41.

**149. Practical applications.** (1.) Stability dependent on extent of base: candlesticks and inkstands are made with broad bases. Stone walls are broader at the base than at the top. Tall monuments are made with their sides inclined, and often have very large bases. The legs of chairs are inclined outward. A child's high chair has a very wide base. (2.) Stability dependent on the height of the center of gravity: a load of hay is more easily overturned than the same weight of stone. In loading a wagon or a ship, the heavier articles should be placed at the bottom. (3.) Stability dependent on the line of direction. There are y towers in Italy, as at Pisa and Bologna, which incline from a perpendicular position, but in these the line of tion still falls within the base.

0. **General considerations.** The center of gravity in man etween his hips, his base is the area inclosed by his feet. The ent attitudes assumed by persons in standing or moving are the ts of instinctive efforts to keep the line of direction within the s of support. In standing, a man widens his base by turning is toes, or by using a cane. In moving about, the center of ty is perpetually changing, and the positions of the several of the body are changed to correspond. Thus, when a person from a chair, he either throws his body forward, or draws eet backward, to bring the center of gravity over his feet. In ng or ascending a hill, a person throws his body forward so as rry his weight with less effort. In descending a hill, he leans ard, so that his weight shall not cause him to fall forward. A standing with his heels against a vertical wall, finds it difficult op to the floor without falling.

en a person carries a load, the effort is to preserve the line of tion, common to himself and the load, within his base. If the is in his right hand, the person inclines his body to the left, and s out his left hand as an additional assistance. If the person s the load on his head, or an equal portion in each hand, there tendency to lean to either side. If the load is on his back, he forward; if carried in his arms, he leans backward.

## 151. Recapitulation.

I.

anics considers
- Equilibrium of
    - Solids.....Statics,
    - Liquids..Hydrostatics,
    - Gases.....Aërostatics.
- Motion of
    - Solids....Dynamics,
    - Liquids..Hydrodynamics,
    - Gases.....Aërodynamics.

II.

n is classified
- With regard to a given point.
    - Absolute,
    - Relative.
- With regard to rate.
    - Uniform,
    - Varied.
- With regard to force.
    - Simple,
    - Compound.

### III.

Newton's laws regard................
- 1. The inertia of bodies.
- 2. The action of forces.
- 3. Action and reaction.

### IV.

Equilibrium is.........................
- Stable—support above center.
- Unstable—support below center.
- Neutral—support at center.

## STATICS.

**152.** Hitherto we have considered the action of forces as directly applied to bodies; but there are many instances in which force acts indirectly, through the intervention of some instrument.

Thus, it is possible to arrange the burning coals in a grate by the direct application of the hands, but it is certainly safer and more convenient to apply the requisite force to a poker, which will communicate it to the coals. The poker then becomes a *machine*.

**153. A machine** is an instrument by means of which a force, applied at a certain point, is made to exert force at another point, more or less distant. The effective force generally differs in intensity from the force applied.

The force employed in a machine is called the *power*. The resistance overcome by a machine, at the point where the power acts, is called the *weight* or *load*. It may be considered as a force acting in a direction opposite to that of the power. The *work* is the product of either the power or the load, by the vertical space through which it moves.

**154. The foot-pound.** In order to estimate the efficiency of any force, an arbitrary unit of work has been adopted, called the *foot-pound*. The foot-pound is the mechanical value of a force capable of raising one pound through a vertical space of one foot. The work of the power is, therefore, equal to the product of an equivalent weight in pounds multiplied by the vertical height in feet through which it passes. The work of the load is found in a similar manner.

Thus, to raise a load of one thousand pounds of water thirty-three feet high, requires a power equal to thirty-three thousand foot-pounds.

**155. Horse-power.** To estimate the work of any force, acting through a limited period of time, another unit has been adopted, called the *horse-power*. A horse-power is the mechanical value of a force capable of raising thirty-three thousand pounds one foot in one minute. Its work is, therefore, equal to thirty-three thousand foot-pounds in a minute.

Thus, one horse-power can raise one thousand pounds thirty-three feet high in one minute, or five hundred and fifty pounds one foot high in a second, or one million nine hundred and eighty thousand foot-pounds in an hour.

**156. No machine can create power.** It is merely an inert instrument for the advantageous application of power. In explaining the theory of machinery, many circumstances are at first neglected which must afterward be taken into account. Thus, it is assumed that the parts of a machine move without friction, without resistance from the air, that they have neither weight nor inertia; also, that the ropes and chains employed have neither thickness, stiffness, nor weight. As these conditions are never satisfied, a part of the power must be expended in the machine itself, and hence power is partially lost when applied to machines.

**157. The work of the power** is always equal to the work of the load. Hence, if any machine will enable us to lift a weight of ten pounds by a 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. Therefore, the following laws are applicable to machines of every kind:

1. *The power multiplied by the vertical distance through which it passes equals the load multiplied by the vertical distance through which it passes.*

$$[7.]\quad PD = LD'.$$

2. *The power multiplied by its velocity equals the load multiplied by its velocity.*

$$[8.]\quad PV = LV'.$$

**158.** If we reverse the conditions given in the previous example, and suppose a power of ten pounds to be required to move a weight of one pound, the laws will still hold good; but the results will be exactly opposite, that is, the load will traverse ten times the space, with ten times the velocity of the power. We see, therefore, that machines will enable us (1.) to economize our force by making it act with great velocity, to move heavy loads very slowly; or (2.) to economize our time, by the expenditure of great power to move small loads very rapidly. Practical mechanics express this fact by the axiom, "*What is gained in power is lost in velocity.*"

**159. Among the many advantages** derived from the use of machinery are:

1. It enables us to employ our whole force at the same time.

A person winding thread on a reel will expend only a small part of his strength; suitable machinery will enable him to turn many reels at once.

2. It enables us to change the direction of our force.

A sailor may hoist the sails of his ship while standing on the deck, instead of climbing the mast and laboriously pulling them up.

3. It enables us to perform work 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.

4. It enables us to employ other forces than our own, as the strength of animals, the forces of wind, water, and steam.

5. It enables us to utilize the products of nature.

It is the knowledge of machinery that distinguishes civilized nations from savages, since by it we have mills for weaving cloth, forging iron, grinding flour, etc.

**160. All machinery** may be reduced to six elementary forms, called *simple machines.* The simple machines are (1.) the lever, (2.) the wheel and axle, (3.) the pulley, (4.) the inclined plane, (5.) the wedge, (6.) the screw. A combination of two or more of these constitutes a *compound machine.*

**161. A lever** is an inflexible bar moving freely about a fixed point, called a *fulcrum.*

The arms of the lever are the parts into which the fulcrum divides it. When the arms are not in the same straight line, it is called a bent lever; otherwise, simply a lever.

There are three classes of levers, depending on the relation of the power, load, and fulcrum.

In levers of the first kind, the fulcrum is between the power and the load, as in Fig. 42, I. In levers of the second kind, the load is between the power and the fulcrum, as in Fig. 42, II. In levers of the third kind, the power is between the load and the fulcrum, as in Fig. 42, III. The lever acts on the principle of parallel forces. The power and the load will be in equilibrium when they are inversely as their distance from the fulcrum.

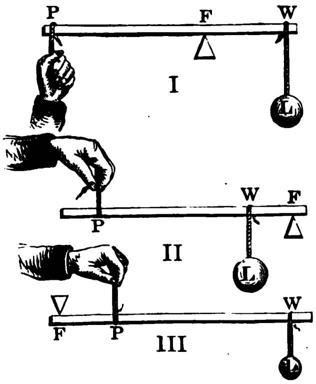

FIG. 42.

[9.] $P : L :: \overline{WF} : \overline{PF}$; or, $P \times \overline{PF} = L \times \overline{WF}$.

[10.] $P = \frac{L \times \overline{WF}}{PF}$. [11.] $L = \frac{P \times \overline{PF}}{WF}$.

**162.** STATICAL LAW.—*The product of the power multiplied by its distance from the fulcrum, is equal to the product of the load multiplied by its distance from the fulcrum.*

A statical law expresses the relation of the power and load when a machine is in exact equilibrium. To produce motion it is necessary that one product should exceed the other. The greater product will determine the direction of the motion.

EXAMPLES.—In a lever of the first kind, sixteen inches long, with the fulcrum four inches from the load, a power of one pound will balance a load of three pounds.

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

On a lever of the third kind, sixteen inches long, with the power four inches from the fulcrum, a power of one pound will balance a weight of one-fourth of a pound.

**163. Familiar illustrations.** A poker is a lever of the first kind, when it raises the coals in the grate by resting on the bars of the grate as a fulcrum. A crow-bar is used as a lever of the first kind when we press *downward* to raise the load above a block used as a fulcrum. Fig. 43. It is also used as a lever of the second kind, when one end rests on the ground as a fulcrum, and we lift *upward* to raise the load. Fig. 44. A fishing-rod is a lever of the third kind; the fish being the load, and the power is applied between it and the other end of the rod. The hinges

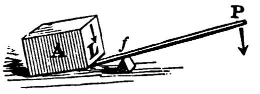

FIG. 43.

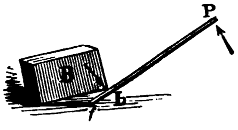

FIG. 44.

of a door are its fulcra, the load is at the center of gravity of the door; in closing it, if the hand be applied near the latch, the door is a lever of the second kind, but if the hand be near the hinges, the door is a lever of the third kind. Scissors, snuffers, and pincers are double levers of the first kind, the pivot being the fulcrum, and the load the object between the blades. Nut-crackers are double levers of the second kind. Tongs are double levers of the third kind.

**164. In levers of the first kind,** the power may be greater, equal to, or less than the load, according to the relative distance from the fulcrum. Thus, in cutting a strip of cloth with a pair of scissors, the power exceeds the load, until we have cut a distance from the pivot equal to that of the hands; at this point the power equals the load, but beyond that the load will require a greater power. As they are generally used, intensity of force is gained with levers of the first and second kinds. They are, therefore, employed 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.

In levers of the third kind, intensity of force is always lost; we, therefore, employ this lever when we wish to move small weights rapidly by the use of greater powers.

FIG. 45.

**165. Bent levers.** When the arms of the lever are bent, or when the power and weight do not act parallel to each other, their respective distances are reckoned by perpendiculars drawn from the fulcrum to the direction of the power and the load. This is exemplified by the bent lever balance shown in Fig. 45. In this the power is constant. As the load is increased, it depresses the scale bar. By this means, the leverage of the shorter arm is diminished, while that of the longer arm is increased. The claw of a hammer used in drawing out nails, is another example; the load is the friction of the nail, the hand applies the power, and the edge of the hammer is the fulcrum.

**166. 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. The lever will be of the second kind. If A and B carry a load between them on a pole, each man will bear half the burden, if the weight hangs from the middle of the pole. If, however, the weight is one-third of the length of the pole from A, he will bear two-thirds of the burden and B one-third. The load sustained by each is inversely as the distance between them and the load. Two horses attached to a wagon may be made to pull unequal loads by placing the bolt of the whippletree nearer the stronger horse.

FIG. 46.

**167. 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. When a compound lever is in 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.*

In the arrangement shown in Fig. 47, A F and A″ F″ are levers of the second kind, and A′ B′ a lever of the first kind. The power P, acting on the lever A F, produces a downward force, at B, as many times greater than itself as the distance A F is greater than B F. If A F is ten times greater than B F, the force at B is ten times the power. This force is then transmitted to A′. If we suppose the arms of the upper lever, A′ F′ and F′ B′, to bear the same proportion of ten to one, the force exerted at B′ will be ten times that at A′ or B. Then the force transmitted to A″ will be one hundred times the power. If the arms of the lowest lever, A″ F″ and B″ F″, are as ten to one, another increase of ten times the power will be gained; hence, a power of one pound at P will balance a load of one thousand pounds at L.

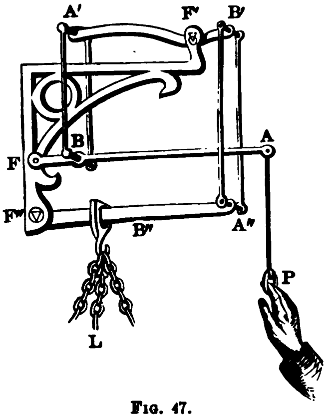

FIG. 47.

**168. When several forces** act upon the same arm of the lever, the effect of each force must be computed, and their sum will be the resultant of all. Theoretically, the weight of the lever does not enter into the calculation, but in experiments it is necessary to consider the weight of each arm as applied at its center of gravity. We shall not obtain satisfactory results in experiments with levers *unless we first balance the levers by a sufficient counterpoise before attaching the power and the load.*

**169. The practical applications** of the lever are very numerous. The most common relate to weighing. Any form of levers of the first kind may be used for this purpose, and the student may construct quite accurate scales for himself from strips of stout wood.

*The steelyard* is a lever of the first kind, having two unequal arms, and employing a constant counterpoise. Fig. 48. The counterpoise *M* is movable along the beam, the load is suspended from W by a hook or scale pan, and F is the fulcrum for light loads. The beam is graduated by bringing the counterpoise into equilibrium with known weights of different magnitude, and the position of the counterpoise is marked by a notch, and numbered for each weight. A second fulcrum F′ is used for heavier weights, to avoid increasing the length of the beam. When the bar is turned half over, the hook turns about the end and falls below the shorter arm.

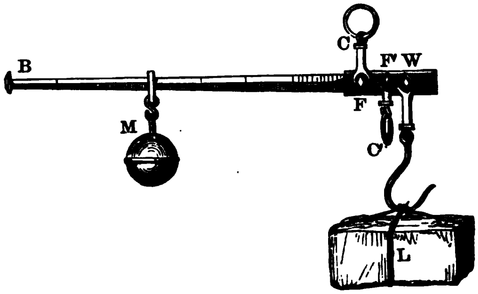

FIG. 48.

If the center of gravity of the unloaded beam were at the fulcrum, the notches on the beam would be at a distance from each other, equal to that of the hook and the fulcrum, but, ordinarily, the longer arm predominates. Hence, the zero point is not at F, but at some point between F and M.

**170. The balance** is a lever of the first kind, having two equal arms. Fig. 49. Delicate balances are furnished with a needle attached to the center of motion, which oscillates before an index, *n*, to show small deviations of the beam. A balance is sensitive, when a very small difference between the weights in the scales causes a perceptible motion in the pointer.

The center of gravity of the balance should be a little below the edge of the fulcrum. This will bring it to a state of stable equilibrium, in which it will most readily tend to return to a horizontal position. If too far below, *it will be less* sensitive, because too stable. If the centers of gravity and motion coincide, it will be in neutral equilibrium. If the center of gravity is above the center of motion, it will be in unstable equilibrium, and the heavier arm will remain depressed. Compare (145).

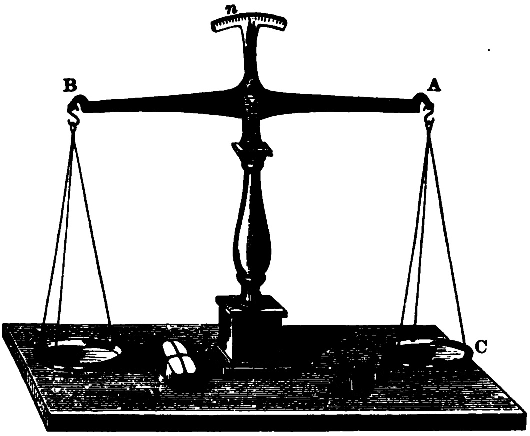

FIG. 49.

The arms should be precisely 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.

**171. 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. We can not find the true weight of a body in a false balance by weighing it in each scale, and then taking half the sum of the two weights, or their arithmetical mean; because the body is overestimated by one weighing, in the *same ratio* that it is underestimated in the other. We must, therefore, take the geometrical mean of the false weights, which is the square root *of their product*. Thus, if a body weighs nine pounds in one scale and four pounds in the other, the true weight is six pounds.

**172.** As all balances are liable to become false, by the unequal expansion of their arms, the best method of weighing is that known as Borda's double weighing, which always secures accurate results in a sensitive balance. Place the body to be weighed in one scale pan and counterbalance it with shot, then remove the body, and in its stead place known weights which will exactly restore the equilibrium of the balance. These weights will be the exact weight of the body.

**173. The compound lever,** shown in Fig. 47, may readily be converted into a weighing machine. It only needs a scale pan attached to the chains, and a counterpoise to move along the middle lever. The common platform scales consist of a system of compound levers, and are used for weighing heavy articles.

**174. The wheel and axle.** The space through which a load may be raised by a single action of the lever, is ordinarily very small. To raise a load higher than the sweep of the short arm, requires a repeated adjustment of the fulcrum, and a contrivance for supporting the load while this is being effected. In such cases, the action of the lever is intermittent. When continuous motion is required, as to raise a box to the top of a building, the wheel and axle is frequently employed.

**175.** 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 as a perpetual lever of the first kind, the fulcrum being at F, the common center, and the arms of the lever being respectively A F and F B, the radii of the wheel and the axle. The power and load will be in equilibrium when they are inversely proportional to the *radii of the* wheel and the axle.

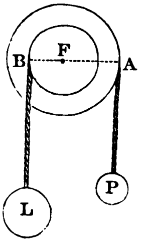

FIG. 50.

$$[12.]\quad P : L :: \overline{BF} : \overline{AF};\ \text{or},\ P \times \overline{AF} = L \times \overline{BF}.$$

$$[13.]\quad P = \frac{L \times \overline{BF}}{\overline{AF}.} \qquad [14.]\quad L = \frac{P \times \overline{AF}}{\overline{BF}.}$$

STATICAL LAW.—*The power multiplied by the radius of the wheel equals the load multiplied by the radius of the axle.*

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

**176.** In the various forms of this machine, the load is generally attached to a rope coiled around the axle; the power is applied in various ways.

The form represented in Fig. 50 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. As radii are proportional to their circumferences, it is manifest that the rope unwound from the wheel will be as many times longer than that wound up on the axle, as the load exceeds the power. The power may also be applied to pins projecting from the wheel, as in the steering apparatus on large vessels.

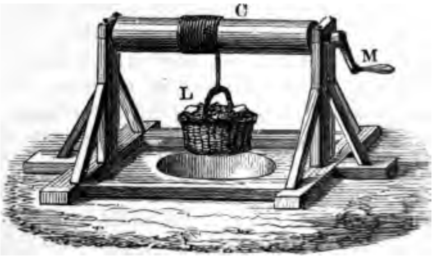

FIG. 51.

**177.** It is not necessary that the power be applied to a complete wheel, since a single spoke will answer. This modification is the windlass employed in raising water from wells. The *winch* constitutes the power arm—the radius of the axle the load arm. In the windlass used on ships there is no fixed handle, or winch, but handspikes are fitted into slots cut in the axle, and are shifted as occasion requires. When the windlass has a vertical axis, it constitutes a *capstan.* Fig. 52. This is turned by men walking around it, and pressing against handspikes inserted in the top or drum.

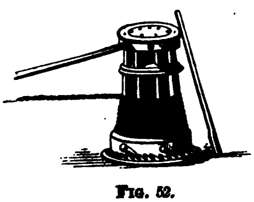

FIG. 52.

**178. The effective power** of this machine may be augmented by increasing the radius of the wheel, or by diminishing that of the axle; but very large wheels are too unwieldy, and very small axles too weak for practical use. These inconveniences may be obviated by making the axle of two parts, with different radii, having the same rope so attached that, as it winds around the thicker, it unwinds from the thinner. This contrivance is called the *differential wheel and axle.*

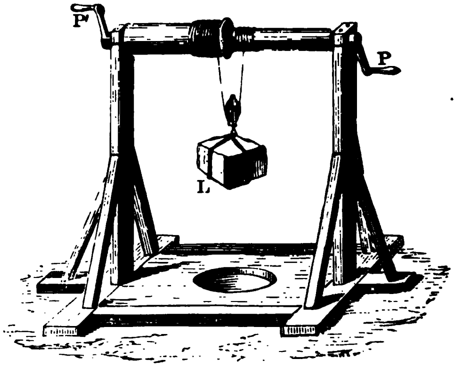

FIG. 53.

The effect is to shorten the rope by which the load is suspended, by the difference between the circumference of the two parts, but the height through which the weight is raised is only half this shortening of the rope. Hence, the efficiency of the differential wheel and axle may be found by this rule: *The power multiplied by the radius of the wheel, equals the load multiplied by half the difference of the radii of the two parts of the axle.*

By making the two parts of the axle of nearly the same size, the effective power may be increased to any required amount.

**179. The power of this machine** may also be augmented, on the principle of the compound lever, by combining several, in such a way that the axle of the first may act on the wheel of the second, and so on. Several wheels and axles combined in one machine are called a *train.*

A train of wheels is frequently connected by cogs, as in clock-work. The cogs on the wheels are called *teeth,* those on the axles, *leaves.* The axle itself is termed a shaft or *pinion.* The mechanical power of a train of wheels may be found in the same way as for a compound lever. Since the cogs are proportionate to the radii of the wheels and pinions, the statical law may be thus stated: The power multiplied by the continued product of the teeth in each wheel, equals the load multiplied by the continued product of the leaves in each pinion.

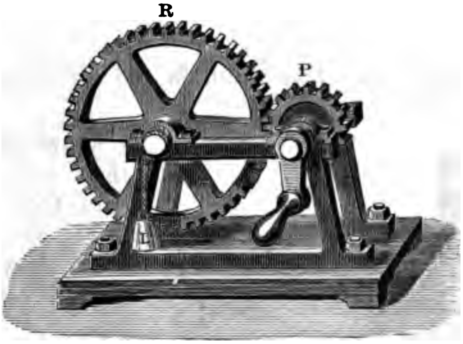

FIG. 54.

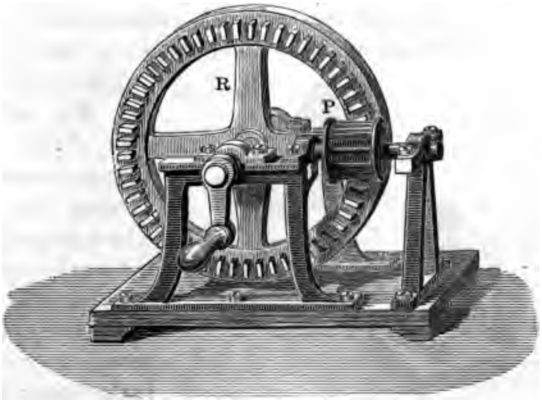

FIG. 55.

In **Fig. 54**, the power is represented as acting on the wheel which carries the first pinion P. By this arrangement, a small power is capable of raising a large load, but with a corresponding loss of velocity. The arrangement *may* be reversed for the sake of augment ing the velocity, at the expense of the power. Thus, in a watch, power is applied to a wheel that revolves once in four hours, to give the second hand a revolution once in a minute.

**180.** Toothed wheels are of three kinds, spur, crown, and bevel.

Spur wheels have their teeth in the direction of their radii, as in Fig. 54.

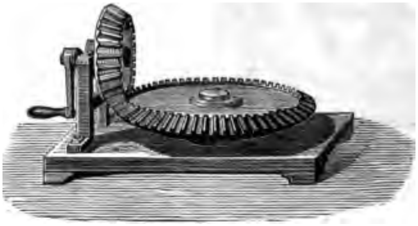

FIG. 56.

Crown wheels have their teeth parallel with their axes, as in Fig. 55. The open wheel shown in this figure is called a *lantern*.

Bevel wheels have their teeth oblique to their axes, as in Fig. 56.

**181. Wheels are also connected** by endless bands, as in Fig. 57. In this case, the motion is communicated by the friction of the bands on the circumferences of the wheels.

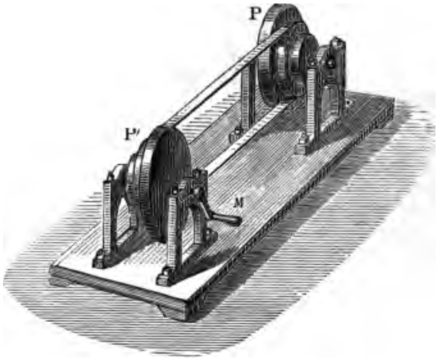

FIG. 57.

The whirling table, Fig. 93, consists of two wheels thus connected; on turning the large wheel around once, the smaller is made to revolve as many times as its circumference is contained in the circumference of the larger. It is used to give great speed to the axis of the smaller wheel.

**182. The pulley.** If a cord, fastened at one end to a hook, supports a weight at the other end, it is manifest that the stretching, or tension, of the cord will be transmitted throughout its whole length, and exert a force on the hook equal to the load. If, now, the cord be passed over the hook and one end held by the hand, the tension of the cord will remain the same, and the hand must exert a force equal to the load. No mechanical advantage will be gained in raising the load in this manner, beyond a change in the direction of the power. In fact, there will be a loss, resulting from 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 rope. Such a wheel is called the *sheave of a pulley.*

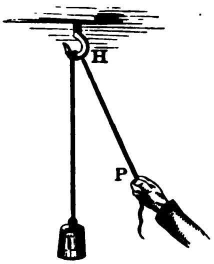

FIG. 58.

**A pulley** is a small grooved wheel, revolving about an axis, and having a cord passing over its circumference.

Pulleys are called fixed or movable, according as their axes are fixed or movable.

**183. In the use of the fixed pulley** there is neither gain nor loss to the power, but only a change in its direction. This is often as great an advantage as an increase of the power would be. Thus, if a fixed pulley be attached to the rafter of a warehouse, a man standing on the ground may raise weights to any floor of the building. It is, besides, so much easier for him to pull the rope down than it would be to lift the weight directly up, that he can afford to overcome the friction of the pulley in addition to the load. By the use of two fixed pulleys, horizontal motion may be converted into vertical, as in Fig. 59.

FIG. 59.

**184. Movable pulley.** If a cord be attached at each end to a hook, and a weight hung by a ring at the center of the cord, the tension of the cord will be transmitted throughout its length. If we suppose the cord to be divided into two parts, each part will support but half the load, and, therefore, have but half the tension. Therefore, if a fixed pulley take the place of one of the hooks, the power required to support the load will be one-half the weight of the load. If it is desired to elevate the load, the friction may be diminished by substituting a movable pulley for the ring. Fig. 61.

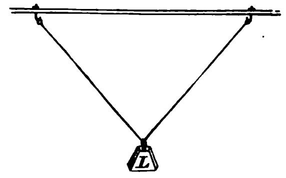

Fig. 60.

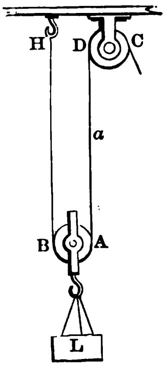

Fig. 61.

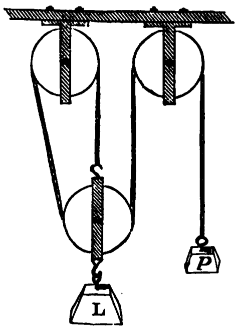

Fig. 62.

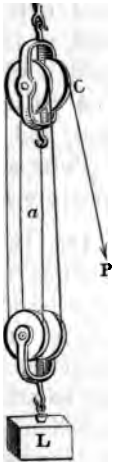

Fig. 63.

If one end of the cord be attached to the top of the movable pulley, as in Fig. 62, the tension of the cord produced by the load will be distributed in three equal portions. Consequently, the tension of the part attached to the power will be measured by 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. 63, the power is one-fourth of the load. In this, there are two fixed and two movable pulleys, each pair secured in a framework called a *block*. A combination of blocks, sheaves, and ropes is called a *tackle*.

**185.** As fixed pulleys do not increase power, the gain in the last three examples must be due to the division of the tension among the parts of the rope supporting the movable block. Hence, representing the number of these parts by $n$,

$$[15.]\quad L = P \times n. \qquad [16.]\quad P = \frac{L}{n}.$$

STATICAL LAW.—*The load equals the power multiplied by the number of parts of the cord engaged in supporting the movable block.*

**186. This law applies** only when one continuous cord passes through the whole system, and when its parts are parallel. Movable pulleys are very seldom used alone; they are generally combined with fixed pulleys which serve to change the direction of the power. These combinations may contain from one to ten pulleys in each block. When the fixed and movable pulleys are equal in number, the parts of the string supporting the load will be twice the number of movable pulleys, as in Figs. 61 and 63.

**187. Spanish burtons** are pulleys containing more than one rope. Such a system, with two ropes, is represented in Fig. 64. The rope, P B A D, sustains a tension equal to the power; consequently, the portions, A B, A D, each have a tension equal to the power. The rope, A C B, sustains the tensions, A B and B P, and, therefore, has a tension of twice the power. Therefore, the united tensions of the ropes supporting the movable block, A, will be four times the power.

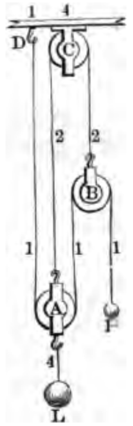

FIG. 64.

In Fig. 65, each pulley has a separate rope. The pulley, B, receives half the load attached to A, C half of B, and so on; hence the power increases by the geometrical ratio of 2. Therefore, the load will equal the power multiplied by two, raised to the power denoted by the number of movable pulleys.

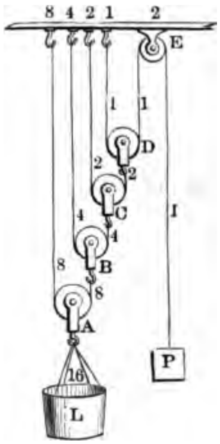

FIG. 65.

Although the power increases rapidly by this system, yet it is practically of little value because of its limited range. In the common system, the motion may be continued until the fixed and movable blocks come in contact; but in this system, only until D and E come together, at which time the other pulleys will be far apart, because C rises half as fast as D, B one-fourth and A one-eighth as fast.

**188. The inclined plane** is a hard, smooth, inflexible surface, inclined obliquely to the resistance. When a weight is placed upon such a plane, a part of the pressure is resisted by the plane, while the remainder tends to cause the weight to slide or roll down the plane. Thus, in Figs. 66, 67, and 68, the weight of the body lies in the line of direction of gravity, L G. This may be resolved into two components, viz.: L N, acting perpendicularly to the plane, and completely resisted by it, and L E, acting opposite to the direction of the power, and to be counterbalanced by it. It is manifest that the component, L N, shows how much of the weight is supported by the plane. If the plane were vertical, L N would be zero, and if the plane were hori-

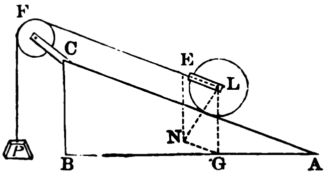

FIG. 66.

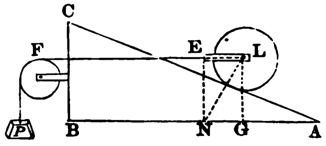

FIG. 67.

zontal, the whole weight would be supported by it. Consequently, the other component, L E, which represents the power necessary to sustain the load, will increase as the plane becomes steeper. It is also manifest that this component, L E, will vary with the direction of the power. There may be three cases.

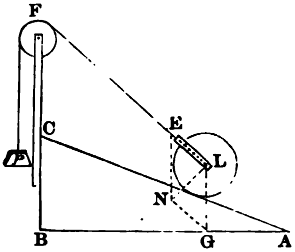

FIG. 68.

**189. In the first case** the power acts parallel with the plane, as in Fig. 66. In the parallelogram, E L N G, the sides L G and E N are equal; hence, E N may be taken as the weight of the body, or load. The triangles, A B C and L E N, are similar, and hence,

Power : load :: L E : E N; or, :: B C : A C.

$$[17.]\quad P=\frac{L\times\overline{BC}}{\overline{AC}.}\qquad\qquad [18.]\quad L=\frac{P\times\overline{AC}}{\overline{BC}.}$$

STATICAL LAW.—*The power equals the load multiplied by the ratio of the vertical height of the plane to its length.*

EXAMPLE.—The power required to keep a barrel, weighing two hundred pounds, on a plank twelve feet long, with one end on the ground and the other in a wagon three feet high, will be fifty pounds.

This is the most advantageous way of applying the power, for its whole effect is expended in raising the load. If the power be directed below the plane, a part of it will be expended in increasing the pressure on the plane; and, if directed above the plane, a part of the power will be used in diminishing the pressure; and hence, only the remaining part is available in drawing the load up the plane. That is to say, in all other cases a greater power will be required to raise the same load.

**190. In the second case** the power acts parallel with the base, as in Fig. 67. The triangles, L E N and L N G, are **each similar to** A B C, *and* we shall find, Power : load :: L E : E N; or, :: B C : A B.

$$[19.]\quad P = \frac{L \times \overline{BC}}{AB.} \qquad [20.]\quad L = \frac{P \times \overline{AB}}{\overline{BC}.}$$

STATICAL LAW.—*The power equals the load multiplied by the ratio of the vertical height of the plane to its base.*

**191. Third case.** In any other direction of the power, the triangles formed will not be similar, and no simple expression of equilibrium can be given, beyond the general law of (157.) *

**192. Familiar examples.** The grandest examples are found in roads, which are seldom perfectly level. In ascending mountains the roads wind about, so as to increase the length of the incline. So, also, a careful driver, in ascending a steep hill, will guide his team from side to side of the road, preferring to increase his distance for the sake of lightening his load. On a level road, the power of the horses is expended in overcoming friction, which, on common roads, varies from one eighteenth to one fiftieth of the load, and on iron railways, from one one-hundred-and-fortieth to one two-hundredth. On a road rising one twentieth, that is one foot in twenty, the horse must lift one twentieth of the load besides overcoming friction. Reckoning friction at one eighteenth, the whole power ($\frac{1}{20} + \frac{1}{18}$) necessary will be almost double that required on a level road. On a railway, with the same grade, the power required will increase from $\frac{1}{140}$ to $\frac{1}{140} + \frac{1}{20} = \frac{8}{140}$, or eight times that required on a level. This rapid increase indicates the reason why steep planes are less admissible on railways than on common highways.

---

* The general proportion for inclined planes is P : L :: sine of inclination of the plane : cosine of the angle formed by the direction of the power and the plane. Suppose the weight to be concentrated in the point L, and the line A C to pass through it; then,

Fig. 68. P : L :: sine B A C : cos. C L E.

In Fig. 66. Cos. C L E = radius $\therefore$ P : L :: sine B A C : 1.

In Fig. 67. C L E = B A C and is the complement of E L N; hence,

P : L :: sine B A C : cos. B A C.

The method by construction may also be applied. (125.)

**193. The wedge** is a movable inclined plane. If, instead of moving the weight along the inclined plane, Fig. 67, 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,

$$P : L :: BC : AB.$$

$$[21.]\quad P = \frac{L \times \overline{BC}}{\overline{AB}.} \qquad [22.]\quad L = \frac{P \times \overline{AB}}{\overline{BC}.}$$

STATICAL LAW.—*The power is to the load as the height of the wedge is to its base.*

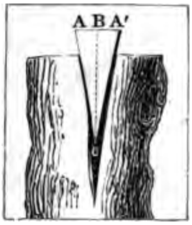

FIG. 69.

**194.** As commonly applied for separating surfaces, a *double wedge* is used, as A C A′ in Fig. 69. As each face meets with half the resistance, the power is to the resistance as half the thickness of the wedge is to the length, B C.

**195.** These laws are of little practical value, beyond the general deduction that the efficiency of the power increases with the thinness of the wedge. The reasons for this are:

1. The power is applied, not by a continuous force or pressure, but by *percussion*, for which we have no numerical standard of comparison.

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

3. The value of the wedge is often dependent entirely upon friction, as is the case with nails, pins, and the keystones of arches. If it were not for friction, the wedge would recoil after every blow.

**196. Practical applications.** The wedge is especially useful where very great force is to be exerted through very small space. Masses of timber and stone are cleft by wedges. Ships are raised by wedges driven under their keels. The most extensive application of the wedge is in tools for cutting and piercing, as knives, awls, hatchets, chisels, nails, etc. The angle varies with the purpose for which the instrument is designed. Although the mechanical power is increased by diminishing the angle, yet the strength of the tool is diminished in the same proportion. Accordingly, in tools used for cutting wood, the angle is about 30°; for iron, from 50° to 60°; for brass, 80° to 90°.

**197. The screw** is another variety of the inclined plane, as may be shown by winding a triangular piece of paper around a cylinder. Fig. 70. The hypotenuse will form a spiral path about the cylinder exactly resembling the threads of a screw. The ratio of the base, A B, to the circumference of the cylinder, will determine the number of turns the triangle will make, and, by consequence, the number of parts into which the height, C B, will be divided. Each of these parts, as *b c*, corresponds to the vertical distance between the threads of the screw. As in the wedge, the power acts parallel with the base; the action of the screw is, therefore, the same as the second case of the inclined plane; hence,

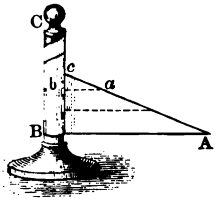

Fig. 70.

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

**198. 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.

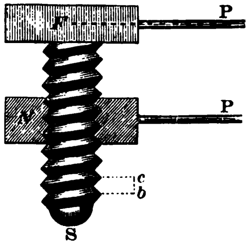

Fig. 71.

In either case, it is generally found convenient to apply the power at the end of a lever, fitted either to the screw or to the nut. This renders the contrivance a compound machine, whose advantage may be found by the following

STATICAL LAW.—*The power is to the load as the vertical distance between two contiguous threads is to the circumference described by the power.*

$$P : L :: bc : 2\pi R;\ \text{or,} :: bc : 6.2832\ \overline{FP}.$$

$$[23.]\quad P = \frac{L \times bc}{6.2832\ \overline{FP}.} \qquad [24.]\quad L = \frac{P \times 6.2832\ \overline{FP}}{bc.}$$

EXAMPLE.—If the threads of the screw are one inch apart, and the lever is four feet long, a power of one pound will exert a pressure of 301.6 pounds.

**199. The mechanical efficiency** of the screw may be increased by lengthening the lever, or by dimishing the distance between the threads; and, as we may modify the screw in both these ways at once, to an indefinite amount, the pressure which may be exerted by a screw is limited only by the strength of the materials. To obviate the practical difficulty of making the lever too unwieldy, or the thread too delicate, John Hunter invented the *differential screw*. This consists of the ordinary right handed screw, into the end of which works a left handed screw, so that the two move in opposite directions. The distance between the threads of the second screw is somewhat less than that between the threads of the first. This second screw is prevented from turning round, but may move up and down. On turning the lever of the larger screw, it will *descend* through its nut, and, at the same time, the smaller screw will *ascend within it*; consequently the plate,

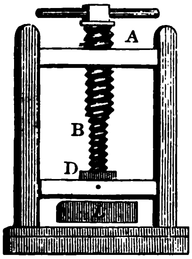

FIG. 72.

D, will descend the difference between the pitch of the two threads. Therefore, with the differential screw, the power is to the weight as the difference of the distances between the threads of the two screws is to the circumference described by the power.

This principle is employed in the *micrometer screw*, which is an apparatus used to measure very small distances.

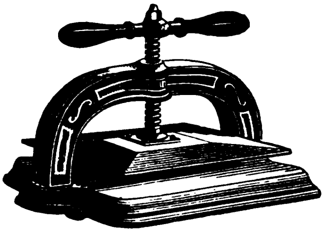

FIG. 73.

**200. Practical applications.** The screw is used for compressing. cotton, hay, and goods, for expressing the juices of plants and fruits, to raise buildings, to elevate grain and water, to propel ships, and to fasten securely the framework of structures of all kinds. Fig. 73, is the ordinary press used for copying letters.

COMPOUND MACHINES.

**201.** One of the most useful of these contrivances, is the endless screw, which is so secured by its shoulders that it has no longitudinal motion. Its thread works obliquely into the teeth of a wheel, which supplies the place of a nut.

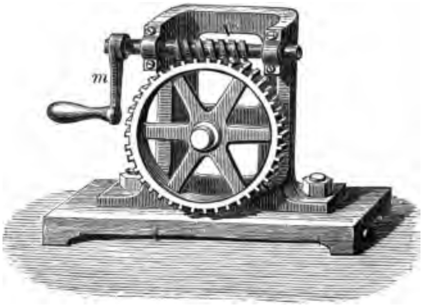

FIG. 74.

Cranes and derricks are combinations of pulleys with a wheel and axle. One form of the crane is shown in Fig. 75. This contains the wheel and axle, G, two fixed pulleys, E and F, and one movable pulley, P. The vertical axis, A, is supported by suitable framework.

The power of any compound machine may be found by estimating the effect of the parts separately, and then compounding them.

**202. The human mechanism** exhibits many examples of simple machines.

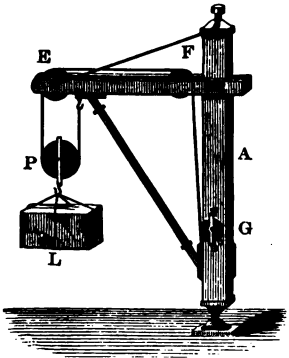

FIG. 75.

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 Achillis, 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 horizontally. The hand, and any thing 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. 76. 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 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.

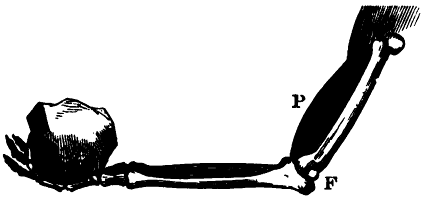

FIG. 76.

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.

### 203. Recapitulation.

Machines are classified as simple and compound.

| | | |
|---|---|---|
| I. Simple machines employ | 1. Leverage, | Lever.<br>Wheel and axle. |
| | 2. Tension of ropes. | Pulley. |
| | 3. Inclined surfaces. | Inclined plane.<br>Wedge.<br>Screw. |

II. Machines are compounded:

1. By repeating the same simple machine; as the compound lever, the burton, the differential screw.

2. By uniting two or more simple machines; as the endless screw, cranes.

IMPEDIMENTS TO MOTION.

**204.** It has already been stated that power is generally lost in machines through rigidity, and the mutual adhesion of the materials, and the consequent diminished mobility of the parts of the machinery. For this reason, the results actually reached in practice are somewhat less than those determined by the statical laws. Therefore, in calculating the useful work of any machine, due allowance should be made for the various impediments to motion. If (1.) the purpose for which a machine is designed is merely to *support* a load, the greater the impediments the less will be the power required: but, (2.) if the object sought is to *move* a load, the greater the impediments the greater will be the power required.

In the first case, the impediments may constitute the entire mechanical advantage of the machine, as is shown by the incalculable utility of friction in nails and screws, when employed in holding different materials together. So, also, friction is necessary in almost every application of power, whether employed in simple motion or applied to machines. Without friction, the wheels of a locomotive would turn on the rails without moving forward, belts would slide on their pulleys without starting them, all knots would readily untie, and nearly all manufactured articles separate into the parts of which they are composed. In the second case, any impediment to motion is a mechanical disadvantage, involving a loss of power.

**205. Friction is termed sliding,** when one surface slides over another, as a sleigh upon ice; and *rolling,* when one surface rotates on another, as a carriage wheel on the ground. Sliding friction has been determined for many different surfaces by the apparatus shown in Fig. 77. Blocks of different materials, carrying varying weights, were made to move over various surfaces, by means of weights placed in the pan, P. The quotient obtained by dividing the force necessary to move the body, by its weight in pounds, is called the *coefficient of friction.* This quantity, therefore, represents the friction due to the normal pressure of one pound. Rolling friction is determined by substituting, in place of the block, a cylinder about which were placed cords, loaded at each end, with equal weights, *c c* *c′ c′*. The following results have been determined by experiments:

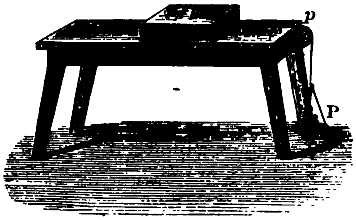

Fig. 77.

Fig. 78.

**206.** 1. *Friction increases with the roughness of the surfaces,* because a rough surface contains many projections which fit into corresponding cavities of the opposing surface, and these projections must be either lifted out, bent down, or broken off in moving.

2. *Rolling friction is less than sliding,* because a rolling motion avoids the breaking down of the minor inequalities of the surface.

3. *Friction is generally diminished by polishing the surfaces, and by the interposition of unguents,* because the projections are smoothed down and the cavities are filled up.

4. *Friction is greater between soft bodies than hard ones,* because soft bodies allow the opposing surface to sink somewhat into them, and thus increase the number of particles to be abraded.

5. *Friction is generally greater at starting than after motion has commenced,* because, if either surface is compressible, the contact becomes more intimate after a period of rest. If wood rests on wood, friction at starting attains its maximum in a few minutes; but when metals rest on wood, the maximum intensity is not attained for several days.

6. *Friction is greater between surfaces of the same materials than between those of different kinds,* because cohesion is added to the usual adhesion. Hence, it is usual to make axles of materials different from those of their supports.

7. *Friction is very nearly proportional to pressure.*

8. *Friction is not affected by extent of surface, except within extreme limits.* A brick will slide as easily on its side as on its edge, because the weight is distributed equally among all points in the surface on which it rests. Therefore, although there are more points in the side than in the edge, yet, as each point in the side receives a less friction than one in the edge, the sum of the friction of all the points will be the same.

Besides these, other factors of friction sometimes need to be considered. Thus, in ordinary vehicles, the inequality of the ground and the rapidity of motion increase the friction on hard ground, but do not on soft. The width of the tire does not affect friction on hard roads, but on soft roads the friction is diminished by the use of broad tires. The friction of carriage wheels is inversely proportional to *the diameter* of the wheel.

### 207. *Table of Coefficients of Friction.*

| Materials. | Without unguents. | | Unctuous surfaces. |
|---|---|---|---|
| | Starting. | Friction of motion. | |
| Oak upon oak, fibers parallel | .625 | .478 | .108 |
| Oak upon oak, fibers cross | .540 | .324 | .143 |
| Wrought iron upon oak | .619 | .619 | .085 |
| Wrought iron upon wrought iron | .137 | .138 | .077 |
| Wrought iron upon cast iron | .194 | .194 | .076 |
| Wrought iron upon brass | | .172 | .075 |
| Cast iron upon cast iron | .162 | .152 | .144 |
| Brass upon cast iron | | .217 | .107 |

### 208. *The Friction of Wagons on Level Roads.*

| | | | |
|---|---|---|---|
| Loose sand | 0.25 | Macadamized road | .033 |
| Common by-road | 0.1 | Well paved road | .014 |
| Dry highway | 0.025 | Railroads | .0035 to .0059 |

**209. The rigidity of cords,** passing over wheels, also occasions a loss of power in transmitting motion, which varies with the materials and the circumstances attending their use. Thus, it has been found that the loss due to this cause is

1. Directly proportioned to the suspended weight.

2. Directly proportioned to the diameters of the cords.

3. Inversely proportioned to the diameters of the wheels.

4. And is greater in tarred than in white ropes, and in strongly twisted ropes than in those loosely twisted.

**210. Resistance of fluids.** The resistance which a moving body encounters in air or in water, is only an effect of the transference of motion. The moving body constantly sets in motion the particles of the surrounding fluid, and effects this by the loss of an equal amount of its own motion. It has been found that the resistance of fluids to bodies moving in them is directly proportioned:

1. *To the density of the fluid;* for the moving body will displace its own bulk of either water or air; but as the water is eight hundred and twenty-nine times heavier than air, volume for volume, the weight of the fluids displaced will be exactly as their densities. The resistance of a square plane, of one foot area, moving in water with a velocity of one foot per second, is 0.975 pounds.

2. *To the square of the velocity of the moving body;* for very swift motions the resistance increases even more rapidly. The resistance of the air to a cannon-ball, moving with a greater velocity than twelve hundred feet per second, is greater than would be expected under the law. The increase seems to be due to the fact that air flows into a vacuum at the rate of twelve hundred and eighty feet per second, and, consequently, under very high velocities, the ball is retarded not only by the resistance of the air, but also by having the pressure of the atmosphere on the advancing side not counterbalanced by the pressure on the other.

3. *To the extent of surface of the moving body;* for the larger the body, the greater will be the mass of the fluid set in motion by it.

4. *The form of the surface also influences the resistance.* Thus, if the resistance to a given plane surface be taken as unity, an umbrella of the same area of section at the tips will meet with almost double (1.94) the resistance, when the concave surface is presented to the air; and only about three-fourths the resistance (.77), when its convex surface is presented. For this reason, the bows of fast sailing vessels are made sharp, so as to divide the water readily. It has also been found that the shape of the stern of a vessel modifies this resistance.

5. *Large bodies encounter proportionally less resistance than small ones of the same figure and density.* In cannon-balls, the extent of surface meeting the resistance is as the squares of their diameters; but their weight, which is one of the

factors of their momentum, increases as the cubes of their diameters. Thus, if two balls have their diameters in the ratio of one to two, the area of resistance will be as one to four, but if their velocities are the same, their power to overcome resistance will be as one to eight.

6. *Bodies of the same figure and volume, moving freely within a fluid, will be enabled to overcome resistance in proportion to the square root of their density.* Balls, one-fourth of an inch in diameter, falling through the air, will soon reach the limit of accelerated velocity, through the resistance of the air, and will attain a final velocity as follows: lead, one hundred and eighteen feet per second; water, thirty-six feet; cork, eighteen feet.

**211. The useful effect** of a machine, is that fraction of the power which is applied to its proper work after overcoming the various impediments to motion. As no two machines are exactly alike, the fraction which expresses the average work is not likely to be exactly applicable in any special case. Nevertheless, the following table will give some general idea of

*The Useful effect of Machines.*

| | | | |
|---|---|---|---|
| Lever | .98 | Chain pump | .50 |
| Wheel and axle | .90 | Undershot wheel | .27 to .45 |
| Pulley | .40 to .80 | Breast wheel | .45 to .65 |
| Endless screw | .50 | Overshot wheel | .60 to .80 |
| Screw press | .33 | Turbine wheel | .60 to .90 |

## 212. Recapitulation.

The useful effect of machines is lost,

(1.) Either within the machine itself; or,

(2.) By external impediments.

The impediments to motion may be classified:

1. Friction, either internal or external.
2. Rigidity of cords and belts.
3. Resistance of fluids.

DYNAMICS.

**213. Gravitation.** We have learned (1.) that the force of gravitation tends to make all bodies approach each other; (2.) that, for our globe, the direction of gravity is toward the earth's center, and (3.) that the point of application is at the center of gravity of the body. If we attach to a spring balance, balls of the same material but of different size, the tension of the spring, due to the force of gravity acting on the balls, will be proportional to the number of particles in each ball.

If two of these balls be dropped from a height, they will reach the ground in very nearly the same time, although the resistance of the air is slightly in favor of the larger ball. If the balls were of the same weight but of different material, as lead and cork, the difference in bulk would cause so great a difference in the resistance of the air, as to make the cork fall perceptibly slower.

FIG. 79.

If, however, any two bodies whatever, as a bullet and a feather, be allowed to fall through a perfect vacuum, they will reach the ground at exactly the same time. Therefore, (4.) gravity acts with equal intensity on every particle of matter, and (5.) is measured by the weight, which is proportional to the quantity of matter.

Now, if we catch balls dropped from different heights, we shall find that the swiftest balls are those which have fallen through the greatest spaces, thus showing that the motion is *accelerating*, and if this experiment could be conducted in a vacuum, we should find that the increase of velocity is uniform, which proves (6.) that for bodies near the surface of the earth, gravity is a constant force.

**214. The velocity attained** by bodies falling freely through *the air, in*creases so rapidly that it is a difficult matter to determine with precision the spaces passed over in successive seconds. GALILEO determined the laws of falling bodies, by rolling very smooth balls down a polished groove cut in a plane, which he inclined at different angles of elevation.

In the study of the inclined plane, we learned that the weight, or gravity, of any body resting upon it, is resolvable into two portions, one producing pressure on the surface, and the other tending to produce motion down the plane. As this latter portion bears the same ratio to the whole force of gravity as the height of the plane does to its length, we may diminish it at pleasure by lowering the height. We shall thus diminish the initial velocity, so as to make the motion slow enough to be accurately measured. Nevertheless, as this ratio is invariable for the same plane, only the absolute motion will be changed. The motion of the body will be accelerated by the same law of constant forces, and pass, in successive moments, through spaces bearing the same ratio to each other as if it fell freely through the air.

**215. To repeat the experiment of Galileo,** stretch two parallel wires between the walls of a room, at any convenient angle, as in Fig. 80. On the lower wire hang a pulley with a weight suspended beneath it, and on the upper wire fasten any convenient index, as a bell, or slip

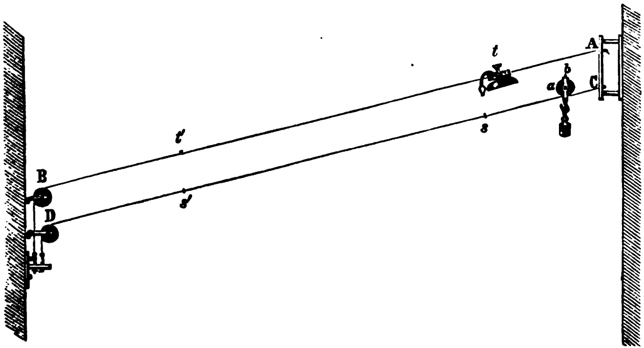

FIG. 80.

of paper, to be moved by the top of the pulley, *b*. Suppose the angle of inclination of the wire to be such that, in the first second, it passes over the space, *a s*; in two seconds it will pass over the space, $as'$; in three, $as''$, and so on.

If, now, we measure these spaces we shall find that the spaces passed over in each successive second, viz.: *a s*, $s s'$, $s' s''$, etc., increase in the order of the series of odd numbers, 1, 3, 5, 7, etc., or at the rate of two spaces for each second. This law of increase is a direct consequence from the nature of constant forces. For, as gravity may be considered as exerted in an infinite number of equal successive impulses, the final velocity, at the end of any second, will be due to the aggregate of all the impulses during the whole time of fall. Hence, the average velocity will be that at the middle of the interval during which it falls, and the final velocity will be double the average velocity.

216. **The average velocity** of the first second carried the pulley over the space, *a s*, and the final velocity is double the space, *a s*. Therefore, if gravity were now to cease to act, the velocity already acquired will be sufficient to carry the body in the next, and each succeeding second, through twice the space, *a s*. But during the next second, the fresh impulse of gravity will carry the body over a space equal to *a s*; consequently, in the second second, the body will pass over three spaces, each equal to *a s*, or $s s' = 3 a s$, as determined by experiment.

In two seconds the body will have passed over $a s'$, which is equal to $1 + 3 = 4$ spaces, and, as before, its final velocity will be double its average velocity. Since it has moved four spaces in two seconds, in the next two its acquired velocity would carry it over eight spaces, which is the same as a velocity of four spaces for one second. But as gravity adds a new increment at each second, it will traverse $4 + 1 = 5$ spaces in the third second, and will have descended, in three seconds, through $a s''$, which equals $1 + 3 + 5 = 9$ times the space, *a s*. The final velocity will

÷ 3 × 2

be ~~9×2~~÷~~3~~=6 spaces. By similar reasoning, the body will be found to pass over seven spaces during the fourth second, and to have fallen through sixteen spaces at the end of the fourth second, and so on.

**217.** We may express these results by the following table, wherein *t* represents the number of seconds in any given time of fall. The last term in each series is merely a generalization of the whole, derived by simple inspection of the previous terms in each series.

| Number of seconds. | Spaces fallen each second. | Velocities acquired. | Total space fallen through. |
|---|---|---|---|
| 1 | 1 | 2 | 1 |
| 2 | 3 | 4 | 4 |
| 3 | 5 | 6 | 9 |
| 4 | 7 | 8 | 16 |
| 5 | 9 | 10 | 25 |
| 6 | 11 | 12 | 36 |
| ... | ... | ... | ... |
| $t$ | $(2t-1)$ | $2t$ | $t^2$ |

It is evident that these results will always be the same, whatever be the inclination of the plane, or the space passed over during the first second. If, in the actual experiment, the height of the plane had been one foot and the length sixteen feet, the pulley would have traversed, 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. *

**218. It has been determined,** by careful experiment, that in 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 *incre-*

---

* The apparatus devised by Atwood and by Morin will attain the same result, but as the description of either is of little use without the apparatus, the simple method of Galileo has been preferred.

*ment of velocity* due to gravity, and is generally represented by $g = 32.16$ feet. The space passed over during the first second is $\frac{1}{2}g = 16.08$ feet.

If we now employ the constant $\frac{1}{2}g$ for the indefinite term "space," used hitherto, and denote by $s$, the space passed over *during* any given second; by $v$, the velocity *at the end* of any given second; and by $S$, the total height of the fall *at the end* of any second, we may embody the results of the preceding table in the following formulas and laws:

| For bodies falling freely. | For bodies sliding down inclined planes. |
|---|---|
| [25.] $s = \frac{1}{2}g\,(2t - 1).$ | [25′.] $s = \frac{1}{2}g\,(2t - 1)\,\frac{h}{l}.$ |
| [26.] $v = tg.$ | [26′.] $v = tg\,\frac{h}{l}.$ |
| [27.] $S = \frac{1}{2}gt^2.$ | [27′.] $S = \frac{t^2 gh}{2\,l}.$ |

**219.** First law.—*The space described by a 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.*

Thus, a body will fall, during the ninth second, $\overline{(2 \times 9} - 1)\,16.08 = 273.36$ feet.

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.*

Thus, the velocity attained at the end of the ninth second is $32.16 \times 9 = 289.44$ feet.

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.*

Thus, the total fall during nine seconds is $16.08 \times 81 = 1302.48$ feet.

**220.** We may combine the preceding formulas by algebraic processes and determine five other values for each term, some of which may be of service. Thus, by eliminating $t$

in [26.] and [27.] we find $v^2 = 2gS$; or, [28.] $v = \sqrt{2gS}$. If $g$ be taken as 32.16, [29.] $v = 8.02\sqrt{S}$. Therefore, *the velocity acquired by any body falling through a given height is equal to the square root of the height multiplied by* 8.02. So, also, from [27.] we find [30.] $t = \sqrt{2S \div g}$ which is very nearly the same as $\frac{1}{4}\sqrt{S}$. The number of seconds required for a body to fall through a given space is very nearly one-fourth of the square root of the height, expressed in feet.

**221. These formulas** are also applicable for any constant force whose intensity, $g$, may be found. In any inclined plane, $g$ is diminished, in the ratio of the height to the length, and becomes $gh \div l$. The total space, $S$, is identical with $l$. If these changes be made in the preceding formulas, a new series will be found, applicable to bodies on inclined planes. Formula [27′.] becomes [31.] $l = 4t\sqrt{h}$, from which we derive, [32.] $t = l \div 4\sqrt{h}$. Therefore, when the heights of planes are equal, the times of descent are proportional to their length.

Formula [28.] becomes $v = \sqrt{2ghS \div l}$. $S$ and $l$ cancel each other, and $v = \sqrt{2gh}$; or, [29′.] $v = 8.02\sqrt{h}$, a formula identical with [29.] whenever $S$ represents any vertical space. Therefore:

**222. The final velocity** of a falling body is proportional only to the vertical distance through which it falls, and is altogether independent of the path it follows. Thus, a body, Fig. 81, starting from A, will have the same velocity on reaching the level, $bc$, whether it falls through either of the grooves or vertically through $ab$. The time

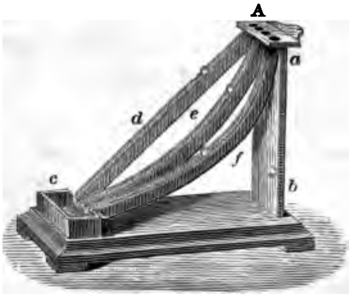

Fig. 81.

of descent will be shortest on the vertical, but on any other line than the vertical, on the groove *f*. This curve is known as a *cycloid*. In the cycloid, the curve falls more rapidly at first, and the body acquires at the start a greater velocity than is possible in the other grooves. Another curious property of the cycloid is that the body will descend the whole length of the curve in the same time as from any intermediate point, as *f*.

**223. If a body is thrown downward,** to the constant force already found must be added the impulsive force given the body. This is proportional to the velocity imparted and the time of its action.

Thus, if a body be thrown downward with a velocity of fifty feet per second, and is three seconds in falling, gravity alone would carry it $3^2 \times 16\frac{1}{12} = 144\frac{3}{4}$ feet; the impulse acting through three seconds would carry the body $50 \times 3 = 150$ feet, and therefore the total height of the fall is $144\frac{3}{4} + 150 = 294\frac{3}{4}$ feet.

**224. 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 $g = 32.16$. Therefore, the time of its rise will be found by dividing its original velocity by $g$, that is $t = v \div g$, an equation identical with [26.] Hence, the time of ascent is the same as that of a descending body, having an equal final velocity. From [29.] $S = v^2 \div 64.32$, the height in feet, to which a body ascending vertically will reach, is equal to the square of its velocity divided by 64.32.

**225.** The results thus attained by theory are never realized in practice, on account of the friction on inclined planes, and the resistance of the air in every case, as has been shown in the previous section.

**226. Projectiles.** If a body be hurled in an oblique or horizontal direction, as when a ball is shot from a cannon, the horizontal distance, measured from the point of starting to where it strikes the ground, is called the ***random***, or ***range***.

The range of a projectile is due to (1.) the force and direction of projection, (2.) the force of gravity, and (3.) the resistance of the air. Suppose a ball to be fired horizontally, Fig. 82, its velocity, due to the force of projection, will be uniform, and may be represented by a number of equal spaces, set off along AB. The force of gravity draws it vertically toward the earth with accelerated velocities, which may be denoted by the unequal spaces, 1, 3, 5, 7, etc. The resultant described by these two varying forces, will be the curve *Aabcd*, which is of the kind called a *parabola.*

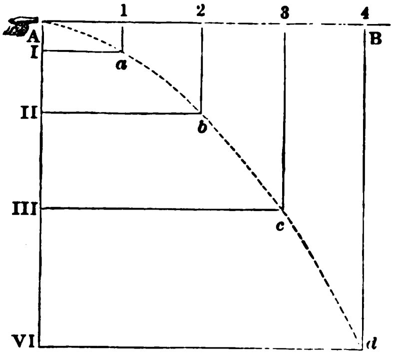

FIG. 82.

If the ball be fired obliquely, its path will also be a parabola, as represented in Fig. 83. The greatest range is obtained with an elevation of 45°. It will be seen by inspection, that the range is diminished equally by equal deviations above and below this angle, as for 20° or 70°.

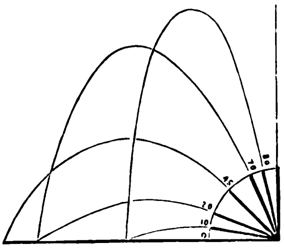

FIG. 83.

**227. These results are true** only for bodies moving in a vacuum. The resistance of the air always acts perpendicularly to the resultant already obtained, and with a force so varying that, in gunnery, the theoretical results are of very little value. By reason of this resistance, the path of the ball never rises so high nor has so wide a range as the parabola, but is an unsymmetrical line, called a *ballistic curve.* For the same reason, the greatest range for swift motions is somewhat less than 40°.

As each force acts independently of the other, it is evident that the ball shot horizontally will reach the earth in exactly the same time as if it had been dropped; and, if fired obliquely, in twice the time required to drop the ball from the highest level it attains.

**228. Universal gravitation.** Thus far, without sensible error, we have considered gravity as a constant force; because the heights through which terrestrial bodies ordinarily pass are insignificant when compared with the radius of the earth, and their distances may therefore be neglected. But when we consider the earth's attraction upon remote bodies, or universal gravitation acting between distant bodies, we must take into account not only (1.) the quantity of matter, or 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.*

Representing gravitation, mass, and distance of any body by G, M, and D, and of any other body by the same letters accented, the statement of each portion of the law becomes,

[33.] $G : G' :: M : M'$.

[34.] $G : G' :: D'^2 : D^2$; or,

[35.] $G : G' :: M D'^2 : M' D^2 = \frac{M}{D^2} : \frac{M'}{D'^2}$.

**229.** The student will notice: 1. That the greater the mass the greater the attractive force of the body.

If the mass and attractive force of the earth be taken as unity, the *masses and attractive* forces of other celestial bodies will be respectively: the Sun, 314,760; the Moon, .0128; Mercury, .065; Venus, .785; Jupiter, 300.

2. The attraction diminishes as the square of the distance increases.

Thus, the sun is 380 times farther from the earth than our moon, and by reason of its distance exerts but $(\frac{1}{380})^2 = \frac{1}{144400}$ part of the force with which the earth attracts the moon. Nevertheless, its attractive force, due to mass, is 314,760 times that of the earth; therefore, the product of these two quantities, or $\frac{314760}{144400}$, shows that the sun actually exerts on the moon $2\frac{1}{5}$ times greater attraction than the earth exerts.

3. The attraction is mutual.

The earth attracts the moon by its mass, and the moon attracts the earth by its mass. If the earth and moon were to fall together, the moon would move 81 times the distance traversed by the earth because its mass is but $\frac{1}{81}$ that of the earth. When any body falls to the earth, the earth also falls toward it, but of course passes through an inconceivably small space, by reason of its greater mass.

**230. Whenever the distance** between any two bodies varies to a sensible amount, gravity must be considered as a variable force, which may be measured by taking as unity the effect of gravity at the earth's surface, as shown either by a unit of surface weight, or by the increment of velocity, $g = 32.16$.

Thus, if a body be taken 1000 miles above the earth's surface, it is 5000 miles distant from the center. The force of gravity will, therefore decrease in the ratio $(\frac{4000}{5000})^2 = \frac{16}{25}$. At this distance a body will weigh $\frac{16}{25}$ of its surface weight, and acquire a velocity of $\frac{16}{25}$ of 32.16 feet, or 20.6 feet during a fall of one second. At a distance of 2000 miles above the surface, the weight will become $\frac{4}{9}$, and $g = 14.3$ feet. At 4000 miles, weight $= \frac{1}{4}$ and $g = 8.02$ feet. At the distance of the moon, which is about 60 times the earth's radius, the weight, considered with reference only to 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 about $\frac{1}{20}$ of an inch (.0534 inch).

If the dimensions of the earth be taken as unity, the relative gravity of any heavenly body may be found by dividing its mass by the square of its radius.

**231. Since the earth's equatorial radius** is thirteen and one-fourth miles longer than its polar radius, we should expect to find that the force of gravity would increase in going from the equator to the poles. Careful experiments have determined that a body, on being carried from the equator to the poles, will gain $\frac{1}{194}$ in weight. The oblateness of the earth causes a gain of $\frac{1}{590}$ part; and the rotation of the earth on its axis causes a gain of the remaining $\frac{1}{289}$ part. Consequently, the increment of gravity will vary with the latitude, being at the equator 32.0934 feet; at New York, 32.166 feet; at London, 32.1912; at Spitzbergen, 32.2528. These facts could be verified by attaching a load to a delicate spring, and watching the changes of the spring on sailing from the equator to Spitzbergen.

**232. If a body could be carried below** the surface of the earth, it is manifest that the portion of the earth above the body would attract it from the center, and thereby diminish the weight of the body. If a ball could be placed in an empty space at the earth's center, it would be sustained there by equal and opposite attractions, and, of course, would weigh nothing. If the earth were of uniform density throughout, a mass one thousand miles from the center would weigh one-fourth of the surface weight; at two thousand miles, one-half the surface weight; at three thousand miles, three-fourths of the surface weight: and, in general, *the weight of a body below the earth's surface would be inversely proportional to its distance from the surface.*

### 233. Recapitulation.

Gravity is a constant force when mass alone is taken into account, but is a variable force when the distance between two masses varies sensibly. 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. It acts as a variable force in the phenomena of the heavenly bodies, and, also, to a limited degree, in different places on the same meridian of the earth.

The intensity of gravity 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.

This last point is a deduction from the following section.

## THE PENDULUM.

**234. About the year 1581,** Galileo noticed that a lamp, swinging by a chain from the ceiling of the cathedral in Pisa, performed its vibrations in equal intervals of time. This observation led him to the invention of the pendulum. It was first employed in clocks by Huyghens, in 1656. If a heavy bob, as B, Fig. 84, 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, B G, will be partially resisted by the string, acting in the line B L, and the remaining component of gravity will force the ball in the line B T.

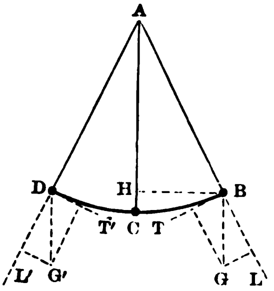

Fig. 84.

Moving slowly at first, it will gradually gain in velocity, and on falling the whole height, H C, will have acquired 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 pendulum may be considered simple, although it is really compound.

A *simple pendulum* is conceived to be a heavy material particle, suspended by a line without weight, and oscillating about a fixed point.

**235. The motion of the pendulum,** from B to D, or from D to B, is called a *vibration* or *oscillation*, The *time* of vibration, is the time occupied by the pendulum in describing this arc. The *amplitude of vibration*, is measured by the angle B A C, or by the arc B C, divided into degrees, minutes, and seconds. The *center of suspension*, is the point about which the pendulum vibrates. The laws of the pendulum may be found, experimentally, by using simple pendulums of different lengths and weights, as shown in Fig. 85.

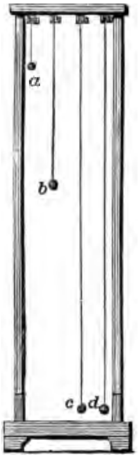

FIG. 85.

**236. Since the vibrations** of any given pendulum are caused by gravity alone, the time of vibration will not vary with the quantity or quality of the weight suspended. Thus, if the ball *c* be copper and *d* wood, they will vibrate in the same time. Neither will the time sensibly vary if the amplitude of vibration does not exceed certain limits; because the increase in the length of the arc is so compensated by 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.

**237. The length of the pendulum** is a very important consideration, for it can be proved, mathematically, that the time of vibration of a simple pendulum in a very small arc, is equal to the ratio of the circumference of a circle to its diameter (expressed by $\pi = 3.1416$) multiplied by the time of falling vertically half the length of the pendulum.

Now, if we make $\frac{1}{2}l$ equal to $S$ in the formula [30.] $t = \sqrt{2S \div g}$, we may express this law more conveniently by the formula : [36.] $t = \pi \sqrt{l \div g}$; that is, the time of one vibration of any pendulum is equal to 3.1416 times the square root of the quotient of the length of the pendulum divided by the increment of gravity.

**238.** If another pendulum, vibrating in another place, be represented by the same variable factors accented, as $t' = \pi\sqrt{l' \div g'}$, we may form the proportion,

$$t : t' :: \pi\sqrt{\frac{l}{g}} : \pi\sqrt{\frac{l'}{g'}}: \text{ or, canceling } \pi,$$

$$[37.] \quad t : t' :: \sqrt{\frac{l}{g}} : \sqrt{\frac{l'}{g'}}.$$

If the pendulums be taken in the same place, $g = g'$, and the proportion becomes

$$[38.] \quad t : t' :: \sqrt{l} : \sqrt{l'}: \text{ or, } t^2 : t'^2 :: l : l'.$$

First law.—*The times of vibration of any two pendulums are proportional to the square roots of their lengths.*

Second law.—*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. The length of a two seconds pendulum is $39.1 \times 2^2 = 156.4$ inches: of a half seconds pendulum, is $39.1 \times (\frac{1}{2})^2 = 9.77$ inches; of one vibrating once in three-fourths of a second, is $39.1 \times (\frac{3}{4})^2 = 22$ inches.

If $l = l'$, that is, if the same pendulum be carried to different places, [37.] becomes

$$[39.] \quad t : t' :: \sqrt{\frac{1}{g}} : \sqrt{\frac{1}{g'}} = \sqrt{g'} : \sqrt{g}.$$

$$[40.] \quad t^2 : t'^2 :: g' : g.$$

Third law.—*The intensities of gravity at any two places are inversely proportional to the square of the times of vibration of the same pendulum.*

Since the force of gravity increases (231) from the equator toward the poles, the same pendulum will vibrate in less time in being carried from the equator to the poles. As the number of vibrations in a given time is inversely proportional to the time occupied in one vibration, the intensity of gravity in any two places will be directly as the squares of the number of vibrations performed in a given time by the same pendulum. [41.] $g : g' :: n^2 : n'^2$.

**239.** If $t = t'$, that is, if two pendulums vibrate in the same time in different places,

$$[42.] \quad l : l' :: g : g'.$$

FOURTH LAW.—*The lengths of any two pendulums vibrating in the same time are directly proportional to their increments of gravity.*

It follows, from this, that a seconds pendulum must be lengthened as its distance from the equator increases. This important deduction is amply confirmed by careful experiments, made in various latitudes. The length of a seconds pendulum, at the level of the sea, is, at the equator, 39.02167 inches; at New York, 39.10237 inches; at London, 39.13983 inches; at Spitzbergen, 39.21614 inches.

**240. Since the length of a seconds pendulum** can be determined with great accuracy, we have in it a ready means of determining the variation in the intensity of gravity on the earth's surface, and, by consequence, can calculate the figure of the earth, to which, combined with its rotation, the variation is due.

In the original equation, $t = \pi \sqrt{l \div g}$, if $t$ equals one second, $g = \pi^2 l = 9.87\, l$. Hence, at New York, the increment of gravity is $39.10237 \times 9.87 = 385.94$ inches = 32.16 feet. The fall of a body, in vacuo, at New York, during the first second, is one-half this quantity, or 192.97 inches.

**241. These laws are strictly true** only when the pendulum vibrates in a cycloidal arc, or an infinitely small circular arc. If two pendulums of the same length vibrate in unequal arcs, the one moving in the shorter arc will gain on the other. The daily loss through increase in the length of the arc is equal to $\frac{5}{3}A^2$, in which A represents the amplitude, expressed in degrees.

The daily loss for an arc of 1° is $1\frac{2}{3}$ seconds; for 4°, $26\frac{2}{3}$ seconds; for 6°, 1 minute; for 12°, 4 minutes. Therefore, unless the arcs are very unequal, we shall not be able to detect any difference in their times of vibration, except after a long interval.

**242. The compound pendulum** usually consists of a heavy bob, suspended by an inflexible bar, from a fixed point. In this, the mass of the bob and the weight of the bar are both to be regarded. If the motions of any three particles of the system, as *a*, *o*, and *b*, be considered, it is manifest that those nearest the center of suspension will tend to move with the greatest velocity. Hence, the particle at *a* will accelerate the more distant particles at *b*, and the more distant particles will retard those nearer. There will, however, be one particle, as at *o*, which moves at the average rate of all, and 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. It will, therefore, move as if it were vibrating alone by a thread without weight, thus fulfilling all the conditions of a simple pendulum. If all the matter of the pendulum were concentrated in this particle, its rate of vibration would remain unchanged. This point, which generally lies below the center of gravity, is called the *center of oscillation*.

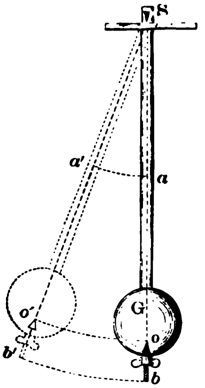

FIG. 86.

**243. 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. 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. Good results may be attained by the following simple apparatus. Fig. 87. Make of hard wood a slender bar about 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 19.55 inches above and below this point insert two bits of knitting needles, or, preferably, knife edges.

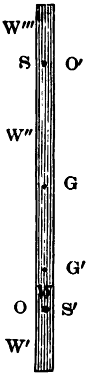

FIG. 87.

The bar, made to swing from either point, will vibrate in about one second. If the vibrations from the two centers are not performed in exactly 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 from either point of suspension are the same, the distance between them is the length of the pendulum. If the precise time of this vibration is known, the length of a seconds pendulum can be calculated. A shorter rod may be used to attain the same result.

**244. Suppose such a bar** to be suspended from S, and a pound weight, W, to be attached to the bar exactly at O; then, since all the matter of the pendulum may be considered as concentrated in the center of oscillation, without regard to the quantity of matter, any addition at that point will have no influence on the time of vibration, although the bar will then have a new center of gravity, as at G′.

If this weight be applied below the point O at W′, its effect will be not only to depress the center of gravity, but also that of oscillation, and thereby lengthen the pendulum.

If the weight is applied between S and O at W″, its effect will be to raise the center of gravity and oscillation, and thereby shorten the pendulum. Thus any addition of matter made below the point of suspension, except at the center of oscillation, lengthens or shortens the pendulum.

**245.** If, now, the weight is applied above the center of suspension, at $W'''$, it tends to retard the vibration of the bar, because the particles above S move in exactly opposite directions from those below. The time of vibration is thereby lengthened, and, consequently, the center of oscillation is lowered. We may lower the center of oscillation to any extent by increasing the weight, or by increasing its distance above S. Every successive addition, while it raises the center of gravity, lowers the center of oscillation.

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

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 increase the distance of 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 vibration of pendulums whose lengths are 156.4, 351.9, and 977.5 inches.

**246. The utility of a pendulum,** as a measure of time, depends upon the perfect equality in the times of its vibrations. 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. This tendency may be counteracted by raising the bob to make the clock go faster, and by lowering the bob to make the clock go slower.

**247. Compensating pendulums** are those which are made self-regulating, by constructing them 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.

Thus, the gridiron pendulum, Fig. 88, 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 $\frac{100}{61}$ that of the brass. The mercurial pendulum, Fig. 89, beating seconds, has, at the end of a steel rod, a stirrup holding one or two glass cylinders, each containing a column of mercury about 6.7 inches high.

FIG. 88.

**248.** The mode in which the pendulum is applied to clocks is shown in Fig. 89. 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.

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.

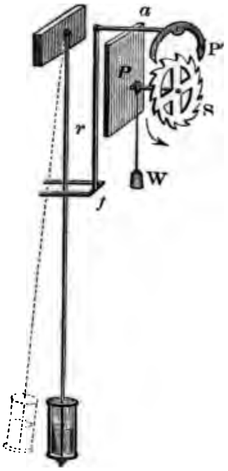

FIG. 89.

**249. If we swing a simple pendulum in our fingers, in**

any direction, then, by virtue of the second law of motion, it will tend to vibrate in the same direction incessantly. We may even twirl the string, so as to make the ball revolve on its axis, without altering the direction. In other words, *the plane of vibration of a pendulum is invariable*, and is not affected by rotating the point of suspension.

Foucault has applied this principle in demonstrating the diurnal revolution of the earth. Suppose a long pendulum were suspended over the north pole and set to vibrating toward a given star, in the line *m m′*, it would continue to vibrate in the same direction, toward or from the star. Meanwhile the earth, revolving on its axis, would bring a new meridian beneath the arc of the pendulum at each vibration, and, as an observer on the earth's surface is unconscious of his own motion with the earth, the pendulum would appear to move toward the right; that is, from east to west, or in opposite direction from that of the earth. In twenty-four hours, every meridian of the earth would have been brought beneath it, and hence the pendulum at the poles has an apparent motion of fifteen degrees per hour. *At the equator*, the plane of vibration

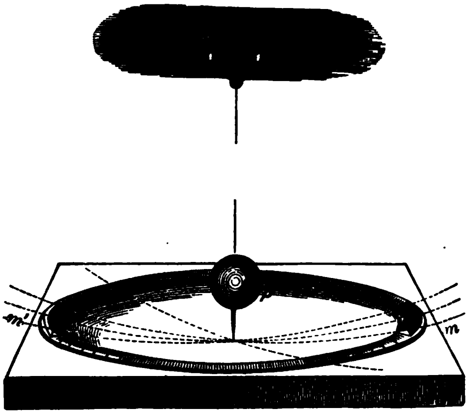

Fig. 90.

is carried forward by the revolution of the earth, and, therefore, the pendulum will undergo no change, in reference to the direction of its vibration.

Between the equator and the poles, the apparent change increases as we recede from the equator, from 0° to 15° each hour. *

The experiment is best performed with a long wire and a very heavy bob. Foucault hung from the dome of the Pantheon, in Paris, a pendulum two hundred and twenty feet long, so as to vibrate over a table, and within a circular frame divided into degrees, minutes, and seconds. The path of the pendulum was marked by means of fine sand sprinkled on the table. The pendulum, at each double vibration, returned to a point about one hundred seconds to the ~~left~~ ri of its starting point, and, as the experiment was performed on a large scale, this motion could be detected by the eye, and thus the motion of the earth on its axis was rendered visible.

**250. If it were required** to stop the motion of a pendulum instantly, without producing any pressure on the center of suspension, the force must be applied at the center of oscillation. Hence, this point is also called the *center of percussion*, because it is the point in which all the impetus of a moving body may be considered as concentrated. The effect of any blow given or received at this point will be greater than at any other. If a stick of uniform thickness, held at one end, be twirled around by a motion of the wrist, and made to strike an obstacle at a point on the stick nearer or more remote than two-thirds of its length, a disagreeable jar will be felt. The jar will not be noticed if the blow is given at exactly the center of percussion.

Since the centers of suspension and oscillation, or percussion, are interchangeable, if we strike a blow at one end of the stick, we shall avoid strain by holding the rod at one-third of its length from the other end. A good ball or

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* The hourly variation is proportional to the *sine of the latitude;* hence, at Cincinnati, it should be about nine degrees twenty-five minutes per *hour.*

cricket player soon learns by experience at what point he can strike the most effective blow with his bat. In axes, hammers, etc., the head is made heavy, so that the centers of gravity and percussion are very near each other. As the center of oscillation is sometimes outside of the body, so, also, a hammer may be so made, or held, as to have no center of percussion within it. Such a body will expend part of its impulse in a strain upon its axis.

**251.** A beautiful illustration of the center of percussion is seen in the *ballistic pendulum*, an instrument employed to measure the velocity of projectiles. This consists of a heavy mass of wood, suspended at the end of a long iron bar. If a cannon ball strikes the ballistic pendulum at the center of percussion, it simply makes it swing like a pendulum; but if the impact is at any other point, a part of the force tends to tear it away from its axis. The velocity with which it begins to move when the cannon ball first strikes it, may be determined by observing the length of the arc through which the mass is driven; the weight of the mass being also known, the momentum and velocity of the ball may be calculated.

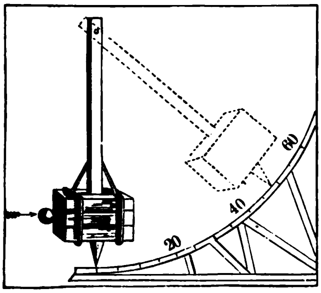

Fig. 91.

### 252. Recapitulation.

The pendulum may be simple or compound.

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

The time of vibration depends,

1. On the force of gravity.
2. On the length of the pendulum.
3. On the amplitude of vibration.

### CIRCULAR MOTION.

**253.** Suppose a ball to be whirled in a circle, by means of a rubber cord held by the hand. The ball will tend to fly off, and will exert a certain tension on the cord, which will be resisted by the elastic force of the rubber. The ball is, therefore, revolving by reason of two forces, viz.: the impulse given by the hand, and the restraining power of the cord.

**Circular motion** is always produced by the action of two forces, which are called the *centripetal* and *centrifugal* forces. The centripetal force acts along the radii of the circle, and tends to draw bodies toward the center. The centrifugal force acts at right angles to the radii, and tends to make bodies fly farther from the center, in the direction of the tangent to the circle. In the previous example, the elasticity of the rubber represents the centripetal force, and the tension exerted by the ball, the centrifugal force.

**254.** It is only when these forces are exactly equal, that circular motion can be maintained; for if, at any time, the centripetal force is destroyed by breaking the cord, the ball will fly off in a tangent. If the centrifugal force is destroyed, the cord will draw the ball again to the hand. If either force were weakened, the ball would describe some other curve than a circle. If both forces are increased or diminished in the same proportion, the effect will be merely to increase or diminish the amount of motion.

**255. If a stone be hurled** from a sling, we may measure either force by the momentum of the stone as it leaves the strap. We can readily determine that, when the other factors are unchanged, the centrifugal force (1.) will increase with the number of revolutions made in a second, and (2.) also with the weight of the projectile. A more precise determination will require a closer analysis of circular motion.

Suppose a body at the point *a*, to be under the influence of two forces, viz.: (1.) a constant force acting at infinitely small intervals, and capable of moving the body in the direction of a fixed point, C, with a force equal to $ab$; and (2.) an impulsive force at right angles to the constant force, and represented both in intensity and direction by $ad$. Under the joint action of these forces, the body will move in the diagonal $aa'$, which will also measure the intensity with which it would continue in the same direction forever, were the constant force to cease. But the constant force acts in the second instant with equal intensity, $a'b'$, toward the point C, and, therefore, the line traced in the second instant will be $a'a''$. In like manner, the body will pass, in succeeding instants, over lines which form the perimeter of the polygon, $aa'$, $a''a'''$, etc. Now, as the instants of time considered are infinitely small, the perimeter of the polygon will not differ from a circle whose center is C.

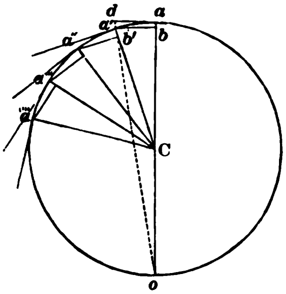

FIG. 92.

To determine the measure of these forces, we find, by Geometry (325), $ab : aa' :: aa' : ao$; or, $ab = aa'^2 \div ao$; but $ab$ represents the centripetal force, and its equal, the centrifugal; $aa'$ represents the velocity of the body, and $ao$ the diameter of the circle in which it revolves. Therefore, the centrifugal force equals the square of the velocity, divided by twice the radius of the circle in which the body revolves:

$$[43.] \quad C = \frac{v^2}{2r}.$$

**256. To ascertain the relation** of centrifugal force to gravity, we have only to compare the spaces in feet through which a body would move in a second under gravity alone, and under the centrifugal force alone. Thus, we know that a body whose weight, or gravity, is W, will fall in one second $\frac{1}{2}g = 16.08$ feet. Hence,

$$W : C :: \tfrac{1}{2}g : \frac{v^2}{2r}; \text{ or, } [44.] \quad C = \frac{Wv^2}{gr} = \frac{Wv^2}{32.16r}.$$

That is, *The centrifugal force of a body is equal to the product of its weight by the square of its velocity per second in feet, divided by* 32.16 *times the radius of the circle expressed in feet.*

**257. A different expression** may be given to this formula, by employing, instead of velocity (1.) the number of seconds required to perform one revolution $= t$, or (2.) the number of revolutions performed in one second $= n$. Since the circumference of a circle equals $2\pi r$, if $v$ is made to represent the space described in one second, the number of seconds required to make one revolution is $t = 2\pi r \div v$. Whence, $v^2 = 4\pi^2 r^2 \div t^2$. Substituting this value in [44.],

$$[45.]\quad C = \frac{W}{g\,r} \times \frac{4\pi^2 r^2}{t^2} = \frac{W\,r}{t^2} \times \frac{4\pi^2}{g} = \frac{W\,r}{t^2} \times 1.2275.$$

Again, the velocity is the number of revolutions, or fraction of a revolution, made in one second; or $v = 2\pi r n$. Whence, $v^2 = 4\pi^2 r^2 n^2$. Substituting this value in [44.],

$$[46.]\; C = \frac{W}{g\,r} \times 4\pi^2 r^2 n^2 = W r n^2 \times \frac{4\pi^2}{g} = W r n^2 \times 1.2275.$$

The last formula may be thus expressed: *The centrifugal force of a body revolving in a circle is equal to the product of its weight by the number of feet in the radius of the circle, multiplied by the product of the square of the number of revolutions per second by* 1.2275.

If, for example, a sling two feet long whirl a ten pound weight at the rate of five revolutions per second, the centrifugal force is $10 \times 2 \times 5^2 \times 1.2275 = 613.75$ pounds, or it would require that force to retain it in the sling. To retain any weight in this sling at all possible positions, the centrifugal force must equal gravity, or $C = W$, and the equation becomes $1 = r n^2 \times 1.2275$, from which we find that the sling should revolve at the rate of two-thirds of a revolution per second.

**258.** By the inspection of these equations, we find:

1. *That the centrifugal force increases with the weight.*
2. *When the radii are equal, the centrifugal forces are directly*

*as the squares of the velocities per second, or as the squares of the number of revolutions per second.*

3. *When the times of revolution are equal, the centrifugal forces are directly as their radii.*

4. *The centrifugal forces of any two bodies are in the compound ratio of their weights, their radii, and the squares of their velocities.*

**259. These laws may be fully verified** by the whirling table, Fig. 93. Thus, the first and third may be verified by attaching to the axis of rotation a frame on which a wire, *a b*, is stretched. Two perforated balls, united by a string, are placed on this wire, and the frame is made to revolve rapidly. (1.) If the balls are of unequal weight and equally distant from the axis, the heavier ball will draw the other to its own side of the frame. (2.) Unequal balls will remain at rest if placed on opposite sides of the axis, at distances inversely proportional to their weights.

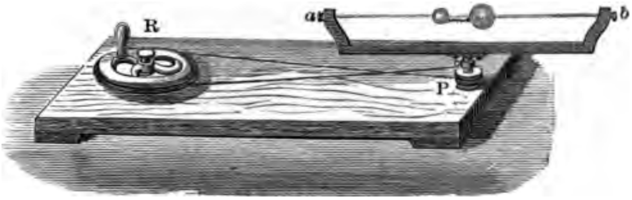

FIG. 93.

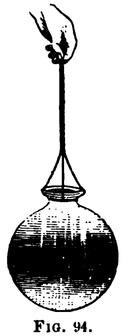

FIG. 94.

Other apparatus attached to the table may be used to demonstrate the other laws; but as this apparatus is not common, the following examples are also adduced:

If a glass bottle, containing a little colored water and some mercury, is swiftly revolved by a twisted string, both fluids will be whirled away from the axis, but the mercury, having the greater relative weight, will occupy the equator of the bottle, leaving a belt of water on each side. Fig. 94. This confirms the first law. When a circus rider drives into the ring, he stands erect, that the line of direction may fall between his feet. As he increases his motion around the ring, the centrifugal force gives both himself and his horse an outward tendency which they counteract by leaning toward the center of the circle. By so doing, the rider causes his line of direction to fall without his base and within the ring, and thus the resultant between the outward action of the centrifugal force and the downward action of gravity is kept in a line perpendicular to the circular bank around the ring. As a consequence of this, a less portion of the weight of the rider is supported by his saddle, and it is easy for him to keep his balance merely by regulating his speed. If he is likely to fall within the ring, he increases his speed to increase his centrifugal force, which throws his body outward, and thus restores the equilibrium. This confirms the second law. The same illustration will also confirm the third law, for if the ring be enlarged so as to be very nearly a straight line for a short distance, the rider will derive little or no advantage from centrifugal force in maintaining his balance, even if the velocity be greatly increased.

**260. Familiar examples** of centrifugal force are seen in the mud and water flying off from the wheels of a carriage in rapid motion. Large grindstones are frequently broken in pieces by turning them too rapidly. In large laundries clothes are dried by placing them in a large wire basket, which is then revolved many hundred times a minute. Railways, in turning curves, have the outer rail higher than the inner, to counteract the centrifugal force. If a cup of water be balanced on the inner edge of a hoop, the cup and its contents may be whirled over the head without spilling the water. It has been shown that we may compute the figure of the earth by the different intensities of gravity, as determined by the pendulum, and it has been proved by Newton that the spheroidal shape of the earth is precisely that which a globe of plastic material would take by virtue of the centrifugal force.

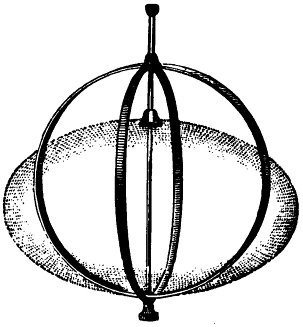

FIG. 95.

An easy illustration of the reason of the flattening of the earth, is afforded by passing an axis through two thin hoops of tin, and twirling them around with moderate velocity. They will take the shape shown in Fig. 95.

**261. If a cylinder, suspended by a string,** which coincides with its axis, be revolved rapidly by twisting the string, the centrifugal force of all the particles about the axis will be in equilibrium, and the direction of the axis will be unchanged. If, however, the string be attached a little to one side of the axis, or, what is the same thing, if the particles of the body are not symmetrically disposed about the axis of rotation, the more remote particles will have a greater centrifugal force than those nearer, and the cylinder will throw itself into a position such that it will revolve about an axis perpendicular to its length, and passing through its center of gravity, as shown by the dotted lines of Fig. 96. *The axis about which a body tends to revolve is the shortest axis of its figure.*

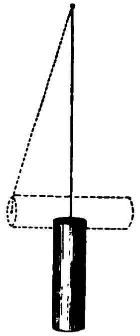

FIG. 96.

The same fact may be shown by using, instead of the cylinder, a cone, an oblate or prolate spheroid, a ring, or a chain.

**262. The gyroscope,** Fig. 97, is an instrument which illustrates the composition of rotary motions. One form of this consists of a brass ring, C, within which a heavy disk, T, revolves on its own axis, independently of the ring. Motion is communicated to it, by first winding a cord about the axis, and then suddenly pulling it off. If, when the disk is rotating speedily, the end of the axis be supported on a pivot, *p*, the axis of the disk will begin to revolve in a horizontal plane

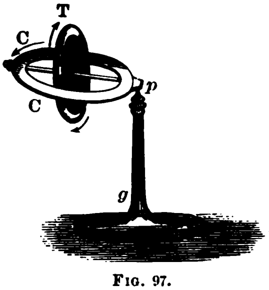

FIG. 97.

about the vertical support, *p g*, and in a direction corresponding with the movement of the lower part of the disk.

The forces which act upon the instrument are the rotary motion of the wheel about its axis, and gravity, which tends to turn the wheel downward at right angles to the axis. The wheel moves in a resultant between these two motions.

If the disk be set in rapid motion and held in the hand by the ring, and we attempt to turn the axis up or down, it will oppose a sensible resistance to such a change in the plane of its rotation. The momentum of the disk gives a certain inertia by virtue of which the instrument "*persists in the plane of its rotation.*"

If the wheel be suspended so that gravity can not act to bring it downward, the axis will continue to point in the same direction during the rotation of the wheel. This form of the gyroscope is used to demonstrate the invariability of the axis of the earth during its rotation.

### 263. Recapitulation.

Circular motion is due to
  Centripetal force in the direction of the radii.
  Centrifugal force in the direction of the tangents.

These forces vary,
  (1.) With the weight.
  (2.) With the length of the radii.
  (3.) With the squares of the velocities.

## CHAPTER IV.

### MECHANICS OF FLUIDS.

**264. Hydrostatics** treats of the equilibrium and of the pressure of liquids. *Hydrodynamics* treats of the movements of liquids. *Hydraulics* considers the practical application of the laws of Hydrodynamics to the conveying of water in pipes.

**265. All solids** act in masses: even the particles of the finest powder must each be considered as a mass whose figure is dependent on the cohesion of its molecules. On the other hand, each molecule of a fluid acts independently of every other molecule, and will, therefore, move on the application of the slightest force. In practice it is found that the particles of all liquids have some cohesion, as may be seen by dropping them slowly from the mouth of a bottle. The formation of drops is an evidence of cohesion, and the varying size of the drops in different liquids is an evidence that cohesion varies in liquids as well as in solids: thus a drop of alcohol is only two-thirds the size of a drop of water, and this, in turn, is smaller than a drop of sirup. The greater the cohesion of its molecules the less will be the fluidity of the liquid. When the cohesion is considerable, as in tar, the liquid is termed *viscous*. Fluidity is perfect only in aeriform bodies; nevertheless, cohesion is not taken into account in the mechanics of liquids.

**266. The principal difference** between liquids and gases arises from the fact that gases may be compressed to almost any extent, while liquids may be considered without material error as *non-compressible* fluids. Nevertheless, all liquids are somewhat reduced in volume when submitted to pressure. Under a pressure of 15 pounds to the square inch, mercury suffers a compression of 0.000005 parts of its original volume; water, a compression of 0.00005. It has been found that, within certain limits, water and mercury continue to decrease in volume in the same ratio under additional pressures. In every case, as soon as the pressure is removed, all fluids return to their original volume.

Except for the difference in compressibility, liquids and gases are governed by the same laws. For this reason, the term fluid will be employed only when both liquid and aeriform bodies are meant.

### TRANSMISSION OF PRESSURE.

**267. From the constitution of liquids** just determined, follows a most important distinction between solids and liquids. Solids can transmit pressure only in the direction of the force acting upon them; but liquids will transmit an impressed force in every direction—upward, downward, sideways—at the same time. 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, 5, and fill the vessel with water. Suppose the pistons to play without friction and the water to have no weight, then there will be no tendency to motion anywhere in the vessel. Now apply a pressure of one pound upon the piston representing unity. Each molecule beneath the piston will be slightly pressed, and a certain elastic force will be developed in each. Each one will then react upward against the piston, sideways against the sides of the vessel or against adjoining molecules, and downward against the molecules beneath. The adjoining molecules will transmit the pressure in a like manner to those of a third series, and they onward,

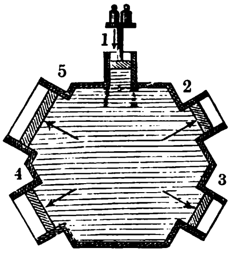

Fig. 98.

so that every molecule in the vessel will both receive and transmit an equal pressure. Therefore, each piston will be thrust outward with a force proportional to the number of molecules beneath it, and as these molecules are of the same size, the pressure on each piston will be proportional to its area; 1 will be pressed outward with a force of one pound, 2, by a force of two pounds, 3, by three pounds, etc. It will be found necessary to apply the amount of force thus indicated to keep the pistons in place. Any portion of the sides of the vessel, or any solid immersed in the fluid, will in like manner sustain pressure in proportion to the area of its surface.

**268.** It is also evident that *the pressure exerted on the surface at any point must be perpendicular at that point,* for if it is not, it may be resolved into two portions, one perpendicular and the other parallel to the surface—of these, the former would exert pressure and the latter would produce motion in the fluid.

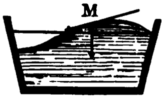

FIG. 99.

**269.** From similar experiments, Blaise Pascal deduced this important law:

1. *Fluids submitted to pressure transmit it undiminished in every direction.*

The following corollaries are a necessary consequence:

2. *The pressure sustained by any surface is proportional to its area.*

3. *The direction of the pressure at any point is perpendicular to the surface at that point.*

No apparatus can perfectly demonstrate these laws, because no liquid is without weight. A rough demonstration can be had by fitting open tubes to two necks of a Woulfe's bottle full of water, and thrusting a cork into the other neck. The height to which the water will rise in the tubes will be proportionate to the force of the thrust.

### EFFECT OF GRAVITY.

**270.** Fluids also exert pressure in consequence of their weight. Suppose the vessels A B C D filled with any liquid to the level C D, and consider each divided into an infinite number of strata by horizontal planes, indicated by the lines of the diagram. Each stratum may then be considered as a cylinder exerting a pressure on its base equal to its own weight. By Pascal's law the weight of each stratum above will be transmitted to each stratum below in the ratio of their areas, so that the pressure sustained by any section, as A B, G L, G R, will be equal to the weight of a column of liquid whose base equals the area of the section and whose height equals its depth.

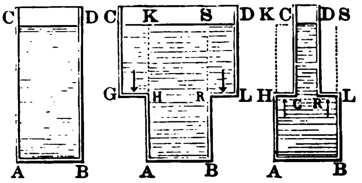

Fig. 100.

**271.** Several important conclusions may be deduced from this:

1. The pressure on the bottom of a vessel is independent of the form of the vessel.

This may be illustrated by Haldat's apparatus, Fig. 101. Fill the bent tube with mercury to the level *c*, and pour water in the larger vessel till it reaches the index rod *o*. The water will press the mercury as high as the ring *a*. Now replace the larger vessel M by the smaller P, and fill with water to the index rod, when the mercury will rise to the same height as before, thus showing that the pressure is independent of the quantity of water, or of the shape of the vessel.

2. The pressure is proportioned to the density of the liquid.

In the last experiment, if the depths of the two liquids are measured, it will be found that the water column is 13.6 times longer than the column of mercury.

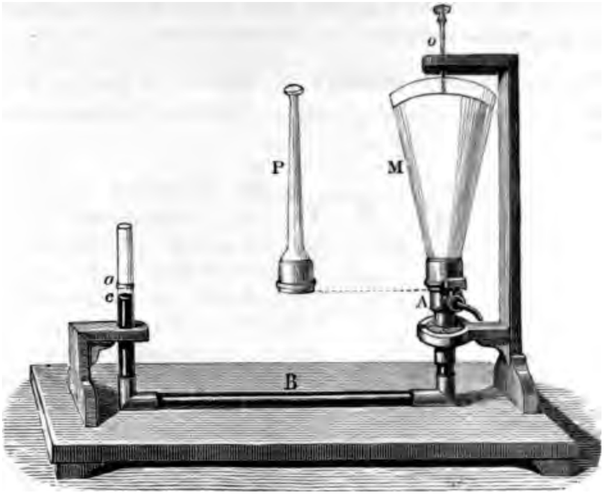

FIG. 101.

3. The pressure exerted by a fluid is proportional to its depth.

Tie 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.

**272. The upward pressure of liquids** is easily shown by reversing the last experiment: *i. e.* by thrusting the closed end of the empty tube into water, when the rubber will be driven into the tube farther and farther as the depth increases.

FIG. 102.

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 sum of the weights of the interior column and the disk exceeds the weight of the exterior column.

**273. The lateral pressure of liquids** is shown by the velocity with which they escape from orifices at different depths.

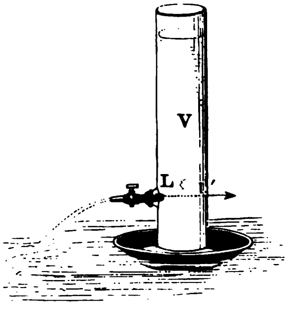

FIG. 103.

A fine illustration is shown in Fig. 103. This 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 be closed, the lateral pressures at L and L′ will be equal. Hence, equilibrium will be preserved and the jar will remain at rest; 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.

**274. The pressure on the bottom of a vessel** is equal to the weight of a column of fluid having the same base as the vessel, and a height equal to the depth of the fluid in the vessel.

If the fluid is water, since a cubic foot of water weighs 62.42 lbs, the total pressure equals the product of the area of the base in feet, by the depth in feet, and this by 62.42. Thus, suppose a cubical vessel two feet on each side. The pressure on the bottom will be equal to $2 \times 2 \times 2 \times 62.42 = 499.36$ lbs.

The pressure upon a body sunk to any depth may be calculated in the same way.

**275. The lateral pressure** may be computed for the whole side, or for a piston in the side, by the following rule:

The lateral pressure upon any surface is equal to the weight of a column of the fluid, the area of whose base equals the area of the surface, and whose height is the depth of the center of gravity of the surface below the level of the fluid. The center of gravity will be at the mean depth of the surface.

Suppose a square gate, C, in a canal lock has its upper edge 9 feet, and its lower 11 feet from the surface. The area will be 4 feet, the mean depth 9 + 11 ÷ 2 = 10 feet: hence, the pressure will be 4 × 10 × 62.42 = 2496.8 lbs.

It is important to observe that this pressure has nothing to do with the length of the vessel in the direction A B, or in other words with the amount of back-water; so that the gates of a canal lock sustains a pressure proportioned only to the depth of water and its own area.

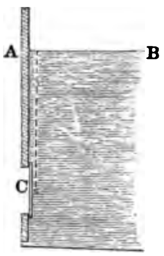

FIG. 104.

**276. Since the area** of any given body remains constant, the fluid pressure which it may be made to sustain, will vary as the depth. A body submerged in fresh water sustains a pressure on each square inch at the depth of one foot of 62.42 ÷ 144 = 0.4335 pounds. The compression of water is so slight that even for oceanic depths the pressure on each square inch may be taken without great error in multiples of this factor. Thus the pressure on each square inch at 10 feet will equal 4.335 pounds; at 100 feet 43.35 pounds; at 10000 feet 4335 pounds, or over two tons.

Empty bottles hermetically sealed have been sunk in the open sea with the uniform result that, at no very great depths, either the bottles have been crushed, or the corks have been forced through their necks. So pearl divers find it impossible to pass beyond a certain depth. When a ship founders at sea, the enormous pressure at great depths forces the water into the pores of the wood, and so increases its weight that no part ever comes again to the surface.

**277. Pascal demonstrated** the same fact for vessels containing fluids, in 1647. He fitted to the upper head of a strong cask a tube of small bore about forty feet long. The cask being filled with water he succeeded in bursting it by pouring a very small quantity of water into the tube. As an ounce of water will fill a tube $\frac{1}{15}$ of an inch in diameter and 40 feet long, even that quantity 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 pressure would multiply itself 277 times for each square inch on the vessel, which becomes 17.34 pounds for each inch. Either head of an eight gallon cask would have to sustain about 2500 pounds, and the total pressure on the cask would have exceeded 15,000 pounds. The pressure would have been the same whatever the diameter of the tube, provided the length was unchanged: thus, had the tube been an inch in area, the pressure must have been $0.4335 \times 40 = 17.34$ lbs. to the square inch.

FIG. 105.

Pipes conveying water from high reservoirs should be of great strength. A four-inch pipe, laid 100 feet below the level of the reservoir, sustains an internal pressure of more than 6000 pounds on each foot of its length. When a drain becomes clogged, the pressure of the accumulated water is sometimes sufficient to burst it.

**278. 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

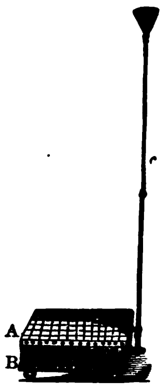

FIG. 106.

of one hundred square inches, and the height of the tube is three feet, the weight capable of being supported on A will equal $.4335 \times 100 \times 3 = 130.05$ pounds.

**279.** 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 Pascal's law, a pressure equal to that upon the piston would be communicated to each equal area in the bellows.

**280. Bramah's hydraulic press** is constructed on this principle.

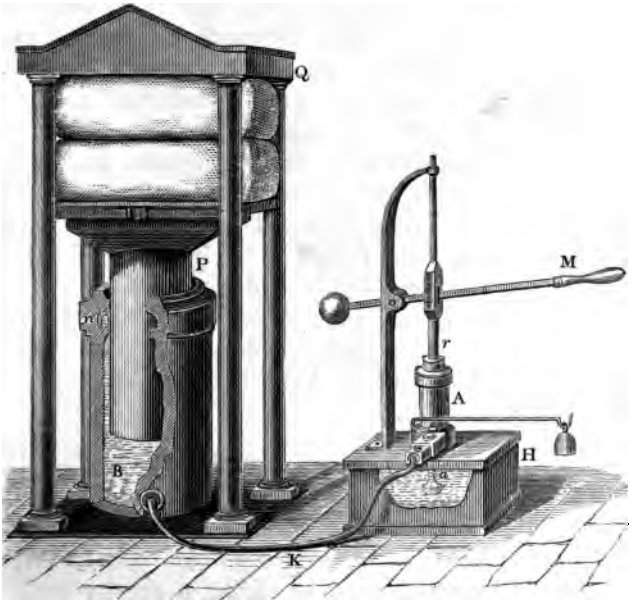

FIG. 107.

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 of 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.

281. 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 (157) 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, in pressing cotton, hay for shipment, and in various other industrial uses. 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.

## EQUILIBRIUM OF LIQUIDS.

282. **A liquid is not at rest** unless its particles are somehow restrained by a vessel or its equivalent. When the liquid is in equilibrium, the force of gravity tends to bring each molecule as near the earth's center as possible. This condition is attained only when the surface is perpendicular to the force of gravity.

**283. As two verticals,** near each other, are sensibly parallel, any liquid surface included between them is *level* or *horizontal.*

Whatever be the shape of the vessel, its surface will be level. In a common teapot, the water in the pot is always at the same level as that in the spout. So, a liquid poured into any system of communicating vessels, will rise to the same level in each. A common expression for this fact is "Water always seeks its lowest level." On this principle, water is conveyed from reservoirs through pipes to supply cities: the water will rise 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.

Fig. 108.

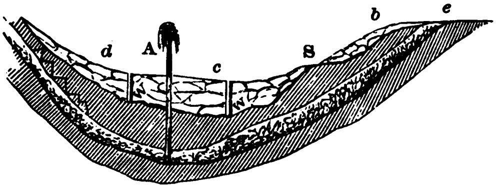

Fig. 109.

**284. Many natural phenomena** depend on the same principle. The crust of the earth is made up of various materials, arranged in strata, as in the diagram. Some of these, as clay or dense rock, can not be penetrated by water; others, as gravel or sand-stone, will permit it to trickle through them. Let the shaded portions of the diagram represent the impermeable strata, and the light portions the porous strata. The rain falling upon the surface at *d c b e*, will seek its lowest level, and, as it can not penetrate the underlying rock, will accumulate in whatever natural basins it affords. Thus,

1. Whatever rain falls upon the surface *b* will sink as low as possible, and finally come to the surface as a *spring*, at *s*.
2. The rain falling upon *c* and *d* will find a natural reservoir at *w* and *w′*, the overflow at *w* passing to the lower level at *w′*. A shaft sunk to either of these points would make a *well*.
3. The rain falling upon *e* would be confined between two impervious strata, one of which would prevent its passing to lower levels, and the other prevent a natural outlet. For this reason it must descend to its lowest level between the strata. A tube sunk through the intervening strata to the porous stratum, as at A, would allow the water to rise in it to a height proportioned to the amount of accumulation in the reservoir. Such wells are *Artesian*, because they have been long employed for obtaining water at Artois, in France.

The Artesian well at Louisville, Ky., was sunk to the depth of two thousand and eighty-six feet, and delivers, every twenty-four hours, at a height of one hundred and seventy feet above the surface, over three hundred thousand gallons of water, at a constant temperature of 76°.5 F.

**285. A spirit level** is used to determine horizontal lines, and operates on the principle that water always seeks its level.

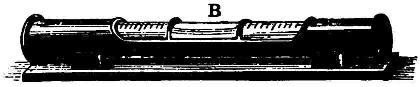

FIG. 110.

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

**286. As the verticals** drawn at two distant points incline toward each other, large surfaces of liquids are curved, to correspond with the general form of the earth's surface.

The surface of a large body of water is easily proved to be convex, by the phenomena presented by ships sailing from the shore. The hull first disappears, then the lower sails, and so on, until, at last, the whole sinks below the horizon.

The amount of curvature increases as 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 |

From this it appears that if the eye of the observer were at the water's edge, an object eight inches high would be visible at the distance of a statute mile. At the distance of ten miles, the height of a visible object would be over sixty-six feet. A mountain, a mile high, could be seen at a distance of almost ninety miles.

**287. As the earth revolves** on its axis, the surface of the ocean at rest is actually perpendicular to the resultant of gravity and the centrifugal force.

Under the influence of gravity alone, the surface of the ocean would be spherical, but in consequence of the centrifugal force, it is spheroidal, being elevated at the equator and depressed at the poles. This spheroidal surface is the *true level* of the ocean; a horizontal plane at any point is the *apparent level.*

**288. The attractive force** of the sun and moon constantly disturbs the true level of the ocean; the attractive force of the earth as constantly tends to bring the water to a level; hence the periodical oscillations of ebb and flow in the tides.

## BUOYANCY OF LIQUIDS.

**289.** When any solid is immersed in a fluid, every portion of its surface will undergo pressure, proportional to its depth. The horizontal pressures on the sides of the cube, Fig. 111, will all be equal and opposite, and will have no tendency to move the solid in any direction. The upper face will be pressed downward by the column M A B N, and the lower face will be pressed upward by the column M C D N. The solid is, therefore, urged upward by a force equal to the difference between these two pressures, which is evidently equal to the weight of the column of the fluid having the same base and the same height as the solid. This force is called the ***buoyant effort*** of the fluid.

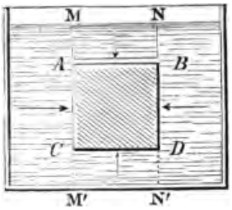

FIG. 111.

Now, as the force of gravity tends to lower the body, and as the buoyant effort tends to raise it, the effect of buoyancy will be to lessen the weight of the body. Consequently, *a solid immersed in any fluid loses an amount of weight equal to the weight of an equal volume of the fluid.*

**290. This principle** was discovered by Archimedes about 230 B. C. It may be verified by hanging to one arm of a balance a hollow cylinder, A, having a solid cylinder of copper, B, which exactly fits within it, suspended from the scale pan by a hook. Having first counterpoised the beam by weights put in the other scale pan, immerse the copper mass, B, in water. The cylinder will then lose a portion of its weight, and the equilibrium will be destroyed. On filling the bucket, A, with water, the equilibrium will be again restored; thus proving that the loss of weight occasioned by the immersion of the solid in water, is exactly equal to the weight of an equal volume of water.

FIG. 112.

The same truth is exemplified by the fact that a mass of stone can be more easily lifted at the bottom of the sea than on land, being lighter by the weight of an equal bulk of water.

**291. When different solids** are thrown into a given liquid, (1.) those that are heavier than an equal volume of the liquid will sink; (2.) those that are of the same weight for equal volumes will remain at rest in any position in the liquid; (3.) the others will float. When a solid floats on a liquid, the weight of the solid will be exactly equal to the buoyant effort of the liquid which it displaces. Hence, *A floating body displaces its own weight of the fluid.*

This principle may be proved by the apparatus in Fig. 113, which represents a vase with an L tube, to the base of which a stop cock, *r*, is attached. Pour in an amount of any liquid, and mark the level by the ring, *a*. Now place a floating body in the liquid—it will raise the level of the liquid. By means of the stop cock, *r*, draw out enough liquid to reduce the level again to *a*. The weight of this liquid will be found exactly equal to that of the floating body.

FIG. 113.

Many solids that sink in oil or alcohol will float on water; some woods that sink in fresh water will float on salt water; iron and copper will float on mercury, but gold and platinum will sink in it.

**292. If liquids which do not mix** are poured into the same vessel, the lighter will rise to the surface, as oil does upon water.

An interesting experiment may be made by pouring several liquids, of different densities, into a tall jar; as coal-oil, or naphtha; alcohol reddened by cochineal; water saturated by carbonate of potassa and tinged with litmus; and mercury. These, shaken together, will come to rest arranged in the order of their densities. The experiment may be further varied by floating balls of cork, wax, wood, and glass on the different surfaces.

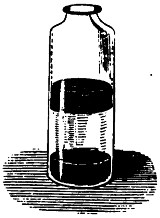

FIG. 114.

**293. If dense solids** are fashioned into thin-walled vessels, so as so displace a volume of water whose weight is greater than their own, the solids will float;

thus, iron, wrought into ships, not merely floats, but, as in the Great Eastern, has an enormous capacity for carrying its machinery and cargoes.

294. **The Cartesian diver** well exhibits the principles of flotation. This toy, which is made in various shapes, consists, essentially, of a figure connected with a hollow bulb, having a small opening beneath. The bulb is filled with water and air to such an extent that, when placed in a vessel nearly full of water, it just floats. The mouth of the vessel is tightly covered with sheet rubber or moist bladder. On applying pressure to the rubber by the fingers, several facts may be noted.

FIG. 114.

1. That pressure is transmitted undiminished. The air transmits the pressure to the water, and this compresses the air in the bulb, and drives the water within it.

2. That the pressure is in all directions; for the result is the same in every position of the vessel.

3. That the pressure is as the depth; for less pressure is required as the figure sinks.

4. Before the pressure is applied, the figure is lighter than the water and floats; on forcing water into the bulb, it becomes heavier and sinks. By carefully regulating the pressure, the figure may be brought to rest at any depth.

295. In like manner, fishes are enabled to float at any depth by expanding or contracting an air bladder with which they are provided. The weight of the human body is about the same as that of an equal bulk of water. *When the lungs* are well filled with air, the body is lighter,

but, when the air is expelled, the body is heavier than water. Therefore, if a person lies on his back in water, so as to leave only his mouth and nostrils out of water, he is not likely to sink. Drowned persons rise when enough gases have been generated through decomposition to render the body specifically lighter than water.

The buoyancy of swimmers is increased by the use of life preservers, which are bags filled with air or cork. As the buoyant effort of a liquid increases with its density, ships draw less water in the ocean than in fresh water; so, also, it is easier to swim in salt water than in fresh. On the same principle, farmers determine the saltness of brine by observing whether an egg or a potato will readily float in it.

**296. As the weight of a solid** may be considered as emanating from its center of gravity; so the upward pressure of a liquid acting upon a floating body, may be considered as acting at a single point, which is called its *center of buoyancy*. This point will evidently coincide with the center of gravity of the liquid displaced, and may be regarded as the center of support of the floating body.

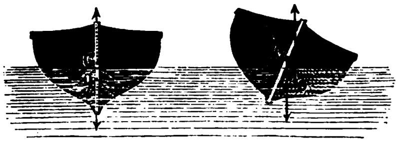

FIG. 115.

Thus, in the figure, G represents the center of gravity of the solid, and O the center of buoyancy of the fluid. A floating body will be in equilibrium only when the center of gravity and the center of buoyancy are in the same vertical line.

**297.** The equilibrium will be either neutral, unstable, or stable.

1. The equilibrium is neutral, when the form of the body is such that the relative positions of the centers of gravity and buoyancy can not be changed. This will be the case with spheres of uniform density.

2. The equilibrium will be unstable, when the center of gravity is over the center of buoyancy. The least force will then overturn it.

3. The equilibrium will be stable, when the center of gravity is under the center of buoyancy. If the body is disturbed from this position, it will constantly tend to resume its original position.

**298. The stability of ships** increases with the breadth of the part submerged, and also increases in proportion as the center of gravity is lowered. For this reason, vessels must either carry heavy cargoes over their keels, or make up the deficiency by ballast. In small boats, the equilibrium is stable so long as the passengers are kept near the bottom of the boat; but when they rise, the center of gravity is elevated, the equilibrium is thereby rendered unstable, and any unguarded movement will overturn the boat.

## SPECIFIC GRAVITY.

**299. To determine the specific gravity** of a substance, it is necessary (1.) to select some standard for comparison; (2.) then to find the weights of equal volumes of the standard and the body under consideration; and, finally, (3.) to divide the weight of the body by the weight of an equal volume of the standard. The quotient will be the specific gravity of the substance.

**300.** The standard usually taken for aëriform bodies is air, but it is probable that hydrogen will soon come into general use. The standard for all liquids and solids is distilled water.

As all bodies vary in size with the changes of the weather, all observations should be reduced to the same conditions of temperature and atmospheric pressure.

The normal pressure adopted in this country is thirty inches of the barometer; in France it is 760 m m. = 29.922 inches. This item may be neglected, except in the case of aëriform bodies.

The usage respecting temperature is still unsettled: many retain the old English standard, 60° F., although the tendency is to adopt the French, which is the freezing point of water, 32° F., for all bodies except water, which is taken at 39°.2 F., its point of greatest density. Observations at any other temperature are easily reduced to the normal by means of tables, specially prepared for that purpose.

**301.** Having this standard, the formula for the specific gravity of solids and liquids becomes,

$$[47.]\quad \frac{\text{Weight of given volume of substance}}{\text{Weight of equal volume of water}} = \text{specific gravity.}$$

When any two of these are given, the other can be found. Therefore:

(1.) The weight of any given volume of a body equals the specific gravity of the body multiplied by the weight of an equal volume of water.

(2.) The weight of any body divided by its specific gravity will equal its loss of weight in water, or equal the weight of an equal volume of water.

(3.) As one cubic inch of water weighs 252.456 grains, the volume of a solid may be found by dividing its loss of weight in water by 252.456 grains. The quotient will be the volume of the solid expressed in cubic inches.

**302. The specific gravity of solids** is found by the application of the principle of Archimedes (289). Weigh the body in air $(= W)$, then suspend it by a hair and find its weight in water $(= W')$. The difference in weight is the weight of an equal volume of water $(= W - W')$. Therefore, the specific gravity may be found by dividing its weight in air by its loss of weight in water.

$$[48.]\quad \text{Sp. gr.} = W \div (W - W').$$

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

**303. If the body is lighter than water,** sink it by attaching a heavy mass, whose weight in air and in water is known, and find the weight of the combined bodies in air and in water. 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 bulk of the lighter body. Therefore, the weight of the lighter body in air divided by this remainder will give its specific gravity.

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

**304. If the solid is soluble in water,** weigh it in some other liquid, and allow for the difference between its specific gravity and that of water.

Thus, 131 grains of nitrate of baryta lost 32 grains when weighed in absolute alcohol, having a specific gravity of .8. Its specific gravity, as compared with alcohol, is $131 \div 32 = 4.1$; then 4.1 multiplied by .8, the specific gravity of alcohol, equals 3.28, the specific gravity of the salt.

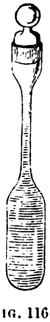

FIG. 116.

**305. The specific gravity of liquids** is found (1) by the specific gravity bottle. Counterpoise a small flask by a weight in the other arm of the balance, and weigh exactly one hundred or one thousand grains of water into the flask. Mark the volume of the water by a line cut in the glass. Now empty out the water, fill the flask as high as the line, with the liquid whose specific gravity is sought, and weigh. The weight of the liquid in grains divided by one hundred or one thousand is its specific gravity. The figure represents an elegant form of the one hundred grain flask.

Thus a 100 grain flask contains 79.38 grains of alcohol; hence, the *specific gravity* of the alcohol is 0.7938.

(2). By the specific gravity bulb. Suspend any insoluble solid by a hair, and, having determined its weight in air, find its loss of weight in water, and also in the liquid. The loss of weight is equal to the weight of the fluid displaced by the same volume: hence, the loss in the liquid divided by the loss in water equals the specific gravity of the liquid.

The figure represents a glass specific gravity bulb containing mercury. It can easily be made out of a small test tube, and loaded with shot instead of mercury.

Suppose the air weight of the bulb is 480 grains; its water weight, 400 grains; its weight in alcohol, 416 grains. The losses will be, respectively, 80 and 64 grains; then 64 ÷ 80 = .8, the specific gravity of alcohol.

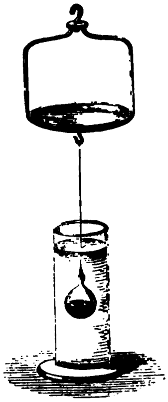

FIG. 117.

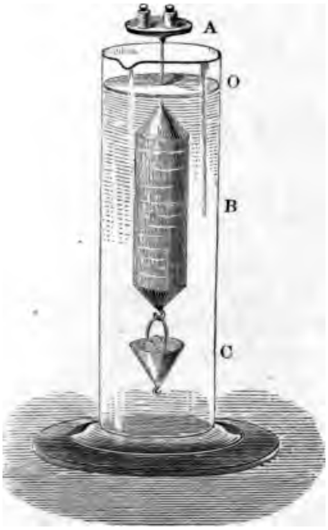

FIG. 118.

**306. Either of these methods** affords accurate results, but for rapid determination, hydrometers are used. These instruments are of two kinds. (1.) *Hydrometers of constant volume.* (2.) *Hydrometers of constant weight.*

1. Nicholson's hydrometer. This instrument, shown in Fig. 118, consists of a hollow cylindrical vessel, B, to which is attached a lead basket, C. The basket is made heavy to bring the apparatus into a condition of stable equilibrium. A wire at the top of the vessel supports a pan, A, and has a fixed point, O, marked on it.

To use the apparatus for determining the specific gravity of liquids, it is only necessary to determine the total weights required to bring the hydrometer to the point O, in distilled water, and in the given liquid.

Thus, suppose the hydrometer weighs 1000 grains, and it requires 500 grains additional to sink it in water and 200 grains to sink it in alcohol. Then, the total weights are 1500 and 1200 grains. 1200 ÷ 1500 = 0.80, the specific gravity of the alcohol.

It may also be used for solids. As before, suppose that 500 grains will sink the hydrometer in water to the fixed point, O. Place any solid, not too heavy, as a bullet, on the pan, A, and add weights until the hydrometer sinks to O. It is evident that the weight of the body and the added weights are together equal to 500 grains. Then, if 100 were added, the weight of the body, in air, must be 400 grains. Now place the body in the basket, C; of course, as the body is submerged, it will be buoyed up by a weight equal to the volume displaced. It will be necessary to make good the loss, by adding weights to the pan, A, enough to bring the hydrometer to the fixed point once more.

Suppose 50 grains are required; then, as this equals the weight of a volume of water the size of the solid, 400 ÷ 50 = 8, the specific gravity required.

When the solid is lighter than water, it is necessary to fasten the solid to the basket, C, before submerging it.

**307. 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 calculated by dividing the volume which a floating body displaces in water, by the volume which it displaces in the given liquid. On this principle *hydrometers of constant weight* are constructed.

The common form 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 graduated by placing the instrument in a liquid whose specific gravity is known; the point to which it sinks is marked, and the intermediate space subdivided into a scale of degrees, according to the fancy of the maker. As a long stem would be inconvenient, it is customary to have two hydrometers, one for liquids lighter than water, in which the zero point is near the bulb, and the other for heavier liquids, with the zero point at the top of the stem.

FIG. 119.

**308. Thus Beaume's hydrometer** for liquids heavier than water, sinks in pure water to the zero mark near the top of the stem; in a solution containing fifteen parts of salt to eighty-five parts of water, it sinks to the mark 15. All the subdivisions of the stem are of the same size as those between 0 and 15. As the specific gravity of the salt solution is known to be 1.1095, the specific gravity corresponding to any degree may be determined.

Let $x$ equal the volume of water equal to the weight of the instrument to the zero point; then $x-15$ will be the volume of an equal weight of the salt solution. Therefore, $x \div (x-15) = 1.1095$, from which, $x$, the number of equal parts displaced by water is found to be 152. The number of equal parts displaced by any other liquid will be $152-n$, in which $n$ represents the degrees on the scale. Consequently, the specific gravity corresponding to any degree on the scale will be found by the formula $152 \div (152-n) =$ specific gravity.

For liquids lighter than water, Beaume made the zero point correspond to a solution containing ten per centum of salt, and marked the point at which the instrument floated in pure water as 10°. By a similar calculation to that previously employed, the formula for the hydrometer for liquids lighter than water, is found to be: specific gravity $= 146 \div (136+n)$.

**Alcohometers, lactometers, etc.,** have scales arranged to show the per cent. by volume or by weight of the liquid in a given solution.

**309. The specific gravity of a gas** is always found by direct weighings of equal volumes of air and of the gas. For this purpose, a large flask is weighed (1.) when entirely empty; (2.) when full of air, and (3.) when full of the gas in question. The weight of the gas divided by the weight of the air, will be the specific gravity required.

The accurate determination of the weights of aëriform bodies is attended with many difficulties, which can not be detailed here.

As gases have weight, the principle of Archimedes applies to bodies weighed in them, as well as in other fluids.

**310. The practical applications** of specific gravity are numerous and important. It enables the manufacturer to know what degree of concentration a solution, or an acid, has reached. Thus, a Beaume's hydrometer stands in a well manufactured sirup at 35°, and in strong sulphuric acid at 66°. It often enables the merchant to determine the purity of the articles offered. Thus, the value of ardent spirits is dependent on the proportion of alcohol they contain. This is indicated at once by the alcohometer.

**311.** The famous problem offered Archimedes was to determine the purity of King Hiero's crown. Suppose the crown to have been an alloy of gold and silver, weighing 22 ounces in air, and losing 1.5 ounces in water.

The general solution of this problem, as applied to any alloy, gold nugget, or other mineral, is as follows:

Let M be the mass of the body, and $m$ its specific gravity.

Let H be the mass of the heavier substance, and $h$ its specific gravity.

Let L be the mass of the lighter substance, and $l$ its specific gravity.

Then, $M = H + L$. Since the volume of a substance equals its mass divided by its specific gravity,

$$\frac{M}{m} = \frac{H}{h} + \frac{L}{l}.$$

From these two equations, it is found that

$$H = M\frac{h}{m}\left(\frac{m-l}{h-l}\right). \qquad L = M\frac{l}{m}\left(\frac{h-m}{h-l}\right).$$

The specific gravity of the mass can be determined the usual way; the specific gravity of the components may be found by tables, or ascertained from fragments of the body. The proportions of the ingredients may then be found by the formulas.

In the case of the crown as supposed, the gold, being the heavier, is found by the first formula.

$$\text{Gold} = 22.\ \frac{19}{14.66}\ \frac{(14.66-10.5)}{(19-10.5)} = 13.95.$$

$$\text{Silver} = 22.\ \frac{10.5}{14.66}\ \frac{(19-14.66)}{(19-10.5)} = 8.05.$$

## 312. Recapitulation.

I. Liquids are both compressible and elastic.

II. They transmit external pressure in every direction.

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

III. They produce pressure by their weight, and transmit this as if it were an external pressure.

IV. A liquid always seeks its lowest level. The surface of a liquid in equilibrium is horizontal.

1. At any given vertical, an apparent level.
2. Between distant verticals, a true level.

V. The upward pressure of a liquid upon a solid, wholly or partially submerged, is its buoyant effort. This is always 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 fluid equal to this weight.

VI. The specific gravity of bodies is found by comparison with water or air.

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

## HYDRODYNAMICS.

**313.** If a vessel be filled with any liquid, the pressure at any point will be proportioned to its depth below the surface.

Hence, if apertures, *r*, *g*, *m*, *n*, *p*, be made in the vessel, the liquid will flow out with unequal velocities, being less for *r* than for any point below it, and equal for any two points, as *p* and *v*, at the same vertical depth below the surface.

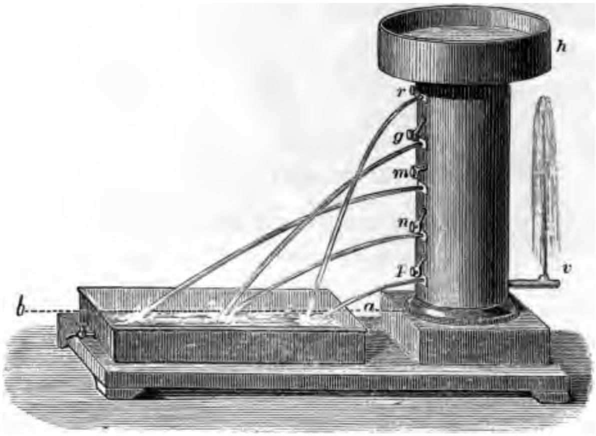

FIG. 120.

But the velocity does not increase in the simple ratio of the depth. The jet at *v* will tend 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, *h v*, in opposition to gravity, this velocity must be equal to that which a body would acquire in falling through the same space. If the aperture were in the bottom of the vessel, the velocity of the escaping liquid would be the same as if it had fallen freely through the vertical depth of the liquid above the orifice.

As the same fact is true of any aperture in the side of the vessel, the laws of escaping liquids are comprised in the following:

THEOREM OF TORRICELLI.—*Particles of liquids, flowing from an aperture, have the same velocity as if they had fallen freely in vacuo from a height equal to the vertical distance of the surface of the liquid above the center of the aperture.*

This distance is called, technically, the *head* or *charge*.

**314. The velocity due** to a body falling through any given height is expressed by the formula [28.] $v = \sqrt{2gh}$. As the factors $2g$ are constant for the same place, *the velocity with which a liquid escapes varies as the square root of the head.* If we assume $g = 32.16$, the actual velocity of the liquid may be calculated by the formula $v = 8.02\sqrt{h}$.

Conversely, [49.] $h = v^2 \div 64.32$: hence, if the velocity is known, we may calculate the head due to the velocity.

As water and mercury would fall, *in vacuo*, from the same height in the same time, so they, or other liquids, will flow with the same velocity under the same head: therefore, *the velocity is independent of the density of the liquid.*

**315. The course of a stream,** spouting out in any other direction than the vertical, is that of a parabola, and is governed by the law of projectiles. The range of a horizontal jet is easily calculated. For example: if the jet, $g$, is four feet below the surface, the velocity due to the head, $h$, is sixteen feet per second. If its elevation above the point where it strikes, $b$, is nine feet, it will be three-fourths of a second in falling. Inasmuch 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 calculation may be simplified by the use of the following formula: $R = 2\sqrt{HE}$, in which R represents the range, H the depth below the surface of the liquid, and E the vertical distance of the aperture above the point upon which the stream falls.

As H and E are parts of the same perpendicular, the value of R will be greatest when H = E. Therefore, the range will be greatest when the aperture is at the middle point. Further, since the product of H and E determines the range, their values may be interchanged without altering the value of R; therefore, two jets at equal distances above and below the center have the same range. These conditions are shown in the figure.

316. **To calculate the volume** of liquid discharged from an orifice in a given time, multiply the area of the orifice by the velocity of the stream per second, and, then, this product by the number of seconds.

Thus, if the jet *g* have an inch area, there will issue, in one second, a prism of water one inch in area and sixteen feet long, the contents of which is $1 \times (16 \times 12) = 192$ cubic inches. If the given time be three minutes ($= 180$ seconds), the discharge will be equal to $192 \times 180$ cubic inches, or twenty cubic feet.

317. **The velocity of discharge** will not be constant unless the liquid is kept at the same level. If a cylindrical vessel is allowed to empty itself through an orifice at the bottom, the velocity will be uniformly retarded as the surface of the liquid sinks. When motion, uniformly retarded, comes to an end, the average velocity is half the initial velocity (215); consequently, the quantity of liquid discharged from a vessel allowed to empty itself, is just half the quantity that would have been discharged in the same time if the original head had been maintained.

Conversely, the time required to empty an unreplenished vessel is double the time required to discharge the same quantity of liquid if the original head is maintained.

318. **The results thus given by theory** are never attained in practice. Only the central part of the jet attains the theoretical velocity. The outer particles converge with less velocity, and, by their interference, retard the flow. By suspending in water small particles of amber or litmus, this convergence can be exhibited by the movement of the *particles*. In consequence of the interference of the cur-

rents, the jet contracts on leaving the orifice, and at a distance from the orifice equal to half its diameter, the section of the stream is only .64 the area of the orifice. The point of greatest contraction, *VC*, is called the *vena contracta.*

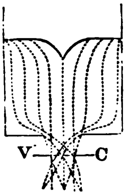

FIG. 121.

If the wall of the vessel is a thin plate, the area and head of the *vena contracta* must be considered as the real orifice in calculating the volume of liquid discharged.

If the wall of the vessel has considerable thickness, or if a short tube is attached to the orifice, the rate of discharge is increased. A cylindrical tube, or *adjutage*, whose length is four times its diameter, increases the flow to eighty-four hundredths of that required by theory. The effect is still greater (.92) if the discharge tube is made conical both ways, first contracting like the *vena contracta* and then widening. On the other hand, if the discharge pipe projects within the vessel, the velocity is impeded.

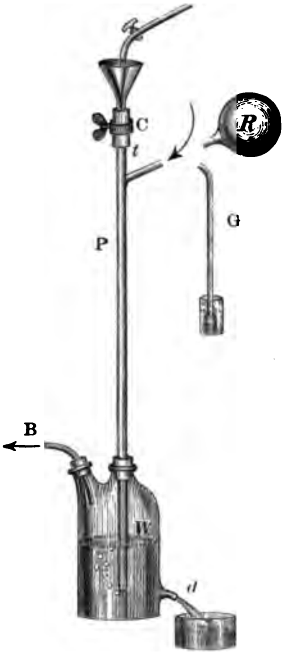

FIG. 122.

**319. The lateral pressure** exerted by a liquid in motion, is always less than when at rest. If water flows vertically through a long cylindrical pipe, it will exert no lateral pressure.

Suppose a reservoir of water to be connected by rubber tubing controlled by a clamp, *C*, to a pipe which is connected with a cistern having a discharge pipe, *d*, at the bottom, and an open pipe, B, at the top. The water flowing through the pipe will never entirely fill it, so long as it is in motion, but will be surrounded by a thin film of air. If, now, a small open tube, *t*, be inserted near the top of the pipe, the adhesion of the water will drag down the particles of air, which, on *rising* through the water in the cistern will rush out in a steady stream through B. On this principle the blowers of the Catalan forges are constructed, but even a small apparatus of this sort will furnish sufficient air for most blow-pipe purposes.

Now, suppose the tube, *t*, to be connected by rubber tubing to a glass tube dipping in some colored fluid. The water falling through the pipe will, as before, drag the surrounding particles of air along with it, and thereby tend to produce a vacuum in the tube, *G*. Consequently, the liquid will be forced up the tube by the pressure of the external air, to a height proportioned to the rarefaction of the air in the pipe. With a long discharge pipe, the flow may be so regulated by the clamp, *C*, as to produce a very nearly perfect vacuum in the tube, *t*. If, then, a receiver, R, be attached to the tube, it will soon be exhausted of most of its contents. Hence, this apparatus may also be used as an air pump. Sprengel's and Bunsen's air pumps are constructed on this principle.

In Sprengel's air pump, mercury is used, and the length of the discharge pipe is a little more than thirty inches. The clamp should be so regulated that the mercury may fall intermittently in large drops. These drops will form in cylinders and act as valves, completely closing the pipe, and driving all the air before them out of the apparatus. The mercury in the cistern will prevent the return of the air up the tube. As fast as the reservoir is emptied it is replenished from the cistern.

In Bunsen's air pump, water is used. To obtain the best results, the discharge pipe should be at least thirty-four feet long. This form is very convenient for laboratory use, since it needs for its construction only to have the bent tube, *t*, inserted into the waste pipe of the sink, and that a stream of water, under proper control, should enter this pipe a little above the mouth of the tube.

**320. In horizontal pipes** the discharge is less than that due to the head, owing to the adhesion of the liquid to the pipe, and to the cohesion of the particles of the liquid. The resistance to the flow increases, (1.) with the length *of the pipe*; (2.) with the number of bends and obstructions; (3.) as the diameter is diminished; and (4.) very nearly as the square of the velocity of the stream.

The rate of discharge diminishes as the resistance increases, consequently, unless a large allowance is made for the resistance, the quantity delivered will fall short of the estimate. Under ordinary circumstances, the diameter of the discharge pipe should be at least one-half greater than that required by theory.

**321. The size of rivers** depends on the physical character of the countries drained by them. Their velocity is dependent on (1.) the volume of water to be discharged; (2.) the shape of the channel, and (3.) the slope of the bed.

Thus the velocity of a river is greater during freshets than in dry seasons, and is greater in narrow and straight channels than in a broad or winding bed. By reason of the friction of the banks the velocity is greatest in mid channels, a little below the surface, and least near the banks. As the lateral pressure diminishes with the velocity, the more sluggish particles at the sides press upon the central portions, and thus heap them up, to produce equilibrium. This renders the surface slightly convex.

**322. The smallest inclination** capable of giving motion to water, is nearly one inch to fifteen miles. Three inches per mile, in a smooth, straight channel, give a velocity of three miles an hour; three feet per mile are sufficient to produce a mountain torrent.

The wearing away of the banks and bottom of a river or canal depends on the velocity of the current. A velocity of thirty feet per minute will not distuib clay or sand; one of forty, will sweep along coarse sand; of sixty, fine gravel; of one hundred and twenty, rounded pebbles; of one hundred and eighty, angular stones. For this reason, rapid rivers are stony, slow ones sandy or muddy.

If the velocity of rivers were not checked by friction, their force would be frightful. The Ganges, at a distance of eighteen hundred miles from its mouth, is eight hundred feet above the level of the sea. The velocity due to this fall is over one hundred and fifty miles per hour, which is more than fifty times the velocity actually attained.

## WATER POWER.

**323.** Flowing water acts as a moving power, (1.) by its weight, (2.) by the force of the current, or (3.) by the combined effect of both.

The gross power of a fall of water is equal to the weight of water discharged in a unit of time multiplied by the head.

Let H represent the head, Q the volume in cubic feet discharged per second, and 62.4 lbs. the weight of one cubic foot of water; then, $Q.H\,(62.4) = P$, the gross power in foot-pounds per second.

If the velocity of the stream is given, since [49.] $H = v^2 \div 64.32$, the formula becomes

$$[50.]\quad P = Q\left(\frac{v^2}{64.32}\right)62.4 = (Q\,v^2)\,0.97.$$

As the last factor does not differ greatly from unity, we may use the following rule for most purposes.

*The gross power of a water fall in foot-pounds per second, is equal to the volume of water discharged, in cubic feet, multiplied by the square of the velocity, in feet.*

There is always a loss of energy, arising from the shape and friction of the weir, so that the *effective* power is somewhat less than the gross.

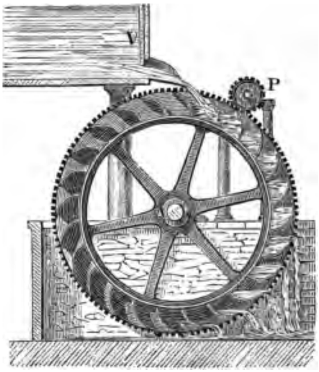

FIG. 124.

**324. Water wheels** are either vertical or horizontal. In vertical wheels, the effective power of the stream is applied to buckets or boards fixed to the circumference of the wheel. The wheel is connected with the machinery to be moved. There are three varieties of vertical wheels: (1.) the overshot, (2.) the undershot, (3.) the breast wheel.

*In* the *overshot wheel*, Fig. 124, the stream falls into buckets at the top of the wheel, and acts principally by its weight.

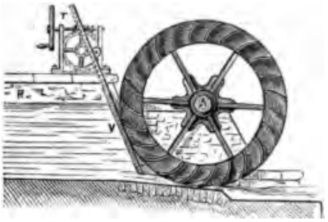

FIG. 125.

In the *undershot wheel*, Fig. 125, the stream strikes against boards at the bottom of the wheel, and acts by the force of the current.

In the *breast wheel*, Fig. 126, the stream may be made to act both by its weight and the force of the current. *High* breast wheels receive the stream in buckets above the axis; *low* breast wheels receive the stream on boards below the axis.

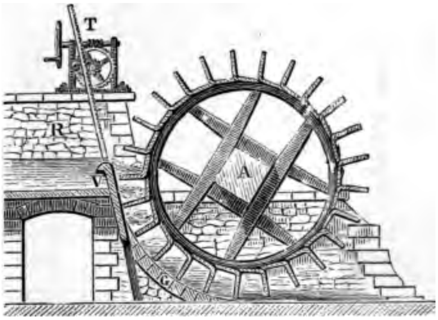

FIG. 126.

**325. The availability of any wheel** depends on the character of the fall. Undershot wheels are well adapted to low falls 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.

**326. The efficiency of a wheel** is largely dependent on the shape of the buckets, or floats, and the readiness with which the water may escape after having been used. The actual impulse of the stream is only the excess of its velocity above that of the float boards: thus, if the stream has a velocity of eight feet in a second, and the float boards three feet, the velocity of impact is five feet. For these, and other reasons, the maximum effect of the wheel is always less than the effective power of the stream. Overshot and high breast wheels utilize from .6 to .8 of the power; low breast wheels, from .45 to .65, and undershot from .25 to .45.

It is important to notice that the head is the same, whether the water flows from an orifice in a reservoir, or falls freely the same distance, as has been shown in (313).

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

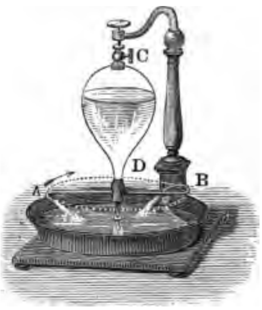

FIG. 127.

The *reaction wheel* may be represented by Barker's mill, which acts on the principle of unbalanced lateral pressure (273.)

A vertical axis, C D, which revolves upon a pivot, terminates 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.

**328. 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. 128 shows a vertical, and Fig. 129, a horizontal section of this turbine.

A column of water, confined by 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.

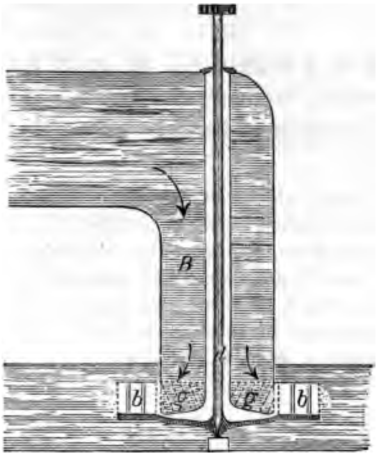

FIG. 128.

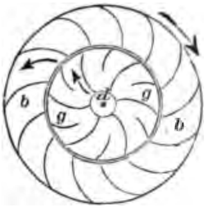

FIG. 129.

**329. If it were possible** for water to flow in a pipe entirely unimpeded, so that its velocity would ever be that required by theory ($8.02\sqrt{h}$), there would be no lateral pressure; and, if the pipe were pierced, no water would flow out. But when the velocity is diminished by friction, and other causes, a portion of the pressure is not carried off, and becomes a bursting pressure on the pipe. This pressure is unequal at different portions of the pipe. At the end, E, Fig. 130, where the water flows out, it is almost nothing, but increases toward the reservoir, as shown by the dotted line, being, at any point, equal to the difference between the calculated and actual velocity.

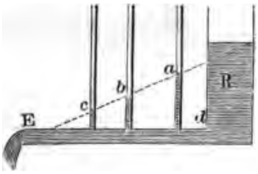

FIG. 130.

If, now, the current of water be suddenly stopped, much of the momentum will be changed to lateral pressure, and the water will rise in the open pipes, *a b c*, to a height proportioned to the reaction of the momentum. This will be greatest in the tubes near the end, E. In common household water pipes, if the faucet is suddenly closed, a certain shock is felt near it, and, if the head is sufficient, the pipe will burst.

**330. The hydraulic ram** is a contrivance by which the impulse of running water, when suddenly checked, can be made available for raising a portion of itself to a considerable height.

Let R, Fig. 131, be a reservoir, from which the water flows through the pipe, P, to the orifice, *o*. Let a conical valve, C, be fitted to this orifice, of such weight as to remain down, and leave the orifice open, when it is opposed only by the steady pressure of the water in the pipe and reservoir. However, the water, by flowing through the orifice, soon acquires momentum sufficient to raise the valve, C, close the orifice, and thereby communicate a shock to the pipe.

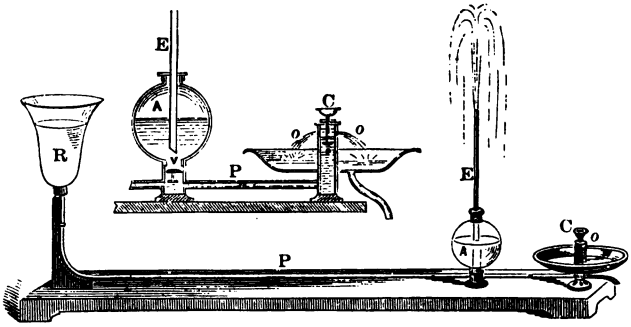

FIG. 131.

A second valve, V, which opens into an air chamber, A, is made to rise by the impulse of the reaction, and allow the water to enter the air chamber, until the pressure of the inclosed air overcomes the shock of the water.

The valve, V, now closes, C opens, and permits the water to flow out at *o*, as before. The accumulated momentum again closes C and forces a second portion of water into the air chamber, and thus the action is continued indefinitely.

The confined air soon acquires sufficient elastic force to drive the water in the chamber through the exit pipe, E, in a continued stream. Much more water escapes at *o* between the pulsations than can be raised in the exit pipe, E. The useful effect of this machine is the greatest when the height to which the water is raised does not much exceed the fall from the reservoir, but it diminishes as the height increases. With a low fall and only a moderate supply of water, a constant stream can be raised by this machine to a considerable height. A fall of two feet is competent to raise one-fortieth of the water expended, to a height of forty feet.

## 331. Recapitulation.

Running water exerts power in proportion to the product of its volume and the square of its velocity, diminished by the impediments to motion.

It acts as a motive power:

| | | | | Useful Effect. |
|---|---|---|---|---|
| I. By its momentum. | Water wheels. | Vertical. | Undershot. | .25 |
| | | | Breast. | .60 |
| | | | Overshot. | .75 |
| | | Horizontal. | Turbine. | .90 |
| | | | Reaction. | .40 |
| II. By the impulse of one part of the stream on another | | | Hydraulic ram. | .50 |

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### THE MECHANICS OF AERIFORM FLUIDS.

**332. Aeriform** bodies are fluids which are highly compressible, elastic, transparent, and usually colorless. In an aëriform fluid, the repulsion of its molecules so far exceeds their attraction for each other, that they tend to separate and expand indefinitely into space, unless controlled by external forces, or pressures. The force with which an aëriform fluid tends to expand, is called its *elastic force* or *tension.*

**333.** Aëriform bodies are divided into vapors and gases.

1. *Vapors* are produced by the action of heat upon solids and liquids, *and readily* return to their original state upon *cooling. Steam is the* type of all vapors.

2. *Coercible gases* are aëriform under ordinary circumstances, but may be condensed into liquids, and even solids, by the aid of pressure and of low temperatures; as chlorine, carbonic acid ($CO^2$). There are twenty-nine coercible gases.

3. *Permanent gases* are fluids which have, thus far, retained their aëriform state, under all circumstances of temperature and pressure. Only five gases are permanent, viz.: oxygen, nitrogen, hydrogen, carbonic oxide ($CO$), and nitric oxide ($NO^2$).

It is reasonable to suppose that all solids and liquids may be changed to vapor, at very high temperatures, and that all gases may be liquefied under sufficient cold and pressure. Therefore, the distinction between gases and vapors is merely conventional, as they differ from each other only in their specific properties, as density, odor, etc.

**334.** PNEUMATICS treats of the mechanical properties of aëriform fluids.

The atmosphere, which is mainly a mixture of nitrogen and oxygen, will be assumed as the type of all bodies in the aëriform state. Whatever physical property is established regarding atmospheric air, is to be understood as applying to all vapors and gases.

Air has been proved to possess extension and impenetrability, the essential properties of matter, and to have mobility, inertia, and momentum. 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.

**335.** The air is kept in its place about the earth by the joint action of its molecular repulsion and the attraction of gravitation. 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 the point to the upper limit of the atmosphere. At any given elevation above the surface of the sea, the effect of gravity in producing upward, downward, and lateral pressures, will be the same as in liquids.

**336. The pressure of the atmosphere** was first ascertained by the experiments of Torricelli, in 1643. He filled a glass tube, nearly three feet long, with mercury, closed the open end firmly, and then inverted the tube in a cistern of mercury. On removing his finger, the liquid descended in the tube, and finally came to rest at the height of about thirty inches above the level of the liquid in the cistern, thus leaving a vacuum at the top of the tube.

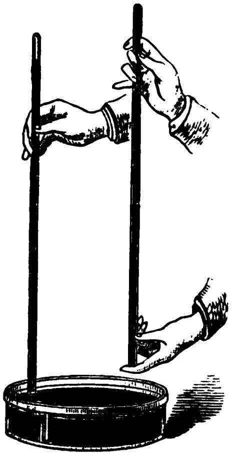

FIG. 132.

Now, as the weight of the mercury tends to make it flow out of the tube, the column must be sustained by an equal and opposite force. The philosophers of the day thought they explained the matter by saying that "Nature abhors a vacuum;" but Torricelli reasoned that, in obedience to the law of equilibrium of fluid pressures, the force that sustains the mercury in the tube is the pressure of the atmosphere on the mercury in the cistern.

Pascal confirmed Torricelli's explanation, by causing the experiment to be repeated on the top of a mountain. He thus reasoned: "If the height of the mercury is less at the top of a hill than at the bottom, it will follow that the weight and pressure of the air are the sole cause of the suspension, and not the horror of a vacuum, since it is very certain that there is more air to weigh on it at the bottom than at the top, while we can not say that nature abhors a vacuum at the foot of a mountain more than at its summit." At the top of the Puy de Dome the column was found to be three inches lower than at the bottom, which settled the question.

**337.** The pressure of the atmosphere is, therefore, equal to the weight of a column of liquid which it will sustain. An instrument used for measuring atmospheric pressure is called a *Barometer.*

FIG. 133.

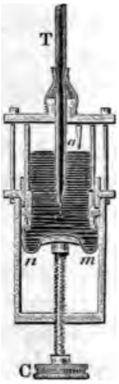

FIG. 134.

The simplest form of the barometer is the Torricellian tube, but for convenience of transportation, other forms have been devised. Fortin's is one of the best. Figs. 133 and 134. It consists of a straight glass tube, about thirty-three inches long, filled with mercury, and dipping into a glass cistern containing the same fluid. The base of the cistern, *m n,* is made of leather, and can be raised or lowered by means of a screw, *C.* On using this barometer, the mercury in the cistern is brought to a level with the point of an ivory pin, *a,* by turning the screw, C, up or down. The scale, B, gives the exact height of the column above this point. The tube and cistern are protected from accident by a brass case. In traveling, the interior of the tube and cistern are filled with mercury by raising the screw, so as to prevent the accidental introduction of air. A thermometer is attached to the scale. As mercury expands by heat, all barometrical observations should be reduced to the same temperature, by tables prepared for that purpose.

It is essential to a first rate barometer (1.) that the mercury should be pure, (2.) that the scale should measure the exact distance between the levels of the mercury in the tube and cistern, (3.) that the vacuum at the top of the tube be perfect. With the best precautions, it will contain a trace of the vapor of mercury. Air is excluded by pouring the mercury into the tube, small portions at a time, and boiling it after each successive addition.

**338.** The pressure of the atmosphere may be estimated in pounds, or by the height of the barometer. At the level of the sea, the height of the column varies from 28 to 31 inches, the average being 29.922 inches. The weight of a column of mercury of this height, and one inch in area is 14.7 pounds. We say, therefore, that the pressure of the atmosphere is nearly fifteen pounds to each square inch of surface.

No other liquid is so serviceable in the construction of barometers as mercury. Barometers have been made, having their tubes filled with water and with sulphuric acid, but they are very expensive and unwieldy. The pressure of the atmosphere will sustain a column of water 13.6 times longer than the column of mercury, or thirty-four feet.

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

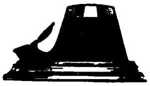

FIG. 135.

FIG. 136.

FIG. 137.

1. In the *pneumatic inkstand*, Fig. 135, 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.* 136.

*3. Take a small open tube,* or a *pipette*, Fig. 137, plunge it vertically in water until it is filled, then close the upper end by 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. 138. 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.

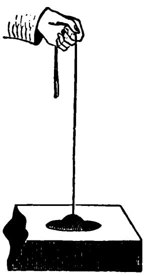
FIG. 138.

**340. The tension of gases** may be shown by the following experiment. Bend the closed end of a barometer tube, as in Fig. 139, and pour just enough mercury into the tube to fill the bend, as shown in the figure. The air inclosed in the short arm is now in its natural condition, under the pressure of one atmosphere. If thirty inches of mercury be poured into the long arm, the confined air will be under the pressure of two atmospheres, one of air and one of mercury, and will be reduced in volume one-half. If thirty inches more mercury be added, the pressure will be three atmospheres, and the


FIG. 139.

volume will be reduced to one-third. And so on, for every like increase of pressure, the volume will be reduced to one-fourth, one-fifth, etc. Therefore,

1. *The volume of a given weight of air is inversely as the pressure to which it is exposed.*

This proposition is known as Mariotte's law, and is true for all gases, within small limits of error. As the density of a body is inversely as its volume, and as the pressure is always sustained by the tension of the air inclosed,

2. *The density and tension of a given weight of air are directly as the pressure to which it is exposed, and inversely as its volume.*

**341. To prove the same law** for pressures less than one atmosphere: Fill a long jar with mercury, and fill a barometer tube to within four inches of the top with mercury. Then invert the tube in the jar, and sink it until the level of the mercury in the jar and tube is the same. The confined air is now under the pressure of one atmosphere. On raising the tube, as in Fig. 140, the tension of the confined air equals one atmosphere minus the weight of the mercury in the tube. If the column of mercury raised is fifteen inches, the air will have a tension of one-half an atmosphere, and will have doubled its volume. When the column of mercury is 20 inches the tension of the air will be one-third of an atmosphere $(30 - 20 = 10)$, and its bulk will be trebled. Mariotte's law, therefore, applies both to condensed and rarified air.

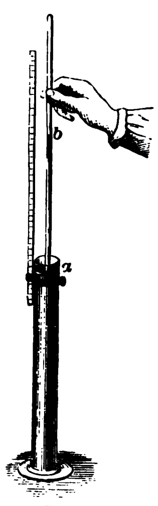

FIG. 140.

**342. The tension of aeriform fluids,** may be measured by *manometers* or *gauges*. One of the simplest forms is the closed manometer, Fig. 141, which acts on the principle of Mariotte's tube. It consists of a U tube, closed at one end, and half filled with mercury. The closed end contains dry air, at the ordinary tension.

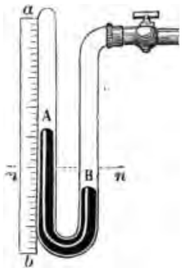

FIG. 141.

When the open end communicates freely with the atmosphere, the level of the mercury is the same in both tubes. If the open end is connected with aëriform fluids whose tension is to be measured, as with the steam in a boiler, the air will occupy one-half, one-third, one-fourth, etc., of its original space, according as the pressure increases to two, three, four, etc. atmospheres. Or if the pressure is less than one atmosphere, the air will expand as the pressure diminishes.

**343. Bourdon's gauge,** Fig. 142, is one of the most useful manometers known. It consists of a metallic tube, A B, closed at one end, B, and fixed at the other, A. The cross section of the tube is a flattened ellipse, having its greatest breadth perpendicular to the plane in which the tube is curved. When the pressure within the tube is greater than the pressure without, the tube becomes less curved, or tends to straighten; when the pressure without is the greater, it becomes more curved. The extent of the motion depends on the elasticity of flexure in the tube. The movements of the closed end of the tube are communicated by the link, D, to an index, which moves along a graduated arc. The arc is graduated by comparison with other manometers. The tube and mechanism are contained in a brass box with a glass cover. The sensibility of the gauge depends on the flexibility of the tube. Some are made to measure pressures of less than one atmosphere, and some of several hundred.

FIG. 142.

In steam gauges, the fixed end of the tube communicates with the boiler, by the stop-cock, C. A modification of this gauge is well known in this country, under the name of Ashcroft's gauge.

To measure pressures of less than one atmosphere, the tube is exhausted of air, and the fixed end hermetically sealed. The stop-cock is then removed. This gauge then becomes an *aneroid barometer*.

### AIR PUMPS.

**344. An air pump** is an instrument for removing the air from a closed vessel.

Fig. 143 shows the Leslie air pump, and Fig. 144 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

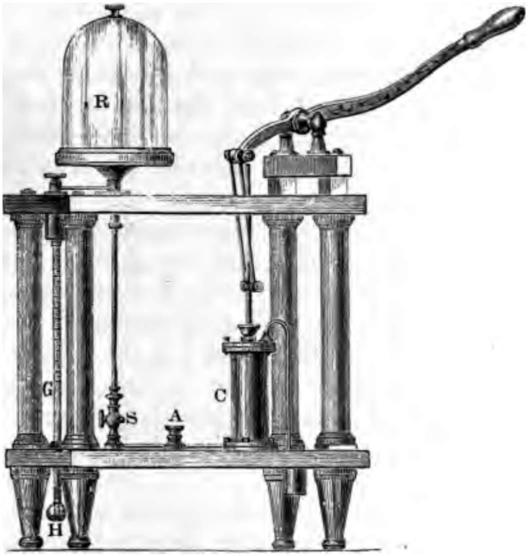

FIG. 143.

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.

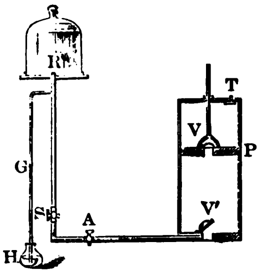

FIG. 144.

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.

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, Fig. 144, 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.

**345.** 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 be here 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.

Many bottled liquors are charged with condensed gases. When the pressure is removed by drawing the cork, the thin liquids, like champagne, sparkle; viscid liquids, like ale, froth.

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

3. *Pressure of the atmosphere.* Take a small open receiver and close the upper end tightly with a piece of sheet rubber. On working the pump the air will be withdrawn from below the rubber, and the external air will press the rubber downward so as to fill the receiver.

If the rubber is replaced by a piece of moistened bladder, Fig. 145, and the bladder suffered to dry, 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.

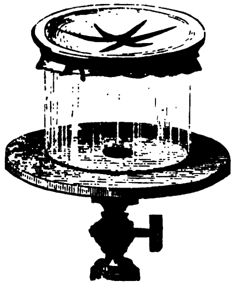

FIG. 145.

*The Magdeburg hemispheres,* Fig. 146, 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.*

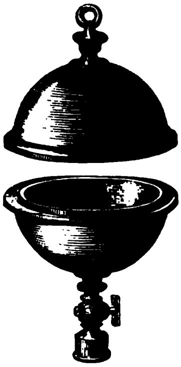

FIG. 146.

Fig. 147 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.*

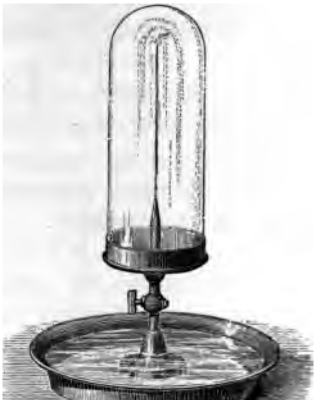

FIG. 147.

FIG. 148.

*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.

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.

6. *The buoyancy of air.* By the principle of Archimedes (289), 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.

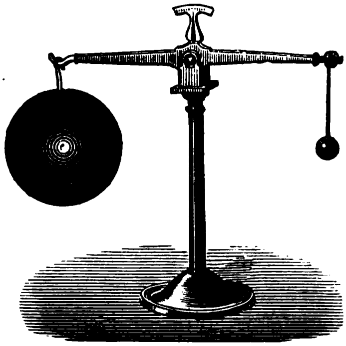

FIG. 149.

Suspend to one arm of a balance a hollow globe, Fig. 149, or a ball of cork, and counterpoise it with a lead weight. Now place the balance under a receiver and exhaust the air. 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 made from hot water and 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 or coal gas. The silk is strengthened by a netting of small ropes, which also serve to suspend a light basket. 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 silk, and other parts of the balloon, the aeronaut, and a large quantity of sand used for ballast. If the aeronaut 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. The greatest height ever reached in a balloon is a little over seven miles. This was attained by an English aeronaut, named Glaisher, in 1861.'

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.

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

**346. 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. 150. 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.

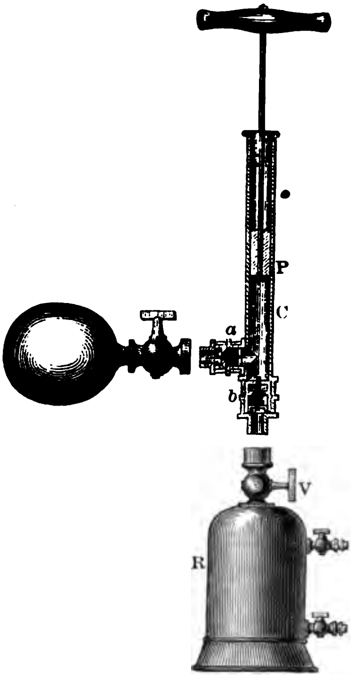

FIG. 150.

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.

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.

347. **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.

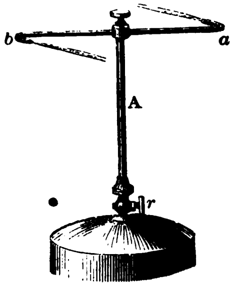

FIG. 151.

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 Barker's mill, Fig. 151.

## THE HEIGHT OF THE ATMOSPHERE.

348. **Mercury** is about eleven thousand times denser than air, at the level of the sea. If air were every-where of this density, the height of the atmosphere required to balance the column of mercury in the barometer would be 11,000 × 29.922 inches, or 27,400 feet. The pressure of 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.

This would be the actual height of the atmosphere if air were incompressible. We know that the air extends to a greater height, because aeronauts have actually ascended to higher altitudes. Moreover, as the air at any level is compressed by the weight of the column above it, the air must become rarer as we ascend from the level of the sea. If a barometer were carried one thousand feet above the sea-level, the column would descend about an inch. The air at this level sustains a pressure one-thirtieth less than at the sea-level, and, in accordance with Mariotte's law, it is proportionally of less density. Therefore, we shall have to ascend rather more than one thousand feet to reduce the column another inch; and so on, in increasing ratio. At the height of 3.4 miles, the barometer will stand at fifteen inches, showing that one-half the atmosphere is below that level. Every additional ascent of 3.4 miles will reduce the pressure one-half, and consequently the density of the air. The following table is prepared in accordance with this rate of decrease:

*Pressure of the Atmosphere at different Levels.*

| Height above the sea in miles. | Height of the barometer in inches. | Density of the air. Sea-level = 1. | Pressure in pounds to the square inch. |
|---|---|---|---|
| 0 | 30 | 1 | 15 |
| 3.4 | 15 | $\frac{1}{2}$ | 7.5 |
| 6.8 | 7.5 | $\frac{1}{4}$ | 3.75 |
| 10.2 | 3.75 | $\frac{1}{8}$ | 1.875 |
| 13.6 | 1.87 | $\frac{1}{16}$ | .9375 |
| ...... | ...... | ... | ......... |
| 51 | .0009 | $\frac{1}{32768}$ | .0004 |

At the height of 13.6 miles the air would be rarer than hydrogen. At the height of fifty miles the mercury would be elevated about one-thousandth of an inch, and the air would be less than one thirty-thousandth of its density at the sea-level. At this height, therefore, the limit of the atmosphere is practically reached.

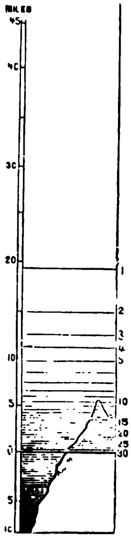

FIG. 152.

**349. The intense cold** of the upper limits of the atmosphere, tends to diminish the expansion of the air, by diminishing the repulsion between its molecules, so that it is probable that the height of the atmosphere does not exceed forty-five miles. This result is confirmed by the phenomena of refraction of the heavenly bodies.

Fig. 152 is an attempt to represent to the eye the decreasing pressure of the atmosphere.

**350. Heights are measured** by the barometer, in accordance with the facts thus established. 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 heights of the atmospheric columns above the two stations. Allowance must then be made for the temperature at the time of observation, and for the latitude of each station. Formulæ have been computed for this purpose, but they do not fall within the scope of this book.*

**351. Fluctuations of the barometer.** 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 falls again, as the depression of the wave succeeds. Except for extraordinary causes, the range in height at the equator does not exceed one-fourth of an inch; at New York the range is about two inches, and in Great Britain it exceeds three inches. The mean annual height at any station is the same from year to year. The mean annual height is greatest (30.04 inches) near the thirty-sixth parallel of latitude.

**352. The barometer** is subject to slight variations, which

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* An approximation to the vertical distance between the two stations may be found by multiplying the difference of the logarithms between the two barometric columns by 60159 feet. This, increased by $\frac{9}{4000}$ of itself for every degree that the mean temperature of the two stations is above 32° F., will give a result not far from the truth.

EXAMPLE.—The barometric pressures at the bottom and top of a mountain were, respectively, 31.725 and 27.866. The mean temperature was 50° F.; required, the difference in height.

Log. of the lower station, 31.725 = ........................ 1.50140
Log. of the upper station, 27.866 = ........................ 1,44508

Difference of logarithms of the two stations = ............ .05632

60159 × .05632 = 3388 = approximate height. The correction for temperature is (50° − 32° = 18°), 18 × $\frac{9}{4000}$ × 3388 = 137 feet; 3388 + 137 = 3525 feet = the height more nearly.

occur at *regular periods,* from hour to hour and from day to day. The mean monthly height is greater in winter than in summer. The mean daily height occurs at about twelve o'clock, noon, and midnight; the maximum height is reached between eight and nine o'clock; the minimum, between three and four o'clock, both morning and evening. These hours are, therefore, the best for taking observations.

**353. Besides these periodic variations,** the barometer is subject to *accidental* variations which increase with the latitude. It has been noticed that such accidental variations are often coincident with the changes in the weather, because the column of air is generally heavier in fair weather, and lighter in foul 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 absolutely worthless. The variations in the height of the barometer indicate changes in the pressure of the atmosphere, which may be followed by changes in the weather. The following rules are generally reliable.

*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, is the sure forerunner of 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.

**354. 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.

**355. On ascending to great heights**, the respiration is much accelerated, because of the rarefaction of the air. If the ascent is made rapidly, as in a balloon, other uneasy sensations are often felt, which are very likely occasioned by the expansion of the air inclosed in the body. If the ascent were made slowly, this air would have time to accommodate itself to its new conditions. If it be true that the "skin cracks and bursts, and the blood issues from the pores of the body," at high elevations, as is related by travelers in South America, the cause must be sought rather in the dryness of the air, or the greater cold, than in the diminished pressure.

Men who descend in diving bells to the depth of thirty-four feet, endure the pressure of at least two atmospheres without serious inconvenience.

## MACHINES FOR RAISING WATER.

**356. 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 withdraw the air 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 on the water outside of the pipe, 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.

FIG. 153.

**357. The length of the suction pipe** can never exceed **thirty-four feet,** because the pressure of the atmosphere is only capable of supporting a column of water 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.

**358. 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.

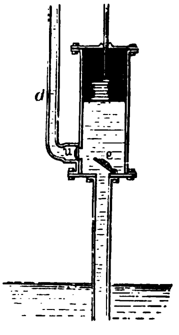

FIG. 154.

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.

**359. 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. 155. 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.

**360. 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.

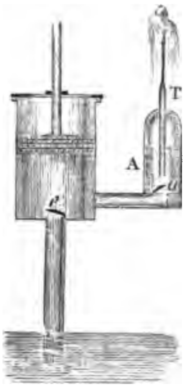

FIG. 155.

**361. 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. 156. 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.

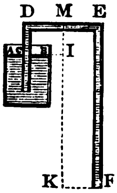

FIG. 156.

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.

**362.** 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. 157. 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 of length of the two arms.

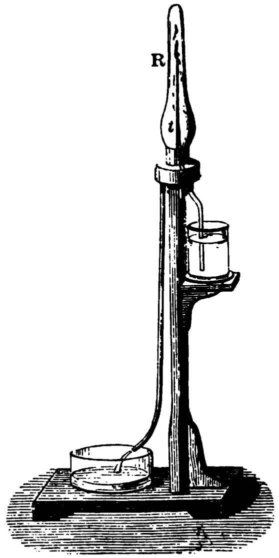

Fig. 157.

**As the greatest pressure on the surface, A B, Fig. 156, can never exceed one atmosphere, the vertical height, MI, of the column sustained can never exceed thirty-four feet, if the liquid is water, or thirty inches if the liquid is mercury.**

By drawing the end of the long arm out to a fine tube, and giving it a horizontal or upward direction, it may be employed to advantage in illustrating the flow of liquids through orifices.

The acid siphon, Fig. 158, has a suction tube attached for convenience in exhausting the air, and, at the same time, preventing the entrance of corrosive liquids into the mouth.

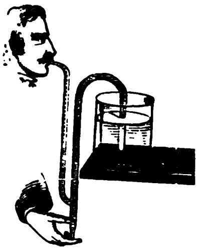

Fig. 158.

FRICTION OF FLUIDS AGAINST EACH OTHER.

**363. The atomizing tube** is a contrivance for breaking up the particles of a liquid into spray. A common form *is shown* in Fig. 159.

*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.

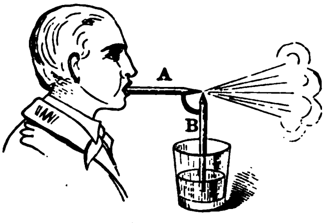

FIG. 159.

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.

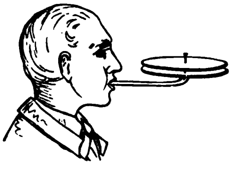

FIG. 160.

**364. The pneumatic paradox** affords another illustration of the same sort. It may be made by taking two small circular disks of card board, and fitting to one a small tube or goose quill. 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 stream of 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.

### 365. 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 V.

### UNDULATIONS.

**366. The kinds of motion** thus far considered in mechanics, are mainly those which relate to masses of matter taken collectively. A pendulum vibrates as a concrete whole, without reference to the atoms of which it is composed. Each molecule partakes of the vibration common to the entire mass, and is at rest with regard to contiguous particles. We are now to consider movements which involve the entire mass of a body, by reason of the temporary displacement of its particles.

The atoms of all bodies are held in a state of equilibrium by the *joint action* of the molecular forces and gravity. If the molecules of *any body* are disturbed by any external force, not too great, they will *tend to* resume their original positions by a series of movements, to and fro, which gradually decrease in extent and finally cease. Such alternating motions are known as *vibrations*, *oscillations*, *waves*, or *undulations*, according to the circumstances under which they are produced.

**367. Any body may be thrown into vibrations** of some sort, but the character of the waves formed varies (1.) with the state of the body, whether solid, liquid, or aëriform; (2.) with its form and specific properties, and (3.) with the nature of the disturbing force.

**Formation of undulations.** If an elastic cord, AX, fixed at one end, be stretched by the hand grasping the other end, and the hand be jerked upward, an apparent movement will be transmitted along the cord, like the waves upon water. The first effect of the jerk will be to produce the crest, A E N, which rises above the position of repose. This will be succeeded by the corresponding hollow, N D O, depressed below the horizontal plane to the same extent. If the cord be jerked but once, the curve, A E N D O, will advance along the cord, assuming successively the positions II and III until it reaches the end, X. It will then return in an inverted curve, IV, V, and VI, again to the hand.

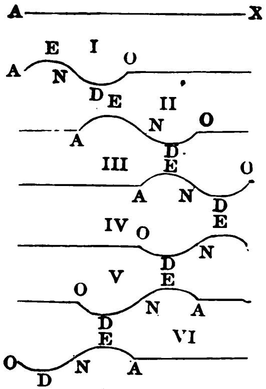

FIG. 161.

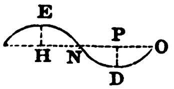

FIG. 162.

The curve, A E N D O, Fig. 162, is called a *wave*

A N O is the *length* of the wave.

H E is the *height* of the wave.

D P is the *depth* of the wave.

A E N is called the *phase of elevation* of the wave.

N D O is called the *phase of depression* of the wave.

The greatest distance *through* which any particle moves is called the *amplitude of vibration*, or the *intensity* of the wave. It equals the *sum of the height and depth* of the wave, H E + D P.

368. **Although the particles of the cord** appear to move from one end to the other, it is evident that this is impossible, but that each particle has moved only up and down, successively passing through the highest and lowest points of the wave. A wave which moves in a certain direction by the successive motion of material particles, is called a *progressive undulation.*

If a pebble be dropped into a placid pool, a circular elevation will be formed around the depression caused by the pebble. The gravity of the liquid particles tends to bring them to their former level, but their inertia will carry them below the horizontal plane, and, at the same time, extend the impulse to surrounding particles. In this way, progressive undulations will be produced in ever widening circles. Each undulation will consist of a phase of elevation and of depression. The motion of each particle, in obedience to the original impulse, and to the force of gravity, can only be up and down, as is proved by the alternate rise and fall of bodies floating on the surface. A progressive undulation is, therefore, merely an advancing form, and any apparent progression of the particles of the wave is merely an optical illusion.

The circular waves of liquids decrease in intensity, and finally become inappreciable, because the number of particles through which the impulse is diffused increases as the circles widen.

369. **The surface waves of fluids** are propagated by gravity. All other waves are dependent, mainly, on the elastic force developed among the particles of a body by the disturbing force. Any body through which waves are transmitted is called a *medium.*

Undulations may be confined to the body in which they are formed, or may be formed in one body and transmitted through several others. Thus, the vibrations of solids may be transmitted to water, to the atmosphere, or to other solids.

370. **The undulations of solids** are dependent on the degree of their elasticity and the manner by which it is developed. Solids of an elongated form, as rods and tense *cords,* are subject to (1.) transverse, (2.) torsional, and *(3.) longitudinal* vibrations, according as their elastic force *is developed* by flexure, torsion, or traction.

If a rubber tube be suspended from one end, and stretched by a weight at the other, and the weight be pulled down and suddenly let go, the cord will perform a series of *longitudinal vibrations*, causing the weight, A, to oscillate alternately above and below its normal position. If the weight be turned to one side, so as to twist the cord, and let go, the torsion of the cord will cause the weight to oscillate back beyond its original position, and then return in a series of *torsional vibrations*. If the cord be stretched and made fast at both ends, and then plucked at the center, by drawing it out and letting it go, it will oscillate to and fro in *transverse vibrations*, as shown by the dotted lines of the figure.

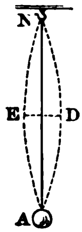

FIG. 163.

In each case, the elasticity of the cord tends to restore it to the normal position, the inertia of the cord carries it beyond, and again develops the elastic force. The greater the disturbing force, the greater will be the amplitude of the vibration, E D; but as the elastic force increases with the amplitude, the time of vibration will be the same. Thus the vibrations of an elastic body, like those of the pendulum, are isochronous, or performed in equal times. Therefore, the vibrations of the same body will be continued in equal times, though with decreasing amplitude, until they are brought to rest by gravity and the resistance of the air.

The strings of musical instruments vibrate transversely. Such vibrations are called *stationary*, because all the particles assume and complete their vibration at the same time. The motion from E to D is called a *simple* vibration; the motion from E back to the same point is called a *double* or *complete* vibration. Hereafter the word vibration will be used to denote complete vibrations, unless the contrary is distinctly stated.

**371. Let the cord** A B be divided into any number of equal parts, and be fixed temporarily at the points of division, as N and N′, and let the segments be set in vibration in contrary directions at the same time, as shown in Fig. 164. Now, if the points N and N′ are set free, no change will take place in the vibrations of the cord. The cord will remain at rest at the points N and N′, and *stationary undulations* will be formed along the cord, whose phases of elevation and depression will be alternately above and below the line A B. Rings of paper placed along the cord will be thrown into vibration at every other point than N and N′. **Points at rest in a vibrating body are called *nodes*, as N and N′.**

FIG. 164.

**372. Progressive undulations may be converted into stationary.** Suppose a progressive undulation to be started along the cord, AB, by a single jerk; and suppose the pulse, A *m*, to be completed in half a second. The advancing wave, E F, will reach the end of the cord in one second, and will then begin to return. At this moment, let an equal impulse be started at G. The two pulses will meet at the center of the cord in opposite directions; the

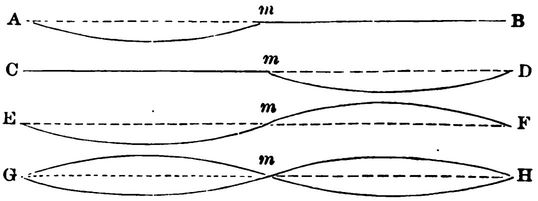

FIG. 165.

advancing wave will tend to move the point *m* downward, the reflected wave will have an equal tendency to move it upward. The point, *m*, being thus urged by two equal and opposite forces at the same time, will become a *node*. The two halves of the cord will then vibrate independently of each other, in stationary undulations. By timing the pulses, so that each shall occupy one-third, one-fourth, etc., of the length of the cord, three, four, etc., nodes will be formed along the string. The segments between the nodes vibrate independently of each other as stationary undulations, two, three, or four times faster than the cord vibrates as a whole. The theoretical length of a wave is that of two segments, including one phase of elevation and one of depression. The position of the nodal points can be ascertained by placing on the cord light rings of paper; these will be thrown off at any point other than a node.

**373. A cord which vibrates transversely** along its whole length, can be made to vibrate in any number of segments, by gently touching it at one of its nodal points, one-half, one-third, one-fourth, etc., of its length, either at the moment the cord 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, four, or more segments, according to the distance of the point touched from the end. Fig. 166.

FIG. 166.

**374. The vibrations of all elastic solids** bear a general resemblance to those of cords. Transverse vibrations may be excited in cords, rods, or thin plates, by percussion, or by the friction of a resined fiddle-bow. Longitudinal vibrations may be produced in cords and rods by rapidly rubbing them in the direction of their length with a bit of cloth or leather covered with powdered resin. The transverse vibrations of cords are maintained by the tension employed in stretching them. All other vibrations are maintained by the elasticity of the material. By so much as this molecular *elasticity differs* from that developed by ten*sion, will the rapidity of* the vibration differ from the transverse vibrations of cords. The same rod will vibrate longitudinally much faster than transversely.

**375. The nodal lines in plates** may be shown by a plate of glass or metal fastened in a horizontal vice. If the plate be covered with fine sand and set into vibration, the sand will be thrown off from the parts in vibration and will gather about the nodal points. If the vibrations of the plate are quenched at any point by touching the plate, nodal lines will be formed symmetrically on the plate, as shown by Fig. 167. In this way, an almost infinite number of nodal lines may be formed.

FIG. 167.

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

**376. Undulations in liquids.** The circular waves formed on the surface of liquids may be considered as made up of

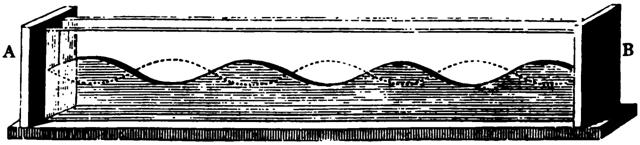

FIG. 168.

*an infinite* number of linear undulations, extending in rays *equally from* the center, in the direction of the radii.

Whatever may be proved in regard to one ray applies to every ray similarly situated.

Wave motion may be illustrated by the apparatus in Fig. 168, which consists of a long, narrow canal, with glass sides, partially filled with water. On tilting either end, a *progressive undulation* will pass to the other end and be there reflected. If new waves be formed at proper intervals, by fresh impulses, the advancing and receding waves may be made to meet in any part of the canal, and in any phase of their undulation.

**377. Combination of waves.** The resultant motion produced by the meeting of two waves, in opposite directions, will be equal to their algebraic sum. It is customary to consider the elevated phase as positive, +, and the depressed phase negative, —.

1. If the crest of one wave coincides with the crest of the other, the height of wave formed will equal the sum of the elevations of the two waves, and, consequently, its depth will equal the sum of their depressions.

2. If the crest of one wave coincides with the hollow of the other, the height of the wave formed will equal the difference of the elevations of the two superimposed waves, and its depth will equal the difference of the depths of their depressions.

3. If the amplitudes of two waves meeting in different phases are equal, both waves will disappear and the surface become horizontal. This phenomenon, which results in the mutual destruction of waves, is called the *interference of waves.*

4. If the impulses be so timed that the length of the wave is an aliquot part of the canal, as $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, the descending particles of one wave will meet the ascending particles of the opposite, nodes will be formed, and two, three, or more *stationary undulations* will be produced, as shown by *the dotted lines of the figure.*

**378. The undulations of the waters** of the globe are seen in tides, waves, and currents.

The tide wave is an alternate ebb and flow of the waters of the ocean. It is due to the difference in the attraction of the moon upon different portions of the ocean, modified by the attraction of the sun. In theory, two tide waves encircle the earth, and pass around it in a little less than twenty-five hours. In fact, the advance of the tide is so retarded by the shape and depth of the oceanic basin, that the tide wave which starts south of Australia does not reach London until forty-eight hours afterward. The height of the tide wave in the open sea does not exceed three feet; but in wide-mouthed bays, like the bay of Fundy, it sometimes exceeds seventy feet.

**379. The ordinary sea waves** are caused by the unequal pressure of the wind upon the surface of the water.

The average waves in a storm do not exceed ten feet in height. Dr. Scoresby measured waves during a violent storm on the Atlantic, that were forty-three feet from the crest to the hollow of the wave, which is their height and depth combined. The length of the waves he found to be five hundred and fifty-nine feet, and their rate of travel to equal nearly fifty feet per second. The great height of the waves in a storm is due to the accumulation of wave upon wave. Three or four waves may sometimes be seen on the same billow. This storing of force, by the successive increment of many feeble impulses, is a striking peculiarity of wave motion. It is not likely that the force of the most violent storm extends to a depth of more than two hundred feet.

**380.** The waves continue long after the wind dies away, producing what is known as a dead swell. These waters in the open sea have no onward motion whatever, but while the storm is raging, the wind, striking the water more or less obliquely, has a tendency to drag the surface particles along with it, in the same manner that it drives floating logs and ships.

Sir John Herschel thinks that constant winds, like the trades, *are competent* to accumulate, by their steady action, enough of this *sort of* motion to produce the oceanic currents. It is generally believed that the currents of the ocean are due to the difference in temperature and density of its different parts, aided by the rotation of the earth on its axis.

**381. Undulations in aeriform bodies.** Surface waves, which are due to the force of gravity, may be produced in gases as well as in liquids. Aëriform bodies are also subject to undulations, caused by their elasticity, which are called *waves of condensation and rarefaction.*

If the piston in the air syringe, Fig. 279, be driven to the bottom of the cylinder, and the pressure be suddenly removed, the elasticity of the condensed air will force the piston upward. If there were no resistance to be overcome, the inertia of the air would cause it to expand beyond its original volume. It would then contract again, and thus the piston would be made to oscillate about the position of repose. In the same way, the load attached to the weight lifter, Fig. 148, oscillates by the alternate rarefaction and condensation of the air within the receiver.

**382. The same phenomena** will take place in free air. Let a soap bubble, containing a mixture of oxygen and hydrogen, be exploded by the flame of a candle. The vapor formed by the chemical union of these elements fills 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, until at length its oscillation ceases.

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 exterior shell; it, in turn, upon another, and so on. Thus the initial force will be propagated in a series of alternate condensations and rarefactions, extending in spheres about the center of disturbance.

*These movements are* analogous to the waves on the sur-*face of liquids, extending* in circles from the center; the phase of elevation corresponds to the condensation, and the phase of depression to the rarefaction. An aërial wave consists of a condensation and a rarefaction. Fig. 169 is an attempt to represent to the eye four aërial waves.

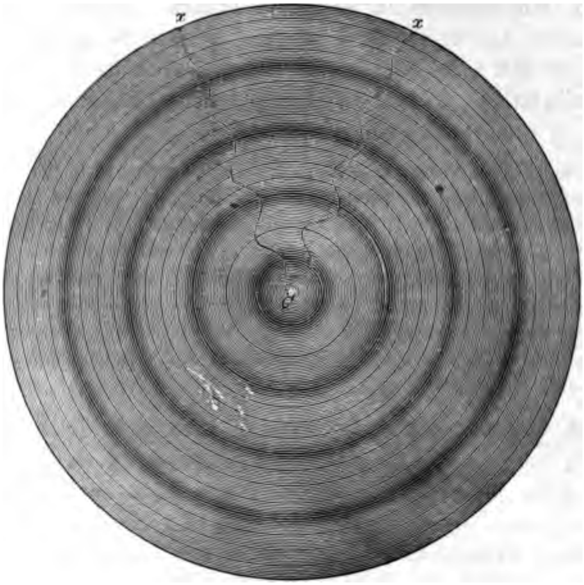

FIG. 169.

**383. The propagation of aerial undulations** will be best understood by considering the motion of the particles along one of the rays of the sphere, as *a x*.

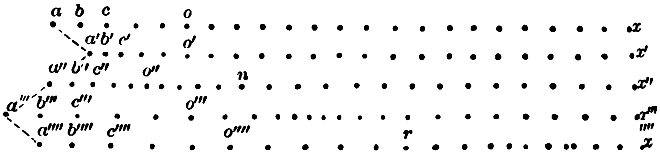

FIG. 170.

Let the upper line of dots represent the air particles along one of the radii, in a state of rest, and suppose the particle, *a*, to be driven toward $x$, so as finally to occupy the position $a'$, in the second line of dots. The moment that $a$ begins to move, its impulse begins to be transmitted, by the elastic force between the particles, to $b$; in the following moments the impulse will be transmitted, successively, through $b, c$ to some point, as $o$, more or less distant from $a$. The particles between $a'$ and $o'$ are all compressed, but not equally; the condensation is greatest at $a'$, and least at $o'$.

Now, suppose the particle $a'$ to have reached the limit of its swing, and to begin to return. In successive moments, the particles, $b' c'$, etc., will complete their vibration, reach their greatest condensation, and then follow $a$ in returning; while, at the same time, the particles beyond $o'$, will, in turn, be set in vibration. At the supposed rate of transmission, when the particle, $a'$, has attained its original position, at $a''$, the state of greatest condensation will have reached the particles at $o''$, and $a''n$ will constitute a wave of condensation.

The inertia of the returning particles, $a''$, $b''$, etc., will now carry them beyond $a''$, $b''$, etc., toward $a'''$. The greater inertia of the foremost particles, will tend to separate them from those following, so that when $a''$ shall have reached $a'''$, $o''$ will have resumed its original position, and the particles between $a'''$ and $o'''$ will be in a state of unequal rarefaction. The point of greatest rarefaction will be at $a'''$.

When the particle at $a'''$ is ready to swing again toward $x$, $b'''$ will have reached its limit and the point of greatest rarefaction. So, in succession, the maximum rarefaction will be transmitted through each particle, toward $x$. The motion is evidently that of a progressive undulation, which will continue until external causes bring it to rest. The length of a rarefied wave is $a^{iv} r$, which is double $a''' o'''$.

The distance that $a$ travels toward $a'$, depends on the intensity of the disturbing force, and, at the same time, measures the degree of compression of the wave. The distance through which any particle vibrates, as from $a'$ to $a'''$, is called the *amplitude* of the vibration. The motion to and fro, as from $a'$ to $a'''$ and back, constitutes a *complete vibration*. The *length* of an aërial undulation is the distance through which the motion is transmitted during the time of a complete vibration. It consists of a condensed and a rarefied wave, and is the sum of the distances $a''n + a^{iv} r = a^{iv} x^{iv}$. The more rapid the vibrations, the quicker the waves will succeed each other, and the shorter will be the length of each wave. The amplitude of the vibration may be only a small fraction of an inch, while the length of an undulation may be many feet. The greater the amplitude, the greater will be the alternate condensations and rarefactions, and the greater will be the intensity of the wave.

384. **The velocity** with which undulations are transmitted through aëriform bodies of constant temperature, varies directly as the square root of their elasticity, and inversely as the square root of their density. So long as these factors are unchanged, all waves are transmitted with equal velocity.

Suppose the distance the undulation traverses in a second to be one thousand feet, the shorter the waves, the more there will be of them; the longer the waves, the fewer their number; the greater the amplitude, the greater will be the resistance to be overcome, and *vice versa*, and, by consequence, all the waves will move over equal spaces with equal velocities.

385. **What has been shown to be true** of a single line of particles, applies to all the lines extending in radii from the center of disturbance. Consequently, aërial waves expanding freely form spherical surfaces, continually increasing, and thereby involving a greater number of particles in their motion. The intensity of a wave will be diminished in proportion to the space over which its motion is diffused. Therefore, as the surfaces of spheres are as the squares of their radii:

*The intensity of a wave diminishes as the square of the distance from the center of propagation increases.*

This law is inapplicable, whenever the radial diffusion of the wave is prevented by interposing obstacles.

386. **The combination and interference** of aërial waves follow the laws already found for liquids. If confined in *tubes* and pipes, the combination of the direct and reflected

waves may produce nodes and stationary undulations. The meeting of two waves may result either in greater condensation or in greater rarefaction; or the waves may quench each other, wholly or partially, according to the algebraic sum of their undulations.

**387. The reflection of waves** from solid surfaces is governed by the same laws that apply to the impact of elastic bodies, *i. e.: the angles of incidence and reflection will be equal.*

Let a circular, progressive wave, emanating from the center, O, strike the plane surface, S B, with a velocity sufficient to have carried it in the next moment to S P′ B. The particles in the perpendicular ray, O O′, will first strike the surface, and be first reflected in the direction, O′ P. When the diverging rays, O D′ and O I′, reach the surface, they will be reflected on the other side of the perpendiculars, M′ E and M K, in the lines, O′ D and O′ I. Now, as the velocities of the direct and reflected rays are the same, the reflected wave will reach the points D P I, in the same time that the direct wave would have arrived at the points, D′ P′ I′, and the same is true of all intermediate points. Hence, the reflected wave proceeds as if from the center, O′, at a distance from the surface, S B, equal to that of the center of the incident wave, O, but on the opposite side.

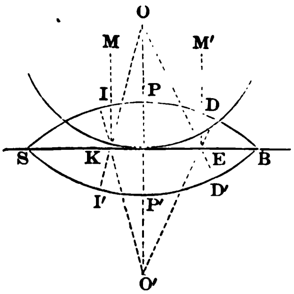

FIG. 171.

**388. When the origin of the wave** is far distant from the reflecting surface, the waves will then be apparently rectilinear, being arcs of very large circles. In all such cases, the diverging rays, falling upon small surfaces, may be considered parallel. Parallel rays, incident upon plane surfaces, will also be parallel after reflection.

**389. The principles of geometry** enable us to determine the direction of waves reflected from curved surfaces. We may regard each wave as made up of an indefinite number of linear rays, falling upon so many points in the curve. Each point so taken constitutes a part of a straight line; as, T T′, tangent to the curve at that point. As every radius is perpendicular to the tangent at its extremity, the radii of a circle constitute so many perpendiculars, which we may employ in laying off the incident and reflected angles in circular arcs.

Suppose a rectilinear wave of the sea to enter a rocky bay, of semicircular shape. As each portion of the wave in turn strikes the rock, it will be reflected toward a point, F, half way between the center of the bay and the shore. There will, therefore, be a commingling of all the parallel rays of the direct wave, to form a circular wave, whose center is this common point. The interference of the direct and reflected waves will soon "chop up" the bay into an infinite number of little waves. These interfering waves may be imitated by allowing a tiny stream of mercury to trickle from a pin hole in a paper cone upon a basin, containing the same metal, at a point half way between the center and circumference.

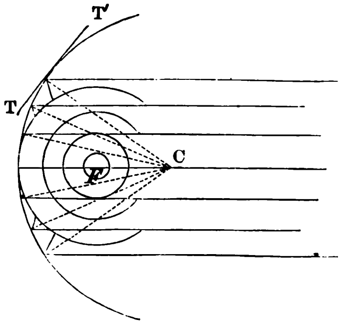

FIG. 172.

**390. Lines drawn from any point** in an ellipse to the two foci, make equal angles with the tangent, T T′. These angles are, therefore, complements of the angles of incidence and reflection, and may be used in their stead. Hence, waves originating in either focus of an ellipse will converge, *after reflection*, in the other focus.

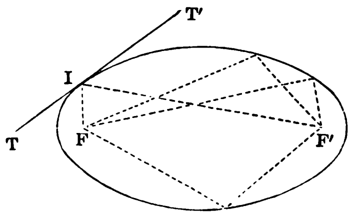

FIG. 173.

**aves diverging** from the focus of a parabola will d from the surface in parallel lines, and, conversely, riking the parabola in ays, will converge after upon the focus. It is hat two parabolas may ach other that rays di- rom one focus shall be converge in the other. surfaces thus related to r are termed *conjugate*.

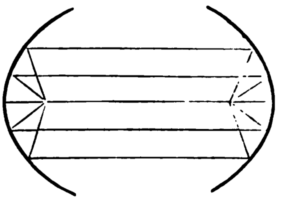

FIG. 174.

**imultaneous vibrations.** It is possible to subject in Fig. 163, to transverse, longitudinal, and tor- rations at the same time. Not only so, but the be made to vibrate as a whole, while, at the same is vibrating in halves and thirds. The motion ch particle assumes, in obedience to many simul- impulses, is very complex, but each impulse pro- ecisely the same kind of vibration as if it were ne. The possibility of many independent motions ed further evident by the movements of the bodies: thus, the moon revolves (1.) on its own ) about the earth; (3.) with the earth, about the ) with the sun about some distant center.

nvestigations have made it probable that every particle of n in the most rigid bodies, is constantly in motion, and, in several directions at the same time. If these particles us in a state of rest, it is only because our senses are in- detecting their motion. We know that a plant increases t we can not see it grow. We can neither see the motion r hand of a watch, nor in the flight of a bullet. But we the plant, the hour hand, and the bullet move, by the he motion. So the deductions of experiment have proved ce of many motions, too obscure to be easily apprehended, atus has been contrived to render some of them manifest es. *Physicists now hold* that all phenomena appreciable by re *the results of* different modes of motion, impressed upon material particles. Thus we may have the following modes of motion:

1. Gross mechanical motion of machines.
2. The regular oscillations of pendulums and elastic bodies.
3. Vibrations resulting in the sensation of sound.
4. Vibrations resulting in the sensation of heat.
5. Vibrations resulting in the sensation of vision.
6. Vibrations producing the phenomena of electricity.
7. Movements resulting in chemical changes.
8. Finally, we hear, taste, touch, smell, and see, because external impressions excite, in the different nerves, vibrations, which, when transmitted to the brain, produce all our sensations.

### 393. Recapitulation.

There are two varieties of waves:

1. 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 of heat.
2. 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, to the ear, by waves of this sort, which are therefore called *sonorous waves*.

We are justified in believing that all our sensations are due to different modes of motion impressed upon matter.

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## CHAPTER VI.

### ACOUSTICS.

**394. Hearing** is a sense depending upon vibrations excited in the auditory nerve, and transmitted to the brain. The sensation is called *sound*. Except in case of disease, the sensation can not originate in the nerve, but is the impression *(1.)* caused by the vibrations of bodies, (2.) transmitted ough an elastic medium, and (3.) conveyed to the auditory rve by the mechanism of the ear. These three conditions always requisite for the sensation of sound.

1. Every species of sound may be traced to the vibra-ns of some elastic body.

When the strings of a violin are sounding, the transverse vibrations pear as a broad, shadowy surface. When a tuning fork sounds, vibrations may be felt by placing one of its prongs lightly upon teeth. If a wire, or knife blade rests against the edge of a bell, a glass receiver, when ringing, it will be made to rattle. The sounds wind instruments are due to the vibrations of the air they contain. e tremors produced in the external air by vibrations of an organ e, are distinctly perceptible. Bodies capable of producing sound called *sonorous*.

2. An elastic medium is required for the transmission of nd. The ordinary medium is the atmosphere.

he vibrations of sonorous bodies produce in the air waves of con-sation and rarefaction, which correspond in rapidity and intensity 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.

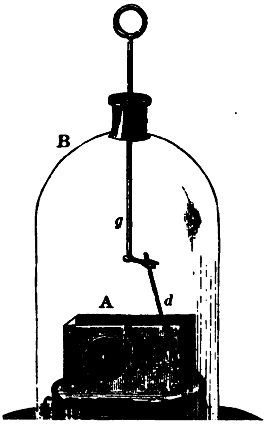


*Fig. 175.*

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 is at first distinct, being conveyed from the bell through the air in the receiver to the glass and the pump plate, and thence to the ear by the outer air. When the air is gradually exhausted, the sound grows more and more feeble, and ceases to be heard when a vacuum is obtained.

In like manner, sound is quenched by the interposition of any body having feeble or imperfect elasticity. Thus, a partition filled with sawdust, or covered by a thick carpet, will prevent the transmission of sounds from one room to another.

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

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

In accordance with these facts a second definition may be given to sound, viz.:

**Sound** is that mode of motion which is capable of affecting the auditory nerve.

**Acoustics** is the science which treats of the cause, nature, and phenomena of sound.

395. **The quality of sound** depends on the elasticity and form of the sounding body. All sonorous bodies are elastic, but all elastic bodies are not sonorous. Lead is not sonorous, because its *elasticity is too imperfect* for continued vibrations. The fibers of wool and cotton are highly elastic, but are not sonorous, because their *elasticity is feeble*, so that their vibrations are slow and inaudible. Steel, glass, silver, brass, and cat-gut are sonorous, because these substances are highly elastic, and possess sufficient force for rapid vibrations.

Compact masses, as spheres and cubes, do not permit the free vibrations of their particles, and hence are less sonorous than rods and thin plates. A spherical shell is not as sonorous as its hemispheres, which are bell shaped.

396. **Quality of sound.** Noise is the sensation produced by unequal or confused vibrations. A musical sound is produced by vibrations recurring at short and equal intervals. If the vibrations are rapid, the sound is high, or acute;

[redacted]

but if slow, the sounds are low or grave. Therefore, *the pitch, or tone, depends on the rapidity of the vibrations.*

These facts may be shown by pressing a card against a toothed wheel in motion. If such a wheel be attached to the axis of a whirling table, or a gyroscope, it will be found that when the card, E, strikes against less than sixteen teeth per second, only a succession of taps will be heard, but if the number exceeds sixteen per second, the sounds blend together in a clear musical sound. As the velocity is increased, the sound is more and more acute.

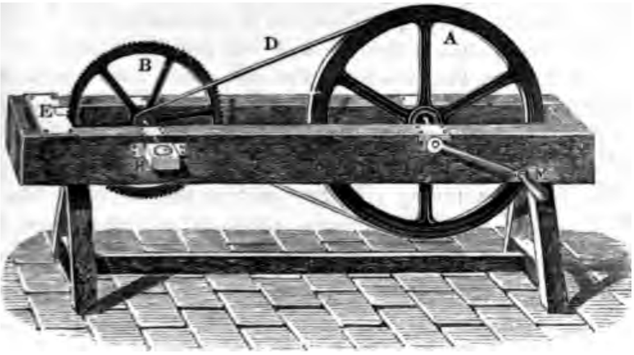


FIG. 176.

The number of vibrations per second may be found by multiplying the number of teeth in the wheel by the number of revolutions the wheel makes per second. Sounds are *in unison* when the rapidity of vibration is the same. The rate of vibration in tuning forks, violins, and other musical instruments, may be found by making the wheel sound in unison with them. The same thing may be done more advantageously by the *syren*, which is a wind instrument so constructed as to register the number of vibrations at the same time it produces the sound. In Savart's wheel, Fig. 176, H is an apparatus which indicates the number of revolutions in the toothed wheel.

**397. The intensity or loudness of the sound** depends on the amplitude of the vibrations; because this measures the degree of condensation of the sonorous wave. If the amplitude is large, *the sound is* intense, or loud; but if small, *the sounds are feeble,* or *soft.* A sound may maintain the same pitch while it varies in intensity; thus, a tuning fork continues to sound the same tone until its vibrations are too feeble to be audible.

*The intensity of sound varies inversely as the square of the distance of the sounding body.*

This is because the undulations form spherical waves of ever increasing extent. 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. For this reason, loud sounds are propagated further than feeble ones. The sound of the volcano, Tumbora, was heard at the distance of eight hundred and fifty miles.

**398.** When a string vibrates in free air, it emits but a feeble sound; but if it vibrates above a sounding box, as in the case of a violin, guitar, or piano, the sound is much 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 thus unite to form sonorous waves of greater intensity. Hence, *Sound is increased in intensity by the proximity of a resonant body.*

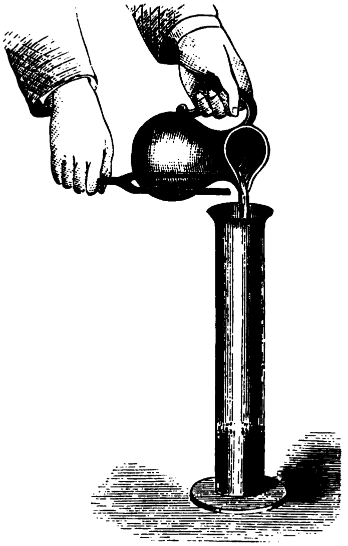


Fig. 177.

This effect may be shown by holding a vibrating tuning fork over the mouth of a tall glass jar, and carefully pouring water into the jar. When the water fills the jar to a certain level, the sound of the fork will be greatly increased by the vibration of the column of air within the jar. At any height above or below this level, the intensity of the sound will be lessened. The length of the air column diminishes as the rapidity of vibration increases, and is always one-fourth of the length of the wave produced by the fork.

**399. Sympathetic vibrations** are always produced when one sounding body vibrates near another capable of emitting the same tone. Thus, if the voice utters a prolonged tone near a piano, that wire will be set in vibration whose sound is in unison with the pitch of the voice. By changing the pitch, other wires will respond. This is because the sonorous waves excite to vibration wires which are capable of vibrating at the same rate.

**400. Qualities of media.** The experiment in (394) proves that sound diminishes in intensity as the air is rarefied. If the receiver be filled with other gases, it will be found that the bell has a feeble sound in gases lighter than air, as hydrogen, and an intense sound in gases denser than air, as carbonic acid. Hence, *the intensity of sound depends on the density of the medium in which it is generated.*

These experiments are confirmed by the facts that the sound of a pistol fired on the tops of high mountains resembles the report of a fire-cracker, while a whisper is painfully loud to the occupants of a diving bell sunk to a considerable depth. The energy with which liquids and solids transmit sound, exceeds that of the atmosphere. Franklin found that a person with his head under water could hear the sound of two stones struck together at the distance of half a mile. The scratch of a pin at the end of a long stick of timber seems loud to a person whose ear is at the other end.

**401. Mixed media.** If the lungs be filled with hydrogen, the voice is weak and piping. A bell under a glass receiver is less distinct than in the open air, although glass is among the best conductors of sound. A noise made under water is feebly heard in air, and *vice versa.* Hence, *the intensity of sound is diminished in passing from one medium to another.*

The conducting power of air is diminished when it is disturbed by alternating currents of different densities. For this reason, sounds are less distinct by day than by night. So, also, peals of thunder penetrate to a less distance than would be anticipated from their intensity.

**402. Limits of hearing.** All ears are deaf to some vibrations. The gravest sound perceptible to the human ear is produced by sixteen complete vibrations in a second; the highest sound is caused by thirty-eight thousand complete vibrations in a second. The auditory range is not the same for all persons. Some can not hear the highest notes of a piano, others are insensible to the note of a cricket, or even the chirrup of a house swallow. The hearing of these persons may be exceedingly acute within their limit; that is, they may be able to distinguish very feeble sounds, as the lowest whisper.

Naturalists assert that many insects produce sounds that are perfectly appreciated by their mates, although too acute for human ears.

**403. The distance at which sound is audible** varies with its original intensity and the circumstances which modify it.

Still air, of great density and uniform temperature, is favorable to the transmission of sound. Under ordinary circumstances, a powerful voice is distinct at a distance of seven hundred feet. In the arctic regions, Lieutenant Foster conversed with a sailor at the distance of a mile and a quarter. The cry of a sentinel, "All 's well," has been conveyed, in still air, over calm water, ten miles. Winds and currents increase or diminish the conducting power of air, according to their direction and force.

The earth transmits sound further than air. The cannonading at Antwerp, in 1832, was heard in the mines of Saxony, three hundred and twenty miles distant.

**404. Acoustic tubes.** If the sonorous wave is not permitted to expand, its intensity can be maintained for a great distance. This may be effected by causing the wave to pass through a tube. Speaking tubes are employed in large buildings for transmitting messages from one story to another. If the tube terminate in a suitable sounding box, a complicated symphony, played by a band in the basement, is perfectly transmitted to an upper hall, though inaudible in the intermediate stories.

**405. The speaking trumpets** employed by firemen and mariners reënforce the voice by the vibrations of the column of air contained in the trumpet, and thus increase its intensity. The hearing trumpet is in principle the same, though its form is the reverse of the speaking trumpet. The sonorous wave which reaches the trumpet transmits its compression or rarefaction to portions of air smaller and smaller, and thus transmits it with increasing intensity. The form of the external ear is favorable to the collection of sound. The hand held concave behind the ear concentrates the sound in the same manner.

**406. Velocity of sound.** Every one must have noticed that the flash of a distant gun is seen before the report is heard. Experiments based on this observation have determined that *the velocity of sound in still air at* 32° *F. is one thousand and ninety feet per second.* The velocity increases as the temperature rises, at the rate of 1.12 feet for every degree Fahrenheit. At 60° F., sound has a velocity of eleven hundred and twenty-one feet per second. The velocity also varies with the direction and velocity of the wind.

These facts enable us to compute the distance of a sounding body, when the time of transmission is known. When a flash of light accompanies the sound, the distance may be found by multiplying the velocity of sound by the number of seconds that elapse between the flash and the report.

Thus, if when the air is at 80° F., five seconds elapse between a flash of lightning and the succeeding peal of thunder, the stroke is $1150 \times 5 = 5750$ feet distant. In the same manner, we may estimate the height of a cliff by dropping a stone from the top and noting the number of seconds that elapse before the sound is returned to the ear. Suppose the time to be eight seconds. A part of the time, $x$, was occupied by the falling body, the rest, $y$, by the sound; hence,

$x + y = 8$, but 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, $1090\,y$ also equals the height. Hence, $x^2 . 16\frac{1}{12} = 1090\,y$. From these two equations $y = 0.77 +$; therefore, the height of the cliff is 839.7 feet.

**407. The different notes** simultaneously produced by the instruments of an orchestra reach the ear of a distant auditor at the same moment. This proves that *all sounds are transmitted with the same velocity in the same medium.* If this were not so, a musical performance would produce only discords to all except those in the immediate vicinity.

This law is strictly true only for sounds not differing greatly in intensity, for it has been noticed that the report of a cannon is sometimes heard before the command given to fire. Mathematical investigations also lead to the conclusion that a very intense sound, like a peal of thunder, is transmitted with greater velocity than a gentler one.

**408. The velocity of sound in gases** is directly proportioned to the square root of their elasticity, and inversely as the square root of their density. $v \propto \sqrt{e \div d}$. This is shown by the following table:

*Velocity of Sound in Gases at 32° F.*

| | Feet. | | Feet. |
|---|---|---|---|
| Air | 1090 | Carbonic oxide | 1107 |
| Oxygen | 1040 | Carbonic acid | 858 |
| Hydrogen | 4164 | Protoxide of nitrogen | 859 |

In this table, the elasticity and density are due to the pressure of one atmosphere. By Mariotte's law the density varies with the elasticity, so that any decrease in density is counteracted by an equal decrease in elasticity. Therefore, sound will move up or down a mountain, or at any altitude, with the same velocity as at the base, if the temperature is uniform. The effect of heat on gases submitted to a constant pressure is to increase their elasticity without altering their density. Hence, as the heat is generally greater at lower altitudes, the velocity of sound in air will generally be greater at the sea level than on mountain tops. Newton applied these facts in calculating the velocity of sound in air. The velocity obtained by theory is about one-sixth less than that found by experiment. This discrepancy is due to the fact that condensation develops heat, and rarefaction produces cold. Hence, the condensation of the sonorous wave is accomplished with greater rapidity, because the heat developed increases the elastic force between the particles; the rarefaction of the wave is also more rapid, because the cold produced diminishes the elastic force to be overcome. Therefore, the velocity of the wave must be augmented both by the heat and by the cold developed in its progress. This result would not follow if the heat were transmitted to contiguous particles.

**409. The velocity of sound in liquids and solids** is greater than in air, because their elastic force increases in greater ratio than their density. The velocity of sound in fresh water is four thousand seven hundred feet per second. In sea water it is a little more, and in alcohol nearly one-fourth less. The velocity of sound per second, in lead, is four thousand and thirty feet; in silver, five thousand seven hundred and seventeen feet; in steel and glass, sixteen thousand six hundred feet; in pine, ten thousand nine hundred feet; in ash, fifteen thousand three hundred and fourteen feet.

The difference of velocity in solids and in air may be demonstrated by placing the ear at one end of a long bar 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. The interval between them will vary with the length of the solid. The approach of a railway train may be soonest heard by applying the ear to the rail. The velocity of sound varies also with the molecular structure of the medium. Wood conducts sound in the direction of its fiber two or three times faster than across the grain.

**410. Co-existence of sonorous waves.** 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 instrument in an orchestra. This is analogous to the little waves formed on the large billows of the ocean. A very intense sound deafens the ear so as to render feeble sounds inaudible.

**411. Combinations of sonorous waves.** Many feeble sounds, separately inaudible, may unite to produce a sort of murmur, as is exemplified in the rustle of leaves, or the hum of a whispering school. Two sonorous waves, meeting in the same phase, form a resultant wave of increased intensity.

**412. Interference of sonorous waves.** If two sonorous waves of equal intensity, meet in opposite phases, both are destroyed, and silence results. The feeble sound of a tuning fork, held in the hand, is mostly due to the partial interference of the two waves produced, by each prong vibrating in an opposite direction. If a tuning fork, when vibrating, is turned slowly round, 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.

**413. The reflection of sound** is in accordance with the laws already deduced for the reflection of waves. (387.)

A sonorous wave, reflected from a surface of considerable magnitude, is returned to the ear with more or less distinctness, in proportion to the distance of the surface. The repetition of a sound by reflection is called an *echo*. Articulate sounds require a distance of one hundred and nine feet to produce a distinct echo, because the voice can not utter, nor the ear hear, more than five syllables in a second.

At a distance of one hundred and nine feet, a monosyllabic echo may be perfect; but if a word of two syllables be pronounced, the echo of the first will be commingled with the direct sound of the second, and confusion will result. At a distance of two, three, or more times one hundred and nine feet, the echo will be dissyllabic, trisyllabic, and so on. In Woodstock Park, England, is an echo from a reflecting surface twenty-two hundred and eighty feet distant, which returns seventeen syllables by day, and twenty by night.

**414. Multiple echoes** are those which repeat the same sound several times. This happens when two surfaces, as parallel walls, reflect the sound successively.

An echo in Italy repeats the same sound thirty times. When a cannon is fired on the shores of Echo Lake, in New Hampshire, the sound is reflected from a succession of cliffs, at different distances, and produces an echo like a peal of thunder. The reverberation of thunder is also due to echoes, for sound is reflected not only from solid surfaces, but also from clouds, drops of water, and even on passing into air of greater density than its own. In foggy weather, sounds are rapidly enfeebled, because they undergo so many partial reflections.

**415. The echo may be heard** when the direct sound is inaudible. Thus, if the ear be placed in the focus of a concave mirror, the ticking of a watch may be heard at a distance, when it would be otherwise inaudible. The sound will be strengthened, if the watch be also placed in the focus of another mirror, opposite to the first, Fig. 174.

The same effect may be produced in rooms having smooth walls of a continuous curved form. In such a chamber, a whisper at one focus will be audible at the other, because the undulations reflected from the different points of the walls will be collected at the other focus. The direct rays will be feeble in comparison, and on this account, two persons in the foci could converse, and yet be inaudible to a company at any place between them. Such *whispering galleries* are not uncommon. The dome of St. Paul's Cathedral, London, and of the Capitol, at Washington, are fine examples.

**416. Resonance.** The increased intensity produced by the commingling of the direct and reflected sonorous waves is called *resonance.* Resonance is specially noticeable in empty rooms, with bare smooth walls. If the rooms are small, the direct and reflected waves strike the ear at about the same time, and strengthen the original sound without diminishing its clearness.

This will be the case, if the echoing walls are not distant more than thirty-five feet from the speaker, for at that distance the reflected wave will go and return in one-sixteenth of a second, which is found to be the limit of perceptibility. Such rooms are easier to speak in than the open air. In large halls, the direct and reflected waves only partially coincide, and the words are less distinct. If, however, the echoes are quenched by the furniture, or by the presence of an audience, the direct waves only are heard, and the words are distinct.

Some resonance is desirable, if the room is very large and the speaker's voice weak. The wall behind the speaker should be made to aid the voice, by being a good reflecting surface of proper shape. The ceiling should not be too high, and the room should be rather longer than broad. The echoes from distant walls should be broken up by galleries, and no large and distant surfaces should be parallel to nearer ones.

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

## 418. 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 the 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.

[redacted]

**The intensity of sound decreases**

1. **As the square of the distance increases.**
2. **In passing from one medium to another.**

**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.

**419. The ear recognizes** all sounds of pure tone as agreeable. Nearly thirty-eight thousand different sound waves are possible, each one of which will, by itself, produce a pure tone. If all these were produced in succession, the most practiced ear would be able to distinguish, as distinct tones, less than the one-hundredth part of them. This is because two tones, whose rates of vibration are nearly the same, can be distinguished from unison only by the formation of beats. If the beats are not readily perceptible, the ear recognizes the sounds as the same. Any tone may be selected for a basis of comparison, to which all others are either higher or lower.

**420. Suppose a guitar string,** or wire, to be stretched across a sounding box, of the form represented in Fig. 178, which is called the *sonometer*, or *monochord.* When the whole length of the string vibrates, it produces a sound called the *fundamental tone* of the string. It may, of course, be any one of the thirty-eight thousand perceptible tones. Suppose the tone to be that due to one hundred and twenty-eight complete vibrations in a second, as measured by the toothed wheel or the syren. Musicians have agreed to designate this tone as $C_1$. It corresponds to C, in the second space of the base clef. If, now, the bridge, B, be placed at half the length of the string, the half string will make two hundred and fifty-six vibrations in a second, or twice as many as the fundamental. The tone produced is $C_2$, which corresponds to middle C of the piano. If the string be again shortened, by placing the bridge at one-fourth its length, the number of vibrations will be again doubled, and the new tone, $C_3$, will correspond to C, in the third space of the treble clef, due to five hundred and twelve vibrations per second.

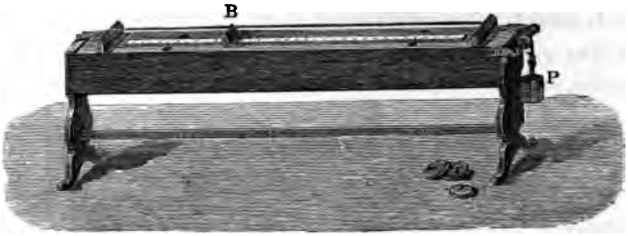


FIG. 178.

Every successive halving of the string will double the rate of vibration, and produce in succession $C_4$, $C_5$, and so on. On the other hand, if strings be taken two, four, eight times the length of the original string, the rates of vibration will be diminished in the ratio one-half, one-fourth, one-eighth, and produce respectively the tones $C_{-1}$, $C_{-2}$, $C_{-3}$, corresponding to sixty-four, thirty-two, and sixteen vibrations per second. If these tones were produced in succession, the relations between vibrations of the strings are represented by the numbers 1 : 2 : 4 : 8 : 16 : 32, etc.

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

*421.* **These eight tones** constitute the diatonic scale or *gamut, in* music. 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 of the scale are:

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

The relative number of vibrations corresponding to these tones is expressed by the reciprocals of these numbers, as follows:

| Tones | C | D | E | F | G | A | B | C |
|---|---|---|---|---|---|---|---|---|
| Relative No. of vibrations | 1 | $\frac{9}{8}$ | $\frac{5}{4}$ | $\frac{4}{3}$ | $\frac{3}{2}$ | $\frac{5}{3}$ | $\frac{15}{8}$ | 2 |

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

These tones may also be produced by increasing the tension of the string, without altering its length. This may be done by increasing the weights, P, by which the string is stretched. To double the number of vibrations, the stretching weight must be quadrupled.

| Tones | C | D | E | F | G | A | B | C |
|---|---|---|---|---|---|---|---|---|
| Relative stretching weight | 1 | $\frac{81}{64}$ | $\frac{25}{16}$ | $\frac{16}{9}$ | $\frac{9}{4}$ | $\frac{25}{9}$ | $\frac{225}{64}$ | 4 |

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

As the elastic force of a string is dependent both on its density and diameter, these functions modify the rate of vibrations produced by strings of the same length and tension. Their combined effect determines the weight of a string. A string four times as heavy as another, makes but half the number of vibrations.

| Tones | C | D | E | F | G | A | B | C |
|---|---|---|---|---|---|---|---|---|
| Relative weight of string | 1 | $\frac{64}{81}$ | $\frac{16}{25}$ | $\frac{9}{16}$ | $\frac{4}{9}$ | $\frac{9}{25}$ | $\frac{64}{225}$ | $\frac{1}{4}$ |

Hence, (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 may be proved by the sonometer. All are applied in the construction of stringed instruments. A harp or piano is a good example. The high notes 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.

**422. The absolute number of vibrations** per second in any tone may be found by multiplying the number found for $C_1$ by the fractions $\frac{9}{8}$, $\frac{5}{4}$, etc., which express the relative number. Thus, the upper octave of the base clef is produced by the following series:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tones.............................. | $C_1$ | $D_1$ | $E_1$ | $F_1$ | $G_1$ | $A_1$ | $B_1$ | $C_2$ |
| Absolute No. of vibrations.. | 128 | 144 | 160 | $170\frac{2}{3}$ | 192 | $213\frac{1}{3}$ | 240 | 256 |

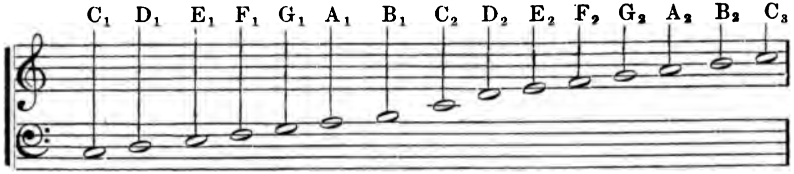
The absolute number of vibrations in the higher scales is obtained by multiplying these numbers by two, four, eight, etc., while for lower scales the same numbers are divided by two, four, eight. Thus, the number of vibrations of $A_3$ is $213\frac{1}{3} \times 4 = 853\frac{1}{3}$ in a second.

The actual number employed by orchestras in different cities is not the same. For this reason a congress of musicians has adopted the following scale, which gives all the tones of the lower octave of the treble in whole numbers.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tones.............................. | $C_2$ | $D_2$ | $E_2$ | $F_2$ | $G_2$ | $A_2$ | $B_2$ | $C_3$ |
| New scale of vibrations...... | 264 | 297 | 330 | 352 | 396 | 440 | 495 | 528 |

**423. The length of a sonorous wave** may readily be found by dividing the velocity with which sound travels in a second by the number of vibrations in the same time. In air at 60° F., sound moves about eleven hundred and twenty-one feet per second. The length of the wave $C_1$ is, therefore, $1121 \div 128 = 8.7$ feet. $C_2 = 4.3$ feet, $C_4 = 1.1$ feet. It must be borne in mind that the length of the wave varies with the medium and the temperature.

**424. The interval** between any two tones is called a *musical interval.* Musical intervals are named by the order of their position with respect to any note taken as 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, or $\frac{3}{2}$. The numerical value of any interval is obtained by viding the number of vibrations in a given tone by the ımber of vibrations in that preceding it. The table on is page is a summary of the results already obtained for ro 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<br>$C_1$ | Re<br>$D_1$ | Mi<br>$E_1$ | Fa<br>$F_1$ | Sol<br>$G_1$ | La<br>$A_1$ | Si<br>$B_1$ | Do<br>$C_2$ | Re<br>$D_2$ | Mi<br>$E_2$ | Fa<br>$F_2$ | Sol<br>$G_2$ | La<br>$A_2$ | Si<br>$B_2$ | Do<br>$C_3$ |
| 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 | 170⅔ | 192 | 213⅓ | 240 | 256 | 288 | 320 | 341⅓ | 384 | 426⅔ | 480 | 512 |
| New scale of vibrations.... | 132 | 148½ | 165 | 176 | 198 | 220 | 247½ | 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 |

The interval between any two successive notes is called a *scale interval.* There are three scale intervals: the *major tone,* $\frac{9}{8}$, between C D, F G, or A B; the *minor tone,* $\frac{10}{9}$, between D E or G A; and the *major* or *diatonic semitone,* $\frac{16}{15}$, between E F or B $C_2$. The interval found by dividing a minor tone by the major semitone is called the *minor* or *chromatic semitone.* Its value is $\frac{10}{9} \div \frac{16}{15} = \frac{25}{24}$, and is the least interval usually regarded in music. Any less interval is called a *comma,* though this term is more specifically applied to the ratio between a major and minor tone $\frac{9}{8} \div \frac{10}{9} = \frac{81}{80}$. When two tones differ only by a comma, they are generally reckoned as of the same value in music, consequently the intervals $\frac{9}{8}$ and $\frac{10}{9}$ are taken as whole tones of equal value, and the intervals $\frac{16}{15}$ and $\frac{25}{24}$ as equal semitones, although they differ respectively by $\frac{81}{80}$ and $\frac{128}{125}$.

The interval between C E, F A, or G B, contains two whole tones, and is called a *major third;* its value is $\frac{9}{8} \times \frac{10}{9} = \frac{5}{4}$. The interval between E G, A $C_2$, or B $D_2$, contains one whole tone and one semitone, and is called a *minor third;* its value is $\frac{9}{8} \times \frac{16}{15} = \frac{6}{5}$. The interval, D F, differs from a minor third only by a comma; $\frac{10}{9} \times \frac{16}{15} \times \frac{81}{80} = \frac{6}{5}$.

**425. The pleasure derived from music** depends on the frequent recurrence of vibrations in the same phase. When different tones are produced in close succession, or simultaneously, the effect on the ear will be more or less agreeable, according as the relations between their vibrations are simple or complex. If the ratio between any two sets of vibrations can be expressed by whole numbers, less than five or six, the combination will be pleasant.

*Melody* is due to the succession of single 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.

Notes in unison are agreeable, because their vibrations are coincident throughout. Next in order is the chord of the octave, because every alternate vibration of the higher tone coincides with the fundamental, in the same phase. Then follow in turn the fifth, the fourth, the major third, and the minor third. The second and seventh are

[redacted]

by no means equally pleasant, because the coincidences are less frequent. Below, is an attempt to represent the relations between the simple chords. The dots represent the rarefaction of the wave, the lines the condensation; the long lines mark coincidences in the phase of condensation.

Unison. 1 : 1. As C C.

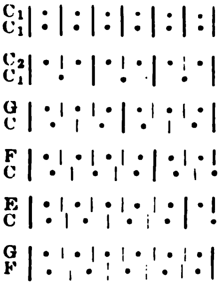
Octave. 2 : 1. As C $C_2$, D $D_2$.

Fifth. 3 : 2. As C G, F $C_2$.

Fourth. 4 : 3. As C F, A $D_2$.

Major third. 5 : 4. As C E, F A.

Minor third. 6 : 5. As E G, A $C_2$



**426. Compound chords** are formed of three or more tones, which, when taken two and two, are harmonious. A *perfect major chord* consists of three simultaneous tones, such that the first and second form a major third, the second and third a minor third, and the first and third a perfect fifth. Thus C E G or F A $C_2$ constitute a perfect major chord, because their intervals taken two and two are C E $\frac{5}{4}$, E G $\frac{6}{5}$, C G $\frac{3}{2}$. The ratios of this triad are very simple, 4 : 5 : 6, and the number of coincident vibrations very many. If the same intervals are taken in the order of a minor third, major third, and perfect fifth, the tones form a *perfect minor chord.* Thus, D F A or E G B ascend in the order D F $\frac{6}{5}$, F A $\frac{5}{4}$, D A $\frac{3}{2}$, and form a *perfect minor* chord.

**427. The diatonic scale** is composed of unequal intervals, because this disposition of the vibrations is found to result in a greater number of concords than would be possible if the intervals were all equal. The scale has two modes. In the first, which is the most common, the first third is a major third; in the other, the first third is a minor third: consequently, the modes are denominated the *major* and the *minor mode.*

The intervals in both scales are the same, though not in the same order. If the diatonic scale begins with C, the mode is major, and the semitones occur in the third and seventh intervals. If the diatonic scale begins with A, the mode is minor, and the semitones are found in the second and fifth intervals. Because the ear seems to require that the seventh interval should always be a semitone, there is this additional peculiarity in the minor mode, that the seventh note is sharped, so as to make the last interval a semitone, as in the major mode. The sixth interval thereby becomes a tone and a half. The sharped seventh is called the *accidental* seventh, and is considered essential to the minor mode in the ascending scale.

**428. Musicians interpolate** other notes in the scale by means of sharps and flats, which are indicated by the signs ♯ and ♭. A note is sharped or flatted by multiplying its value, respectively, by $\frac{25}{24}$, or by $\frac{24}{25}$. The tone of the note is thereby raised or lowered a chromatic semitone. If the lower note of the interval of a minor tone is sharpened, or the higher note flattened, the reduced interval is a diatonic semitone. Thus:

| D | D♯ | E♭ | E |
|---|---|---|---|
| $\frac{9}{8}$ | $\frac{75}{64}$ | $\frac{6}{5}$ | $\frac{5}{4}$ |

The interval, D E♭ or D♯ E, is $\frac{16}{15}$, a diatonic semitone. D♯ and E♭ are not identical, but because they differ only by a comma, they are considered equivalent in music. The difference between the interpolated sharp and flat in the interval of a major tone, as F♯ G♭, is nearly equal to a chromatic semitone. Upon instruments capable of modulation, as the violin or flute, they are not played alike by a skillful performer, in solo pieces.

Upon instruments with fixed keys, the accurate rendering of sharps and flats would require a key-board so large as to be exceedingly inconvenient. For this reason, all the whole tones are made equal and divided into two equal semitones, so that the sharp of one tone is made identical with the flat of the next higher. The octave is thereby divided into twelve equal intervals, called *chromatic semitones*, and forms the chromatic scale, namely:

C, C♯ or D♭, D, D♯ or E♭, E, F, F♯ or G♭, G, G♯ or A♭, A, A♯ or B♭, B, C.

In this system, all the intervals, except that of the octave, differ more or less from their true value, but the errors are so distributed through the scale that each note is sufficiently correct for practical purposes. The white keys of the piano produce the adjusted diatonic scale; the black keys the interpolated sharps and flats. There is no black key between E F or B C, because the interval between them is a semitone; so that E♯ equals F, F♭ equals E, B♯ equals C, and C♭ equals B.

**429. Transposition.** The musical scale which has C for its fundamental is called the *natural scale*, or the key of C. It is evident that whatever be the fundamental tone of a string vibrating as a whole, it may be divided so as to form the relative intervals of the octave. Other scales are thereby formed which take their names from the fundamental, as, key of G, key of D, etc. The same result may be accomplished by means of flats and sharps, so interpolated as to preserve the same relative intervals between the successive tones. The relations of the octave in the major mode are thus indicated:

| Key of C...... | C | D | E | F | G | A | B | $C_2$ |
|---|---|---|---|---|---|---|---|---|
| Name of intervals. | 1<br>Do | 2<br>re | 3<br>mi | 4<br>fa | 5<br>sol | 6<br>la | 7<br>si | 8<br>do |
| Intervals...... | | tone | tone | semi-tone | tone | tone | tone | semi-tone |

The first three intervals of an octave are the same as the last three. Consequently, the fifth of any scale may be taken as the fundamental of the new scale. Therefore, the first transposition from the natural scale is to the key of G.

| Key of G...... | G | A | B | $C_2$ | $D_2$ | $E_2$ | F♯$_2$ | $G_2$ |
|---|---|---|---|---|---|---|---|---|
| | Do | re | mi | fa | sol | la | si | do |

If G be taken as the fundamental, all the intervals succeed each other in the required order, as far as the sixth, E F, which is naturally a semitone. F is, therefore, sharped, to make the sixth interval a whole tone. The seventh interval, F♯ G, thereby becomes a semitone, and the octave is complete. The second transposition is to the key of D.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Key of D...... | D | E | F♯ | G | A | B | C♯ | D |
| | Do | re | mi | fa | sol | la | si | do |

Here C is sharped to make the seventh interval a semitone. A note once sharped remains so in successive transpositions; hence, the key of D contains two sharps, F♯ and C♯. Other transpositions by sharps follow in the order, C, G, D, A, E, B, F♯.

The scale may be also transposed by flats, by taking in succession the fourth tone above the fundamental, as the new key note. Thus:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Key of F ..... | F | G | A | B♭ | C | D | E | F |
| | Do | re | mi | fa | sol | la | si | do |

In this case the third interval is naturally a whole tone, but is made a semitone by flattening B; the fourth interval, B♭ C, thereby becomes a whole tone, as is required.

**430. Harmonics.** We have seen (392) that a cord may be made to vibrate, either as a whole or in any number of parts. It is impossible to sound the cord as a whole without, at the same time, producing, in a greater or less degree, the vibrations of its aliquot parts. There results from this a commingling of the fundamental tone with its higher harmonic tones. There is the same coexistence of different vibrations in all sounding bodies. This intermixture of tones determines the *timbre* or *quality* of the musical sound, and enables us to distinguish one musical instrument from another; thus, a violin and flute sounding the same fundamental are not confounded, because the harmonics of the first are different from those of the other.

**431. Musical instruments** may be grouped in three divisions. (1.) Instruments in which a tense membrane is the source of vibration; as the drum and tambourine. (2.) Stringed instruments, in which the sounds produced by the vibrations of cords are strengthened by a resonant box; as the violin and piano. (3.) Wind instruments, in which the sound is due only to a column of air confined in sonorous tubes; as the flute and clarionet.

**432. The material of which the sonorous tube** is made has no influence on the pitch of the sound, although it modifies the timbre in a striking manner. This is probably due to the production of harmonics by a very feeble vibration of the tubes themselves. With reference to the manner in which the air is made to vibrate, sonorous tubes are divided into (1.) mouth pipes and (2.) reed pipes.

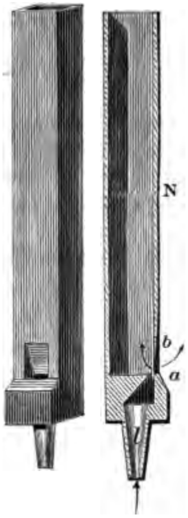


FIG. 179.

Fig. 179 represents the mouth-piece of an organ pipe. The aperture, *l b*, is called the mouth, and *b a*, the lips. 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 are transmitted to the air within the pipe, and a sound is the result.

Fig. 180 represents a reed pipe, made from a wheaten straw, by raising a strip of straw near a joint. On blowing into this opening the reed vibrates and communicates its pulsations to the air in the straw, and produces a musical sound. The sound produced depends, in general, on the dimensions of the pipe and the velocity of the current of air. Thus, a shriller note will be produced if the force of the blast is increased, or if the tube is shortened. The reed remains the same, but is forced to vibrate at the same rate as the column of confined air.

FIG. 180.

**433. The absolute length of pipes.** The sounds of pipes are due to waves of condensation and rarefaction which are transmitted through the length of the pipe. Nodes and segments will be formed, as in the case of vibrating strings.

1. In a stopped pipe, the closed end will always be a node, because the air particles are necessarily at rest, although they undergo rapid alternations of condensation and rarefaction. At the mouth-piece, the air particles will undergo no changes in density, since they are always in contact with the external air, but will have the greatest amplitude of vibration. This point, therefore, corresponds to the ventral segment, and the stopped pipe, sounding its fundamental tone, is one-half of a condensed or of a rarefied wave in length.

2. In an open pipe, both ends are always ventral segments, because the column of air inclosed is in contact with the external air at those points. Hence, when the pipe sounds its fundamental, a node will be formed at the center (N, Fig. 179). The air column will, therefore, equal in length a wave of condensation or of rarefaction; that is to say, one-half of a sonorous wave. (383.) Hence, also, the fundamental tone of a tube, open at both ends, is an octave higher than a stopped pipe of the same length.

**434.** Now, as the velocity of sound in air is eleven hundred and twenty-one feet per second, and as a continuous sound can not be produced by less than thirty-two single vibrations per second, the maximum length of an open pipe is $\frac{1121}{32} = 35$ feet. A closed pipe, producing the same tone, will be half that length, or 17.5 feet. With a gentle blast of air, low C of the treble cleff, which corresponds to two hundred and fifty-six complete vibrations per second, will be produced by a stopped pipe thirteen inches long, or by an open pipe twenty-six inches long.

The velocity of sound in different gases and liquids may be computed by forcing them through properly constructed organ pipes, and by finding the length of the pipe which must be used with each in order to yield a given tone.

**435.** By increasing the blast of air in a stopped tube, the column divides in three equal parts, and an intermediate *node, N′,* and segment, S′, are formed; a second increase produces another node and segment, and so on. Therefore, the same stopped pipe may be made to produce in succession the fundamental and its uneven harmonics, whose vibrations are in the series, 1, 3, 5, 7, etc.

If the tube be open at both ends, the first harmonic will be produced by dividing the column into four equal parts, by nodes and segments, Fig. 181. The second by forming six equal parts, and so on. Therefore, the same open pipe may be made to produce in succession the fundamental and its harmonics, whose vibrations are in the natural series of numbers, 1, 2, 3, 4, etc.

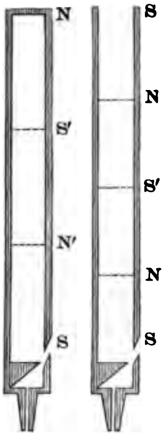


FIG. 181.

**436.** The flute, fife, flageolet, are mouth pipes; the clarionet and hautboy are reed pipes. On opening one of the holes at the sides, a segment is formed at that point, which modifies the distribution of nodes and segments in the interior, and thus changes the tone. The trumpet and trombone are reed instruments, in which the lips of the performer take the place of the reed, and vibrate in the mouth-piece. In the organ, both reed and mouth pipes are used.

### 437. Recapitulation.

1. Any sonorous body may be made to yield a pure tone.
2. The tone chosen as the fundamental is determined by the practice of the best musicians, and the corresponding number of vibrations ascertained.
3. The pleasure derived from music is due to a succession of melodious or harmonious tones.
4. The diatonic scale contains eight tones, of different intervals.
5. The relative number of vibrations in an octave may be expressed by a simple *series.* The corresponding tones may be obtained *by varying the length,* tension, and weight of strings; or by *varying the length of sonorous* tubes and the force of the blast.

6. The chromatic scale contains twelve equal intervals, obtained by interpolating sharps and flats in the diatonic scale.

7. The transposition of the scale is effected by making its fundamental tone higher or lower, and still preserving the natural series of intervals.

## CHAPTER VII.

### OPTICS.

**438.** LIGHT is that mode of molecular motion which excites in us the sensation of vision. Light affects all nature: it influences chemical action, it is necessary to the growth of plants, and it unfolds to our eyes the knowledge of external things.

**439. 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 these vibrations are communicated to the aether and are then transmitted in all directions by spherical waves. And (4.) that these waves or vibrations constitute light.

**440. A medium** is any substance through which light *is* transmitted; as glass, horn. *Transparent* bodies allow light to pass freely through them; as glass, water, air. *Translucent* bodies transmit light so imperfectly that objects can not be clearly seen through them; as ground glass, horn. *Opaque* bodies do not transmit light; as wood and the metals.

*441.* **Luminous bodies** are those in which light originates; *as the sun* and burning bodies. Non-luminous bodies orignate no light, but may be rendered temporarily luminous by the presence of a self-luminous body; thus, a lighted candle renders adjacent objects luminous.

**442.**[a] **The sources of light** are (1.) mechanical action, (2.) chemical action, (3.) electricity, (4.) phosphorescence, and (5.) the heavenly bodies.

Any solid, on being raised to 977° F., begins to emit light, of a dull, red color, and is then said to be *incandescent.* The light of incandescent bodies varies with the intensity of the heat. At 1280° F. it is bright red; at 1440° F., blue; at 2000° F., orange; at 2130° F., white; and it continues to increase in brilliancy above this temperature. A current of gas does not become luminous at 2000° F.

Mechanical action may produce sufficient heat to render solids incandescent. Thus, sparks of light are produced when flint and steel are struck violently together. Most artificial lights depend on the ignition of solid particles in the intense heat developed by chemical action. If oxygen and hydrogen are burned together an intense heat is produced, but the light is feeble, because the product of the combustion is gaseous. If, however, a solid, as a bit of lime, is held in the flame, it becomes incandescent, and emits a light of great intensity.

In ordinary combustion, the hydro-carbons contained in the oil, coal, gas, etc., are decomposed by the heat; the hydrogen then burns with a pale flame; into this flame the solid particles of the carbon rise, become incandescent, and finally burn.

The transient light of the electric spark and the brilliant glare of lightning are familiarly known, but electricity may be made to furnish a continuous and abundant supply of light.

*Phosphorescence* is a pale light, emitted in the dark, without any manifestation of heat. The light of the glow-worm and the fire-fly are examples. In tropical climates, the sea is often covered with a bright phosphorescence, due to extremely small animalculæ. Under certain conditions, rotten wood and decaying flesh become phosphorescent. Phosphorescence may also be developed in some minerals by heat, friction, and crystalization.

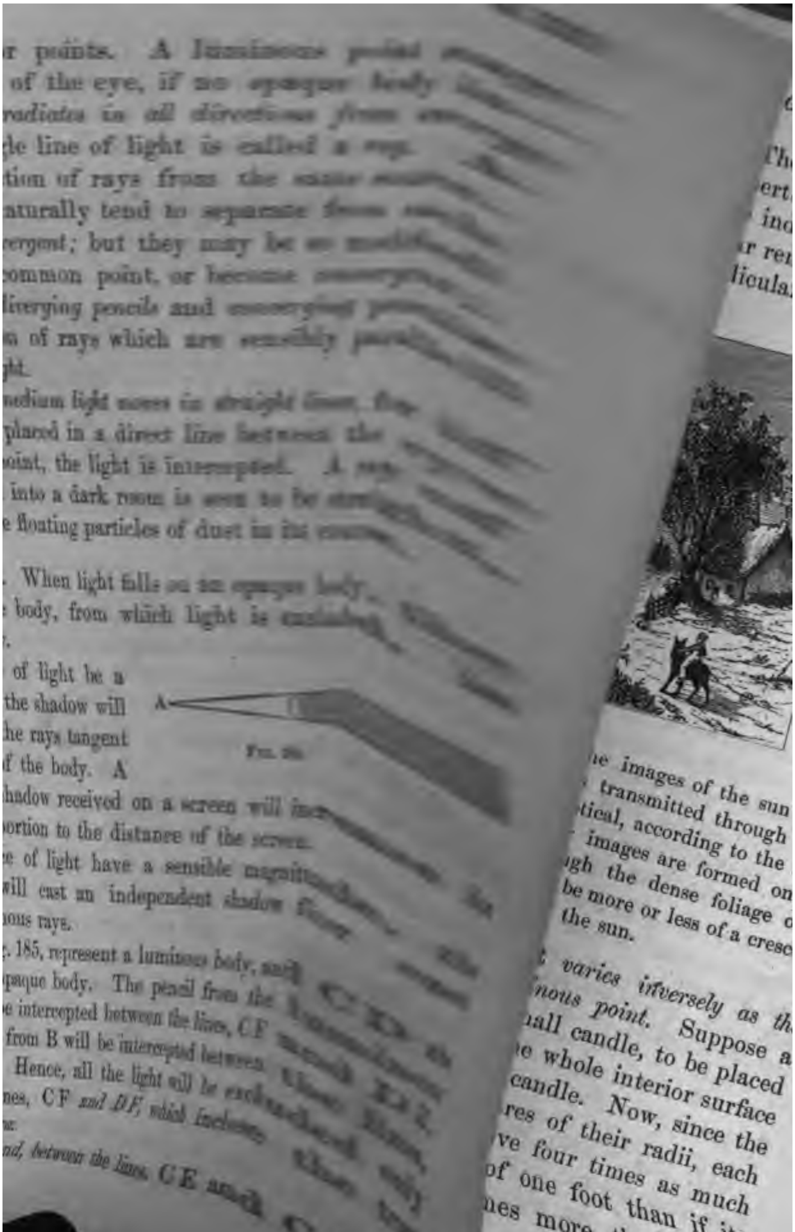
The cause of the light of the sun and the fixed stars is unknown, but the prevailing opinion is that it is due to some form of mechanical action. The moon and the planets are non-luminous; receiving from the sun the light by which they shine.

**442b. The velocity of light** was first ascertained by Roemer, by means of the eclipses of the first satellite of Jupiter. Jupiter is a planet attended by four moons which revolve about it, as our moon revolves about the earth. These moons are observed by the telescope to undergo frequent eclipses, by passing behind the body of the planet. The exact moment when the moon becomes eclipsed, as would be seen by a spectator at the mean distance of the earth from the sun, is calculated by astronomers.

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 about one hundred and eighty-three millions of miles, or the whole diameter of its orbit, nearer to Jupiter than in the latter. Now, it is found by observation, that the eclipse of the first moon is seen about $16\frac{27}{60}$ minutes sooner when the earth is nearest to Jupiter than when it is most remote from him; therefore, the light must occupy this time in crossing the earth's orbit. The velocity of light is then about one hundred and eighty-five thousand five hundred miles in a second.

The velocity of light has also been determined by direct experiment, and found to vary in different media; being, in water, one hundred and forty-four thousand miles per second; in glass, one hundred and twenty-eight thousand *miles;* and in diamond, seventy-seven thousand miles.

**443a. Luminous bodies** may be considered as a collection



r points. A luminous point
of the eye, if no opaque body
radiates in all directions from
gle line of light is called a ray.
tion of rays from the same
aturally tend to separate from
ergent; but they may be so modified
common point, or become convergent
diverging pencils and converging
n of rays which are sensibly parallel
ght.

medium light moves in straight lines
placed in a direct line between the
point, the light is interrupted. A ray
into a dark room is seen to be
e floating particles of dust in its course.

When light falls on an opaque body
body, from which light is excluded
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of light be a
the shadow will
he rays tangent
f the body. A
hadow received on a screen will increase
portion to the distance of the screen.
e of light have a sensible magnitude
will cast an independent shadow
ous rays.

. 185, represent a luminous body, and
paque body. The pencil from the
e intercepted between the lines, CF
from B will be intercepted between
Hence, all the light will be excluded
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between D F and D H, receives light from certain points of the luminous body, and not from others. It is brighter than the true shadow, but not so bright as the illuminated space, and is, therefore, called the partial shadow, or *penumbra.*

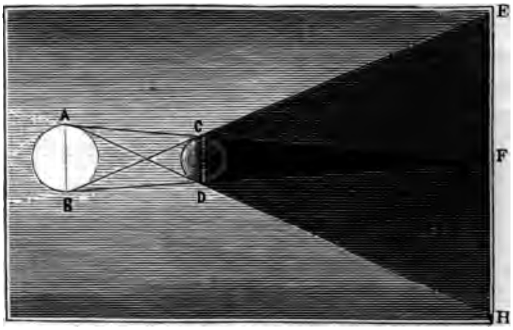

FIG. 185.

If the luminous body is smaller than the opaque object, the shadow will be larger than the body; thus, if the hand be held near a candle, a gigantic shadow of the hand may be thrown on a distant wall. If the luminous body is larger than the opaque object, the breadth of the umbra will gradually diminish to a point, but the breadth of the penumbra will increase with the distance to which it is thrown.

**444. Images formed by direct light.** If luminous rays are transmitted through a small aperture into a dark room, and are then received on a screen, they form inverted images of external objects. The luminous rays proceed in straight lines; those from the top of the object, Fig. 186, 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, therefore, must cross each other without interfering. A darkened room, so arranged, is one form of the *camera obscura.*

A single luminous point will give an image the shape of the aperture; if the aperture is triangular, the image will be triangular. Hence, a luminous body will give an infinite number of superimposed triangular images; the union of all these partial images produces a total image of the same form of the luminous object. Therefore, the image is independent of the shape of the aperture, if the latter is sufficiently small. The image will be indistinct if the aperture is large, or if the screen is too far removed. It will be distorted if the screen is not perpendicular to the direction of the rays.

FIG. 186.

In accordance with these principles, the images of the sun which are formed on the floor when its light is transmitted through small openings in the blinds, are round or elliptical, according to the inclination of its rays to the floor. Similar images are formed on the ground by the solar light passing through the dense foliage of a forest. During an eclipse the images will be more or less of a crescent shape, in proportion to the obscuration of the sun.

**445. The intensity of the light** *varies inversely as the square of the distance from the luminous point.* Suppose a luminous point, or the flame of a small candle, to be placed in the center of a hollow sphere; the whole interior surface of the sphere will be lighted by the candle. Now, since the surfaces of spheres are as the squares of their radii, each square inch of the surface will receive four times as much light, if the sphere have a radius of one foot than if its radius were two feet, and nine times more than with a radius of three feet.

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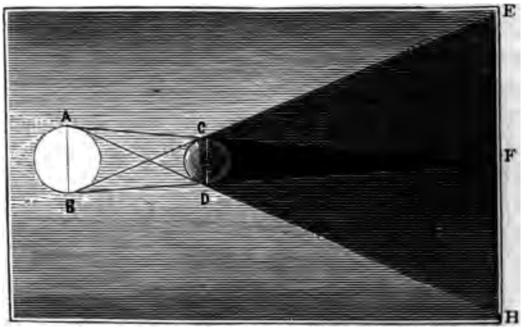

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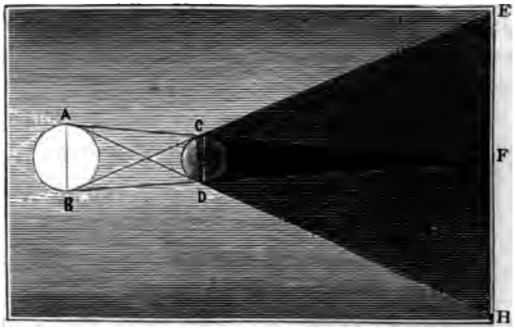

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**45. The intensity of the light** *varies inversely as the are of the distance from the luminous point.* Suppose a ninous point, or the flame of a small candle, to be placed the center of a hollow sphere; the whole interior surface the sphere will be lighted by the candle. Now, since the faces of spheres are as the squares of their radii, each are inch of the surface will receive four times as much ıt, if the sphere have a radius of one foot than if its ius were *two feet,* and nine times more than with a *ius of three feet.*

This law may be proved, experimentally, by shadows. A boar having a surface one foot square, placed one foot from a candle, wil cast a shadow that will cove four square feet at doubl the distance, nine square fee at three times 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.

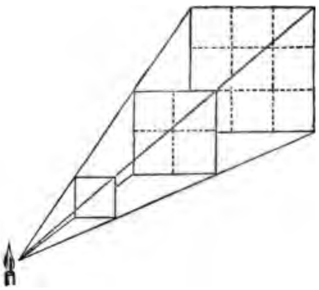

FIG. 187.

**446. 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, or of ground glass, 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 the shadows appear equally dark. If the shadows are sensibly equal, the amount of light falling on the screen from each source must be equal also; the relative intensities of the two lights are then found by squaring the distance of each light from the screen.

The light which we receive from the sun, at a distance of ninety-one million miles, is equal to the concentrated glare of five thousand five hundred and sixty-three wax candles at the distance of a foot. The light of the full moon is three hundred thousand times less than that of the sun. The brightest of the fixed stars shines with only one twenty-thousand-millionth part of the light which we receive from the sun. For this reason, the stars are invisible when the sun shines, being lost in his superior brilliance.

**447. The visual angle** is the angle contained between two lines drawn from the center of the eye to the two *extremities* of the object. (1.) For the same distance, the *visual* **angle** increases with the size of the object. (2.) For

[redacted]

the same object, the angle decreases with the distance of the object; thus, if the same object, A B, is removed to A′ B′,

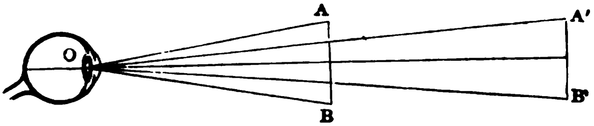

FIG. 188.

the visual angle decreases. Hence, if the size of an object is known, we may estimate its distance by its visual angle, having learned, by experience, to associate together *distance* and *angular size*.

**448. The optic angle** is the angle contained between two lines drawn from a luminous point through the centers of the two eyes when they are both directed to the same point.

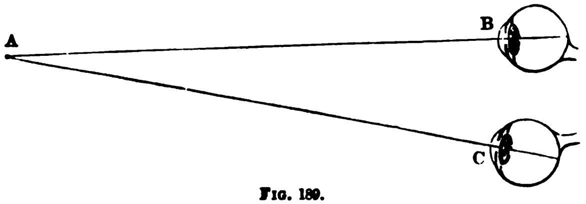

FIG. 189.

The optic angle, B A C, increases with the nearness of the object. We may judge of the relative distance of an object by the muscular effort required to turn our eyes so as to direct them toward the object. Nevertheless, this power comes only from long experience, as persons born blind, whose sight has been restored by a surgical operation, imagine, at first, that all objects are at the same distance.

**449. Our estimate of distance** is more correct when many objects intervene; the stars overhead all appear at the same distance, because we have no standard for comparison. Finally, the more distinct an object is, the nearer it seems to be. Distant mountains, if seen for the first time in pure air, appear nearer than they really are, and the reverse if the air is foggy.

**450. Our estimate of size** is closely associated with our judgment of distance. If the object is unknown, we form an estimate of its distance by comparison with that of known objects, and then estimate its size by the visual angle. Any thing that increases our estimate of distance also increases our estimate of size. The moon appears larger near the horizon than when above us, because it seems more distant by reason of intervening objects. So, also, objects, seen in a fog, often appear enormously large, because they appear to be distant by reason of their indistinctness.

**451. Disposition of incident light.** When a pencil of light falls on any substance, it is separated into parts. (1.) Some of the rays are *absorbed.* (2.) Some are *reflected,* and (3.) some may be *transmitted,* or, with more or less change in direction, *refracted.*

**Absorption.** A very thin plate of glass is almost perfectly transparent, but as its thickness is increased, its transparency is diminished, and it may be made so thick as to transmit no light. Each thin layer, therefore, weakens the vibrations, so that, if they pass through a certain number of layers, the undulations become so feeble as to be insensible.

Even the purest air absorbs so much light that the atmosphere would not transmit the rays of the sun, if it had the depth of seven hundred miles. On the other hand, gold may be made so thin as to transmit light of a violet-green color.

### 452. Recapitulation.

I. Bodies are classified, in accordance with their relations 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.

**453. Whenever a pencil of light** falls on a body, some portion of it is reflected, or thrown back into the medium it was just leaving. If a ray of light, IB, falls on a plane surface, AC, it will be reflected in the line, BR. Draw the line, PB, perpendicular to the reflecting surface, at the *point of incidence*, B. The angle, IBP, is called the *angle of incidence.* The angle, PBR, the *angle of reflection.* If these angles are carefully measured, it will be found that

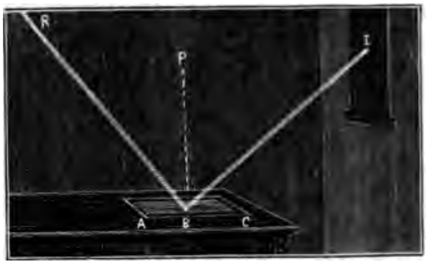

FIG. 191.

1. *The angle of incidence is equal to the angle of reflection.*

2. *The incident and reflected rays are both in the same plane, which is perpendicular to the reflecting surface.*

**454. These laws apply** to every reflecting point of incidence. There may be two modes of reflection: (1.) when a pencil of light falls on an unpolished surface, the reflected rays are scattered in every direction, and are said to be *irregularly reflected,* or *diffused.* (2.) When a pencil of light falls on a perfectly polished surface, the reflected rays proceed in a determinate direction, and are said to be *regularly reflected.*

When examined by the microscope, most flat surfaces are found to consist of an infinite number of minute planes, inclined to each other in all possible angles, and, therefore, capable of receiving and reflecting light in all possible directions; by the operation of polishing, these irregularities of surface are so much reduced that very many points of incidence lie in the same plane, and the light reflected from them will proceed in the same direction.

**455.** Non-luminous bodies are rendered visible by light irregularly reflected. Bodies not in the direct sunlight, are illuminated by the diffused light reflected from the air, the clouds, and the surrounding objects.

If a sufficient portion of incident light is regularly reflected, the eye may perceive an image of the body which *emits* the light. A tarnished mirror will reflect a dim image of an object by regularly reflected light, and is itself visible, in all its parts, by irregular reflection. On polishing the mirror, more light is regularly reflected, and the image becomes brighter; but no mirror can be so highly polished that it will diffuse no light, for then the mirror would itself be invisible. So, also, no substance can absorb or transmit all the light which falls upon it, for the blackest body, or the most transparent, is still visible.

**456. The intensity of reflected light** increases (1.) *with the degree of polish;* (2.) *with the angle of incidence, except in case of the metals.* A sheet of writing paper will reflect an image of a candle, if the eye be held close to the paper so as to receive the reflected rays very obliquely, but not otherwise.

(3.) *The intensity of reflected light varies with the nature of the reflecting substance.* In polished metals, the reflection is almost perfect; in charcoal, it is almost wanting. A common looking-glass reflects light both from the anterior surface of the glass, and from the amalgam of tin with which it is coated on the back. In good mirrors, the superior intensity of the image from the metallic surface overpowers the faint image from the anterior surface of the glass; but in mirrors badly coated, both images may be seen.

The regular reflection of waves of light follow the general laws of undulations already considered in pages 209, 210. Some further details are necessary in order to understand the formation of images in mirrors.

**457. Mirrors** are either *plane* or *curved.* An ordinary 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 the *surface* of a sphere, reflecting light from the external face.

a concave spherical mirror, is a portion of the surface of a sphere reflecting light from the internal face.

7 **458. The formation of images** by plane mirrors may be determined by investigating the images due to a series of points. Let M N be a plane mirror, and A a luminous point. The reflected rays will make the same angles with the perpendiculars, D P, as the incident rays, and hence the reflected rays will make the same angles with each other as they did before reflection, but will appear to diverge from the point, A′. By an easy geometrical construction, it may be shown that *if a pencil of rays, diverging from a luminous point, fall on a plane mirror, the reflected rays will appear to diverge from a point similarly placed behind the mirror, and at a distance equal to that of the luminous point before the mirror.*

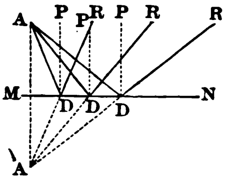

FIG. 192.

Of the great number of rays emitted from a luminous point and reflected from a mirror, a few enter the eye and form a *virtual image* of the point. The image is called virtual, because the image has no real existence, and the rays only appear to come from the other side of the mirror.

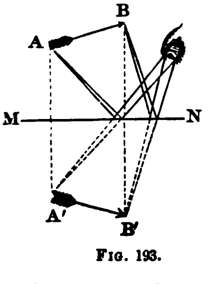

FIG. 193.

Let A B be an arrow in front of a mirror, M N. The image of the point, A, will appear to come from A′; that of B, from B′, and those of intermediate points on the arrow between A′ and B′. Hence, if an object be placed before a plane mirror, the image will be formed at an *equal distance* behind the mirror, of the *same size* as the object, and *equally inclined* to the mirror.

**459.** The object and image have to each other twice the inclination that each has to the mirror. Hence, trees appear inverted by reflection from a tranquil surface of water.

If the mirror and object are parallel to each other, there is a semi-inversion in one dimension only. If a person stands before a vertical mirror, the image of his right hand will be on the left side of his image. So, also, if a printed page is held before a plane mirror, the letters appear reversed in a horizontal direction, or right and left. Since the angle of incidence is equal to the angle of reflection, a person may see his entire image in a vertical mirror of half his length.

**460. Multiple images.** If two mirrors are at right angles, a luminous point placed between them will give three images. If the mirrors are inclined 60°, five images are produced, and seven if the angle is 45°. The number of images increases as the angle diminishes, and would be infinite when the mirrors are parallel, if the light were not gradually weakened at each successive reflection.

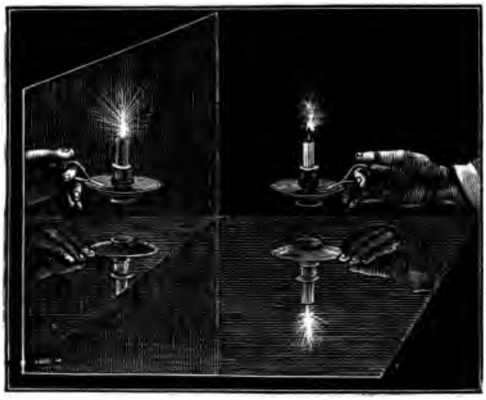

FIG. 194.

**461. The kaleidoscope** is an optical toy which illustrates this property of inclined mirrors. It consists of a paper tube containing two or more long and narrow mirrors, inclined to each other; one end of the tube is closed by ground glass and the other by plain glass. Small bits of colored 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.

That there may be perfect symmetry in these forms, the angle of the mirror must be an aliquot part of 360°. The best inclination for two mirrors is 30°. Three mirrors are usually employed, furnishing three angles of 60° each. In a well constructed instrument, an endless variety of beautiful and symmetrical figures may be obtained.

**462. Curved mirrors** may be considered as made up of an infinite number of plane mirrors, inclined to each other. Each ray of light will be reflected exactly as if it fell on a plane, tangent at the point of incidence. Let T T''' be a section of a small portion of a spherical surface. C will be the *center of curvature.* The line, C V, which passes through the vertex of the mirror is called the *principal axis* of the mirror, and any other line, as 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, C' I is perpendicular to the convex surface.

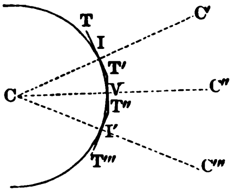

FIG. 195.

**463. Concave spherical mirrors.** If a luminous point be on the principal axis, the image formed on reflection will vary in position with the distance of the point. If the point is at an infinite distance, the rays will be sensibly parallel to the axis.

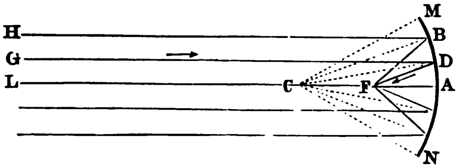

FIG. 196.

(1.) In Fig. 196, the radii, C M, C B, C D, are perpendicular to the surface. The parallel rays, H B, G D, L A, will each be reflected so that the angle of incidence for each ray equals the angle of reflection, and hence will converge after reflection. If the mirror is not more than 10° of angular aperture, all the rays will meet at F, half way between the center of curvature and the mirror. This point is called the *principal focus* of the mirror.

If the luminous point is at a finite distance, the rays will be divergent.

(2.) If the point is at L, beyond the center of curvature, Fig. 197, the rays will converge, on reflection, to a point, *l*, between the center and the principal focus. (3.) Conversely, if the luminous point is at *l*, rays will converge, on reflection, to the point L. The points, L and *l*, are, therefore, called conjugate foci. The nearer the luminous point, L, is to the center of curvature, the nearer will its conjugate focus, *l*, approach to the center.

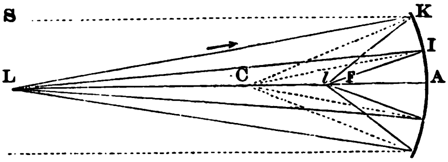

FIG. 197.

(4.) If the luminous point be at the center of curvature, all the rays will fall perpendicularly on the mirror, and will be reflected back to the center. In all these cases the focus is real, and on the same side of the mirror as the object.

(5.) If the luminous point be at the principal focus, the reflected rays will be parallel, and there will be no focus. Fig. 196.

(6.) If the luminous point be between the principal focus and the mirror, the rays will diverge as if from a point, *l*, behind the mirror. Fig. 198. This point is called the *virtual focus*. When the luminous point is near the principal focus, the virtual focus will be at a great distance behind the mirror; but as the luminous point approaches the mirror, the virtual focus also approaches it; and (7.) when the luminous point is at the surface, *the two coincide.*

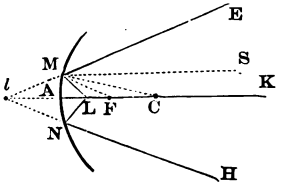

FIG. 198.

**464. Secondary axes.** If the luminous point be on a econdary axis, the focus of any point, L, will be found on his axis, by the same reasonng as in the preceding cases. Fig. 199.

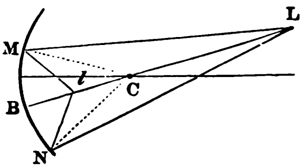

FIG. 199.

**465. The images formed by concave mirrors** may be determined by finding the foci for a series of points. A collection of these foci will constitute an image, either real or virtual.

**The real image** will be formed when the object is beyond the principal focus. The image is real, for it may be received on a screen, or it may be seen by placing the eye in the direction of the reflected rays.

1. If the object is at an infinite distance, no image will be formed, but there will be a concentration of light at the focus.

2. Let the object be placed at a finite distance beyond the center of curvature, as AB, Fig. 200. From the point, A, draw the secondary axis, A E, and the incident rays, A D, A H. Make the angle of reflection, *a* D C, equal to the angle of incidence, A D C. The point, *a*, where the reflected ray cuts the secondary axis, is the conjugate focus of the point, A. Similarly, *b* is the conjugate focus of the point, B.

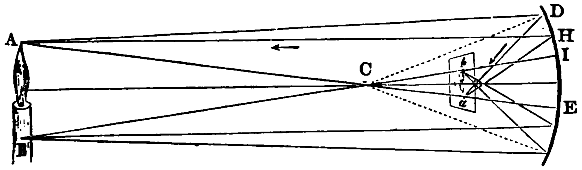

FIG. 200.

Between these two extremes, the images of the other points of the object will be found, and hence *a b* is the complete image of A B. The *image is inverted, smaller than the object, and placed between the* center and the principal focus.

3. The image increases in size as the object approaches the principal focus. At the center, the image is *inverted*, of the *same size* as the object, and at the *same distance* from the mirror.

4. If the object is between the center and the principal focus, as at *a b*, Fig. 200, the image will be at A B *inverted*, *beyond the center*, and *enlarged*. The nearer the object is to the focus, the larger will be the image, and the farther beyond the center.

The real image is always inverted, and recedes from the mirror as the object approaches it, and *vice versa*. Reflecting telescopes give a small but very distinct image of the heavenly bodies, which are viewed after being enlarged by the use of lenses. Burning mirrors are concave reflectors, which collect the parallel rays of the sun at the principal focus. The light and heat increase in intensity as the area of the mirror exceeds the area of the focus.

5. No image is formed when the object is at the principal focus, for the rays are reflected parallel.

This principle is applied in light-houses. The light is placed in the focus of a concave mirror, and its rays are reflected in parallel lines from every point of the mirror.

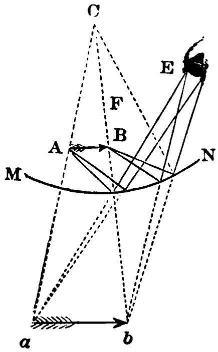

FIG. 201.

**466. The virtual image** is formed when the object is between the principal focus and the mirror.

6. Let A B be an object between the principal focus and the mirror. Draw the axes, C A, C B, and produce them behind the the mirror. The pencil at A will be reflected to the eye at E, appearing to radiate from *a*, in the same axis; likewise those from B, as from *b*.

The image is *virtual* because it is behind the mirror, *erect*, as the rays do not cross each other, and *enlarged*, because the visual angle of the image is larger than that of the object.

The visual angle is largest, when the object is near the focus. As the object approaches the mirror, the image becomes smaller, and when the object is at the surface, the image is of the same size.

**467. Convex spherical mirrors.** In a convex mirror all the foci are virtual. They may be found in the manner already detailed for finding the foci of concave mirrors.

In Fig. 202, the parallel rays, S I, T K, take, on reflection, the directions I M, K H, which appear to diverge from the point, F, which is the *principal virtual focus* of the mirror. This point lies half-way between the center of curvature and the mirror.

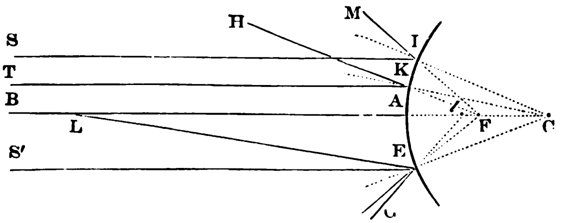

FIG. 202.

Rays diverging from a luminous point, as L, at a finite distance from the mirror will form a virtual focus, *l*, between the principal focus and the mirror. Diverging rays are rendered more divergent by reflection from a convex mirror.

**468. Formation of images in convex mirrors.** Let A B, Fig. 203, be an object placed at any finite distance. The pencil from A appears to radiate from *a*, in the same axis, A C; that from B, as if from *b*, in the axis, B C. Therefore, the image formed by convex mirrors is always *virtual*, *erect*, and *smaller than the object.*

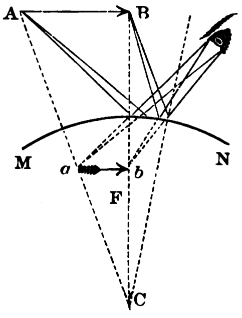

FIG. 203.

**469a. In all cases of spherical mirrors** the diameter of the image varies with the distance of the object from the mirror; hence, the *size of the image* is independent of the area of the mirror. An increase in the area of the mirror increases the *brightness* of the image, by intercepting more of the luminous rays proceeding from the object.

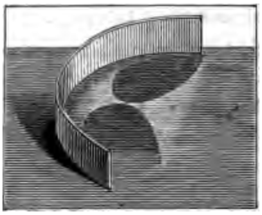

FIG. 204.

**469b. Spherical aberration.** The laws already deduced for the formation of foci and images from spherical mirrors, are not strictly accurate unless the mirror is a very small portion of a spherical surface. If the aperture of the mirror exceeds 10°, the rays reflected from the borders of the mirror meet the axis nearer the mirror than those which are reflected from points nearer the vertex. The effect of this is to render the image indistinct or less sharply defined. This defect is termed *spherical aberration by reflection.* Every pair of reflected rays successively intersect each other, and their foci form a curved line, called a *caustic by reflection.* Fig. 204. 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.

Surfaces generated by the revolution of parabolas about their axes, reflect without aberration. Hence, parabolic mirrors are used for the lanterns of locomotives, because, if a luminous point be placed in the focus of a concave parabolic mirror, all the rays which fall on the mirror will be reflected exactly parallel. The light thus reflected maintains its intensity for a great distance.

## 470. Recapitulation.

The intensity of light varies:

- I. When emitted by luminous bodies:
  - 1. With the source.
  - 2. Inversely as the square of the distance.
- II. When reflected from non-luminous bodies:
  - 3. With the nature of the surface.

[redacted]

4. With the polish of the surface.
5. With the angle of incidence.

**Mirrors** are either plane or curved.

| | | |
|---|---|---|
| Curved mirrors are................ | Spherical | Convex.<br>Concave. |
| | Conical | Paraboloid.<br>Ellipsoidal, etc. |

### REFRACTION OF LIGHT, OR DIOPTRICS.

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

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 gently filled with water, the coin will appear to be elevated and 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, will be so refracted when it passes from the water into the air as to appear to come to the eye in the line *m′* I E.

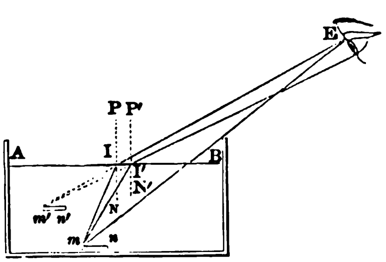

FIG. 205.

**472. Suppose an incident ray of light**, A C, moving in air, to meet the surface of water, R S, and let C E be the refracted ray. Draw P C F perpendicular to the surface at the point of incidence, C; thus, A C P is the angle of incidence, and the angle, E C F, lying between the perpendicular and the refracted ray is called the *angle of refraction.* If, now, we

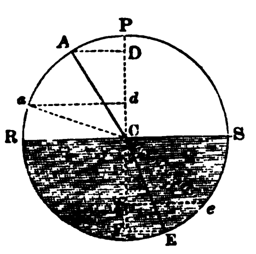

FIG. 206.

make the distances, A C and C E each equal to some unit of length, and draw A D, E F each perpendicular to P F, the line, A D, is the *sine of the angle of incidence*, and the line, E F, the *sine of the angle of refraction*. If the incident ray falls more obliquely, as at *a* C, the sine of the angle of incidence, *a d*, becomes larger, and the sine of the angle of refraction, *ef*, increases in the same proportion, so that the ratio between the sines of the angles of incidence and refraction is constant for the same two media. This ratio is called the *index of refraction*, and may be obtained by dividing A D by E F.

**473. The index of refraction** varies with the media: thus, if light passes from air into water, the index of refraction is about $\frac{4}{3}$, from air into glass, about $\frac{3}{2}$. The reciprocals of these numbers will give the indices of refraction when light passes in the opposite direction; thus, from water to air it is $\frac{3}{4}$, and from glass to air $\frac{2}{3}$.

The following table gives the indices of refraction when light passes from a vacuum into any of the substances named. The index of refraction for any two substances may be found by dividing the absolute index of one by that of the other.

*Table of Absolute Indices of Refraction.*

| | | | |
|---|---|---|---|
| Vacuum | 1.00000 | Crown glass | 1.534 |
| Air | 1.00029 | Quartz crystal | 1.548 |
| Carbonic acid | 1.00045 | Oil of cassia | 1.641 |
| Ice | 1.309 | Bisulphide of carbon | 1.768 |
| Water | 1.336 | Flint glass | 1.830 |
| Alcohol | 1.374 | Diamond | 2.439 |
| Alum | 1.457 | Chromate of lead | 2.974 |

**474. The direction of refraction** depends on the relative velocity of light in the two media. The velocity of light is least in the more highly refractive media.

The refractive power increases, in general, with the specific gravity of the substance; but inflammable bodies, like alcohol and the essential oils, have a greater refractive power than water, although their specific gravity is less.

In optics, the word *dense* is used to signify of great refractive power, and *rare*, of little refractive power, without reference to specific gravity; in this sense water is rarer than alcohol.

**Laws of refracted light.** 1. *When light passes perpendicularly from one medium to another, it is not refracted.*

2. *When light passes obliquely from a rarer to a denser medium, it is refracted toward the perpendicular.*

3. *When light passes obliquely from a denser to a rarer medium, it is refracted from the perpendicular.*

**475. Total reflection.** As a consequence of the third law, when light passes from a denser to a rarer medium, the angle of refraction is always greater than the angle of incidence.

Thus, if light passes from water into air, as the angle of the incident ray, I, I′, I″, increases, the angle of the refracted ray, R, $R^1$, $R^2$, also increases. There will be found some ray, as L, where the angle of refraction is a right angle, and the ray, if refracted, would coincide with the surface O B. But if the incident angle exceeds this limit, as T, the ray can not pass into the air, but will be *totally reflected* to T′. The limiting angle varies inversely as the refractive power: for water, it is 48° 28′, for crown glass, 40° 49′, for diamond 24° 12′.

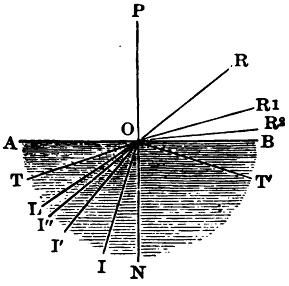

FIG. 207.

This result may be shown by filling a glass with water and placing in it a silver spoon. An eye, placed a little below the level of the water, may see a bright image of the part of the spoon immersed, reflected from the surface of the water.

**476. Atmospheric refraction** causes the heavenly bodies to appear higher than they really are, except when in the zenith. The nearer the sun or a star is to the horizon, the greater will be the effect of the refraction in increasing its altitude. The sun and stars are visible, even when they are below the horizon. The refractive power of a gas increases with its density, and, as the successive strata of the atmosphere are denser as they approach the earth, the rays from a luminary near or below the horizon are refracted more and more, describing a curve, and appearing to the eye to be in the direction of a tangent to this curve. Twilight is due to the successive refractions and reflections of the sun's rays when it is below the horizon.

477. **When the density of the atmosphere** varies from its ordinary state, the unusual refraction thus arising produces various phenomena. Distant objects, not usually visible, sometimes appear to be near and elevated in the air. The *looming* of objects at sea is due to an increase in the density of the strata near the earth's surface.

The *mirage* of the desert results from a decrease in the density of the strata of the air caused by contact with

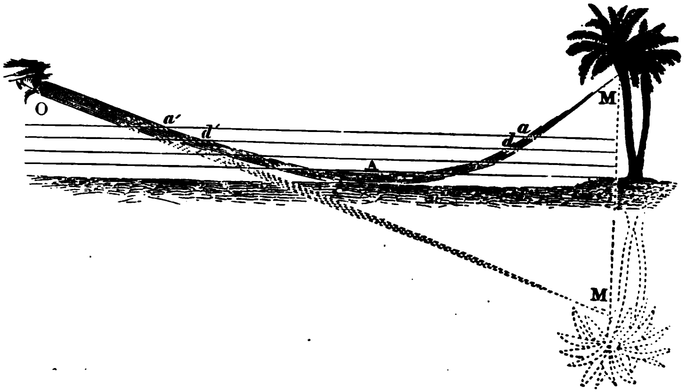

Fig. 208.

the heated soil. Rays from an elevated object, M, Fig. 208, are transmitted through strata which grow less refracting, and, ultimately, the incident ray reaches the limiting angle, and is totally reflected. The ray then rises, and is refracted in a direction contrary to the first, until it reaches the eye in the same direction as if it had proceeded from a point below the ground. Hence it gives an inverted image of the object, just as if it had been reflected at A, from the surface of a tranquil lake. This illusion often deludes the traveler in arid regions with the hope of finding water; but as he approaches it recedes, until, at last, the real objects are seen by means of direct light.

The inverted images of very distant ships are frequently seen at sea. This form of mirage is the reverse of the preceding, because the lower strata of the atmosphere are rendered colder and denser than those above by contact with the water. Sometimes this phenomenon is combined with extraordinary looming, so that an erect image is observed in the air above an inverted image, when the ship is really below the horizon.

**478. Refraction by regular surfaces.** If a transparent medium is denser than the air, and is entirely surrounded by air, a ray of light, on entering the medium, will be refracted toward the perpendicular, and, on emerging from the medium, will be refracted from the perpendicular. The relative direction of the incident and emergent rays, will depend on the inclination of the two faces of the medium.

1. **Parallel planes.** When a ray of light is transmitted through a medium, bounded by plane and parallel surfaces, the incident and emergent rays are parallel, because the ray is refracted an equal amount at each surface, but in a contrary direction. The two refractions do not produce a change in the general direction of the ray, but simply produce a lateral aberration, whose amount increases with the thickness of the medium, and the obliquity of the incident rays.

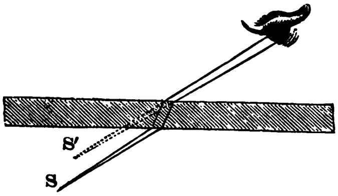

FIG. 209.

A pane of glass, whose sides are perfectly parallel, occasions no distortion of objects seen through it; if, however, the sides are not parallel, the objects seen through the glass are distorted in propo to the inequality in the thickness of the glass.

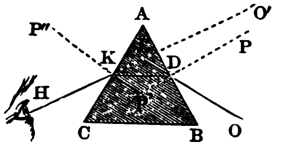

FIG. 210.

2. **A prism** is a transpa medium, having two plane faces, not parallel. The pı may be a solid wedge of gl ice, or crystal, or may consis liquids inclosed in hollow pri with sides of plane glass.

Let A C B be the section of a prism, and O a luminous p The incident ray, O D, on entering the prism is refracted towarc perpendicular, P P′, because it enters a denser medium, and proceed in the line, D K. On leaving the prism for a rarer med it will be refracted from the perpendicular, P′ P″, and will em in the direction, K H. The light is thus twice refracted *towar base of the prism*, and the eye which receives the emergent ray, I sees the object at O′ nearer the summit of the prism than the position of the point, O.

3. **A lens** is a transparent medium having two cuı surfaces, or one curved and one plane surface. Lenses usually made of crown or of flint glass with spherical faces. There are six varieties of spherical lenses, viz. is a *double convex*, B is a *plano-convex*, C is a *meniscus*,

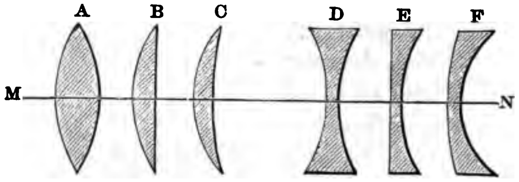

FIG. 211.

vex on one side and concave on the other, the convex face having the shorter radius. D is a *double concave*, a *plano-concave*, and F is a *concavo-convex*, the concave face having the shorter radius.

**479. Lenses** are divided into two groups, the first t *are converging*, and are thickest at the center; the others

[redacted]

*diverging*, and are thinner at the center than at the edges. The double convex lens will be taken as the type of the first group, and the double concave lens as the type of the second, as the properties of these lenses will represent those of the others.

The right line, M N, which passes through a lens perpendicular to both surfaces is called the *axis* of the lens. The *centers of curvature* are the centers of the spherical surfaces. 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. The perpendiculars drawn to the points of incidence and of emergence will, evidently, correspond to the radii of the spherical surfaces. Hence, as a prism refracts light toward its base, a convex lens will refract light toward its axis, or tend to converge the rays; and a concave lens will refract light away from the axis, or tend to disperse the rays.

**480. The principal focus** of a convex lens, is the point at which parallel rays unite after refraction. Any incident ray, as L B, will be twice refracted toward the axis, which it cuts in F. This focus is *real*, for the rays of the sun may all be collected at this point. The ordinary burning glass is simply a large double convex lens. The distance of the point, F, from the center of the lens, is called the *principal focal distance*. This varies with the radii of curvature, and also with the index of refraction. In a double convex lens of crown glass, it is equal to the radius of curvature, and in a plano-convex glass it is equal to twice the radius. The greater the refracting power of the substance, the nearer will the principal focus be to the lens.

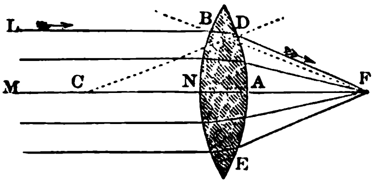

FIG. 212.

**481. Real conjugate foci** are formed when a near object is beyond the principal focus. Thus, if a luminous point be at L, Fig. 213, the diverging rays will converge on refraction to *l*, and, conversely, rays from *l* will converge on refraction at L. If a luminous point be placed at the principal focus, Fig. 212, the emergent rays will be parallel. A lamp so placed will illuminate objects at great distances.

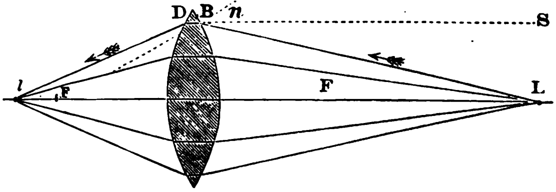

Fig. 213.

**482. A virtual focus** is formed when the luminous point is between the lens and the principal focus. Thus, rays diverging from L, will be rendered less divergent on refraction, and will appear to come from the point *l* on the axis. Thus, the virtual focus is on the same side of the lens as the object; the real foci are on the opposite side.

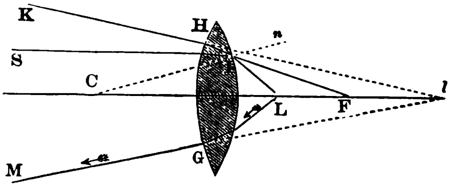

Fig. 214.

**483. Secondary axes.** If two radii, C A, C′ A′, Fig. 215, are drawn parallel to each other, their tangents will also be parallel. Hence, a ray of light which reaches A at such an angle that after refraction it takes the direction, A A′, will emerge from A′ as if transmitted through a medium with parallel faces. Therefore, the emergent ray, K′ A′, will be parallel to the incident ray, K A. The lateral aberration caused by the slight thickness of the lens may be neglected,

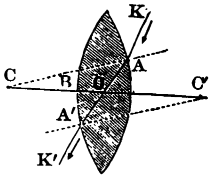

Fig. 215.

and the incident ray considered as in the same straight line with the emergent ray. The point, O, where the line, A A′, cuts the principal axis, is called the *optical center* of the lens. Any right line which passes through the optical center without passing through the centers of curvature, is a *secondary axis*. A luminous ray, coinciding with a secondary axis, suffers no deviation in direction.

So long as secondary axes are nearly parallel with the principal axis, foci may be formed on them in the same manner as on the principal axis. A collection of these foci will determine the position of images formed by lenses.

**484. Formation of images by convex lenses.** Real images are formed when the object is at a finite distance beyond the principal focus. Let A B be an object so placed. Draw a secondary axis, A *a*, from the top of the object A. Any other ray diverging from A, as A C or A E, after being twice refracted will cut the secondary axis at *a*. This point is the conjugate focus of A. In the same manner, the conjugate focus of B will be found at *b*, and intermediate points on the object will have their foci between *a* and *b*. Hence, a real and inverted image of A B will be found at *a b*. Reciprocally, if *a b* were a luminous object, its image would be formed at A B. Hence,

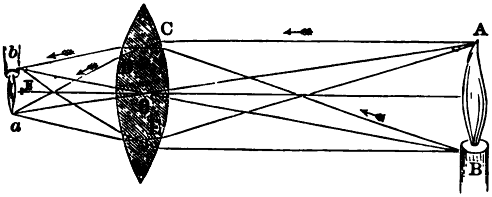

FIG. 216.

1. If an object be placed more than twice the principal focal distance from a double convex lens, the image will be *smaller* than the object, *real*, and *inverted*.

2. If a small object be placed less than twice the principal focal distance, but beyond the focus, the image will be *larger* than the object, *real*, and *inverted*. In both cases,

the diameter of the object is to that of its image as the distance of the object is to the distance of the image from the lens. These principles can be verified by placing a candle at different distances from a double convex lens, and receiving its image on a sheet of white paper.

**485. Virtual images** are formed when the object is placed between the lens and the principal focus. In Fig. 217, draw the secondary axis, O *a*, through the point A. Every ray, as A C, after two refractions, appears to emerge divergent from this axis. The point, *a*, where the emergent ray, continued backward, cuts the secondary axis, is the virtual focus of A. The virtual focus of the point B, is at *b*. There is, therefore an image of A B at *a b*, *virtual*, *erect*, and *larger than the object*.

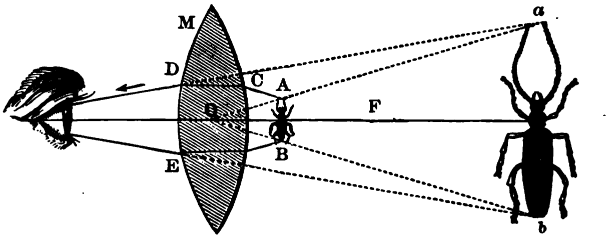

Fig. 217.

In this case, the lens is a simple magnifying glass. *The size of the image* is independent of the area of the lens, but is greater as the lens is more convex, and the object nearer the principal focus. The image is *brighter* as the area, or *field of view* increases, because more rays from the object enter the lens.

**486. The foci of concave lenses** are always virtual. Let L, Fig. 218, be a luminous point. The incident ray, L I, will be refracted at I, toward the perpendicular, C I, and, on emerging, it is refracted from the perpendicular, G C′, so that it is twice refracted away from the axis, L C′. As this is the case with every ray, the emerging rays, G K,

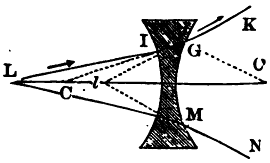

Fig. 218.

M N, will appear to diverge from a virtual focus, *l*, which is between the principal focus and the lens.

**487. The images formed by concave lenses** are always virtual. Let A B be an object in front of a double concave lens. Draw the secondary axis, A O. Each ray from the point, A, as A I, A C, is twice refracted, diverging from the axis, so that the eye, placed in the direction of the emergent rays D E and G H, receives them as if coming from the point *a*, where their prolongations cut the secondary axis. The rays from B appear to diverge on emerging from *b*. Therefore, the eye sees at *a b* an image of A B, which is always *virtual*, *erect*, and *smaller than the object*.

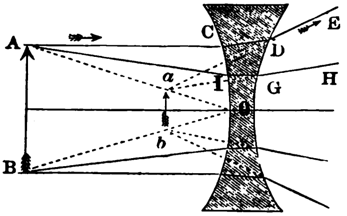

FIG. 219.

**488. Spherical aberration by refraction** is due to the fact that the rays refracted near the edge of the lens meet the axis a little nearer the lens than the focus of the rays passing through the center. The effect of spherical aberration is to render the image less distinct and well defined, and is a serious defect in the lenses used in photography. If the angular aperture, which is obtained by drawing lines from the principal focus to the edges of the lens, does not exceed 10°, the defect is not usually regarded. It may, therefore, be partially obviated by placing before the lens a diaphragm which cuts off the rays from the edges, and may be entirely destroyed by combining two lenses of suitable curvatures.

### 489. Recapitulation.

Light is not refracted

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

**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.**

- Lenses are........................
  - Converging
    - Double convex.
    - Plano-convex.
    - Meniscus.
  - Diverging
    - Double concave.
    - Plano-concave.
    - Concavo-convex.

**The effects of concave mirrors and convex lenses are analogous;** that is, 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 more than twice the principal focal distance, but finite,**
   **The image is real, inverted, and diminished.**
6. At an infinite distance
   **There is concentration of light at the principal focus.**

**The effect of convex mirrors and of concave lenses are also** analogous, **forming images which are always virtual, erect, and** smaller than the object.

## CHROMATICS, OR COLORS.

**490. Decomposition of light.** 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. 220. If, now, a prism be placed near the aperture in the path of the pencil, the rays will be unequally refracted, and will form on a screen an elongated, colored image, which is called the *solar spectrum.* As each ray forms an image of the sun, the spectrum may be considered as an infinite number of colored images, overlapping each other from end to end. If any ray of the spectrum be transmitted through a small aperture in the screen, and received on another prism, it will again be

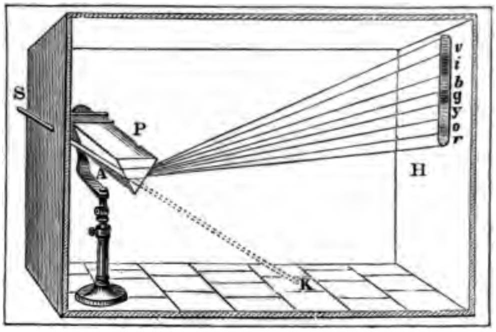

Fig. 220.

refracted, but will undergo no further change in color. Hence all the prismatic colors are simple. Newton distinguished seven of these colors as *primary*, which are in order, beginning with the least refracted, *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, *violet*.

**491. 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 of the sun will be formed in the focus. If a circular card be painted with the seven colors, in sectors proportional in extent to the spaces occupied by these colors in the spectrum, then on revolving the card very 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. 221.

**492. Complementary colors** are any two colors which combined will produce white. If the red rays of the spectrum are intercepted, and the remaining colors are combined by means of a convex lens, the resulting image will be green. Hence, green and red are complementary, because the two combined contain all the rays of white light. In this manner it is found that blue and orange, violet and yellowish green, indigo and orange yellow are complementary colors.

FIG. 221.

Complementary colors may be seen by gazing intently at any bright colored object for a few minutes, and then turning the eye toward a white wall. Thus, if the object be a bright red wafer, placed on a sheet of black paper, the eye, on turning away, will retain an impression of the wafer, in its complementary color, green. If the object is bright, the eye will see a ring of a color complementary to that of the object before it is turned away; hence, a color tends to produce in the eye its complement.

**493. When two colors** are placed near each other, each color will be modified, as though mixed with the complement of the adjacent color.

If a red wafer be placed beside a green wafer, each color will be heightened, because the red wafer will tend to tinge the adjacent object green, or to make it greener; and the green wafer will, in the same manner, tinge the red with red. If it be desired to heighten a color, it should be placed beside its complement, but if it be desired to weaken its effect, it should be contrasted with others. Thus, a green dress or scarf increases the freshness of a rosy complexion. Florid complexions will bear dark hues in dress, but a pale face appears still paler when a black dress is worn. A yellow shawl and an orange dress, when worn together, appear mutually dull, but the contrast of either with an appropriate shade of violet would be pleasant and tasteful.

**494. Fraunhofer's lines.** If light be admitted through a very narrow slit and received on a good flint glass prism, it will be found not only that the colors of the spectrum are not continuous, but also that they are interrupted by numerous dark spaces, known as Fraunhofer's lines. On viewing the spectrum with a powerful telescope, two thousand of these lines are visible. Seven of these 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. The positions of these lines in the spectrum, due to solar light, direct or reflected from the moon and planets, is invariable, but their distances from each other vary with the material of the prism. Each fixed star has a stellar spectrum, which differs from that of the sun and other fixed stars, in regard to the number and position of the dark lines.

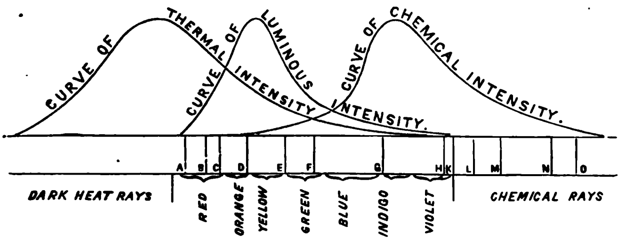

FIG. 222.

**495. Dispersion of light.** The index of refraction for the different colors is fixed with precision by ascertaining the refraction of Fraunhofer's lines, B, C, etc. The table on page 258 gives the indices of refraction for the line, E, in the yellowish-green rays, which is taken as the mean of all the rays. If similar prisms are made of different substances, the mean refraction may be 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 which it produces in the extreme rays, compared with the amount of refraction in the mean rays. Thus, the refractive power of flint glass is but little greater than that of crown glass, but its dispersive power is almost double.

*Table of Dispersive Powers.*

| | | | |
|---|---|---|---|
| Oil of cassia | 0.139 | Green crown glass | 0.036 |
| Bisulphide of carbon | 0.130 | Water | 0.035 |
| Flint glass | 0.052 | Alcohol | 0.029 |
| Diamond | 0.038 | Quartz crystal | 0.026 |

**496. Chromatic aberration.** As lenses are merely a series of prisms, with infinitely small faces, they disperse light like a prism. The violet rays, being most refracted, come to a focus, *v*, Fig. 223, nearest the lens, then the other colors in order, the red being the most remote. Hence, if a screen be placed a little nearer the lens than the focus of the mean rays, the image will be fringed with red. If the screen is beyond the focus, the image will be fringed with violet, because the violet rays cross after coming to their focus, and form the outside of the diverging pencil. The difference between the focal distance of the red and violet rays causes what is called the *chromatic aberration* of the lens. The chromatic aberration of a quartz lens is small, by reason of its low dispersive power.

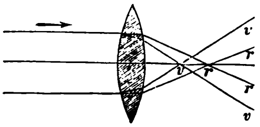

FIG. 223.

**497. Achromatism.** If two prisms, exactly alike, are placed near each other, with their bases turned in a contrary direction, one will exactly neutralize the other, and the light will emerge from the second as if from a medium with parallel faces. If, however, the first prism, B C F, be of crown glass, and the other of flint glass, the dispersion may be destroyed without entirely neutralizing the refraction. Since the dispersive power of flint glass is almost twice that of crown glass, the refracting angle of the former must be made so much smaller than the latter, that the dispersion of the two prisms shall be equal. The flint glass will then entirely neutralize the dispersion of the crown glass, but will destroy only about half of its refractive power.

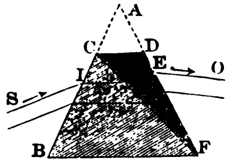

FIG. 224.

On the same principle, *an achromatic lens* may be made by combining a double convex lens of crown glass with a concavo-convex lens of flint glass. The two lenses must have such curvatures that their focal lengths shall be as their dispersive powers. An achromatic lens is, therefore, free from chromatic aberration.

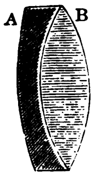

FIG. 225.

**498. Homogeneous light** is light of only one color. 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 any salt of sodium, as common salt, and held in a colorless flame, it vaporizes and yields a homogeneous yellow light. Every flame may be considered as the combustion of a body in the state of vapor. Several other substances yield characteristic colored flames; thus, strontium gives a red color; potassium, purple; copper, green, but the light is never perfectly homogeneous.

**499. Spectrum analysis.** The spectra formed by artificial lights are usually wanting in several colors, but yield the remainder with the same refrangibility as the corresponding *colors in the solar* spectrum. Their relative inten*sities will vary with the* predominant colors of the flame.

The *spectroscope*, Fig. 226, is an instrument used for analyzing flames. The light is admitted from the Bunsen's burner, E, through a narrow slit into one end of the tube, A, where it is condensed by lenses, and thrown on the prism, P. The refracted rays are thrown on the object glass of the telescope, B, and pass through it to the eye. The tube, C, contains, at the end nearest the prism, a lens, and at the other a scale divided into equal parts. When a bright light is placed in front of the tube, C, it casts a bright image of the scale on the prism, which is reflected into the telescope, B, so that the observer can read off on the scale the exact position of the rays he is observing.

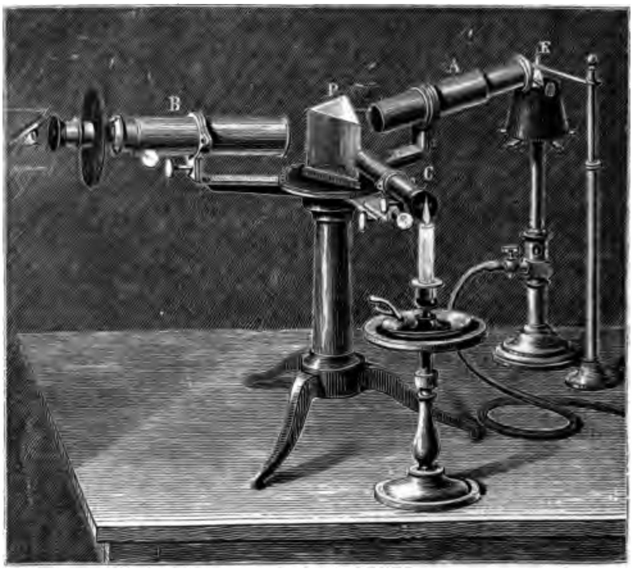

FIG. 226.

If platinum wires are dipped in solutions of the metals to be examined, and placed in the flame of the Bunsen's burner, E, their spectra may be observed through the telescope, B. In this way it is found that sodium gives a bright, double, yellow line, identical in *refrangibility* with the dark line, D, in the solar spectrum. Potassium gives a red ray, in the position of the line, A, and a violet ray, between G and H. Any substance which can be volatilized will furnish a spectrum of a few bright lines, which always have the same relative position. This is also true of incandescent gases; hydrogen gives three bright lines, which are identical in position with C, F, and G. These lines remain the same throughout a great range of temperature, and it is highly probable that they are not the same for any two substances. If several substances are mixed, each will give its own system of lines, as if it were burned separately. No chemical reaction is equal to this as a mode of detecting the presence of many substances. It is, in fact, difficult to obtain a flame which does not show the presence of sodium, as $\frac{1}{180000000}$ of a grain will give the characteristic yellow line of sodium. Since the year 1860, five new metals have been discovered by means of the spectroscope. Two of these, coesium and rubidium, are widely distributed, being found in many mineral waters, and even in tobacco.

**500.** Under extreme temperatures new lines are added to many spectra; and, under pressure, hydrogen may be made to yield a continuous spectrum; that is, one in which no dark lines are found.

Any incandescent solid will emit, at 977° F., only red rays, but as the heat increases the orange is added, and then the other colors in succession, until at 2130° F. the spectrum becomes continuous, containing all the colors, and, by consequence, the solid appears white hot to the naked eye. The lime light produced by the oxy-hydrogen blow-pipe affords a convenient method of obtaining a continuous spectrum. The electric spark ordinarily gives a discontinuous spectrum, due both to the metallic connectors and to the atmosphere; but if the spark be very intense the spectrum becomes continuous.

**501. Absorption bands.** 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 due to absorption.

Thus, solutions of didymium give two dark lines, one in the yellow and the other in the green. The blood also produces two dark lines. This effect is produced, not only by light transmitted through a dilute solution, but also when a spectrum is thrown on a screen painted with blood.

The gases also produce absorption bands. Nitrous acid, and 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 the Fraunhofer's lines are undoubtedly due to the air, but the larger portion must have another cause.

**502. If the sodium spectrum** is formed in the ordinary way, and the lime light is transmitted through the sodium flames, a dark line is seen in place of the yellow sodium line, and the spectrum is said to be *reversed.*

So, also, if two sodium flames are placed before the spectroscope, so that one must traverse the other, no spectrum is produced. In other words, sodium absorbs the same rays that it emits. This is found to be the case with so many bodies that it may be stated:

1. *That every substance, when rendered luminous, gives out rays of a definite degree of refrangibility.*
2. *The same substance has the power of absorbing rays of this identical refrangibility.*

**503. Explanation of Fraunhofer's Lines.** 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 metals, each of which would give its own system of bright lines; (3.) that when the intense light of the nucleus is transmitted through this incandescent atmosphere, the bright lines which would have been produced by the atmosphere are reversed; (4.) that Fraunhofer's lines are these reversed lines.

Now, since very many of Fraunhofer's lines coincide with the bright lines of metals, it is fair to suppose that these metals exist in the solar atmosphere. 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, nickel, calcium, magnesium, chromium, copper, sodium, aluminum, hydrogen, and a few other elements. But no evidence has been given of the presence of mercury, silver, lithium, gold, and many others.

The stellar spectra 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.

**504. The properties of the spectrum** are three; (1.) Luminous; (2.) Heating; (3.) Chemical; but all the rays do not possess them in equal intensity. The ordinates of the curves in Fig. 222 show the relative intensity of each property in a spectrum produced by a prism of flint glass.

1. The luminous intensity is greatest in the yellow and least in the violet.

2. A thermometer placed in different parts of the spectrum will indicate an increase of temperature from the violet to the red.

The point of maximum thermal intensity varies with the material of the prism. By using a prism of rock salt, which absorbs but little heat, the point of greatest heating power is found to be beyond the red rays. This fact shows that the spectrum contains dark rays of heat, invisible to the eye, which are refracted less than the red rays.

3. Light acts as a chemical agent, because it is essential to the healthy growth of plants and to various chemical changes. Thus hydrogen and chlorine combine slowly in diffused light, but with explosive violence in direct sun light. The relative chemical effect of the different rays may be determined by placing a film of chloride of silver in the spectrum.

To accomplish this, dip a slip of paper in weak brine made from common salt; then dry the paper, and wash one side of it with a solution of nitrate of silver, and dry the paper again. A film of chloride of silver will thus be formed on the paper, which will remain white if the operation be performed in a darkened room. On exposing this paper to the solar spectrum, the chloride of silver will blacken, but with unequal energy in the different rays. A quartz prism is best adapted for these experiments, because glass prisms absorb a large portion of the chemical rays.

*The chemical effect is* scarcely perceptible in the red and yellow *rays; it is decidedly present* in the blue, and attains its maximum intensity in the violet. The action extends even beyond the violet, which shows that the spectrum contains rays more refrangible than the violet, but not of sufficient intensity to be visible.

If these invisible ultra-violet rays be concentrated by a quartz lens, they form a faint beam of lavender colored light. These rays also become visible when they fall on paper moistened with a solution of quinine, or on glass colored with uranium. This property is called *fluorescence*, and is due to the power which these substances have of changing the refrangibility of the rays.

**505. Interference and combination.** If the wave theory is correct, the luminous vibrations must produce all the phenomena of combination and interference, (377).

These phenomena may be shown in various ways. One of the simplest is that afforded by the reflection of waves from both surfaces of very thin plates. If a convex lens, A B, Fig. 227, with a long radius of curvature, be firmly pressed on a plane glass, D E, a thin film of air will be inclosed between the two glasses, whose exact thickness at any point can easily be estimated. If a beam of homogeneous light be allowed to fall perpendicularly on the upper surface, a portion will be reflected from the convex surface, A C, and another portion from the plane surface, D E.

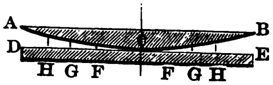

FIG. 227.

These two systems of waves will intersect in crests and hollows, according as their paths differ by a whole number of undulations, or by an odd number of semi-undulations. At a certain distance from C, as at F, the two waves will meet in opposite phases and destroy each other, and the ring at F will appear black. At a greater distance, as at G, the waves will meet in the same phase and increase the amplitude of vibrations, and produce a bright ring the same color as the light. Other points will be found beyond G, in which the waves will meet in opposite or similar phases, and, consequently, a series of black and colored rings will be formed about the center, C. If the yellow sodium flame is employed, we shall have alternately black and yellow rings; if red light be employed, a similar system of red and black rings is produced, and so on for other colors.

FIG. 228.

**506. If solar light be employed, each ring contains all**

the colors of the spectrum in order, from violet on the inner edge to red on the outer, because the different colors have different refrangibilities, and the rings are not exactly superimposed. The smallest rings are the most brilliant, because the vibrations coincide the most frequently.

These rings are known as Newton's rings, and by finding the thickness of the layer of air between the glasses, the following table has been constructed:

| 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 |

**507. Similar phenomena of interference** may be observed in other very thin plates, as in mica, soap bubbles, or in the film of oil on water, or alcohol on glass. Striated surfaces, formed by very fine parallel grooves, reflect bright colors for the same reason. This is the cause of the iridescence of mother of pearl, of labradorite, and of the changeable hues in the plumage of birds and the scales of insects.

**508. Diffraction.** When a pencil of light encounters an obstacle, the rays diverge from the edge of the obstacle as if from a new point. The light then enters the shadow of the obstacle, and is said to be *diffracted.* If a thin body, as a hair, is placed in a small opening, the diffracted rays cross each other and produce fringes of colored light, which are due to interference. Light is always diffracted when it passes the edge of an object, but it is rarely observed, because the fringes are illuminated by light from other sources, and quenched.

**509. The color of light** is determined by the frequency of its vibrations, and its brightness by the amplitude of its vibrations.

The heating, luminous, and chemical rays of the spectrum are the same in kind, and differ from each other only as red differs from violet; that is, in degree of refrangibility and rapidity of vibration. The retina of the human eye is so constructed that only rays of medium refrangibility and rapidity excite the fibers of the optic nerve to vibration. The appreciation of color varies greatly with different individuals, but the reason of this is not yet understood.

From observations made in animals, it would seem that certain fibers of the optic nerve are sensitive to one color, and others to another. The eye which is defective in these fibers is color blind, or unable to distinguish colors appropriate to the lacking nerve fibers. Dalton could not distinguish blue from crimson; others confound different colors, and some can not distinguish colors at all, and yet in every other respect their sight is perfect.

**510. The natural color of a body** is due to the power it has of extinguishing certain vibrations and reflecting or transmitting others. A white screen placed in the solar spectrum appears of all the colors. A red screen appears brighter red in the red rays of the spectrum, and almost black in the blue. A red object can reflect only red rays, and absorbs the rest. Hence, the color of an opaque body is due to the light which it reflects. A body that reflects all the rays of the solar spectrum is white; a body that reflects no light, or but very little, is black. Most natural colors of bodies, when examined by the prism, are found to be compound.

If all the solar light is transmitted by a transparent body it appears colorless. If it absorbs some of the rays, the emergent light will be of the color produced by the transmitted vibrations. Thus, red glass transmits a nearly homogeneous red. An ammoniacal solution of oxide of copper transmits a very pure blue. Some bodies reflect one color and transmit another; thus, gold appears yellow by reflected light and green by transmitted light.

**511. The rainbow** is due to the combined effect of reflection, refraction, dispersion, and interference of the solar rays in passing through drops of rain. For its formation, it is necessary (1.) that the sun shall shine during a shower, (2.) that the observer shall stand with his back to the sun, between the drops of rain and the sun. When two bows are visible, the inner and brighter is called the *primary bow*, the outer, the *secondary bow*. Each bow contains all the prismatic colors, so arranged that in the primary bow the red band is on the outside, and in the secondary bow on the inside. The common center of both arches is always in the prolongation of a line drawn from the sun through the eye of the observer. Fig. 230.

**512. The formation of the primary bow** may be explained by tracing the course of the sun's rays through a drop of rain.

Suppose the parallel rays of the sun, S S′ S″ S‴, to fall on the rain drop. The ray, S I, which falls perpendicularly on the drop *will suffer* no refraction, but will be *partially reflected back*, as it enters and leaves the drop, in

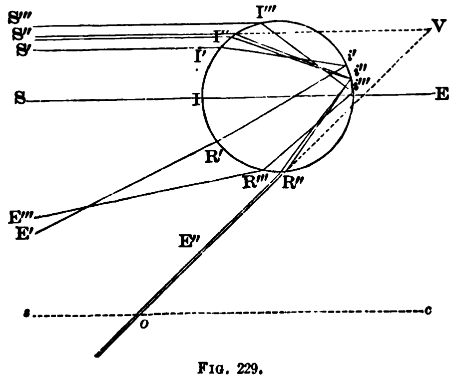

FIG. 229.

the line, S I. Any ray of little obliquity to the surface of the drop, as S′ I′, will be refracted to *i*′, where it will be reflected to R′, and then again refracted in the direction R′ E′, making a small angle with the incident ray, S′ I′. The angle of deviation between the incident and emerging rays will increase until we reach a ray, S″ I″. about 59° from the axis, for which the deviation, S″ V E″, is the greatest possible.

Beyond this limit the deviation of the emergent rays will again diminish, until we reach the ray, S‴ I‴, which is tangent to the top. Hence, of the incident rays near the limit of 59°, those above I″ will emerge very nearly parallel to those below. The rays of the sun are thus dispersed by each refraction as by a nearly spherical prism, but will be more intense in the direction of the parallel rays, R″ E″, so that these only will bring to the eye the impression of color.

Owing to the difference in the refraction of the different rays, the line of greatest intensity is not the same for the different colors. For the red ray, the angle, S″ V E″, between the incident and emergent pencils is about 42°; for the violet, about 40°, and for the other colors between these limits.

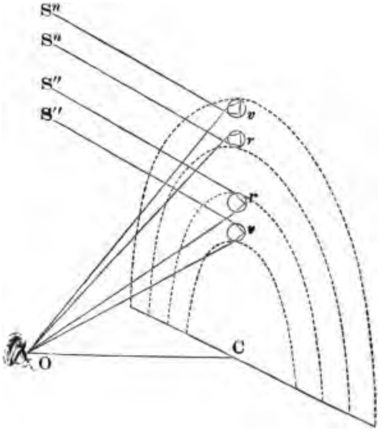

FIG. 230.

If, now, the line, *s o c*, Fig. 229, be conceived to pass from the sun through the eye of the observer, the angles S″ V *o* and V *o* C, are equal, because the solar rays are parallel. Hence, if the eye be taken as the center, the red rays will all be seen in a circle of 42° radius; the violet rays in a circle of 40° radius, and the other colors between these. As the emergent rays are nearly, but not exactly parallel, they will be in a condition to combine and interfere, and will, of course, give rise to colored bands separated by dark spaces. The colors are much brighter by reason of combination, and purer by reason of interference, because a dark band separates each color from the other. The second band of each color is sometimes bright enough to be visible, and then forms a *spurious bow* below the primary.

**513. The secondary bow** is due to two reflections and two refractions. In order that the rays may descend to the observer, the incident rays must enter below the axis of the drop, as in Fig. 231. Only the rays which enter at a distance of about 71° below the axis, will emerge sufficiently parallel to give a bright color at a great distance. The red band has a radius of about 51°, and the violet about 54°. As some light is lost at each reflection, the secondary bow is fainter than the primary.

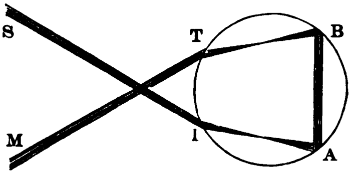

Fig. 231.

The extent of the bow depends on the position of the sun. When the sun is in the horizon, the arches are semicircles; as it rises they diminish, the primary bow ceasing when its altitude is about 42°, and the secondary when about 54°. If the sun is at or a little below the horizon, and the observer is sufficiently elevated, a complete circle may be rendered visible. Such circular rainbows are often observed near waterfalls and fountains.

Faint lunar rainbows are sometimes seen. The *halos* seen about the sun and moon are supposed to be due to light refracted by minute crystals of ice suspended in the air.

## 514. Recapitulation.

When solar light is examined by 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, refraction, and diffraction.**

**Colors are dependent on the frequency of the luminous vibrations.**

## VISION AND OPTICAL INSTRUMENTS.

**515. Camera obscura.** One form of this instrument has already been described in section 444. The *photographer's camera,* Fig. 232, is constructed on the same principle. The box, C, is the dark chamber. The screen, E, is of ground glass, inserted in the movable frame, B. An achromatic convex lens is placed in the tube, A, in order to render the image clear and well defined. The focus may be adjusted to objects at different distances by moving the screen, or the lens backward or forward. The image will be real, and smaller than the object, because the object is placed more than twice the focal distance in front of the lens.

FIG. 232.

**516. The draughtsman's camera** is used for sketching natural scenery. The student can readily make an instrument of this kind by inserting a convex spectacle glass in an orifice at the top of a box, about two feet high, and placing a plane mirror at an angle of 45°, so as to reflect the light from external objects downward through the lens. The image can be received on a paper at or near the bottom of the box. A shawl must be thrown over the open side of the box, in order to shut out the extraneous light.

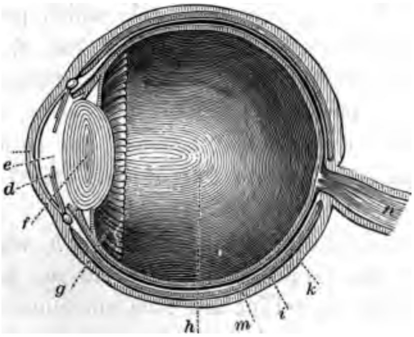

FIG. 233.

**517. The human eye** is very nearly sperical, and is about an inch in diameter. It consists essentially of (1.) three enveloping coats, and (2.) three refracting bodies. Fig. 233 presents these parts in horizontal section.

(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.*

**518. 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 intercepted by the iris, and only those which are nearly parallel are admitted through the pupil to the interior of the eye. These are transmitted through the crystalline and the vitreous humor, and finally fall upon the retina.

The effect of these refracting bodies will be the same as that of a converging system of lenses, and they will, therefore, tend 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 *an image* of the object, which will be inverted, because the *axes of the* pencils cross each other before reaching the retina. The mechanical action of the eye is very similar to that of the photographer's camera.

**519. 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.

**520. 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.

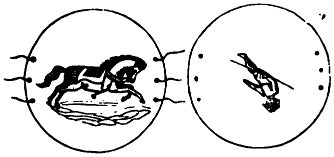

FIG. 234.

Many optical toys owe their effect to the duration of the impression on the retina. The Thaumatrope, or "twirl me round," Fig. 234, 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 side and a rider on the other, that a rapid revolution of the card will cause the rider to appear seated on the horse. The same principle is applied in the familiar Zoetrope, by which an object painted in different positions appears to perform the motions of real life.

**521. 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, for instance, the letters on this page, are seen with most distinctness. This distance, which varies for ordinary eyes from five to ten inches, is called the *distance of distinct vision.*

**522. The limits of distinct vision.** In order that an object may appear distinct, the rays proceeding from it must enter the eye nearly parallel. If rays diverge from a point more than eighteen inches from the eye, those that enter the eye will be sensibly parallel. The nearer the object is to the eye, the more perfect will be the image, provided always that the rays are brought to a focus on the retina. 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. For normal eyes, the farthest point of distinct vision is infinitely distant, the nearest point about three and one-half inches. *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 at a finite distance, varying from three inches to twenty feet.

**523. The normal eye** is very nearly round, and the principal focus of parallel rays falls on the retina, as at E, Fig. 235. From this figure there are two principal devia-

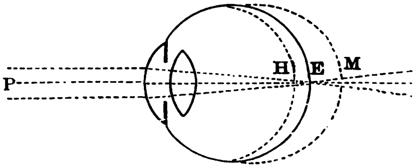

FIG. 235.

tions, producing what are known as *Myopic* and *Hypermetropic* vision. The myopic eye is an oblate spheroid, in which the retina, M, lies beyond the focus of parallel rays. For this cause, only divergent rays are brought to focus on the retina, and thus near-sightedness results. Such eyes will obtain relief by the use of concave glasses.

The hypermetropic eye is a prolate spheroid, in which the retina, H, lies in front of the focus of parallel rays. Hence, only the convergent rays come to a focus on the retina, and far-sightedness results. When such eyes deviate but little from the normal, the power of accommodation may be sufficiently active to produce perfect vision, but in other cases they will require the use of convex glasses.

There are other anomalies of refraction in the eye, among which *astigmatism* is the most common. Persons so affected find it difficult to see horizontal and vertical lines distinctly at the same moment. The glasses used to correct astigmatism are cut from cylindrical surfaces instead of spherical.

Another defect of the eye is called *presbyopia*, because it is generally found only in old persons. This results from a gradual diminution of the elasticity of the crystalline lens, by reason of which the power of accommodation is weakened, and only distant objects are seen distinctly. This kind of far-sightedness may also be remedied by the use of convex glasses.[*]

**524. Magnifying glasses.** If an object be very minute, the image formed on the retina will be too small to affect the optic nerve. If the object be too near, the rays will not focus on the retina, because they are too divergent. Suppose a pin hole to be pricked in a thin card and placed between the eye and a printed page. Now, if the page be brought

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[*] It will at once be seen that it is an error to suppose that presbyopia is due to the flattening of the cornea, and that all treatment based on this theory is absurd. Either of the defects mentioned may be relieved by the use of spectacles; but as there is great danger of injuring the eye by the abuse of spectacles, the glasses suitable for each case should be selected only by competent oculists.

very close to the eye, the outer divergent rays will be excluded, and the eye will be able to converge the few nearly parallel rays to a focus, and thereby form a faint but distinct image. At the same time, the letters will appear magnified, because the visual angle is increased.

A convex lens placed a little nearer the object than its focal distance will converge all the rays on the retina, thus preserving all the light while it magnifies the object by increasing the visual angle. Since the lens may be held close to the eye, the magnifying power may be found by dividing the distance of distinct vision by the focal distance of the lens.

Thus, if a lens have a focal distance of one-half an inch, and the distance of distinct vision be assumed as ten inches, the lens will magnify twenty times in diameter or four hundred times in area. Lenses have been made having a focal distance of $\frac{1}{50}$ of an inch, and a consequent magnifying power of five hundred diameters.

With a powerful lens, the object must be very near the surface; consequently, only the smallest portion of the object will be seen; hence, the *field of view* diminishes as the magnifying power increases. Moreover, from the great nearness of the object, the outer rays are so diverging as to cause spherical aberration; for this reason, only the central portion of a lens can be used, and this is termed its *aperture.*

The diamond has nearly twice the refracting power of glass, and hence the same magnifying power can be attained with a lens of less curvature, and is consequently less subject to spherical aberration than those of glass. The comparative thicknesses and curvatures of three lenses having the same magnifying power are shown in Fig. 236. The loss of light by absorption is in proportion to the thickness of the lens, and also to the size of the aperture. *The illuminating power* of a lens is the amount of light it collects from the object and transmits to the eye; hence, as high magnifying powers require small apertures, their illuminating powers are feeble and require that the illumination of the object should be intense. This is effected by condensing the solar light upon it by means of a concave mirror, or by a large convex lens.

FIG. 236.

From these considerations, it follows that microscopes of different focal distances are required for different purposes. The *magnifying glasses* used for viewing pictures afford a large field of view and magnify but little; the smaller glasses used by watchmakers are of greater magnifying power. Pocket microscopes usually contain two or three lenses, acting as a single thick lens. They do not usually magnify more than from five to ten diameters.

**525. 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, the two images formed on the retina will not be exactly alike. Fig. 237 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. 238, is contrived to assist the eye in blending two slightly different pictures of the


FIG. 237.

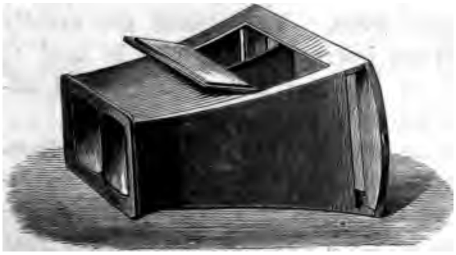
FIG. 238.

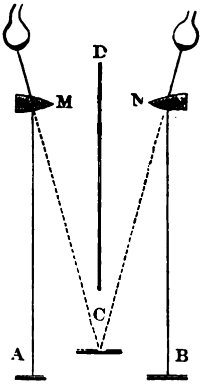

FIG. 239.

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. 239, 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, while rays from B, after emerging from N, appear also to come from C. Thus the two pictures are blended in one, and appear to come from a solid object at C.

**526. The magic lantern** is an instrument by which translucent objects are magnified and thrown upon a screen.

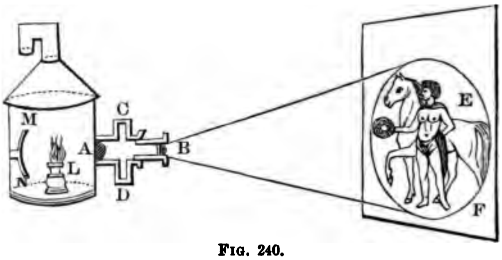

FIG. 240.

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 inserted in the slit, C D. The magnifying lens forms an image of the object on the screen, E F, placed at its conjugate focus. The objects are usually painted on glass, but the instrument may also be used to magnify photographs on glass, or natural translucent objects, as the wings of insects pasted on glass.

The image may be made as large as is desired, by adjusting the lens, B, but as the brightness of the image diminishes in proportion as the object is enlarged, strong illuminating power must be used. The electric and the lime light are sometimes used. The *solar microscope* is essentially a magic lantern, illuminated by the sun.

The *phantasmagoria* and *dissolving views* of the showmen are obtained by combining the effects of two lanterns, whose focal distances are readily adjusted.

**527. The compound microscope** consists of an object glass, or *objective*, 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 objective, 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 by a simple microscope, and hence forms another image, *a′ b′*, which is still more magnified, and is virtual. The magnifying power is equal to the product of the magnifying powers of the two glasses; if the objective magnifies fifty diameters, and the eye piece ten diameters, the total magnifying power is five hundred diameters. The advantage of this form of microscope is, that a comparatively large field of view may be attained with high magnifying power.

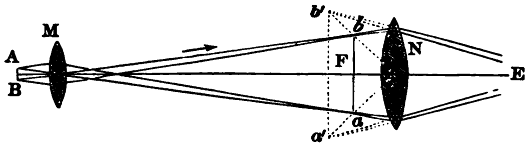

FIG. 241.

To attain a larger field of view, and, at the same time, correct the errors arising from spherical and chromatic aberrations, both the objective and the eye glass are frequently composed of two or more lenses, but each combination acts as a single lens.

The difference between the simple and compound microscopes consists not in the number of glasses employed, but 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 by a common magnifier.

**528. The telescope** is used for viewing distant objects. A real image of the object is first formed in the principal focus of a concave mirror, or of a convex lens; and this image, which is always smaller than the object, is then magnified by an eye glass, in the same manner as by a simple microscope. In the *refracting telescope* the image is formed by an object glass of small convexity; in the *reflecting telescope*, by a concave mirror.

**529. The astronomical telescope** consists of the object glass, M, and the eye glass, N. The object glass forms an inverted image, *b a*, of the distant object, A B, in its principal focus, F; this image is then viewed by the eye glass,

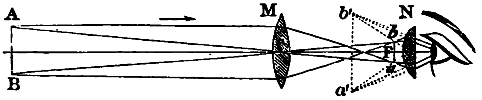

FIG. 242.

N, which is so placed as to receive the image at a distance a little less than its own focal length. If the eye were placed at the center of the object glass, it would see the object and the image under the same visual angle, and consequently of the same size; but by means of the eye glass, the image appears as much larger as the focal length of the eye glass is less than the focal length of the object glass. Hence, the magnifying power of a telescope is found by dividing the focal distance of the object glass by that of the eye glass.

The object glass should, therefore, be of small convexity, that its focal distance may be as great as possible, and the eye glass should be of great convexity, because the magnifying power depends on it. Great magnifying power requires a sufficient illuminating power in the object glass. For this reason the object glass should have as great area as possible, in order to render the real image brighter. The telescope in the Chicago observatory has an object glass eighteen inches in diameter; it, therefore, takes in at least five thousand times more light than the pupil of the naked eye.

A telescope recently constructed in England has an object glass twenty-five inches in diameter. It is the largest refracting telescope in the world.

An astronomical telescope is called an *equatorial* when it is so mounted that it sweeps east or west in the heavens parallel to the earth's equator. It is moved by clock work, so that when it is once directed toward a fixed star it compensates for the diurnal revolution of the earth, and keeps the star constantly in the field of view.

**530. The terrestrial telescope.** The inversion of the image in the astronomical telescope is of little moment in viewing heavenly bodies, but would be a serious inconvenience for terrestrial objects. The terrestrial telescope has, therefore, two additional lenses for rendering the image erect. Two convex glasses, P and Q, are so placed that the lens, P, renders the rays diverging from the image, *b a*, formed by the object glass, M, parallel to each other. After crossing at H, these rays again converge in the focus of the eye glass and form an image, *a′ b′*, inverted with respect to the first image, but erect with respect to the object. This second image is then magnified in the ordinary manner by the eye glass, R. The magnifying power is the same as in the astronomical telescope, provided the correcting glasses, P and Q, have equal focal length, but the absorption of light is much greater.

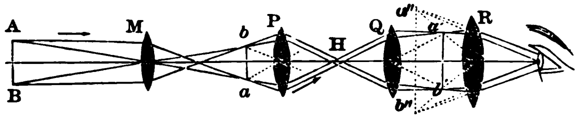

FIG. 243.

**531. Galileo's telescope** consists of a convex object glass and a concave eye glass. The object glass tends to form a real but inverted image at *b a*; but the rays converging to this image, as M *a*, O *a*, are intercepted by the eye glass, R, which is placed at its focal distance in front of the image, and after refraction appear to diverge from the points *a′* and *b′*. Hence, the object will appear erect, and as much larger

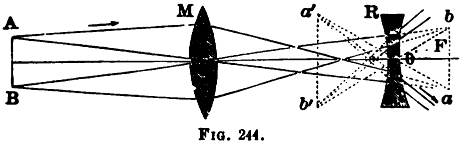

FIG. 244.

than the object as the focal length, O F, of the convex lens exceeds the focal length, O′ F, of the concave lens.

The length of the astronomical telescope equals the *sum* of the focal lengths of the two glasses, but that of the Galilean telescope equals the *difference* of the focal lengths: hence, the Galilean telescope may be made short and portable. The field of view is much limited, because only the central portion of the emergent rays can enter the eye.

The opera glass consists of two Galilean telescopes placed near together, so as to produce an image in each eye. The magnifying power is low, seldom exceeding two or three diameters. Field and night glasses are simply large opera glasses.

532. **Reflecting telescopes** are of several different forms, which take their names from their inventors. Herschel's telescope consists of a single concave reflector, M, and an eye piece, O. The reflector is so inclined to the axis of the tube, that the image of the star is formed in front of the eye piece, near the side of the tube, and is then magnified by the convex lens.

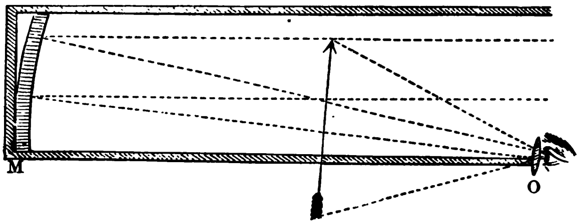

FIG. 245.

In Newton's telescope, the reflected rays are received on a small plane mirror, placed in the axis of the concave mirror, which again reflects them to an eye piece attached to the side of the telescope. Lord Rosse's telescope has a mirror six feet in diameter, whose focal length is fifty-four feet. The amount of available light received at the eye piece exceeds two hundred and fifty thousand times as much light as commonly enters the eye. This enormous illuminating power enables the observer to use eye glasses whose magnifying power is so great that an object as large as the capitol at Washington could readily be perceived at the distance of our moon. Its highest magnifying power is over six thousand diameters.

### 534. Recapitulation.

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

The sensation of sight is produced by luminous undulations passing through (1.) the cornea, (2.) aqueous humor, (3.) pupil, (4.) crystalline lens, (5.) 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.

The ordinary defects of the eye are
1. Anomalies of refraction........................
   - Myopia.
   - Hypermetropia.
   - Astigmatism.
2. Loss of power of accommodation...............Presbyopia.

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

## DOUBLE REFRACTION AND POLARIZATION.

**535. If a crystal of Iceland spar** be placed upon an object, as in Fig. 246, a double image will be perceived. This phenomenon is called *double refraction.* Most transparent crystals have the same property of refracting light in two separate pencils. The manner in which the incident ray is divided is shown in Fig. 247. Let *a x* be a line joining the

FIG. 246.

obtuse angles of a crystal of Iceland spar. It is called the *axis of form*, and any plane, as $adxc$, parallel to this axis and perpendicular to any face of the crystal, is called the *plane of principal section.*

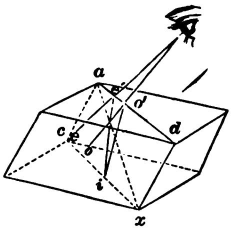

FIG. 217.

Now, suppose a ray of light to proceed from a dot at $i$; it will be refracted in two rays, $io'$, $ie'$, and will give two images of equal intensity, one at $o$ the other at $e$. The first of these rays, $io'$, has a constant index of refraction 1.65, and is governed by the laws of single refraction. It is, therefore, called the *ordinary* ray. The other ray, $ie'$, is called the *extraordinary* ray.

**536. There is one direction** in which the images coincide and the object appears single. This direction is parallel to the axis of form, and is known as the *optic axis* of the crystal. The amount of separation of the two images will be the greatest when the direction of the incident ray is at right angles to the optic axis. If the eye be placed directly above the dot, and the crystal be slowly turned around, the ordinary image will remain stationary, while the extraordinary will revolve about it at varying distances. Hence, the extraordinary ray has a variable index of refraction, and does not, in general, coincide with the plane of the incident ray.

Crystals with but one axis are called *uniaxal*, as Iceland spar, tourmaline, sapphire, quartz. Most crystals are *biaxal;* that is, they have two directions in which the image is single, as sugar, strontianite.

**537. Both the ordinary and extraordinary rays** have acquired properties which distinguish them from rays received directly from the sun or any self-luminous body, and are said to be *polarized.* Light may also be polarized by single refraction, reflection, and absorption. A body capable of polarizing light is called a *polarizer.*

The difference between common and polarized light may be readily shown. Suppose a beam of solar light to have been transmitted through a doubly refracting crystal, $ax$, and one of the emergent rays to be cut off by a screen, S. If the ordinary ray be allowed to pass through a second crystal, $a' x'$, it will in general be separated into two rays, one ordinary, $i'O'$, and the other extraordinary, $i'e'$, but of unequal intensities.

If the second crystal, which is called an analyzer, be turned around until the two principal planes coincide, that is, until their axes make an angle of 0° or 180°, the extraordinary ray disappears, and the ordinary has its greatest intensity. On turning the analyzer farther around, the ordinary ray gradually decreases in intensity, while the extraordinary ray re-appears and increases in intensity. When the principal planes are at right angles to each other, that is, when their axes have been turned 90° or 270°, the ordinary ray disappears, and the extraordinary ray has its greatest intensity.

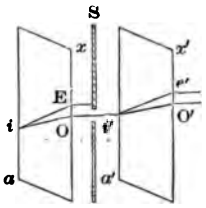

FIG. 248.

If the screen be moved so as to cut off the ordinary ray and allow the extraordinary to fall on the analyzer, the extraordinary ray alone will be transmitted when the principal planes coincide, and only the ordinary when the principal planes are at right angles. At intermediate positions, the refraction is double, but of unequal intensity, except at the middle point of each quadrant.

**538. Explanation of polarization.** If we regard the waves of light to be those of crests and hollows (393), the vibrations will be transverse to the direction of propagation. Now, since common light will be equally transmitted in every conceivable direction, the transverse vibrations must take place in every possible plane.

This can not be the case with polarized light, since its intensity varies from a maximum to zero as its direction to the medium which it encounters varies. It has, therefore, acquired sides; that is, its transverse vibrations may be regarded as moving in a single plane, as east and west, or up and down, or right and left. Hence, polarized light consists of a system of vibrations moving in a single plane or in parallel planes.

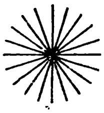

FIG. 249.

FIG. 250.

If, then, the adjoining figures represent sections of two beams of light, the radii of Fig. 249 will represent the transverse vibrations of common light, and the parallel lines of Fig. 250, the transverse vibrations of polarized light.

Now, on the principle of the resolution of forces, polarized light may be considered as moving in a single plane, and common light as equivalent to a system of vibrations, moving in two planes at right angles to each other. Fig. 251. When the beam is polarized, the light is separated into two sets of vibrations, which move in planes at right angles to each other.

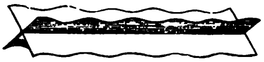

FIG. 251.

In the case of the Iceland spar, the ordinary ray is polarized in a plane parallel to the optic axis, and the extraordinary ray in a plane at right angles to that axis.

**539. Polarization by absorption.** If a crystal of tourmaline be split into plates parallel with its axis, these plates will be doubly refracting, like Iceland spar. They also possess the property of rapidly absorbing the ordinary ray; and hence, if a beam of solar light fall upon a plate of requisite thickness, only the extraordinary ray will emerge. For this reason, a plate of tourmaline is a convenient means for polarizing light, and also for analyzing light that has been polarized by other means.

**The tourmaline pincette** consists of two such plates set in movable disks, *a* and *b*, Fig. 252. If either plate be held between the eye and a candle, the light will be transmitted polarized in all positions of the disk, (but colored by the accidental tint of the crystal.) If the two disks are placed in front of each other, with their axes parallel, little change will be observed; but if the second or analyzing plate be slowly turned, the light will gradually become more feeble, and will entirely disappear when the plate has been turned 90°.

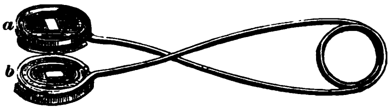

FIG. 252.

The effect of the tourmaline is analogous to that of two gratings with parallel bars. Fig. 253. If a card-board model of a wave of light be presented to the grating, A, only the vertical portion will be permitted to pass. When this portion, which represents a polarized wave, reaches C, it will be stopped if the gratings at C are at right angles to A, but will pass freely if C be turned a quarter round.

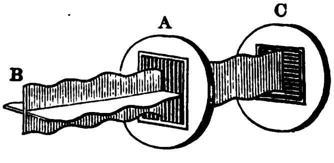

FIG. 253.

If either ray which has been polarized by transmission through Iceland spar be examined by a tourmaline analyzer, it will be found that in certain positions of the analyzer all the light will be absorbed, but if the analyzer be turned 90°, all the light will be transmitted. The ordinary ray will be transmitted where the extraordinary was absorbed, and absorbed where the other was transmitted.

**540. Polarization by reflection.** When light falls upon the surface of any transparent medium, the reflected ray is more or less polarized. Let A B, Fig. 254, be a plate of glass, and I C the incident ray. A small portion of the light will be reflected at each surface, in the direction, C R, E R′, and the remainder transmitted. All the reflected light will be polarized when the angle of incidence is such that the reflected and refracted rays are at right angles to each other. This is called the *polarizing angle.* The polarizing angle for glass is 54° 35′, for water 52° 45′.*

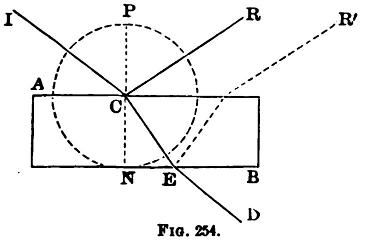

FIG. 254.


FIG. 255.

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* The angle of polarization for light passing from air into a denser medium is such that the tangent of the incident ray, which is reflected polarized, is equal to the index of refraction for the reflecting medium.

If the polarized ray fall upon a second plate at an equal angle, viz.: 54° 35′, it will be entirely reflected when the two plates are parallel, but if the upper plate be turned around this ray as an axis, so as to maintain the same angle of incidence, the ray will gradually decrease in intensity, and will entirely disappear when the two plates are at right angles to each other. Fig. 255.

If the polarized ray be examined by an analyzer of Iceland spar, it will be refracted singly and ordinarily when the principal plane coincides with the plane of reflection; singly and extraordinarily, when the principal plane is at right angles to the plane of reflection, and in all other cases will be separated into two pencils which are, in general, of unequal intensity.

**541. Polarization by refraction.** When light is polarized by reflection from the surface of a transparent medium an equal amount of the transmitted ray, E D, is polarized by refraction. But as the amount of light transmitted is much greater than that reflected, only a small portion of the transmitted ray will be polarized, and will emerge mixed with common light. If, however, several plates of glass or mica be laid one upon another, the light will be partially polarized at each refraction, and if eighteen or twenty plates be used, very nearly all of the transmitted light will be polarized.

If light, polarized by refraction, fall upon a glass plate at its polarizing angle, it will be wholly reflected when the surface is at right angles to the plane of refraction, and wholly transmitted when the reflecting surface is turned 90°. Therefore, the planes of polarization by refraction and reflection are at right angles to each other.

If examined by an analyzer of tourmaline, or of Iceland spar, the reflected ray will be transmitted where the refracted ray is stopped, and stopped where the refracted ray is transmitted.

**542. Rays of light, polarized** in the same plane, may be made to interfere with each other in the same manner as rays of common light. The chromatic effects produced are exceedingly striking and beautiful.

The simplest manner of producing these effects is by interposing a thin plate of any doubly refracting substance between the polarizer and analyzer. Thus, if a thin film of Iceland spar be placed between the disks of a tourmaline pincette, with the axes of the tourmalines perpendicular, a beautiful series of colored rings traversed by a black cross will be seen. Fig. 256. If the analyzer be turned, the colors will gradually change, and when the axes are parallel, the tints will be complementary to the first series, and the cross will become white. Fig. 257. Any uniaxal crystal will produce similar effects. Biaxal crystals produce double systems of rings, with most curious and characteristic combinations.

FIG. 256.

FIG. 257.

**543.** Many other substances, as slices of quills, parings of horses' hoofs, grains of starch, compressed glass, gums, and jellies, will, under like circumstances, give similar colors and rings, and thereby indicate a doubly refracting structure. Whenever there is the least tendency to an axial arrangement in the molecular structure of transparent bodies, it may be determined, at least in part, by transmitting through the body a polarized ray.

If polarized light be transmitted through unannealed glass, irregularly heated, compressed, or bent, the amount of molecular change in the glass caused by the disturbing force may be at once indicated and measured by the colors displayed, by viewing the transmitted ray through an analyzer.

**544. Rotatory polarization.** If two tourmaline plates be crossed, no light will be transmitted. If, now, a section of quartz crystal, cut at right angles to the axis, be placed between the polarizer and analyzer, more or less light will be transmitted, and to extinguish it, the analyzer must be turned through a certain angle. This phenomenon is called *rotatory polarization.*

Some kinds of quartz turn the plane of polarization to the right hand and others to the left, and the crystals are termed right handed or left handed, according to the effect produced. The action of the plate is proportioned to its thickness, and is more energetic the greater the refrangibility of the ray. Thus, for a plate of quartz one twenty-fifth of an inch thick, a ray of red light requires the analyzer to be turned 17°, and a ray of violet light, 44°. If white light be used, the same crystal will give different colors as the analyzer is turned.

**545. Certain liquids** also possess the property of rotatory polarization. Thus, solutions of cane sugar, and oil of lemons, give a right-handed rotation; albumen, and solutions of uncrystallizable sugar, give a left-handed rotation.

Hence, if a ray of polarized light be transmitted through a sirup of pure cane sugar, the strength of the sirup may be determined by the angle through which the analyzer must be turned to produce the violet tint. A mixture of two liquids, acting oppositely, will produce a result equal to the difference between the two; hence, a similar contrivance may be used to determine the proportion of cane and fruit sugars in a sirup, or to determine the adulteration of various essential oils.

**Other uses of polarized light.** By viewing the heavenly bodies through an analyzer, Arago was enabled to decide that the moon and planets shine by reflected light, because much of their light is polarized. On the other hand, the fixed stars are self luminous, because their light is unpolarized.

Polarized light is of great value in microscopic investigations, because, by means of characteristic rings and axial lines, various bodies may be detected in very minute quantities. Thus, the various kinds of starch give characteristic bands which serve to distinguish one from the other.

## 546. Recapitulation.

Light may be polarized by ................. 
- Double refraction.
- Ordinary refraction.
- Reflection.
- Absorption.

# CHAPTER VIII.

## PYRONOMICS.

**547. The sensations of warmth and cold** are due to the action of a force which every one recognizes as heat. These terms are, however, merely relative, as the same substance may at the same time appear warm to one individual and cold to another. If we place the right hand in iced water and the left in hot, and then suddenly transfer both to ordinary cistern water, the sensations of either hand will be reversed. Our sensations, therefore, can not be used as a means of measuring heat accurately. We may accomplish this result by means of the effect of heat on bodies not endowed with sensation.

**548. The first effect of heat** on any body, solid, liquid, or aëriform, is to expand it.

The expansion of gases may be readily shown by the air thermometer. Fig. 258. This consists simply of a bulb of glass, with a long narrow stem, dipping into colored water. If the bulb be warmed by the hand, the air within will so expand that a portion will be expelled and rise in bubbles through the liquid. On cooling, the portion of air remaining will contract to its former volume, and the water will take the place of the air expelled.

The experiment may then be continued indefinitely. The expansion and contraction may be measured by the scale attached to the stem. If other gases than air are used to fill the stem, it will be found that all expand equally and regularly for successive increments of heat.

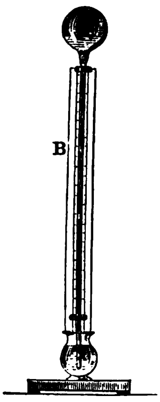

FIG. 258.

The expansion of liquids may be shown by a flask, having a long narrow tube fitted to its neck by a cork. Fig. 259.

Fig. 259.

If the flask be filled with alcohol and plunged in boiling water, the expansion of the alcohol will be manifested by its rise in the tube. If other liquids are used to fill the flask, most of them will expand less than the alcohol, showing that different liquids expand unequally for the same increments of heat.

A scale attached to the tube will convert the apparatus into a thermometer, which may be termed mercurial, alcoholic, water, etc., according to the liquid used.

The expansion of solids may be shown by a *Gravesande's ring.* Fig. 260.

A brass ball is so made that, at ordinary temperatures, it passes freely through the ring, *m.* When the ball is heated, it expands, and will no longer pass through the ring.

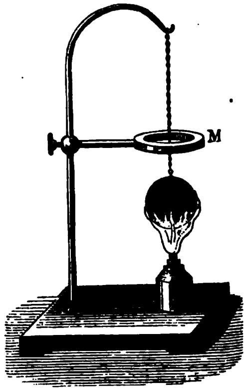

Fig. 260.

The preceding 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.*

**The pyrometer,** Fig. 261, may be used to show the linear expansion of solids.

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. By using rods of different

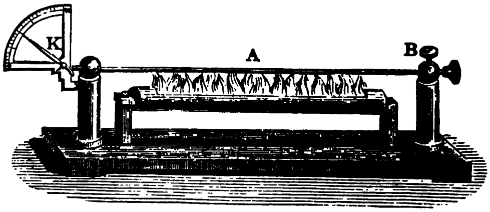

Fig. 261.

substances, it will be seen that different solids expand unequally for equal increments of heat.

**549. The unequal expansion** of different metals is well shown by a compound bar, made by riveting together two bars of iron and brass, at different points along their whole length, as shown in Fig. 262.

If the bar is straight at ordinary temperature, it will so bend when hot water is poured on it that the brass will be on the convex side of the curve, and bend in the opposite direction when cold water is poured on it. The brass expands and contracts more than the iron, and the bar curves to accommodate the inequality of the length which results. This principle has been applied to the construction of metallic thermometers.

FIG. 262.

FIG. 263.

Clay does not expand by heat, but contracts permanently, by reason of chemical changes among its particles. In the experiments detailed, the bodies will be found to contract on cooling, and assume their original volume, as soon as they attain their former temperature. Certain metals, as lead and zinc, are exceptions to this law of cooling, the contraction being at each time a little less than the expansion.

**550. From these experiments** it is evident (1.) that the volume of all bodies is increased by heat; (2.) that this increase of volume is due to motion among the molecules of the bodies, which tends continually to separate them; (3.) that the intensity of the heat may be measured by the degree of the molecular motion. From these and other considerations, to be detailed hereafter, it is assumed that

*Heat is that mode of molecular motion which may be measured by the expansion of bodies.*

By this definition it is understood (1.) that the molecules of every body are in continual motion; (2.) that when this motion increases in intensity, the body becomes warmer; (3.) that when this motion decreases in intensity, the body becomes cooler. An older theory, which regarded heat as imponderable matter, has been generally discarded while some of its terms have been retained: hence, the student must remember that when heat is described as passing from one body to another, it means that the molecular motion of one body is communicated to the molecules of another, and not that any material agent has passed.

**551. Temperature** is the intensity of heat referred to some arbitrary standard. The standards assumed are those of melting ice and of water boiling under the pressure of one atmosphere, which are found by experiment to represent invariable temperatures. These temperatures are called, severally, the *freezing* and the *boiling points*.

A *thermometer* is an instrument which measures temperatures. Thermometers may be formed of any substance in which the expansion on heating and the corresponding contraction on cooling may be determined. The mercurial thermometer consists of a capillary glass tube, at one end of which is blown a bulb; the bulb and part of the tube are filled with mercury.

FIG. 264.

The mercury and the glass are both affected by heat, but, under the same circumstances, the mercury expands or contracts seven times as much as the glass. Therefore, if the instrument is warmed the mercury will rise in the tube; and if it is cooled, the mercury will sink in the tube. For the purpose of comparing one instrument with another, arbitrary scales have been devised, by which the variation in the mercurial column may be designated.

The freezing and boiling points are first determined by immersing the instrument in melting ice and in boiling water, and the height of the column in each case is marked on the tube or on the scale attached to it. These points being determined, the interval between them is then divided into any number of equal parts called degrees, and parts of the same length are set off above and below the boiling and freezing points, as far as may be required.

**552. Fahrenheit's scale** is in common use in this country. It marks the boiling point by 212° and the freezing point by 32°. The zero, or 0°, of this scale was determined by a mixture of ice and salt.

The scale used in France, and generally employed in scientific researches, is the *centigrade*, invented by Celsius. It marks the freezing point by 0°, and the boiling by 100°.

*Reaumur's scale*, which is used in Germany and Spain, marks the freezing point by 0°, and the boiling by 80°.

These scales are distinguished from each other by the letters F., C., and R. 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. The interval between the freezing and boiling points is, therefore, divided by Fahrenheit into 180°, by Celsius into 100°, and by Reaumur into 80°; hence, $180^\circ\,F = 100^\circ\,C = 80^\circ\,R$, or $1^\circ\,F = \frac{5}{9}^\circ\,C = \frac{4}{9}^\circ\,R$.

Bearing in mind that Fahrenheit's zero is 32° below the freezing point, one scale may readily be converted into another, thus:

$$F = \tfrac{9}{5}\,C + 32 = \tfrac{9}{4}\,R + 32.$$

$$C = (F - 32)\,\tfrac{5}{9} = \tfrac{5}{4}\,R.$$

$$R = (F - 32)\,\tfrac{4}{9} = \tfrac{4}{5}\,C.$$

All these scales are alike arbitrary; but undoubtedly the most rational and convenient is the centigrade.

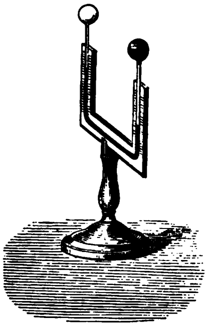

FIG. 265.

**553. As mercury freezes** at —37°.9 F., and boils at 662° F., it can not be used to measure temperatures beyond these limits. Thermometers filled with alcohol are used to measure extreme cold, and various forms of metallic thermometers are used to measure extreme heat. The pyrometer, Fig. 261 is an example. The air thermometer, Fig. 258, is very sensible to changes in temperature, but is affected also by changes in the atmosphere.

Regnault has devised an air thermometer which is by far the most reliable thermometer known. It is very sensitive and may be used for any temperature, but is too complicated for ordinary use.

The differential thermometer, Fig. 265, has two closed bulbs filled with air and connected by a U tube, containing a little sulphuric acid. It indicates only the difference in temperature of the two bulbs; if one is warmer than the other, the liquid in the tube will be forced toward the colder bulb.

For very delicate investigations, the thermo-multiplier, described in (771), is now universally employed.

**554. The coefficient of expansion** is the small fraction which measures the expansion of a body on being raised from the freezing point to one degree above. The rate of expansion for all gases is very nearly the same, being $\frac{1}{490.9}$ of their bulk for each degree Fahrenheit, or $\frac{1}{273}$ of their bulk for each degree centigrade. The rate of expansion for solids and liquids increases as the temperature rises. Between 32° F. and 212° F. this increase in rate is hardly appreciable, so that the coefficient of expansion will very nearly represent the expansion of each degree. For higher temperatures, the increase in rate forms a considerable quantity.

For this reason all thermometers should be graduated by comparison with Regnault's air thermometer. Thus, the temperature of 572° F., as measured by Regnault's thermometer, would be indicated by 586° F. if measured by an ordinary mercurial thermometer, because of the increase in the rate of expansion in mercury, as the temperature rises. Alcoholic thermometers are even less reliable, because the expansion of alcohol at all temperatures is exceedingly irregular.

If a rod, whose length is taken as unity, have a coefficient of expansion represented by $\frac{1}{a}$, then its total length after being heated one degree will be $1 + \frac{1}{a}$. If the same substance be in the form of a *square*, the superficial contents, after heating one degree, will be $\left(1 + \frac{1}{a}\right)^2 = 1 + \frac{2}{a} + \frac{1}{a^2}$. Finally, if the same substance be in the form of a cube, the volume, on being raised one degree, will be $\left(1+\frac{1}{a}\right)^3=1+\frac{3}{a}+\frac{3}{a^2}+\frac{1}{a^3}$. Now, as $\frac{1}{a}$ is a very small quantity, its powers, $\frac{1}{a^2}$, $\frac{1}{a^3}$, may be neglected; consequently, the superficial coefficient of expansion is nearly twice, and the cubical coefficient three times the linear coefficient.

*Table of Expansion from 32° F. to 212° F.*

| Solids. | Linear. | Cubical. | Fluids. | Cubical. |
|---|---|---|---|---|
| Flint glass | $\frac{1}{1248}$ | $\frac{1}{416}$ | Mercury | $\frac{1}{55}$ |
| Platinum | $\frac{1}{1131}$ | $\frac{1}{377}$ | Water | $\frac{1}{21.8}$ |
| Steel | $\frac{1}{926}$ | $\frac{1}{309}$ | The fixed oils | $\frac{1}{12.5}$ |
| Iron | $\frac{1}{846}$ | $\frac{1}{282}$ | Alcohol | $\frac{1}{9}$ |
| Brass | $\frac{1}{536}$ | $\frac{1}{179}$ | Air and the permanent gases. | $\frac{180}{491}$ |
| Silver | $\frac{1}{524}$ | $\frac{1}{175}$ | | |
| Tin | $\frac{1}{516}$ | $\frac{1}{172}$ | | |
| Zinc | $\frac{1}{340}$ | $\frac{1}{113}$ | | |

**555. The amount of force** exerted in expansion or contraction is enormous; for it is equal to that which would be required to stretch or compress the material to the same extent by mechanical means.

Water, at the temperature of 128° F., is compressed .000044 of its volume by the pressure of one atmosphere. On being heated from 32° F., to 212° F., it expands .0466 of its volume. Therefore, to restore boiling water to its bulk at freezing would require a pressure of over one thousand atmospheres. The expansive force of water for each degree F. is nearly ninety pounds per square inch. Hence, if a closed vessel be completely filled with cold water, it must speedily burst when heat is applied.

A bar of wrought iron expands, for each degree F., with a force of nearly two hundred pounds to the square inch. This force had a curious application in the Museum of Arts and Trades, in Paris. The walls of an arched gallery had bulged outward by the weight of the arch. Iron bars were placed across the building and screwed into plates on the outside. The alternate bars were then heated, and as soon as they had expanded the plates were screwed up tightly to the walls. As the bars cooled and contracted, they drew the walls closer together. The operation was repeated until the walls had attained the vertical position.

On the same principle tires are fastened on wheels. The tire, made a little smaller than the wheel, is heated red hot, and while expanded is placed in position. On cooling, it not only secures itself on the rim, but holds all the other parts of the wheel in position.

It is often necessary to take into account the changes of length produced by heat. In railways, a small interval must be left between the ends of the iron rails. Iron bars built into masonry should be left free at one end.

Brittle substances, as glass and cast iron, often crack on being heated suddenly; because the outside is heated sooner than the inside, and thereby causes an unequal expansion. A sudden cooling, by inducing unequal contraction, has the same effect. The thicker the plate the greater the liability to fracture.

**556. Water** presents a singular exception to the general law of expansion and contraction by heat. If a flask, with a long and very slender neck, Fig. 259, be filled with boiling water and allowed to cool, the water will go on contracting, though irregularly, 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 consequently 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 upon the warmer water below. Hence, the freezing takes place only on the surface.

At the moment of freezing, the water undergoes a sudden enlargement, of about ten per cent. in volume, in becoming ice. The ice once formed covers the water like a blanket, and renders the freezing process very slow. If the ice were specifically heavier than water, large masses would form at the bottom each winter, which the heat of the succeeding summer would be unable to melt entirely, and thus our lakes would in time become solid.

## SPECIFIC HEAT.

***557.* The temperature of a body** *affords no indication of the amount* of heat it contains. The zero point is entirely arbitrary, and does not indicate the absence of heat. Bodies have been cooled to —220° F. without reaching the absolute zero, or the point at which molecular motion ceases. It is a mistake, therefore, to say that water at 100° is twice as hot as water at 50°, because ratios can not be drawn except from an absolute zero. It is impossible to measure the absolute amount of heat gained or lost by a body, but we have a measure of the relative amount in the thermal unit. The *thermal unit* is the quantity of heat required to raise one pound of water from 32° F. to 33° F.

**558. The heat lost in cooling** is precisely equivalent to that required to raise the same body through the same number of degrees. Hence, if different bodies of the same weight be heated to the same temperature, (say 212° F.,) and then placed on cakes of ice, the amount of ice melted will be in proportion to the number of thermal units they contain. In comparison with water, sulphur will melt $\frac{1}{5}$, iron $\frac{1}{9}$, mercury $\frac{1}{30}$ as much ice; consequently, these fractions will express the relative amount of heat required to raise them to the same temperature. The heat required to raise one pound of any substance 1° F., compared with the thermal unit, is the *specific heat* of the substance. The specific heat of water is, of course, 1.00.

*Three methods* of measuring specific heat are in use: (1.) the method by melting ice, just mentioned; (2.) by mixtures; (3.) by cooling.

*The method by mixture.* If a pound of water at 212° F. be mixed with another pound at 32° F., the temperature of the mixture will be $\frac{32°+212°}{2} = 122°$; one pound gains exactly the temperature the other loses. This will not be the case if dissimilar substances are mixed together. If a pound of mercury at 212° F. be mixed with a pound of water at 32° F., the resulting temperature will be 37°.8 F. The mercury loses 174°.2, while the water gains 5°.8. The specific heat of mercury is, therefore, $\frac{5.8}{174.2} = .033$.

*The method by cooling.* If two thermometers of the same volume are filled, one with mercury and the other with water, and cooled from a common temperature, the mercurial thermometer will cool more than twice as fast as the water thermometer. For equal volumes, the relative heat of mercury is $\frac{1}{2.4}$, but as mercury is 13.6 times heavier than water, the specific heat of mercury is, as before, $\frac{1}{2.4} \div 13.6 = .033$.

Either of these methods may be employed for finding the specific heat of solids and liquids. Proper allowance must always be made for the heat dissipated in the apparatus employed.

**559. The specific heat of aëriform bodies** is determined by passing a current of heated gas through a coiled metallic tube, immersed in water, and noting the rise of temperature produced in the water when a given weight of the gas has been cooled a known temperature. The specific heat of equal volumes can be calculated from those of equal weights by multiplying the numbers obtained for weights by the specific gravity of each gas.

The specific heat of all substances except the permanent gases increases with the rise of temperature; owing, probably to the expansion caused by heat. A substance in the liquid state has a higher specific heat than when it is in the solid or aëriform condition. Thus, water has double the specific heat of ice, and more than double the specific heat of steam. These facts are shown by the annexed tables:

*Table of Mean Specific Heat.*

| | Between 32° F. and 212° F. | Between 32° F. and 572° F |
|---|---|---|
| Mercury | .0330 | .0350 |
| Platinum | .0335 | .0355 |
| Silver | .0557 | .0611 |
| *Copper* | .0949 | .1013 |
| *Iron* | .1098 | .1218 |
| *Glass* | .1770 | .1900 |

### *Specific Heat of Gases and Vapors.*

| | Equal volumes. | Equal weights. |
|---|---|---|
| Air | .2375 | .2375 |
| Oxygen | .2405 | .2175 |
| Hydrogen | .2359 | 3.4090 |
| Ammonia | .2996 | .5084 |
| Chloroform | .6461 | .1566 |
| Turpentine | 2.3776 | .5061 |

### *Specific Heat of the same substance in Different States.*

| | Solid. | Liquid. | Aëriform. |
|---|---|---|---|
| Water | .5050 | 1.0000 | .4805 |
| Phosphorus | .1788 | .2045 | ....... |
| Bromine | .0843 | .1060 | .0555 |
| Lead | .0314 | .0482 | ....... |
| Alcohol | | .5050 | .4534 |
| Ether | | .5467 | .4797 |

**560. With the exception of hydrogen**, water possesses the highest specific heat known. The presence of large bodies of water has, for this reason, a decided effect in moderating the rapidity of transitions from hot to cold, or from cold to hot, owing to the large quantity of heat which seas absorb or 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 is cooled to 40° F., thus prolonging the season sufficiently to ripen grapes. A daily effect is witnessed on the 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 heated and rises, and cold air rushes in from the ocean, producing a *sea breeze;* in the night, the land is sooner cooled, the air above becomes more dense, and flows out toward the ocean in a *land breeze.*

## FUSION AND VAPORIZATION.

**561. *The second effect*** of heat on a solid is to change its *molecular condition—to* melt it. Some solids, as paper, wood, and wool, do not melt, but are decomposed. The temperature at which solids melt differs for different substances, but is invariable for the same substance, if the pressure is constant. 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 and become plastic before they fuse. It is in this plastic state that glass is worked, and iron or platinum forged. Bodies difficult of fusion are termed *refractory:* such are silica, lime, and carbon.

**562. The melting point of an alloy** is often lower than that of either of its components. Thus, Rose's metal, consisting of four parts of bismuth, one of lead, and one of tin, fuses at 201° F. A mixture of equivalent parts of carbonate of potassa and carbonate of soda, melts at a lower temperature than either salt separately. Such a mixture added to an ore to promote the formation of a fusible medium, is termed a *flux.*

**563. Freezing point.** If a substance in a liquid form is cooled sufficiently, it generally solidifies at the melting point. The freezing point may be lowered by various means.

Thus, the freezing point of water has been lowered by pressure to 0° F. If water, deprived of air, is allowed to cool very slowly, *without* agitation, it may be cooled to 10° F. before it freezes. When *in this* condition, a gentle jolt, or the addition of a bit of ice, will *cause immediate* congelation, and the temperature will suddenly rise to 32° F. In fine capillary tubes, water has been lowered to — 4° F. without solidification. This fact probably explains why sap is not frozen in plants. The freezing point of water is lowered by the presence of salts in solution. Sea water freezes at 27°.4 F. Saturated brine freezes at — 4° F.

In such cases nearly pure ice is formed by freezing. The water appears to crystallize out, leaving the salt behind. Weak alcoholic liquors, like wine and cider, may be concentrated by exposing them to cold and removing the layers of ice as they form.

**564. Change of volume.** At the moment of freezing, water expands with great force. This fact is familiar to northern housekeepers in the breaking of utensils in which water is allowed to freeze. Service pipes often burst unless a little stream is permitted to trickle through them. Bomb shells an inch thick, filled with water, have been burst by the freezing of the water. Cast iron, bismuth, antimony, tin, zinc, and some of their alloys, also expand on solidifying. These substances give sharp casts, because, when the metal sets, the expansion forces it into the minute cavities of the mold. Most substances, except those enumerated, contract on solidifying; hence, coins of copper, silver, and gold require to be stamped.

**565. Latent heat.** *After a solid begins to melt, the temperature remains constant until the whole is melted.* This fact may be verified by watching a thermometer immersed in a tumbler filled with melting ice. A large amount of heat must enter a pound of ice at 32°, before it can be changed to water at 32°. A pound of water at 212° mixed with a pound of water at 32°, gives two pounds at the mean temperature of 122°; but a pound of water at 212° mixed with a pound of ice at 32°, gives two pounds of water having the temperature of only 51°.

In this case, the water has lost 161°, while the ice has gained only 19°, so that 142° have disappeared in changing the ice to water. The heat is not lost, for an equal amount will be given out if a pound of water is converted into ice, but because this is not sensible to the thermometer, the heat which a body absorbs or emits, in changing its molecular condition, is termed *latent heat.*

The latent heat of water is of the greatest value in nature. 1. It retards the melting of snow. To change a pound of snow at 32° into water at 32°, requires as much heat as to warm one hundred and forty-two pounds of water one degree. If it were not for this provision, the inhabitants of northern valleys would be exposed to terrific inundations at every approach of spring.

2. The melting of ice withdraws the heat from surrounding objects. A "thawing day" frequently feels very chilly. Near lake Erie 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 sufficient heat to moderate the effect of the depression of temperature on surrounding objects. Hence, it is a common remark that the weather moderates on a fall of snow.

**566. Every solid** in melting has its own latent heat, which is called the *heat of fusion*, or the *latent heat of liquids.* The amount may be determined by the method of mixtures. The second column in the following table shows the number of pounds of water that would be raised one degree by the solidifying of one pound of each substance named.

*Latent Heat of Liquids.*

| | In ° F. | Water = 1. |
|---|---|---|
| Water | 142.65 | 1.000 |
| Zinc | 50.63 | .355 |
| Tin | 25.65 | .179 |
| Sulphur | 16.85 | .118 |
| Lead | 9.65 | .067 |
| Mercury | 5.11 | .035 |

**567. Freezing mixtures.** In dissolving solids, as in melting, a certain quantity of heat becomes latent. Thus, if snow and common salt be mixed together, the salt causes the snow to melt, and the water dissolves the salt, so that both become liquid, and, by consequence, a large amount of heat is absorbed from the surrounding objects.

This is the mixture used for freezing ice creams. Two parts of snow and one part of salt will reduce the temperature to —4° F. Two parts of snow mixed with three parts of crystallized chloride of calcium will produce a cold sufficient to freeze mercury, and if these substances, and the containing vessel, be previously cooled, a cold of —50° may be produced. A very convenient freezing mixture consists of five parts of common hydrochloric acid and eight parts of crystallized sulphate of soda, previously reduced to powder.

**568. Vaporization.** If a solid be exposed to sufficient heat, when the expansive force of the heat exerted between its molecules equals their cohesive force, the body melts. As the temperature rises, the expansive force becomes greater than the cohesive, and the liquid passes into the aëriform state, as soon as the excess of expansive force exceeds the atmospheric pressure. This, the third effect of heat, is termed *vaporization.* If vaporization takes place slowly and quietly, it is termed *evaporation,* but if the liquid is agitated by the formation of bubbles of vapor, the process is termed *ebullition,* or *boiling.* Some solids, as iodine, arsenic, and camphor, vaporize without becoming liquids. This is termed *sublimation.*

**569. The laws of evaporation** may be studied by introducing a small quantity of ether, or other volatile liquid, through a barometer tube, into the Torricellian vacuum at the top. As soon as the liquid reaches the vacuum, it is instantly converted into vapor, and depresses the mercury by its elastic force; showing, 1. *All volatile liquids in a vacuum are instantly vaporized.* If successive small portions of the same liquid are used, the mercury continues to be depressed until a point is reached where the ether remains liquid. The space above is then said to be *saturated,* and the elastic force of the vapor has reached its maximum tension.

*If, now, the tube be* heated, more ether will vaporize, and the mercury will be further depressed; but if the tube be cooled, a portion of the vapor will be condensed into liquid, and the mercury will rise. Therefore, 2. *In every space void of air the maximum tension of vapor corresponds with the temperature.*

If the tube be plunged in a deep bath of mercury, as in Fig. 140, and the saturated vapor be exposed to increased tension, by depressing the tube, a portion of the vapor will become liquid, and on raising the tube a fresh portion will vaporize under diminished pressure. Therefore, 3. *The maximum tension of saturated vapors is independent of the pressure.* Non-saturated vapors obey Mariotte's law.

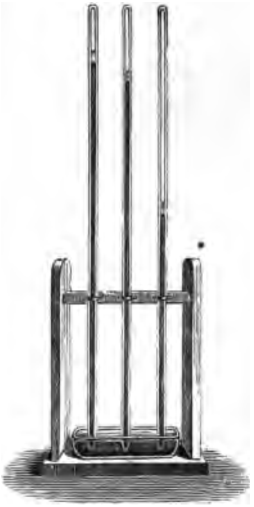
FIG. 266.

If the first experiment be performed with several different volatile liquids, Fig. 266, each having the temperature of 68° F., the mercury will be depressed, in inches, as follows: ether, 17; bisulphide of carbon, 12; alcohol, 1.7; water, 0.7. Hence, 4. *At the same temperature, the saturated vapors of different liquids possess different elastic force.*

If two liquids which do not dissolve each other, as water and bisulphide of carbon, are placed in the same tube, the tension of the mixed vapors will equal the sum of the two taken separately This explains the remarkable fact that the same amount of water will evaporate in a space filled with air, as in a vacuum of equal volume.

**570. 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 cir-

[redacted]

cumstances which influence the amount and rapidity of evaporation are as follows:

1. It varies with the temperature, because heat increases the elastic force of vapors.

2. It varies with the amount of the same liquid in the atmosphere. When the air is saturated, evaporation ceases; it is therefore greatest in air free from vapor.

3. It is assisted by the renewal of the air; because, if the air is not renewed it becomes saturated. Hence, evaporation is more rapid in a breeze than in still air.

4. It varies with the extent of surface exposed; because, evaporation proceeds only from the surface.

5. It varies inversely with the pressure on the surface of the liquid, because of the resistance offered to the escape of the vapor. It is very rapid in vacuo and less rapid in space containing air.

Evaporation may go on at very low temperatures. Mercury begins to evaporate at 60° F. Iodine, camphor, and some other solids vaporize at ordinary temperatures. Snow and ice disappear from the surface of the earth when there has been no thawing. Clothes are dried on a winter's day, when the thermometer shows a temperature below freezing. A warm sultry day is less favorable to evaporation than a cold day with a brisk wind.

**571. Air is said to be saturated** with moisture when it contains as much aqueous vapor as it can hold up at a given temperature. Air, at 32° F., can absorb $\frac{1}{286}$ part of its weight of aqueous vapor. For every increase of 20°, the capacity of air for moisture is nearly doubled; at fifty-two degrees, air can absorb $\frac{1}{118}$, and at seventy-two degrees, $\frac{1}{59}$ of its own weight. If air, saturated with moisture, is cooled, a portion will be deposited as dew. The temperature at which this deposit occurs is called the *dew point.* The more fully the air is saturated with moisture, the nearer will the dew point be to the temperature of the atmosphere.

The dew point may be determined with sufficient accuracy for ordinary purposes, by placing ice in a metallic vessel 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 higher the dew point, the more abundant will be the deposit. The "sweating" of pitchers is indicative 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.

**572. Ebullition.** *The temperature at which liquids boil is constant for the same substance, under like conditions.* Several circumstances influence the boiling point.

1. *The nature of the liquid.* The following table gives the boiling point of several liquids under the pressure of one atmosphere.

*Table of Boiling Points.*

| | | | |
|---|---|---|---|
| Protoxide of nitrogen | — 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 which contains it. Water sometimes boils in a glass vessel at 214°, and in a glass vessel coated with shellac as high as 221°. The ebullition then takes place in bursts, the temperature falling at each gust of vapor to 212°. By throwing iron filings into the water, the boiling point, in either of these cases, is reduced to 212°.

3. *Salts in solution* generally increase the boiling point. Thus, a saturated solution of common salt boils at 227° F.; of nitrate of potassa, at 240° F.; of chloride of calcium, at 355° F. Substances mechanically suspended, like bran, saw-dust, do not influence the boiling point. The vapor which arises from solutions is not permanently hotter than the steam from pure water.

4. *Variations of pressure* increase or diminish the boiling point, because *a liquid boils when the tension of its vapor is equal to the pressure it supports.* If a vessel containing ether be placed under the receiver of an air pump, and the receiver be exhausted, the ether will boil at the ordinary temperature. Water which has cooled considerably below the boiling point may be again made to boil by placing it in an exhausted receiver.

FIG. 267.

The *culinary paradox* illustrates the same principle. A flask containing boiling water is tightly corked while the steam is escaping rapidly, and then quickly inverted. If, now, a stream of cold water be poured on the bottom of the flask the boiling will be renewed, but will speedily be arrested if hot water be poured on. The reason of this is, the cold water condenses the steam above the water, by which a partial vacuum is produced.

A simple proof that the tension of steam is equal to the pressure of the atmosphere is obtained by repeating the last experiment with a tin canister instead of the flask. On corking the canister and pouring cold water upon it, the sudden condensation of the steam produces a vacuum, and the canister is crushed in by the pressure of the external air.

The sirup of sugar and many vegetable extracts are concentrated by boiling them in closed vessels, called vacuum pans. A powerful air pump constantly removes the vapor from the pan, and, consequently, the evaporation proceeds at a temperature so low that it secures the sirup or extract from injury by heat.

**573. A variation** of an inch in the barometric column makes a difference of about 2° F. in the boiling point of water; so that *within the* range of atmospheric pressure in *temperate climates, the* boiling point may vary 5° F.

### *Boiling Points of Water at different Pressures.*

| Boiling point, ° F. | Barometer, inches. | Boiling point, ° F. | Pressure in atmospheres. |
|---|---|---|---|
| 184 | 16.676 | 212 | 1 |
| 190 | 18.992 | 249.5 | 2 |
| 195 | 21.124 | 273.3 | 3 |
| 200 | 23.454 | 291.2 | 4 |
| 205 | 25.468 | 306. | 5 |
| 210 | 28.744 | 318.2 | 6 |
| 211 | 29.331 | 329.6 | 7 |
| 212 | 29.922 | 339.5 | 8 |
| 213 | 30.516 | 348.4 | 9 |
| 214 | 31.120 | 356.6 | 10 |
| 215 | 31.730 | 415.4 | 20 |

**574. The temperature** of the boiling point of water is much reduced on ascending mountains, in consequence of the diminished atmospheric pressure.

### *Boiling Point of Water at different Altitudes.*

| | Above the sea-level. | Mean height of barometer. | Temperature, ° F. |
|---|---|---|---|
| Donkia (Himalaya)............ | + 17337 | 15.442 | 179.9 |
| Mont Blanc......................... | 15650 | 16.896 | 185.8 |
| Quito ................................ | 9541 | 20.750 | 194.2 |
| Mount Washington............. | 6290 | 22.905 | 200.4 |
| Madrid .............................. | 1995 | 27.720 | 208. |
| London ............................. | 0 | 29.922 | 212. |
| Dead sea (below)................ | — 1316 | 31.496 | 214.4 |

The observation of the boiling point of water at any particular elevation, gives a ready means of determining its elevation above sea-level, a difference of about 596 feet of ascent, producing a variation of 1° F. in the boiling point.

**575. Marcet's globe** is used to estimate the tension of high pressure steam. It consists of a small boiler, furnished with three apertures, through one of which a thermometer stem is passed, air tight; through a second is inserted a glass manometer tube, whose lower end opens under mercury placed in the boiler; the third aperture is furnished with a stop-cock. The boiler is half filled with water. On applying heat it will be found that so long as the stop-cock is open, the temperature of the boiling will remain steadily at 212° F. Steam, therefore, at this temperature, has an elastic force equal to the pressure of one atmosphere.

On closing the cock, the steam, which continues to rise from the water, increases in elastic force, as is shown by the rise of mercury in the manometer. When the mercury in the manometer stands at thirty inches, the tension of the steam will be increased one atmosphere. At the same time the boiling point gradually rises, and at the pressure of two atmospheres equals 249°.5 F. The elastic force of the steam increases more rapidly than the rise of the boiling point, as is shown by the preceding table. For this reason, high pressure steam is more economical as a motive power than low pressure.

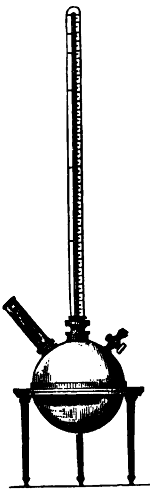

FIG. 268.

Steam, heated apart from water, follows the general law for the expansion of gases. Such steam is called dry, or *superheated steam*, and is applied to the carbonization of wood, and the rendering of lard and tallow.

**576. The spheroidal state** is caused by the slow evaporation of a liquid in apparent contact with a very hot plate. Drops of water scattered on a polished surface of high temperature do not flatten, but assume an ellipsoidal shape, and roll quietly about until they evaporate, without boiling. This experiment may be performed in a smooth metallic capsule, heated over a lamp. Into this any volatile liquid may be dropped from a pipette. Several phenomena are noticeable.

1. The temperature of the plate must be greater than the boiling point of the liquid. Thus, the plate requires to

be heated to 340° F. to produce the spheroidal state with water ;- with alcohol, 273°; with ether, 142°.

2. The temperature of the spheroid is lower than the boiling points of the liquids, being, for water, 206° F.; for alcohol, 168°; for sulphurous acid, 13°.

3. The spheroid does not touch the plate. By using a plane surface of silver, the light of a taper may be seen between the surface and the liquid.

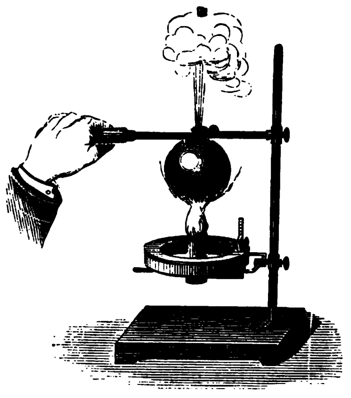

Fig. 269.

If the source of heat be removed, the temperature of the plate will fall until a point is reached when the liquid wets the surface, and then the liquid will boil violently. This may be shown by pouring a small quantity of water into a copper flask, intensely heated, and corking the flask while the liquid is in the spheroidal condition. For a time all is quiet, but when the flask has cooled sufficiently, the water will be suddenly converted into steam, and the cork ejected with violence. It is probable that boiler explosions are sometimes caused in a similar manner.

577. **The explanation** of these facts is that as soon as the drop reaches the hot surface a portion of it is converted into vapor, which both supports the spheroid and prevents the conduction of heat from the plate to the liquid.

The temperature of sulphurous acid, in the spheroidal state, is 13° F.; hence, it is capable of freezing water, although the capsule containing the acid may be white hot. By using a mixture of ether and solid carbonic acid, even mercury may be frozen. So, too, a moistened hand may be drawn without injury through molten iron as it runs from the furnace. The moisture of the hand is converted to a non-conducting envelope, which sufficiently protects the skin ring the short period of its immersion. The most common illustration of the spheroidal state, is that of a drop of water rolling about on a heated stove.

**578. The liquefaction of vapors** may be produced (1.) by cooling, (2.) by compression, and (3.) by chemical action.

1. A saturated vapor condenses at its boiling point. The process of distillation illustrates this principle. Distillation is used (1.) to separate liquids from solids, as when water is distilled to free it from its impurities; or (2.) to separate a volatile fluid from another less volatile, as when alcohol is distilled from fermented liquors. The mixed liquid is first heated in a retort or boiler, the vapors discharged are then condensed by passing them through a pipe kept cool by being surrounded with water. Fig. 270 represents the common still. The boiler, *a*, contains the liquid to be evaporated; the spiral tube, called the *worm*, which is immersed in a tank of cold water, receives the vapors to be condensed.

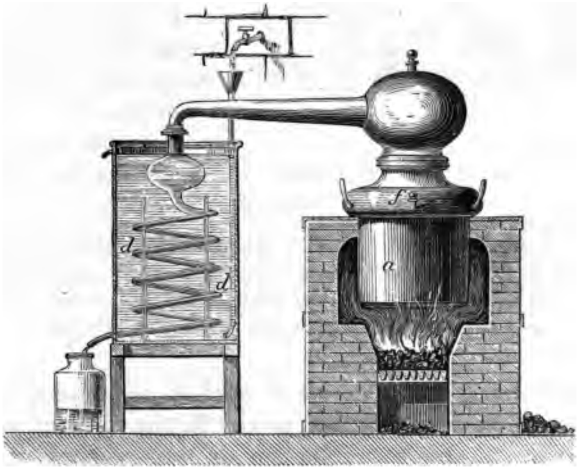

FIG. 270.

2. If a closed cylinder be filled with the vapor of ether, and this compressed by a piston, as soon as the pressure on the piston equals the maximum tension of the vapor, the vapor becomes saturated, and if the pressure be continued, the vapor will be condensed to the liquid state.

FIG. 271.

Faraday succeeded in liquefying gases by the tension of their own vapor. His method consists in inclosing in a bent glass tube the substances by whose chemical action the gas is produced, and then sealing the shorter leg. In proportion as the gas is liberated, the pressure increases and ultimately it liquefies and collects in the empty end. The condensation is further assisted by immersing the shorter leg in a freezing mixture. Fig. 271.

In this way cyanogen is readily liquefied by heating cyanide of mercury in the longer end. Larger quantities of gases are condensed by driving the vapors by means of force pumps into strong receivers. Under the joint influence of cold and pressure, nearly all the gases have been liquefied.

3. Sulphuric acid, chloride of calcium, and several other substances, have so strong an affinity for the vapor of water, that they will absorb it from the air even when it is not saturated. Such bodies, placed in a closed space, will quickly abstract all the moisture from it.

**579. Latent heat of vapors.** Since the temperature of a liquid is constant during ebullition, it follows that a considerable quantity of heat is rendered latent in producing the molecular change from liquid to vapor.

**With the same source of heat, it takes about 5⅓ times as long to change boiling water into vapor as to raise the same quantity 180 degrees, or from 32° to 212°; hence, the latent heat of steam is 180 × 5⅓, or about 960°. The latent heat of vapors is more accurately determined by distilling them, and noting the rise of temperature caused in the water surrounding the worm by a known weight of vapor. The application of both these methods for determining the latent heat of water may be readily made.**

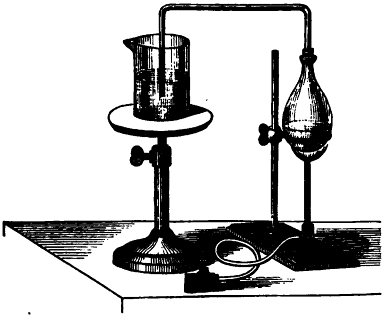

FIG. 272.

**Arrange a glass flask and beaker, as in Fig. 272. Pour one ounce of water, at 32° F., into the flask, and 5⅓ ounces at the same temperature into the beaker, and apply heat. Now note (1.) the time required to raise the water in the flask to boiling, and that required to change the boiling water to steam. The latter will be 5⅓ times longer than the former. (2.) When the water in the flask has been expelled, that in the beaker will be raised to the boiling point, showing that an ounce of steam is competent to raise 5⅓ ounces of water from 32° to 212°.**

*Latent Heat of Vapors.*

| | ° F. | | ° F. |
|---|---|---|---|
| Water | 966.6 | Ether | 162.8 |
| Alcohol | 374.9 | Bisulphide of Carbon | 156. |
| Acetic Acid | 183.4 | Bromine | 82. |

**580. Cold produced by evaporation.** Whatever be the heat at which a liquid evaporates, it grows sensibly colder in proportion to *the rapidity* of evaporation, unless it receives *as much heat from* external bodies as is rendered latent.

*N. P. 28.*

A shower of rain cools the air by absorbing the heat during evaporation. For the same reason, the air of a heated room cools when water is sprinkled on the floor. Any mechanical cause that increases the evaporation enhances the effect. A breeze or current of air produced by fanning causes a more rapid evaporation of the perspiration, and thereby produces a refreshing coolness.

In tropical climates water is cooled by the use of porous jars placed in a draft of air. A small quantity percolates through the pores, and, on evaporating, abstracts so much heat from the remaining liquid as to lower its temperature considerably below that of the surrounding air. Ether and other volatile liquids thrown in spray on portions of the body may so benumb them by cold as to render them insensible to pain during surgical operations.

581. **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 exhausting the receiver, the sulphuric acid absorbs the vapors as fast as they are formed, and thus a very rapid evaporation of the water ensues, which effects the freezing of the water.

A similar result is produced by means of the *cryophorus*. This consists of two glass bulbs, connected by a long tube. In making the instrument, one of the bulbs is partially filled with water, which is then made to boil briskly until the air is expelled by the steam, and the instrument is then hermetically sealed. On cooling, the space above the water is filled only with its vapor. If, now, the empty bulb, A, is plunged into a freezing mixture, this vapor is condensed as fast as it is formed, and evaporation occurs so rapidly from the water in the other bulb, that it soon begins to freeze. Fig. 273.

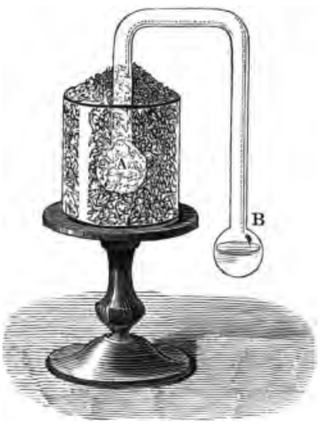

FIG. 273.

*582.* **If liquid carbonic acid** be exposed to the air, it *evaporates* with such rapidity that a portion almost instantly solidifies, and produces a cold of 106° below zero. Mercury is easily frozen by pouring upon it this solid carbonic acid moistened with ether. Natterer obtained a cold of —220° F. by evaporating a mixture of bisulphide of carbon and liquid protoxide of nitrogen in vacuo.

**583. When vapors are condensed** they give out their latent heat. Water may be boiled in wooden tanks by forcing steam into it. Buildings are frequently warmed by the heat of steam generated in a boiler placed in the basement. To this end it is conveyed to the several apartments by coils of iron pipe. The whole amount of heat in the steam is the sensible, plus the latent heat: thus, at the boiling point a pound of steam contains $212 + 966.6 = 1178.6$ *thermal units.*

**584. Equal volumes of different liquids** produce unequal volumes of vapor. The following table shows the volume of vapor furnished by one cubic inch of each of four liquids, at their respective boiling points.

| | Cubic inches. | Boiling point. |
|---|---|---|
| Water | 1696 | 212° F. |
| Alcohol | 528 | 173 |
| Ether | 298 | 95 |
| Oil of turpentine | 193 | 314 |

Water furnishes, bulk for bulk, a greater amount of vapor than any other liquid, one cubic inch expanding to nearly a cubic foot. The mechanical value of the expansive force of different vapors depends upon the bulk of vapor produced from an equal bulk of each liquid. The cost of fuel in generating vapor would be in proportion to the latent heat for equal volumes, but experiments show that, for equal volumes, the latent heat of these liquids is not far different. There would be, therefore, no economy in using other liquids in place of water in the steam engine, even if they cost no more than water.

**585. The *incandescence* of bodies** has already been considered *in $(442^a)$.*

### 586. 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.

The measurement of heat may regard

| | |
|---|---|
| 1. The relative intensity | Temperature. |
| 2. The relative quantity | Specific heat. |
| 3. The amount absorbed or evolved during molecular changes | Latent heat. |

### THE DISTRIBUTION OF HEAT.

**587. Any heated body returns,** sooner or later, to the temperature of surrounding bodies. This tendency of heat to maintain an equilibrium of temperature, is due to a continued exchange of molecular motions by virtue of which every molecule tends to produce in contiguous molecules its own rate of vibration. 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 motion among molecules.
3. By *radiation*, or by thermal undulations through space.

**588. The conducting power** of a body increases, as a general rule, with its density. Hence the metals are good conductors; porous solids, poor conductors; and liquids and gases, almost non-conductors.

*The conductibility of solids* may be shown by equal sized rods, along which a number of small marbles are fastened, at equal distances, with wax. Fig. 274. If one end of this rod be held in a hot flame, the heat will be propagated from molecule to molecule along the rod, and its gradual progress will be manifested by the successive dropping of the marbles, as the different sections of the rod attain the temperature of the fusing point of the wax.

[redacted]

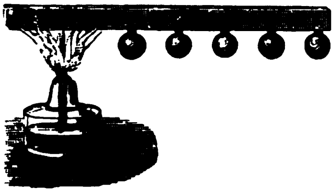

FIG. 274.

That different solids vary much in their power to conduct heat, may be shown by repeating this experiment with rods of copper, iron, brass, glass, etc.

By placing thermo-multipliers at equal distances on similar metallic rods, the following table has been obtained.

*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 |

**589. 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. 275. Now, if ether be poured on the water and ignited, the thermometer will be but slightly affected.

*Gases, when confined,* are almost non-conductors of heat. Fibrous bodies, like wool and furs, owe their non-conducting properties largely to the air which is confined between their meshes.

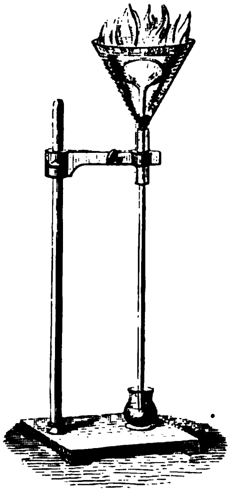

FIG. 275.

**590. The conducting power of a body** may be roughly estimated by the touch. Thus, suppose different substances to be compared at a common temperature (1.) much hotter, and afterward (2.) much colder than the hand. An iron rod, if heated above 120° F., will burn the hand, because it conveys its heat rapidly to the skin, and if cooled below 0° F., will blister the lips, because it conveys their heat away so rapidly.

On the contrary, a bad conductor may be handled with impunity, within even greater limits of temperature. For the same reasons an oil cloth will feel warmer or colder than a carpet in the same room, according as their common temperature is greater or less than that of the skin. So, also, the oven girls of Germany, clad in woolen garments, enter ovens heated to 300° F. without inconvenience, although the touch of any metal while there would surely burn them.

Common observation furnishes abundant illustrations of these facts. Water is sooner heated in a tin cup than in one of porcelain, because the metal is a better conductor of heat. Silver conducts away heat so rapidly, that if a silver spoon be smoothly wrapped with muslin, water may be boiled in it without injuring the muslin. Porous bodies, like ashes and plaster of Paris, are such poor conductors that, if the hand be protected with a thin layer of either, it may carry live coals without danger. So, also, woolen cloths, wrapped about heated irons, protect the hands of the laundress.

**591. The practical applications** of these principles are very numerous. Thus, non-conductors are used (1.) to prevent the escape of heat, or (2.) to exclude heat.

1. Close wooden boxes, Fig. 276, lined with felt, are used in Norway to economize fuel in cooking. For instance, a kettle containing water and vegetables is first heated on the stove to the boiling point, then placed within the felt box and tightly covered. By this means sufficient heat is retained to cook the vegetables. Double doors and windows, which inclose a layer of air, prevent the escape of heat from our apartments. For the same reasons furnaces are lined with fire brick. So, also, straw is wrapped about tender plants to prevent the escape of their heat. In a similar manner a layer of snow preserves the warmth of the earth during the chilling blasts of winter.

2. Fire-proof safes are made with double walls inclosing non-con-

ducting substances, as plaster of Paris or alum. 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.

FIG. 276.

Water coolers are constructed in the same manner. The table mats placed under hot dishes protect the table. Furnace men and firemen wear thick woolen garments to exclude the external heat, because this is greater than that of their bodies.

592. **The main object of clothing** is to prevent the escape of heat from our bodies. The conducting power of the materials used for clothing 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. A bed quilt containing a layer of paper is warm, because the paper prevents the heat from escaping.

The furs of animals in cold countries are finer and closer than those *in warm countries.* The feathers and down of northern birds form *an almost perfect* non-conductor.

**593. Convection.** If heat be applied to the bottom of a flask of water, containing a few fragments of cochineal or sawdust, the particles of the liquid will be seen to rise as they become heated and expanded, while other colder particles descend from the side to supply their place. These currents will then continue until the whole is heated. This process of circulation among molecules is termed *convection.* It may be applied to the heating of liquids and gases, but not of solids.

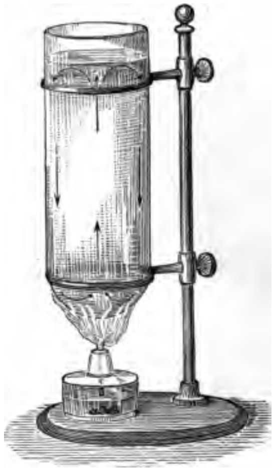

FIG. 277.

In heating by convection, the fire must be applied beneath. Thus, on filling a test tube with water, and, holding it by the lower part so that the top is inclined across a hot flame, the layers of water at the top may be made to boil without communicating any heat to the hand, owing to the low conductibility of the water.

In the process of cooling fluids, the currents are established in a contrary direction. The upper particles become specifically heavier and descend, thereby forcing the lighter particles upward to fill their place. Any thing that hinders this free circulation retards both the heating and cooling of the fluid. Thus, viscous liquids, like molasses or tar, heat and cool very slowly.

**594. The convection of gases** is more energetic than that of liquids, because their expansion by heat is greater. If "touch paper," containing chlorate of potassa, 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.

The column of air in a chimney becomes heated by the fire, and is thereby rendered specifically lighter than any external column of air and rises. Hence, the external air will enter the grate with a *draft,* proportioned both to the height of the chimney and the *intensity* of the fire.

**595. In all cases of convection** there must be two currents in opposite directions.

Thus, 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 will drive the flame outward from the heated room, at the top of the door, while a current of cold air will drive the flame inward at the bottom of the door.

**596. Winds.** These two currents are always attendant on winds, although only the lower one admits of being accurately traced. The atmosphere is heated mainly by convection. The surface of the earth is warmed by the sun, which produces little direct action on the air. The layers of air in contact with the soil become heated and rise, while colder layers descend to supply their place; thus producing upward and downward currents. Moreover, since the earth is not heated equally in all places, a surface current of air will rush from colder toward warmer localities, while an upper current will proceed at the same time in a contrary direction, as in the case of the two rooms above mentioned.

For this reason a surface wind might always be expected to flow from each pole toward the equator, and an upper current to flow from the equator toward the poles. The direction of these winds is modified by the daily rotation of the earth on its axis from west to east. In consequence of this rotation, fixed objects on the surface have a velocity of nine hundred and eighty miles per hour at the equator and a successively diminishing rate at higher latitudes, until at the poles the motion entirely ceases.

The lower current, coming from the poles, partakes of the motion of the surface, and is, therefore, moving more slowly than those regions toward which it proceeds. Consequently the wind appears to come from a direction opposite to that in which the earth is moving, or from the east, with a velocity equal to the difference in the two rates of motion.

Hence, it results that two constant surface currents are produced within the tropics on each side of the equator. Their direction will be the resultant of the effects due to the heat and the diurnal rotation. Therefore, north of the equator there will be a steady north-east wind, and south of the equator a south-east wind. These winds are called *trade winds* from their importance to navigation.

The upper trade winds proceed in the opposite directions, and are sometimes made manifest by clouds and volcanoes. As these winds go northward they become cooler, and gradually descend to the earth. The variable winds in our latitude are frequently caused by the meeting and crossing of the upper and lower currents.

**597. Radiation.** It is evident that the heat of the sun does not reach the earth by conduction or by convection, since heat is propagated by either of these methods with exceeding slowness. A heated body must, therefore, emit thermal rays which have the power of exciting vibrations in aether and other media, in the same manner as light. This emission of heat is termed *radiation.* The laws of radiant heat are identical with those of light, and the phenomena are in all respects similar.

**598. The laws of radiant heat.** If a heated body be suspended in space, a thermometer placed in any position around it, will indicate a rise in temperature; but if a screen be interposed, the thermometer will not be affected: hence,

1. *Heat radiates in straight lines in all directions.*

Since heat is a radiant force,

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.*

**599. Theory of exchanges.** Since no body is known to exist at the temperature of absolute zero, all bodies must emit thermal waves of some degree of intensity; while, at the same time, they receive other waves from surrounding bodies. These waves, like those of light, may and do cross each other without disturbance. If the sum of the motion received is less than that emitted, the body becomes cooler, but if greater, the body becomes warmer. If it receives back just as much heat as it radiates, it remains at a uniform temperature.

If a thermometer be placed before a block of ice, its temperature will fall, because the ice and the thermometer are both sources of heat, and the thermometer receives less heat than it radiates. The ice does not radiate cold, for the opposite result would have been attained if the bulb of the thermometer had contained frozen mercury.

**600. Bodies differ greatly** in their radiating power; but this is dependent more on the nature of their surfaces than of their substances.

Thus, if a canister of tin have one of its sides coated with lampblack, another with paper, a third scratched or tarnished, and the fourth polished, and then be filled with boiling water, a delicate thermometer placed at each side in succession will indicate different temperatures.

Lampblack has the highest emissive power known, the surfaces of paper, and similar loose materials are next in order; the polished metals are the poorest radiators, but gain in radiating power in proportion as their surfaces are tarnished. Hence, a bright silver teapot filled with hot water will retain its temperature longer than one of earthenware.

Pipes for the conveyance of steam, should be kept bright until they reach the rooms where the heat is to be distributed, and there their surfaces should be blackened to increase their radiating power.

**601. Radiant heat, incident** on any surface, may be (1.) reflected, (2.) refracted, (3.) absorbed, or (4.) transmitted.

**602. Reflection.** Substances which reflect light well, are also good reflectors of heat. The proportion of incident heat reflected at an angle of forty-five degrees, from certain polished surfaces, is shown by the following:

*Table of Reflecting Powers.*

| | | | |
|---|---|---|---|
| Silver | .97 | Steel | .82 |
| Gold | .95 | Zinc | .81 |
| Brass | .93 | Iron | .77 |
| *Platinum* | .83 | Cast iron | .74 |

Archimedes is said to have burned the Roman vessels before Syracuse by concentrating upon them the solar rays, by means of concave mirrors. To show that this feat is possible, Buffon constructed a concave mirror that ignited a plank of tarred wood at a distance of two hundred and ten feet.

**603. Refraction.** 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. 222, showing,

1. That the thermal rays extend through and beyond the visible spectrum, and are, therefore, of different refrangibility and wave length.

2. That the maximum heating effect lies beyond the red, or in rays of low refrangibility, and, consequently, of great wave length, but invisible to the eye.

The thermal rays which accompany light are called *luminous thermal rays*, and the dark rays are the *obscure thermal rays*.

If a platinum wire is heated, it first emits only obscure rays; as it becomes incandescent, it not only emits luminous rays, but also adds to the intensity of the obscure vibrations. Hence, the hotter a body the more numerous are the rays, and the more intense are each set of vibrations. The obscure and the luminous thermal rays are governed by the same laws, but differ from each other exactly as one color differs from another.

**604. Absorption and transmission.** 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. A substance that transmits heat is called *diathermanous*, and one that is opaque to heat is called *athermanous*. Incident rays not transmitted are either *reflected* or absorbed. Only the rays absorbed have any effect in warming the body.

**605. The diathermancy** of a body varies both with the nature of the substance and the quality of the heat. The following table shows the proportion of one hundred incident rays, coming from different sources, that will be transmitted by different substances, cut in plates 0.1 of an inch in thickness:

| | Naked flame. | Incandescent platinum. | Copper at 752° F. | Copper at 212° F. |
|---|---|---|---|---|
| Rock salt | 92.3 | 92.3 | 92.3 | 92.3 |
| Sulphur | 74 | 77 | 60 | 54 |
| Iceland spar | 39 | 28 | 6 | 0 |
| Glass | 39 | 24 | 6 | 0 |
| Clear quartz | 38 | 28 | 6 | 3 |
| Smoky quartz | 37 | 28 | 6 | 3 |
| Alum | 9 | 2 | 0 | 0 |
| Rock candy | 8 | 1 | 0 | 0 |
| Ice | 6 | 0.5 | 0 | 0 |

**606. This table shows** that diathermancy and transparency are analogous, but not identical properties. The different sources of heat correspond to different colored flames, and the plates or screens to different colored glasses.

Plate glass is nearly transparent for all rays of light, as rock salt is diathermanous for all rays of heat. In either substance the vibrations not transmitted are mostly reflected. Red glass transmits only red rays, alum transmits only luminous thermal rays; but these substances absorb most of the other rays.

Luminous or thermal rays which have traversed one plate will traverse another plate of the same material with but little loss of intensity. Each substance acts as a sieve, and transmits only those rays which are able to penetrate the material of the screen. Thus light which has passed through one plate of red glass will be largely transmitted by a second red glass: so, also, if the nine thermal rays transmitted by a plate of alum be incident on a second plate of alum, ninety per cent., or eight of the rays will be again transmitted.

In general any medium is diathermanous for certain rays, and absorbs the greater portion of the remainder. Glass is diathermanous for rays *of high refrangibility*, but almost, if not quite, athermanous *for obscure rays.*

If iodine be dissolved in bisulphide of carbon, it will form a very dark and opaque solution. If light from any source be transmitted through layers of this iodine solution, about one-tenth of an inch in thickness, the luminous rays will be entirely absorbed, but the obscure rays will pass freely. These invisible rays may be concentrated by lenses of rock salt, and made to melt and even ignite solid bodies. The same effect may be produced by concentrating the luminous solar rays with lenses of glass, or even of ice.

607. **The following table of diathermancy** of fluids was obtained by transmitting the heat of an Argand lamp through layers of fluids thirty-six hundredths of an inch in thickness, contained in glass cells. It must be borne in mind that the glass employed permitted only the luminous rays to enter the liquid. The table shows the per centage of the incident rays transmitted.

| | | | |
|---|---|---|---|
| Bisulphide of carbon | 63 | Alcohol | 15 |
| Turpentine | 31 | Solutions of salt and sugar | 12 |
| Olive oil | 30 | Pure water | 11 |

608. **The simple gases,** hydrogen, nitrogen, oxygen, and dry air, are almost perfectly diathermanous, but some of the compound gases have great absorptive power, especially for dark heat. This is strikingly shown by the following table of the absorption of heat by various gases, each at the tension of one inch, barometric pressure, in comparison with dry air.

| | | | |
|---|---|---|---|
| Air | 1 | Carbonic oxide | 750 |
| Oxygen | 1 | Sulphide of hydrogen | 2100 |
| Nitrogen | 1 | Ammonia | 7260 |
| Hydrogen | 1 | Olefiant gas | 7950 |
| Chlorine | 60 | Sulphurous acid | 8800 |

From this it will be seen that minute quantities of these gases must have great effect on the diathermancy of the atmosphere. If our atmosphere were coal gas, only twenty per cent. of the thermal rays from the sun could reach the earth. With regard to vapors, it may be said that their absorptive power is in the same order as the liquids from which they are derived. Hence, by reference to the previous table, it will be seen that aqueous vapor is a powerful absorbent.

**609. The absorptive effect** of the aqueous vapor in the atmosphere is calculated to be more than one hundred times that of dry air. The absorptive power of aqueous vapor for obscure rays, is many times greater than for luminous rays. The solar rays pass with comparative freedom to the earth, and are expended in warming the earth. 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 nights are very cold and the winters almost unendurable, because of the dryness of the air.

**610. If heat falls** on a body not diathermanous, the rays that are not reflected are absorbed. Hence, the absorbing power of athermanous bodies is inversely as their reflecting power. That is, good absorbents are bad reflectors. As bodies must give out in cooling the heat 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:

| | Radiation. | Absorption. | Reflection. |
|---|---|---|---|
| Lampblack | 100 | 100 | 0 |
| Indian ink | 85 | 96 | 4 |
| White lead | 100 | 53 | 47 |
| Isinglass | 91 | 52 | 48 |
| Gum lac | 72 | 43 | 57 |
| Polished metal | 12 | 14 | 86 |

**611. The formation of dew** may be explained in accordance with these principles. As soon as the sun sinks below the horizon, the heat radiated from the surface is no longer compensated by the solar rays, and, consequently, the temperature of the surface is speedily reduced below that of the stratum of air in contact with it. If this stratum is charged with moisture, the dew will be deposited on any good radiator, as grass or leaves, but will not ordinarily collect on metallic surfaces.

Clouds or *overhanging* branches of trees *prevent the deposition of dew,* because they return the heat to objects beneath them. So, also, a fresh breeze, which brings new layers of air in contact with the surface, prevents the reduction of the temperature and the formation of dew. The dew will, therefore, be most abundant on still, cloudless nights. If the temperature sinks below 32° F., the dew is deposited in needles of ice, which constitute *white*, or *hoar frost.*

**612. All the phenomena** of radiant heat show a remarkable analogy to those of light. If, now, we add that heat may be polarized and made to exhibit the phenomena of diffraction and interference, we can hardly resist the conclusion that heat and light are identical.

**613. Applications.** The hot beds of the 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 may thus attain a temperature above that of the exterior atmosphere. The effect is enhanced by coating the wooden sides of the bed with lampblack.

Meat roasters are constructed of polished tin, to reflect all the rays of the fire upon the article cooking.

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 the 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. Hence, as the object of clothing is to preserve the body from sudden changes in temperature, white garments are preferable to black.

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.

### 614. Recapitulation.

| | |
|---|---|
| Heat may be transferred by........................... | Conduction.<br>Convection.<br>Radiation. |
| Radiant heat, incident on a body, may be......... | Reflected.<br>Refracted.<br>Absorbed.<br>Transmitted. |

## THE SOURCES OF HEAT.

**615.** The sources of heat may be comprised in three classes: (1.) physical, (2.) chemical, (3.) mechanical.

**Physical sources.** The sun is the ultimate source of most of the available heat of the globe. To measure the intensity of the radiant heat of the sun an instrument, called the *pyrheliometer*, has been devised. It consists of a thermometer, *d*, whose bulb is inclosed in a shallow cylindrical box of silver, A, which is filled with water. The upper surface of the box is coated with lampblack. At the other extremity of the instrument is a disk of the same diameter as the box. The face of the box will be perpendicular to the sun's rays when the shadow of the box exactly coincides with the disk.

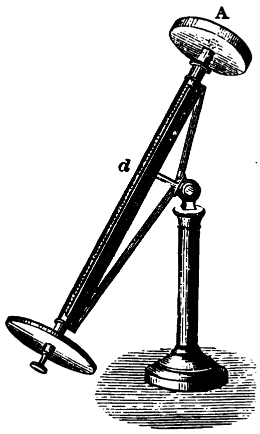

FIG. 278.

The measurement requires three steps:

1. The instrument, sheltered from the sun, is turned toward the clear sky for five minutes. It will lose, by its own radiation, an amount of heat which we may denote by $r$.

2. The blackened face is turned to the sun for five minutes, and will absorb a certain *quantity* of heat. Denote the gain in heat by $A$.

3. While heated, it is again turned to the clear sky for five minutes, and will lose heat equal to $r'$.

Now, since $r$ denotes the loss by radiation into a clear sky before heating, and $r'$ the loss after heating, the radiation during the heating will be the mean between the two, or $\frac{r+r'}{2}$. As this radiation is going on even while the blackened face is absorbing the sun's rays, the whole heating effect of the sun, during the five minutes exposure will equal $A + \frac{r+r'}{2}$.

Now, as the area of the face is known, we may express the effect of the sun's heat on any given surface by stating that it is competent to raise so much water so many degrees in temperature, or to melt a film of ice of proportionate thickness.

**616. By these measurements** it has been found that the *vertical rays* of the sun are competent to melt a film of ice .00728 of an inch thick, every minute. The intensity of the rays decreases with their obliquity, and the atmosphere absorbs 0.4 of the entire radiation of the sun received by the earth. Taking these considerations into account, it is 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.

To compute the total radiation of the sun, imagine a hollow sphere to surround it at the distance of the earth from the sun. Two thousand one hundred and twenty-nine millions of globes, as large as the earth, placed one against the other, would be required to cover this imaginary sphere; hence, the total heat emitted by the sun is two thousand one hundred and twenty-nine million times that which reaches our earth.

**617. It has been estimated** that the fixed stars annually radiate sufficient heat to the earth to melt an envelope of ice eighty feet in thickness. It is evident that were the supply of either solar or stellar heat cut off, the life of the globe would soon be destroyed.

***618.* The phenomena of volcanoes** and hot springs attest the existence of intensely heated fluid matter within the earth itself. The heat received from celestial bodies does not penetrate the earth's surface more than one hundred feet. If thermometers are carried to greater depths in mines and in artesian wells, the temperature is found to rise quite regularly at the average rate of 1° F. for every fifty-four feet of descent.

At this rate, depths would soon be reached at which all known rocks would melt, so that it is not probable that the thickness of the solid crust of the earth much exceeds one hundred miles. Nevertheless, from the imperfect conductibility of this crust, it does not appear that the central heat of the globe affects the annual temperature of the surface more than one-twentieth of a degree.

Besides these physical sources of heat, may be mentioned electricity and the heat attending molecular changes, as absorption, capillary action, and the phenomena of liquefaction and solidification.

**619. Chemical sources.** When any two bodies unite in chemical combination there is usually an evolution of heat. The amount of heat evolved is always the same; but if the combination takes place slowly, the heat can not be measured for any single moment.

Combustion is the rapid combination of two or more substances, attended by the evolution of heat and usually of light. Thus, if water be poured upon quicklime, the two will combine, and may evolve heat sufficient to boil the water. If a grain of iodine be placed upon a slip of phosphorus they will kindle into a flame, which will afterward be continued by the oxygen of the air.

*Ordinary combustion* is due to the union of the oxygen of the air with the carbon and hydrogen contained in the coals, oils, fats, and gases of our fires and flames. The rusting of iron, the decay of wood, the process of fermentation, are examples of slow combustion with oxygen.

*Animal heat* is due to slow combustion. In respiration (1.) oxygen passes through the cell-walls of the lungs by osmosis, and is absorbed by the blood, which it thereby renders *arterial.* (2.) This arterial blood is then distributed to the

[redacted]

capillaries of the different organs, where a greater or less consumption of carbon takes place, with the evolution of carbonic acid. (3.) The blood charged with this carbonic acid is rendered venous and returned to the lungs, where the carbonic acid is exhaled by osmosis, and a fresh supply of oxygen absorbed.

The supply of carbon is furnished by the tissues, which are themselves 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.

The following table shows the total heat of combustion with oxygen of one pound of each of the substances named, expressed in thermal units of one pound of water raised one degree F.:

| | Symbol. | Pounds of oxygen consumed. | Thermal units. | Compound formed. |
|---|---|---|---|---|
| Hydrogen | H | 8 | 62032 | HO |
| Carbon | C | $1\frac{1}{3}$ | 4344 | CO |
| Carbon | C | $2\frac{2}{3}$ | 14544 | $CO^2$ |
| Carbonic oxide | CO | $\frac{4}{7}$ | 4376 | $CO^2$ |
| Sulphur | S | 1 | 4032 | $SO^2$ |
| Phosphorus | P | $1\frac{1}{4}$ | 10344 | $PO^5$ |
| Iron | Fe | $\frac{8}{21}$ | 2836 | $Fe^3O^4$ |
| Alcohol | $C^4H^6O^2$ | $3\frac{1}{5}$ | 12929 | |
| Olefiant gas | $C^4H^4$ | $3\frac{1}{5}$ | 21344 | |
| Marsh gas | $C^2H^4$ | 4 | 23513 | |

**620. It is to be noted** that the total heat is the same, whether the oxydation be reached at once or by successive steps.

For example, one pound of carbon, in burning imperfectly, forms $2\frac{1}{3}$ pounds of carbonic oxide, and evolves 4344 units of heat. If these $2\frac{1}{3}$ pounds of carbonic oxide be burned they will evolve 10210 units of heat in forming carbonic acid, making $4344 + 10210 = 14554$ units of heat, or the same amount that would be obtained by the complete combustion of one pound of carbon.

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percussion. (2.) The production of heat by the compression of gases may be shown by the pneumatic syringe, Fig. 279.

This instrument consists of a thick glass 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 downward in the tube.

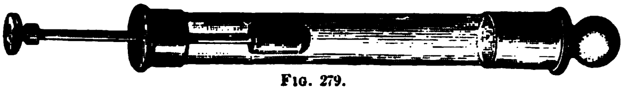

FIG. 279.

The air in the tube is thus compressed, and liberates so much heat as to set fire to the tinder, which is seen to burn when the piston is withdrawn. The disengagement of heat is found to be proportional to the reduction in volume, and the consequent increase in density.

(3.) The friction of two bodies always produces heat, which is the greater the more rapid the motion and the greater the pressure. It is the heat thus produced that ignites the phosphorus on the end of a match, and that causes the axles of car wheels to ignite the wood work in their immediate vicinity. Savages procure fire by revolving the end of one piece of dry wood in the cavity of another.

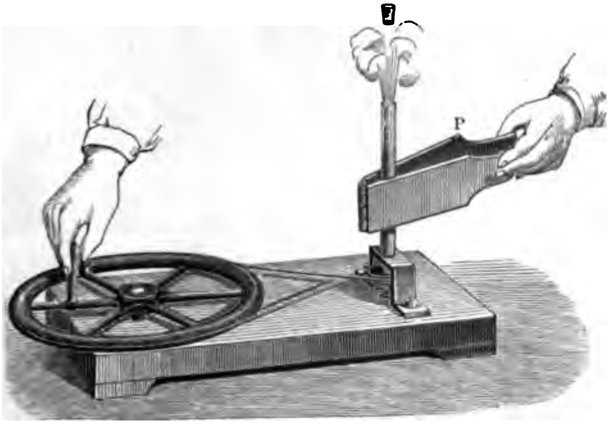

FIG. 280.

An experimental demonstration of the same fact may be strikingly shown by attaching to a *whirling*-table a brass tube filled with water and *corked. Fig. 280. 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 wood against the tube, will be sufficient to boil the water in a very few minutes.

### THE DYNAMICAL THEORY OF HEAT.

**622. The dynamical theory** of heat, which assumes that heat is a mode of molecular motion, affords a satisfactory explanation of these various phenomena. In all cases of friction, compression, and percussion, a certain amount of mechanical force is arrested, the energy of its visible motion is spent in producing molecular motion, and is thus transformed into heat. *The quantity of heat evolved is in proportion to the mechanical force expended.*

Thus, when air is compressed, the rise in temperature is due to the mechanical effect or work which must be spent in driving the particles of the air nearer together.

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 produce mechanical work, (1.) by moving a piston, or (2.) in displacing the air in front of the cylinder. If, now this air is allowed to expand into the atmosphere. the air will be chilled, because mechanical work has been performed by the expenditure of the heat to which the elastic force of the air was due.

**623. The relation which exists** between heat and work, is known as the *mechanical equivalent of heat*, or, simply, as *Joule's equivalent.*

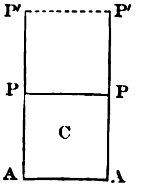

FIG. 281.

To determine it for gases, suppose a tall cylindrical vessel, C, whose section is equal to a square foot, and let P P be a piston without weight moving in the cylinder. If the piston be placed so that the height, A P is one foot, it will inclose a cubic foot of air. Now, if this air be heated 490° F., its volume will be doubled, and will raise the piston one foot, or to P′ P′. In rising it has overcome

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the pressure of the atmosphere above the piston, or has lifted $15 \times 144 = 2160$ pounds one foot, and has performed work equal to 2160 foot-pounds.

With the same amount of heat, only about one-fourth as much water would have been raised 490°, because the specific heat of air is 0.24 that of water. The weight of a cubic foot of air is .08 pounds, hence the heat imparted to perform the work of the air, would have heated only $0.08 \times 0.24 = .0192$ pounds of water 490°. This is equivalent to 9.4 pounds of water heated 1° F. Hence, 9.4 thermal units have been required to raise 2160 pounds one foot high, by the expansion of the air.

If the piston had been fixed so as to retain the air at a *constant volume* while being heated, the quantity of heat required to raise its temperature 490° would have been less than when expanding under a *constant pressure*, in the ratio of 1.421 : 1. Hence, the thermal units required to raise the temperature of the cubic foot of air when kept at a constant volume is found to be $9.4 \div 1.421 = 6.6$ units. Deducting 6.6 units from 9.4 units, we find that the excess of heat imparted to the air when permitted to expand, is competent to raise 2.8 pounds of water 1° F. This excess has been employed in performing the work of lifting 2160 pounds one foot high. Dividing 2160 by 2.8, we find that the quantity of heat required to raise one pound of water 1° F. is competent to lift 772 pounds a foot high. *This is, therefore, the mechanical equivalent of one thermal unit.*

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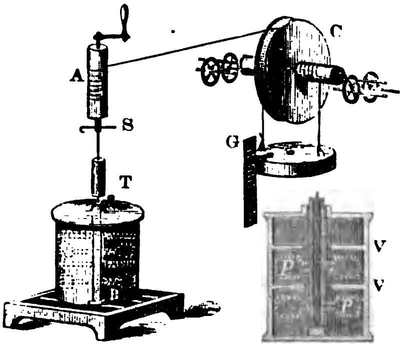

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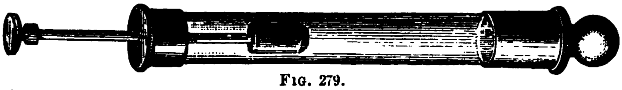

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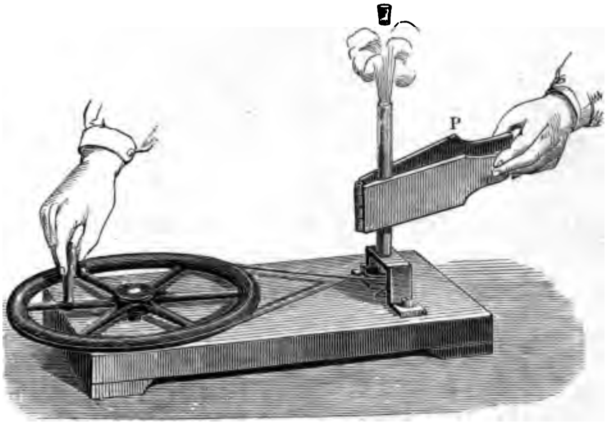

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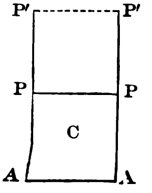

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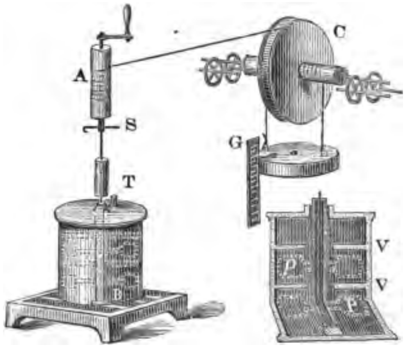

FIG. 282.

**624. Joule determined** the mechanical equivalent of heat by the friction of fluids. A metallic box, Fig. 282, was provided with eight sets of paddles, which were *made to revolve be-*

tween four stationary vanes, V. Weights were attached to cords passing over the pulley, C, and wrapped around the roller, A. The descent of these weights caused the wheel to rotate. The box was filled with water and the weights allowed to sink. The mechanical work expended in producing the rotation was measured by the descent of a known weight through a known distance, and the heat was determined by a thermometer at T.

After allowing for all sources of error, and repeating the experiment with other liquids, and with iron disks sunk in mercury, Joule found that the quantity of heat produced by the friction of bodies is always proportioned to the work expended.

The average of many experiments gave 772 foot-pounds as the mechanical equivalent of the heat required to raise one pound of water 1° F. Hence, heat and mechanical force may be exchanged, one for the other, in the ratio of 772 foot-pounds for one thermal unit.

**625. In calculating the relation** between mechanical motion and heat, all the possible factors must be found and allowed for, in order to obtain the exact equivalence. When a body falls freely through the air, a portion of its force will be expended by friction of the air, and the heat produced will be dissipated by radiation.

If a body, falling through a vacuum, is suddenly arrested by collision with another, the heat generated will be in proportion to the height of the fall. A portion of this heat may be again instantly converted into the mechanical motion of the rebound, and the remainder will be divided between the two bodies. Now, since the height through which a body falls is proportioned to the square of the velocity attained ($V = 8.02\sqrt{H}$), the heat generated by the percussion of bodies moving in any direction will be as the *squares of their velocities* at the time of impact.

*A mass* of water, falling one second, attains a velocity of thirty-two *feet*, *and* on striking the ground would generate sufficient heat to raise its temperature $\frac{16}{772}$ of a degree, Fahrenheit, if the heat could all be concentrated in itself.

The temperature attained by other bodies would vary with their specific heats: thus, a leaden bullet, under the same circumstances, would be raised $\frac{16\times32}{772}=\frac{512}{772}$° F., or nearly 0°.64 F. With forty times this velocity, it would generate sixteen hundred times as much heat; hence, if a rifle bullet strikes a target with a velocity of twelve hundred and eighty feet per second, it will generate an amount of heat sufficient, if concentrated in the bullet, to raise its temperature 1024° F. This heat would be more than enough to fuse the bullet.

**626. If we know the weight and velocity** of any moving body, we can calculate the heat which would be generated by suddenly stopping it. Thus, 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 heat by the collision equal to that evolved by the combustion of five thousand six hundred equal worlds of solid carbon.

From these considerations, it is thought that the maintenance of the solar heat is due to the falling of meteoric masses into the body of the sun. The maximum velocity which it is possible that such a body can attain is three hundred and ninety miles per second. With this velocity an asteroid striking the sun would develop more than nine thousand times the heat generated by an equal asteroid of solid coal. If the earth should strike the sun, the heat developed by the shock would be sufficient to supply the solar radiation for a century.

**627. The dynamical theory** also explains the evolution and consumption of heat which accompany changes in the volume or state of bodies.

Thus, when heat enters a body, its actual energy is absorbed (1.) in increasing the intensity of molecular motion, which is shown by a rise in the temperature; (2.) in separating the molecules, as shown by expansion, and (3.) in re-arranging its molecules, or causing a change of condition. The *work performed is* partly internal and partly external.

The exterior work is employed in overcoming external forces which resist the expansion, and the interior work is employed in separating and re-arranging the molecules within the mass of the body, by overcoming cohesion or affinity.

**628. In whatever way we view it,** the interior work performed by heat is enormous. Thus, in expansion, a slight rise in temperature will produce a dilatation which would require the expenditure of tremendous mechanical power.

Latent heat is merely a consumption of heat proportionate to the interior work required to overcome cohesion in melting or vaporizing a body. The heat required to melt a pound of ice is one hundred and forty-three thermal units, which is equivalent to 110,396 foot-pounds. The heat required to change boiling water into steam is 967 units, which is equivalent to 746,524 foot-pounds. The actual energy of the heat may thus be measured by its equivalent of mechanical motion. Inasmuch as this motion may be again transformed into sensible heat by a contrary change of state, the atoms are said to possess a possible, or *potential energy*.

Thus, when a gas is liquefied by compression, external work is supplied, and the interior work due to the cohesive force which draws the molecules together is transformed into sensible heat. In like manner, the cohesive force which changes a liquid to a solid, performs interior work, and the potential energy becomes actual; that is, the latent heat becomes sensible.

So, also, when two bodies unite by chemical affinity, the molecular motion is transformed to heat. Thus, when $\frac{1}{9}$ of a pound of hydrogen combines with $\frac{8}{9}$ of a pound of oxygen one pound of steam is produced, and 6892 thermal units are evolved, which are equivalent to 5320624 foot-pounds. The molecular force evolved in changing a mixture of these gases to a pound of ice will therefore be:

| | Thermal units. | Foot-pounds. |
|---|---|---|
| . The potential energy of combination | 6892 | 5320624 |
| . The potential energy of steam | 967 | 746524 |
| . The potential energy of water | 143 | 110396 |
| Total energy | 8002 | 6177544 |

This is equivalent to the force required to raise one ton o a height of 3098 feet, or 3098 tons one foot high. Molecular forces are, therefore, by far the most powerful of any with which we are acquainted.

**629. Force may be changed but not annihilated.** The sun is the ultimate source of the available forms of force with which we are surrounded. Let us consider a few of the ways in 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 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 food.

(*a*). Wood and mineral coal are, therefore, transmuted sunshine. In combustion, the solar energy again appears as heat, or may be applied as a moving force for engines.

(*b*). Food is transmuted by animals into animal heat and muscular energy. Beef and mutton are, therefore, due to olar rays, twice transmuted.

### 630. Recapitulation.

The sources of heat are,

| | |
|---|---|
| 1. Physical | The sun.<br>The fixed stars.<br>The molecular forces. |
| 2. Chemical | Combustion. |
| 3. Mechanical | Compression.<br>Percussion.<br>Friction. |

### THE STEAM ENGINE.

**631. The steam engine** is a machine in which the elastic force of aqueous vapor is the motive power. The essential parts are (1.) the boiler, in which the vapor is formed, and (2.) the cylinder, in which the elastic force is applied. Besides these, there are usually other contrivances for transferring, regulating, and economizing the motion which is produced.

Dr. Wollaston's glass model illustrates the action of the atmospheric engine. Fig. 283.

To the boiler, B, is attached a cylinder, C, in which a piston, P, works steam tight. The piston rod is hollow, and is closed by a screw at H. The boiler is first partially filled with water, the screw, H, removed, and the piston forced down to the bottom of the cylinder.

Heat is then applied, and as soon as the steam begins to escape from the piston rod, the screw is replaced on the top of the rod. The tension of the confined steam will then force the piston to the top of the cylinder. Now, if the cylinder be cooled by pouring upon it a stream of cold water, a partial vacuum will be formed within it, by the condensation of the steam, and the piston will be driven down by the pressure of the atmosphere.

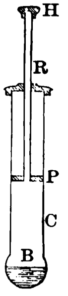

FIG. 283.

By successively heating and cooling this instrument, an alternating, or up and down motion, will be communicated to the piston. If the piston be made to perform work by connecting it with suitable machinery, we shall then have the essential action of *Newcomen's engine.*

**632. This engine,** constructed in 1715, by Thomas Newcomen, was the first in which an alternating motion was given to the piston. It was used to raise water from the coal mines in England. Its structure is exhibited in Fig. 284.

To one end of a walking beam, F F′, was attached the piston rod, D P, and to the other the pump rod, W X. These parts were so counterbalanced that the weight of the pump rod was capable of *raising* the piston to the top of the cylinder. Steam was then admitted to the cylinder through the valve, i, and the air was allowed to escape through the eduction valve, E.

As soon as the cylinder was filled with steam, the valves E and *i* were closed, and a jet of cold water was injected through the valve, *t*, from the reservoir, R. By this means the steam was condensed, and a partial vacuum produced beneath the piston. The pressure of the atmosphere then forced the piston down and drew up the pump rod at the other end of the beam. The jet of cold water was then shut off, the condensed steam drawn out through E, fresh steam re-admitted, and the process was continued.

Humphrey Potter devised an automatic apparatus by which the engine opened and shut its own valves at the proper moments.

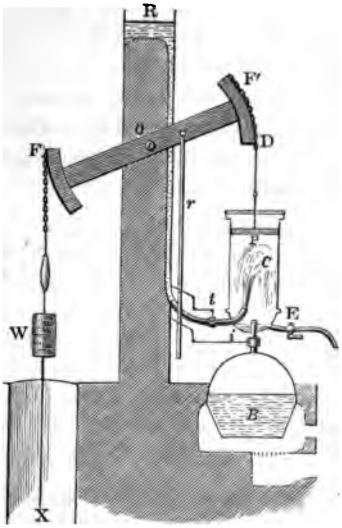

FIG. 284.

**633. The safety valve,** invented by Denis Papin, in 1690, is a necessary part of every steam boiler. This consists of a valve, V, fitting an opening in the top of a boiler.

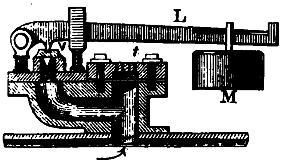

FIG. 285.

A lever of the second kind rests above this, and holds it in its place by a load, M. This load, which should never be equal to the full strength of the boiler, is sometimes applied to the lever by means of springs. Any excess of this tension will be shown by the escape of the steam from the valve. In the recent form, shown in Fig. 285, the small orifices at *t* are filled with an alloy of lead and bismuth.

As the relation between the temperature and tension of steam is known, the fusing point of the alloy is made less than the temperature of steam at its greatest allowable tension. At higher tensions, the alloy will melt and the steam escape. Practically, the safety valves *are only indicators* of high tension, as the openings are never *large enough to permit* much steam to escape.

**634. The modern steam engine** is due to James Watt. In 1763, Watt, while engaged in repairing a model of Newcomen's engine, devised a series of contrivances for obviating its defects, and between that time and 1784 invented the single and double acting steam engines. The improvements added by others, relate chiefly to the details of the mechanism. The following are the principal of Watt's inventions:

1. *The condenser.* This is a chamber (I, Fig. 286), into which the steam from the cylinder and a jet of cold water are admitted at the same time. The vacuum is formed here, and avoids the loss of heat consequent on cooling the cylinder.

2. *The jacket.* This is simply an exterior casing of wood, to prevent the cylinder from losing heat by radiation.

3. *The single acting engine.* Watt admitted the steam at the top of the cylinder, and thereby depressed the piston by the elastic force of the steam instead of by the weight of the air.

**635. These improvements** changed the engine from an *atmospheric* to a *steam engine.* The piston was still raised by the weight of the pump rod, and consequently the steam acted only intermittently. These single acting engines are now used only for pumping water.

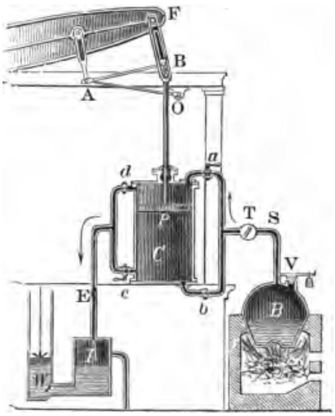

FIG. 286.

4. In 1782, Watt patented the double acting steam engine. In this, the top and bottom of the cylinder are alternately connected both with the steam pipe and the exhaust pipe.

The theoretical action of the condensing engine is shown in Fig. 286. *a* and *b* are the upper and lower valves of the steam pipe; E, the exhaust pipe, with its valves, *c*, *d*; and I the condenser, full of cold water.

Now, suppose all parts of the cylinder and the connecting pipe to be filled with steam, the valves *a* and *c* to be opened, and *b* and *d* closed; the steam will pass from below the piston through the exhaust pipe into the condenser, and thereby a vacuum, more or less perfect, will be formed below the piston.

The steam from the boiler will drive the piston to the bottom of the cylinder. When the piston has reached its lowest point the valves are changed; that is, *b* and *d* are opened, and *a* and *c* shut. Now, a vacuum will be formed above the piston, steam will enter below, and the piston will ascend.

*The non-condensing engine* differs from this simply in the fact that the waste steam passes from the exhaust pipe directly into the air or into the smoke stack of the boiler. Fig. 287 is a condensing engine. The locomotive, Fig. 290, is a non-condensing engine.

5. *The parallel motion.* This was a device to make the piston rod move vertically in its collar, and thus prevent wear and friction. Fig. 287.

This was effected by a system of jointed rods, A B, B F, F D, attached to the rod, A O, moving about a fixed point, O. The lengths of these rods are so proportioned that, while the end of the beam describes an arc of a circle, the point, B, moves in a very nearly vertical line. This is also true of the center of the link, A D, to which is attached the pump rod of the hot well.

In this country, the piston rod is generally attached to a cross piece, which moves in the vertical grooves of a stiff framework.

6. *The crank.* The motion of the beam was transmitted through the connecting rod, F′M, to the *crank*, M O′, which is attached to the *shaft* of the engine, and gives motion to the machinery connected with it. This converts the alternating motion of the piston to a rotary motion.

7. *The fly wheel.* When the crank is at its highest or lowest position the steam has no power to move it, and therefore these points are called *dead points*. To carry the crank beyond these points, a heavy fly wheel, V V, is attached to the shaft.

*This wheel, having* once been set in motion, carries the crank beyond the dead points by its inertia, and brings it into a position where the power again becomes effective.

A steamboat or locomotive has no fly wheel, because its momentum is sufficient to prevent arrest of motion at the dead points.

8. *The throttle valve*, T, is placed in the throat of the steam pipe to regulate the supply of steam to the cylinder. To make this automatic, Watt applied the already discovered principle of the *governor*.

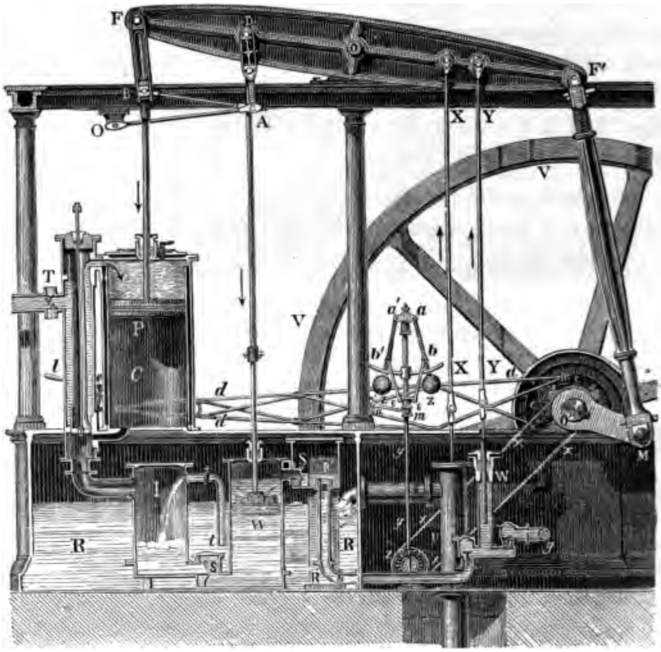

FIG. 287.

This consists of a vertical axis, *y*, which receives from the shaft a revolving motion. Attached to this are two rods, *a b*, *a′ b′*, terminating in heavy balls, *z z′*; at the points, *b b′*, are applied two other rods, *b e*, *b′ e′*, which are connected with a collar, *m*, capable of mo[illegible]ing up and down on the vertical axis. When the engine is at rest, the balls hang nearly vertical, but when the axis, *y*, is turned they are thrown outward by centrifugal force. This raises the collar, *m*, which acts upon the throttle valve, by levers, not shown in the figure, so as to admit a greater or less supply of steam.

The weight of the balls is adjusted so as to regulate the supply to the required speed of the engine. If the shaft moves too rapidly, the balls are thrown out and the throttle valve closes; if too slowly, the balls fall, and a greater supply of steam is introduced.

**636.** Other inventions were added by Watt, which relate to details of construction, and are here omitted. In Fig. 286, the eduction and steam pipes are represented on opposite sides of the cylinder. In the actual engine, the cylinder has but two ports for the alternate admission and ejection of steam. These ports are controlled by valves of various forms and names. Those shown in Fig. 287, are called the long D valves. The short D valve is the one generally used in land engines.

This arrangement for the distribution of steam is shown in Fig. 288. The steam is admitted from the boiler into the valve chest behind the valve. Below the valve is the exhaust port, *o*, which leads sideways to the air or to the condenser. On each side of this are the cylinder ports, which are connected by curved tubes to the top and bottom of the cylinder.

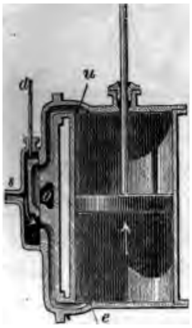

Fig. 238.

The valve is made to close the exhaust port and one of the cylinder ports at the same time, by means of an eccentric rod, *d*, attached to the shaft of the engine. In Fig. 288 the lower port is open for the admission of steam; the upper, is connected with the exhaust port to allow the waste steam to escape. In Fig. 289, this condition is reversed, the lower port being closed, and the upper open.

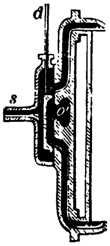

Fig. 289.

Sometimes a second valve, called a "cut off," is attached to the sliding valve, by which the steam may be shut off from the cylinder at any portion of the stroke of the piston, as one-half or one-third. The *expansion* of the steam already admitted to the *cylinder completes* the work of moving the piston.

**637. Steam boilers** vary in shape and size with the purpose for which they are designed. In locomotives, an abundant supply of steam at high tension is required. For this reason, the boiler is pierced with numerous horizontal pipes, which serve as flues for the fire, and, at the same time, expose a large heating surface to the water. To increase the draft, the exhaust pipe is placed in the smoke stack.

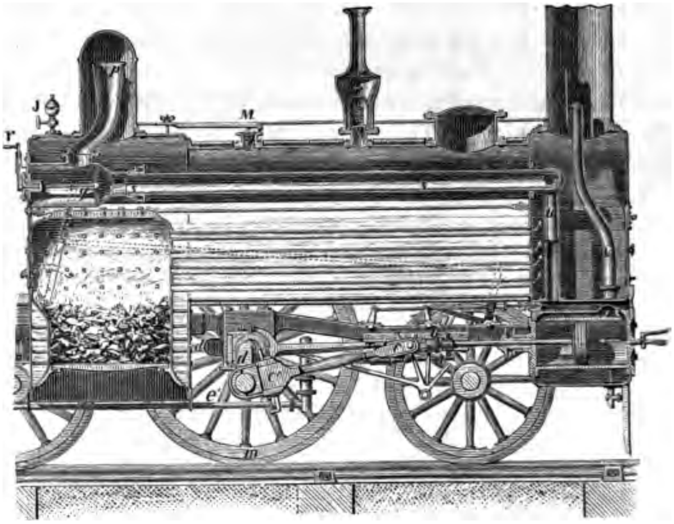

FIG. 290.

**638. The mechanical power of steam** may be estimated in foot-pounds or in horse-powers. A cubic foot of water when converted into steam yields 1696 cubic feet at the pressure of one atmosphere. Hence, if the steam be formed beneath a piston of one foot area, it is capable of lifting a weight of fifteen pounds on each square inch, to the height of 1696 feet. This is equivalent to raising $15 \times 144 \times 1696 = 3663360$ foot-pounds. Deducting one-fifth for loss by friction and other causes, the available power of a cubic foot of water, when converted into steam at 212°, is 2930688 foot-pounds.

The horse powers depend on the rapidity of the evaporation. If the boiler evaporates a cubic foot of water each minute, its efficiency will be equal to $2930688 \div 33000 = 88.8$ horse powers. In rough calculations, it may be assumed that the evaporation of one cubic foot per hour is equal to one horse-power.

To evaporate one cubic foot of water requires the combustion of nearly five pounds of anthracite coal. Hence, for each pound of coal burned per minute, we should have an effect equal to nearly twenty-five horse powers. This is very nearly realized in the Cornish single acting condensing engines. In the United States, it is usual to allow about 6.5 pounds of anthracite coal for each horse power.

### 639. Recapitulation.

The essential parts of a steam engine are:

1. A boiler, for generating the elastic force of steam.
2. A cylinder in which this elastic force is made to produce an alternating motion in a piston.

The accessory parts are:

1. An apparatus by which the piston rod is made to move in the same straight line. (Parallel motion).
2. An apparatus by which the alternating motion of the piston may be converted to rotary. (Crank.)
3. Apparatus for regulating and controlling the motion. (Fly wheel, throttle valve, and governor.)
4. Other parts added for the sake of safety, economy, and convenience. (Safety valve, condenser, jacket, and automatic action.)

## CHAPTER IX.

## ELECTRICITY.

**640.** It has long been known that a certain ore of iron, called the loadstone, has the remarkable property of attracting iron filings to itself: also, that amber when rubbed, and tourmaline when heated, acquire temporarily, the property of attracting light bodies, as bits of cotton and straw. 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 and beautiful in nature. This force is *electricity.* It is convenient to study its phenomena under three divisions: (1.) magnetism, (2.) statical electricity, (3.) dynamical electricity.

### MAGNETISM.

**641. The loadstone** is an abundant and widely distributed ore of iron, having the chemical formula $Fe^3O^4$. Because the ore was first found near Magnesia, a city of Asia Minor, loadstones are called *natural magnets.* If a loadstone be rolled in iron filings, the filings will cling to it, but especially at its ends. Fig. 291. These ends are termed the poles of the magnet. The force residing in a magnet is called *magnetism.*

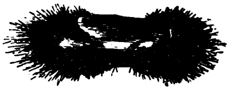

FIG. 291.

**Artificial magnets** are bars or needles of hardened steel which have acquired magnetic properties. These are at once more convenient and powerful than natural magnets. *If a magnetic bar or needle be poised at its center so that it will swing freely, one end will always 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. The north pole is the marked end of the magnet.

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. 292. These lines are called *lines of magnetic force.* The action of the magnet is not diminished by the interposition of any substance that is not itself magnetic, as paper or glass.

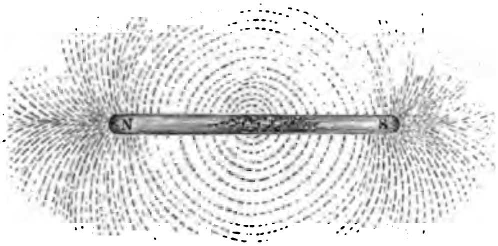

FIG. 292.

**642. Either pole** will equally attract magnetic substances; but if two magnets are brought near each other, it will be found that the marked end of one will attract the south pole of the other, but if the two marked ends are brought near each other, a repulsion takes place. Hence, this law: *Like poles repel and unlike poles attract each other.*

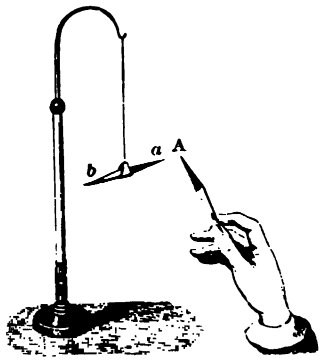

FIG. 293.

A force which exhibits a combination of equal powers, acting in opposite directions, is called a *polar force.*

**643. 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.

Thus, if N S, Fig. 294, represents a magnet, the alternate black and white spaces will represent the polarity of each particle. All the north poles are disposed in one direction and all the south poles in the opposite. The opposite polarities balance each other at the center, which thus remains *neutral*, but are strongly manifested at the ends.

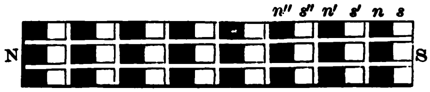

FIG. 294.

**644. Induction.** If a rod of soft iron, (Fe,) Fig. 295, be brought near one of the poles of a magnet, M, the rod will become a *temporary magnet*, having two poles, each capable of attracting iron filings. The polarity of the rod will be opposite to that of the magnet; that is, if the rod be near the marked end of the magnet, the nearer end of the rod will manifest south polarity, and the remote end north. This influence, by virtue of which a magnet can develop magnetism in iron, is called *induction.*

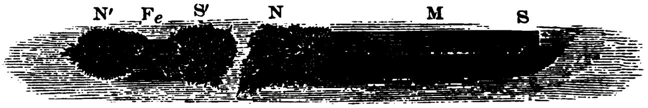

FIG. 295.

The phenomena of induction may be explained by supposing that, in the unmagnetized condition of the rod, all the molecules are endued with magnetism, but so combined that the opposite forces neutralize each other. In the presence of a magnet the two halves of each molecule assume an opposite magnetic condition, or become *polarized*, as shown in Fig. 294.

**645. In any form of induction** there is no *transfer* of any force, but merely a development of polarity among the particles of the body acted upon. The lines of magnetic force, Fig. 292, are due to the fact that the minute particles of iron become temporary magnets, and arrange themselves in accordance with the law of attraction and repulsion.

The inductive force is greatest when the magnet is in contact with the iron, but entirely ceases when the two are separated to a sufficient distance. 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 most powerful magnets are produced by means of a voltaic current, as will be described hereafter. (745.)

**646. A magnetic battery** consists of a number of magnets joined together with their similar poles in contact. The most common form is that of the horse-shoe, Fig. 296. When a magnet exerts its inductive power on a piece of soft iron, its own magnetic intensity is increased. For this reason the magnet is provided with a *keeper,* or *armature,* K, of soft iron. The weight which the armature will support is more than twice that which either pole would bear. The power of a magnet may be doubled by adding daily a small weight to the armature; but if the contact be once broken only the original load will be sustained. The power of a magnet may be seriously impaired by heating, or by any rough usage.

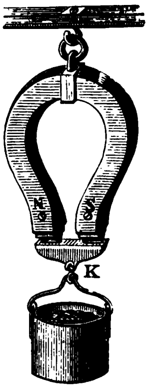

FIG. 296.

**647. Magnetic substances** are those which are attracted by a magnet. Iron, steel, nickel, and cobalt are the only substances in which magnetism can be developed by ordinary induction. *By* using very powerful magnets, Faraday *found a small* number of other substances to be magnetic. Among these are manganese, chromium, platinum, plumbago, and oxygen.

On the other hand, a great number of substances, when suspended between the poles of a strong horse-shoe magnet, take up 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, zinc, tin, resin, hydrogen, and coal gas.

## TERRESTRIAL MAGNETISM.

648. **If a small magnetic needle** be suspended by an untwisted thread over a bar magnet, N S, and be slowly carried from one end of the bar to the other, it will assume in succession the positions shown in Fig. 297. At the center of the bar it will be horizontal, with its marked end pointing toward the south pole of the bar magnet. At either side of the center, it dips or inclines; the south pole dips on the north polar side of the center, and the north pole dips on the south side. The dip will increase as the needle approaches the poles, at which points the inclination will be 90°.

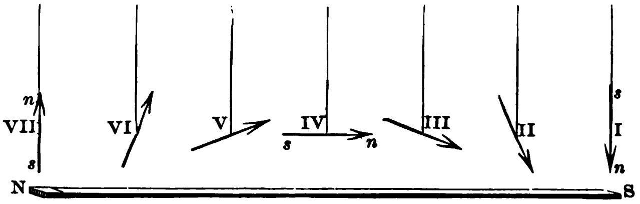

FIG. 297.

Now, if a magnetic needle be freely suspended and carried to different points on the earth's surface, it will not merely be directed toward the north, but will also dip more and more as it approaches the polar regions. These phenomena warrant us in considering the earth as a great magnet, whose poles are very near the terrestrial poles.

**649. The magnetism of the earth** is further manifested by its inductive influence. If a bar of iron be placed in the direction which a dipping needle would assume, it immediately becomes polarized.

This may be shown by moving a small magnetic needle along the bar. The marked end of the needle will be repelled by the lower end of the bar, and attracted by its upper end. If the iron is somewhat hard, its magnetism may sometimes be rendered permanent by striking it a sharp blow with a hammer. This phenomenon is frequently seen in rods which remain at rest for some time in a nearly vertical position, as the poker and tongs.

**650. The magnetic elements** necessary for the full knowledge of the earth's magnetism at any place, are (1.) inclination, (2.) declination, (3.) intensity.

**Inclination.** If an unmagnetized steel bar be accurately balanced and then magnetized, it will be found that its balance is lost, and that it now makes a certain angle with the horizon. This angle is called the *inclination,* or *dip,* of the needle. A *dipping needle,* is one by means of which this inclination can be measured. The inclination, N c *d*, shown in Fig. 298, is the same as that of a dipping needle at Rochester, N. Y., or about 75°.

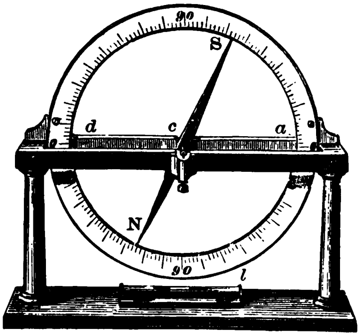

Fig. 298.

**651. The magnetic poles** are points at which the dipping needle is vertical. Sir James Ross found an inclination of 89°59′ in Boothia Felix, at 70°5′ N. lat. and 96° 43′ W. lon. This point is taken as the north magnetic pole. The south magnetic pole is calculated to be in about 75°30′ S. lat., and 154° E. lon. Lines connecting places in which the needle is of equal dip may be drawn about the magnetic poles in irregular curves, somewhat resembling those of the parallels of latitude drawn about the terrestrial poles. Most of the United States lies between the lines of 75° dip and 60° dip. The *magnetic equator* of the earth is a line of no dip, or it is a line connecting those places in which the needle remains horizontal. The magnetic equator crosses the earth's equator in the Atlantic and Pacific oceans, making an angle with it of about 12°

In the northern hemisphere, the marked end of the needle is depressed, and in the southern, the unmarked end. In the mariner's compass, the effect of the dip is corrected by the means of a small sliding weight, which is moved along the needle so as to preserve its equilibrium.

**652. Declination.** Since the magnetic poles do not coincide with the terrestrial poles, the needle, in most places, does not point in a true north and south line. The angle by which its direction deviates from the astronomical meridian is called the *declination of the needle.* The compass, Fig. 299, may be used to determine the declination by observing the angle which the needle makes with the direction of the north polar star. The declination is frequently called the *variation of the compass,* because it is generally different for different places. It is 0° at Pittsburgh, 6° west at New York, and in Baffin's Bay the needle points due west.

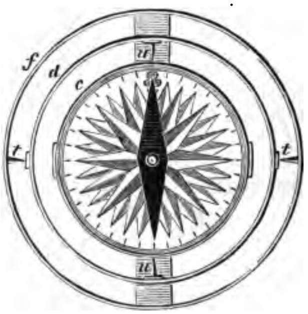

Fig. 299.

**653. A line of no declination,** or one that connects places in which the needle points due north and south, passes in nearly a great circle around the globe. In the *western* hemisphere it runs from the north magnetic pole through Hudson's Bay and Lake Erie, cutting Ohio, Pennsylvania, Virginia, and North Carolina, and enters the Atlantic near Cape Lookout; thence it sweeps eastward of the West Indies, and after passing through the south polar regions, re-appears at the south magnetic pole. It then runs northerly through Australia, but beyond this follows an irregular curve through the Caspian sea to the Arctic ocean.

In the Atlantic hemisphere, which is included within this line, the deviation is every-where westward. In the Pacific hemisphere, which includes the greater part of the United States, the declination is very generally eastward; the exception being an oval area in Eastern Asia, which is bounded by a second line of no declination.

**654. Intensity.** If a magnetic needle be drawn aside from its position of rest, it will recover its equilibrium after a series of oscillations. Since the magnetic force at any given place and time may be regarded as constant, these oscillations of the needle will be governed by laws analogous to those of the pendulum. [41 and 42.] Hence, the intensity of the earth's magnetism in any two places, will be proportioned to the square of the number of vibrations made by the same needle in equal times. The magnetic intensity in Peru has been assumed as the standard of comparison, and is, therefore, taken as unity.

A dipping needle, which, in Paris, made 245 vibrations in ten minutes, when transported to the magnetic equator in Peru, made only 211 vibrations in the same time. The intensity at Paris will, therefore, be $\frac{245^2}{211^2} = 1.348$.

**655. There are four foci** of maximum magnetic intensity, of which two are in the northern and two in the southern hemisphere. The strongest, which lies a little south of Australia, may be represented by 2.06. The American focus lies a little north-west of Lake Superior, the intensity being 1.88. The least intensity hitherto found is in South Africa, and amounts to 0.7, or about one-third of the *highest intensity.*

The *absolute magnetism* of the earth has been calculated to be equal to eight thousand four hundred and sixty-four quadrillion times that of a saturated bar magnet one pound in weight.

**656. The magnetic elements** are subject to constant changes, some of which are regular, and others irregular. Thus, the inclination in Europe is gradually decreasing, and the declination is at present veering eastward. The rate of these changes is not the same for different places, nor is it constant for the same place. The following list exhibits the secular changes in declination and inclination at London:

*Table of Secular Magnetic Changes.*

| Year. | Declination. | Year. | Inclination. |
|---|---|---|---|
| 1580 | 11°17′ E. | 1720 | 74°42′ |
| 1660 | 0° 0′ | 1790 | 71°53′ |
| 1815 | 24°27′ W. | 1818 | 70°34′ |
| 1869 | 20° 2′ W. | 1869 | 67°54′ |

It appears from this, that in 1660 the needle pointed due north, at London; it then varied westward until 1815, when it pointed farthest from the true north. Since that time it has moved eastward at an annual rate of about 8′. The annual decrease in dip is about 2′.6.

**657. These changes show** that the magnetic poles are continually shifting their position, and, consequently, that the lines of equal declination and dip are not the same from year to year.

The needle has also a daily and annual oscillation, apparently connected with changes in temperature. Thus, at Philadelphia it has a maximum westward declination at 1 P. M. and at 2 A. M., and a minimum at 8 A. M. and at 10 P. M. The greatest daily change is between April and September, or during the summer months.

**658. The irregular variations** are indicated by sudden disturbances of the magnetic needle, which are sometimes considerable, but are of short duration. The appearance of the Aurora Borealis is invariably accompanied by these fluctuations. Magnetic disturbances often occur simultaneously in very distant countries, and have received the name of *magnetic storms.*

These storms, which were once thought to be wholly irregular, are found to be periodical, having epochs of maximum intensity every ten years. These epochs coincide with the maximum recurrence of the spots on the sun; this appears to show that magnetic storms are connected with changes in the solar atmosphere.

**659. The source of the earth's magnetism** is now generally attributed to the sun. It is supposed that the solar heat develops electrical currents in the materials of the earth's surface, and that these currents give rise to magnetic phenomena. This hypothesis is supported by the facts already noticed in regard to magnetic storms, and the daily changes in declination, and receives a strong support from the fact that the lines of equal heat and of equal magnetic intensity on the globe, manifest a marked correspondence.

### 660. Recapitulation.

| | | |
|---|---|---|
| Magnets are | Natural or artificial.<br>Permanent or temporary. | |
| Substances | Attracted by magnets are | Magnetic. |
| | Repelled by magnets are | Diamagnetic. |
| The terrestrial magnetic elements are | | Inclination.<br>Declination.<br>Intensity. |
| The changes of the magnetic elements are | Regular | Daily.<br>Annual.<br>Secular. |
| | Periodical, in magnetic storms. | |

## STATICAL ELECTRICITY.

**661. The fundamental phenomena** of statical electricity may be studied by means of the *electric pendulum*, Fig. 300. This consists of a *pith* ball attached, by means of a silk *thread, to a glass support.*

If a stick of sealing wax, or an ebonite ruler be rubbed with dry flannel and be brought near the pith ball, 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 phenomenon of attraction and repulsion will be observed Fig. 300.

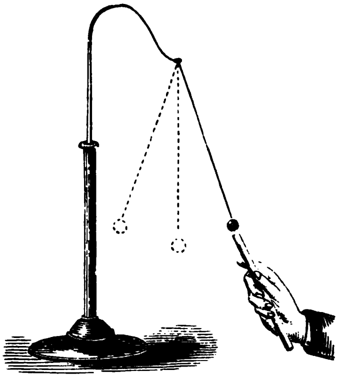

FIG. 300.

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, manifest that the excited glass and wax manifest similar but opposite properties. These properties, thus developed by friction, are due to the force of *electricity*.

662. **Electricity** is a polar 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 of two fluids, called *vitreous*, or *positive*, and *resinous*, or *negative*. Many of the terms of the older theory are still in common use, because they are convenient for describing most electrical phenomena, although the meaning attached to them is taken in a sense different from that originally intended. There is no evidence of the existence of any electrical fluid.

663. **In the preceding experiment,** we suppose that the wax became negatively electrified by the 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.*

**664. Statical electricity** may be developed by any cause that tends to disturb the molecular condition of bodies, as cleavage, pressure. It. may be developed in tourmaline and certain other minerals by heat. The usual source is friction, and hence this form of electrical force is sometimes called *frictional electricity.* It is called statical electricity because it may be retained for a time on an excited or charged body.

**665. 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.*

These classes differ only in degree, for there is no such thing as perfect conduction or perfect insulation. In the following list, the substances named are arranged in the order of their conducting power. Those midway in the list may be term semi-conductors or semi-insulators.

Conductors.
1. All the metals.
2. Charcoal.
3. Graphite.
4. Acids.
5. Water.
6. Vegetables.
7. Animals.
8. Linen.
9. Cotton.

Semi-conductors.
10. Alcohol.
11. Ether.
12. Flowers of sulphur.
13. Dry wood.
14. Paper.
15. Dry ice.
16. Phosphorus.
17. Caoutchouc.
18. Air and gases.
Semi-insulators.

19. Furs.
20. Silk.
21. Gems.
22. Glass.
23. Wax.
24. Sulphur.
25. Resins.
26. Shellac.
27. Ebonite.
Insulators.

**666. 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 green glass; ebonite is the best. * Baked wood covered with shellac varnish will answer very well. Dry air is essential for insulation. In a damp room a film of moisture gathers upon the apparatus and forms a conducting surface.

The reason why electrical excitement is not more frequently manifested by friction is because the electrical force 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 in dry slippers, may develop electricity sufficient to emit a spark from his finger capable of igniting a jet of gas.

**667. 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 negatively electrified when rubbed with flannel, and positively electrified when rubbed with silk.

**668. 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 electrical pendulum, with one or two pith balls. The gold leaf electroscope, Fig. 301, consists of two strips of gold leaf suspended in a glass vessel by means of a metallic rod, which terminates in a knob, or plate. The upper portion of the jar is coated with shellac and the interior is filled *with air* kept perfectly dry. Within the vessel are two metallic

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* This is the material of which hard rubber combs are made.

posts connected with the ground which serve to remove an excessive charge from the leaves.

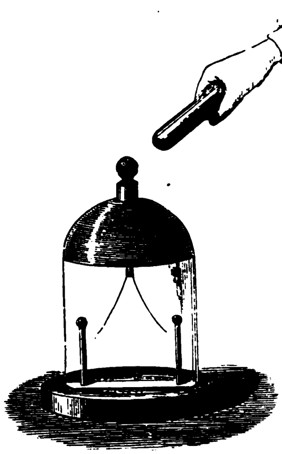

FIG. 301.

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 leaves; for if the electricity be of the same kind as that of the leaves, they will diverge farther, but if of the opposite kind, they will collapse.

**669. Induction.** Electrified bodies influence bodies at a distance in a manner analogous to the action of a magnet on magnetic substances. This influence is called *electrical induction*, and the resulting effect *induced electricity*.

Let A B be a conductor of brass or tin, insulated on a glass pillar and furnished with a number of pith ball electroscopes. If this is

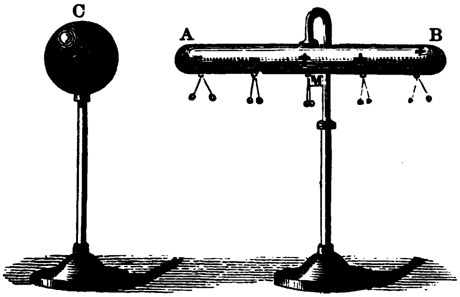

FIG. 302.

brought near an electrified body, C, but without receiving a spark from it, the balls will diverge, as shown in Fig. 302, thereby manifesting the presence of uncombined electricity at each end, and of a neutral line near the center. 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 the same kind. If C be positively charged, its effect will be to attract negative electricity at the nearer end, A, and to repel positive electricity toward the further end, B.

**There is no transfer** of any electrical force in induction, because the action is only temporary; for if C be removed or be discharged by touching it with the hand, the balls immediately collapse.

**670. The two electrical forces may be separated** by induction. Suppose three conductors like A B, placed end to end; or, what is the same thing, 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 parts be separated by removing the central portion. (1.) This part will yield either 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 can be discharged by touching them separately, because their electricities are retained by their mutual attractions. Electrical forces in this condition are said to be *bound*, or *disguised*. If communication be made between them, they will both be discharged by the union of their opposite forces; or if the two are separated, A will yield negative, and C positive electricity.

**671. If the cylinder,** A B, while near the positive ball, C, be touched with 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, and the neutral line will recede to an indefinite distance from A. The negative can not escape, being bound by the attraction of the positive ball. On the contrary, it will increase, because the inductive force of C is no longer subject to the counter-action of the similar force accumulated in the end, B. If the hand be *first* removed and *then* the inducing body, the cylinder will remain negatively charged, and will yield all the phenomena of free electricity.

Thus, a body may be charged by induction as well as by conduction. In conduction, the electrified body loses a part of its force to impart the same kind of electricity to an insulated body. In induction, the charging body loses none of its force, but excites the opposite kind of electricity in an insulated body, which requires to be uninsulated for a time in the presence of an excited body.

**672. The electrophorous** illustrates the action of induction, and affords a ready supply of statical electricity. It consists (1.) of a cake of resinous matter, R, resting on a conducting plate of tin, and (2.) a movable metal cover, T, provided with an insulating handle, G.

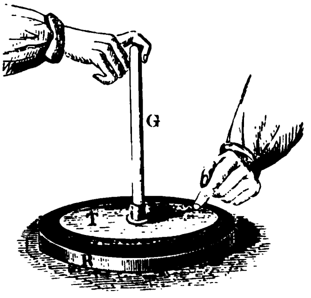

FIG. 303.

If the resinous cake be beaten with cat's fur, or rubbed with a warm flannel cloth, it becomes charged with negative electricity. If, now, the cover be placed on the cake, its condition is that of a conductor under the influence of an electrified body. Its lower surface becomes *positive* and its upper *negative*, by induction.

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. If, now, the finger be first removed, and then the cover be raised by means of its insulating handle, its *positive electricity* diffuses itself over the cover, and *may be made to yield* a brilliant spark by bringing it near a conductor. The reason why the cake does not discharge itself into the cover, is due (1.) to the non-conducting power of the resin, and (2.) to the minute inequalities of its surface, which do not permit an intimate contact of the cover.

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. Instead of the resinous cake a sheet of gutta-percha, or a tin plate coated with melted sealing wax, may be used. The disk may be made of a tin plate, with a stick of sealing wax to serve for a handle. This simple contrivance may be made to yield very excellent results. It may be used to charge movable conductors of a spherical or cylindrical form, like those shown in Fig. 302, or for performing experiments in which a continuous supply of electricity is not required.

**673. Faraday's theory of induction** supposes (1.) that all particles of matter are more or less conductors; (2.) that under the influence of an electrified body, the molecules of the surrounding medium become arranged in a polarized form. Thus, if C represent a positively charged body, the polarization of the contiguous molecules of air, and of A B, a distant insulated conductor, may be represented by a series of black and white hemispheres. (3.) That contiguous particles can communicate their polarity, more or less readily, one to the other. Those that communicate their electrical forces readily, are conductors; those that retain their polarity, or communicate their electrical forces with extreme difficulty, are insulators. (4.) Induction is the action of an electrified body upon insulating matter. If the insulated cylinder, A B, be contiguous to the polarized molecules of air, its particles will also be polarized; but, as they are conductors, they will discharge their electric forces one into the other, and thereby the cylinder itself will become polarized, as if it were a huge molecule.

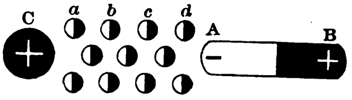

Fig. 304.

**674. Induction is essential** in most, if not all, electrical phenomena.

1. *In attraction.* The pith ball of the electrical pendulum is first polarized, like the cylinder, A B, Fig. 304. 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.

2. *In charging.* In Figs. 302 and 304, 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 permanently 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 one another. At spark or at contact an equal amount of both electricities becomes neutralized, and the cylinder becomes charged, not by receiving more positive electricity, but by discharging its negative. As soon as the negative disappears, the positive diffuses itself over the conductor, and is prevented from escape by the insulation of its support and of the air.

3. *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 conductor become unpolarized, or neutral. Hence, we may say that the cylinder was charged by losing its negative electricity, and discharged by losing its positive. These terms express what is true in effect though not in process.

***675. Nothing passes* from particle to particle but the**

**inductive force.** This first develops the two electrical forces in each molecule by polarization, and then, when of sufficient intensity, causes this polarity to disappear by discharge into contiguous molecules. The molecules of conductors are easily polarized and discharged; the molecules of insulators require a greater force to effect polarization and discharge.

Herein consists the analogy between magnetic and electrical induction. The induction of magnetism in soft iron is instantaneous but temporary; that of steel is effected with greater difficulty, but is permanent. The analogy is not complete in other respects, especially in this, that in magnetic induction the two forces can not be separated. Nevertheless, the polar character of electricity is sustained even in electrical induction, for, although a body may be charged positively or negatively, yet this can only be effected and maintained by the opposite force induced in the insulating molecules which surround it.

**676. Electricity is found only on the surface** of an insulated conductor. This is a direct consequence of the preceding, and may easily be verified. Let a brass ball be suspended by a silk thread, and be covered with two closely fitting hemispheres of brass, provided with insulating handles. If a charge be communicated to the apparatus so compounded, and the hemispheres be withdrawn, no electricity whatever will remain on the sphere. Hence, a hollow conductor is as serviceable as a solid one.

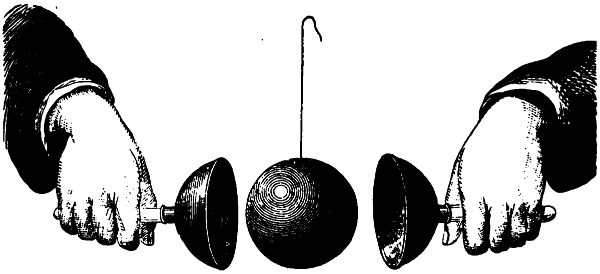

FIG. 305.

**677. The charge is distributed** uniformly only in the case of the sphere. If the conductor be a cylinder with rounded ends, the intensity will be least at the center and greatest at the ends, as represented by the divergence of the balls in Fig. 302. The more pointed the ends, the greater will be the accumulation of intensity at the extremities. The effect of a point, either on a charged surface, or turned toward a charged surface, is such as to discharge a body with extreme facility, and generally without the passage of a spark.

**678. The terms quantity and intensity** will be understood by reference to the analogous use of the terms 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 determines the quantity. *Electrical intensity* has reference to the amount of force lodged in each particle; *quantity of electricity* has reference both to the number of particles affected and to the force lodged in each. Of course, in every electrified body, there is both quantity and intensity, but the charge may be characterized by the predominance of either quality. In statical electricity, the quantity is always small, though its intensity is sometimes enormous. The intensity is due to a high state of polarization, and is measured by its power to effect discharge through bad conductors. Thus, a long spark is an evidence of great intensity.

## ELECTRICAL APPARATUS.

**679. An electrical machine** is an apparatus by means of which large supplies of statical electricity may be developed in a convenient manner.

Fig. 306 *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 glass or of dry wood, and made to revolve by a winch.

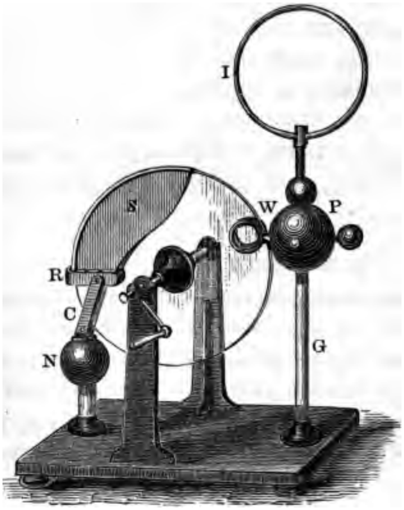

FIG. 306.

Friction is applied to the glass by means of two rubbers, R, made of stuffed leather, and coated with an amalgam of mercury, tin, and zinc. The rubbers are kept in place by means of a pair of clamps attached to an insulated brass ball, N, called the *negative conductor*. Attached to the rubber are two wings of silk, to prevent the electricity from escaping into the air.

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 the glass plate, are two rows of brass points, which are connected by means of tin foil to the prime conductor.

On turning the plate, negative electricity is developed on the rubbers and conducted to the *negative conductor*, N, and positive electricity is developed on the glass plate. As the plate revolves, the positive electricity of the glass 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 space of air and unite with the positive electricity on the glass, and thereby render its surface neutral. The prime conductor, therefore, gives up its negative and remains charged with positive electricity, in the manner described in (674).

**680.** If both the conductors were insulated, this action would speedily 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 tension will he reduced to zero, and thereby leave the electric force on the other conductor free. Hence, when the rubbers are connected to the ground by means of a chain, positive electricity is accumulated on the prime conductor.

When negative electricity is wanted, the chain is removed from the rubbers and attached to the prime conductor, and the negative electricity accumulates on the negative conductor. If the hand is brought near either conductor when charged, a spark follows, which is renewed as the plate is turned.

The length of the spark is wonderfully increased by the addition of a large wooden ring, I, surmounting the prime conductor. An iron wire forms the core of this ring, and is in metallic connection with the prime conductor. The wooden ring acts inductively on the prime conductor and prevents discharge until the electric force attains a high tension. Without the ring, which may be removed at the pleasure of the operator, the machine will give a rapid succession of sparks, two inches in length; with the ring, sparks may be obtained six or seven times as long, but these are proportionally less frequent. The quantity of electricity developed is the same in both cases.

There are many other electrical machines having the same action as the one described. Among these are several varieties of the plate machine, and others in which a hollow cylinder of glass is substituted for the glass plate. Electricity may also be generated in enormous quantity by the friction of steam passing through jet pipes of hard wood. A *hydro-electric machine*, constructed on this principle, yielded sparks twenty-two inches long, and was capable of fully charging a battery of thirty-six large Leyden jars upward of sixty times a minute.

**681. There are *other* machines** which act on the principle *of the electrophorous.* In Holtz's machine, Fig. 307, electricity is developed by the continuous inductive action of a body already electrified.

It consists of two circular plates of glass, about one-tenth of an inch apart. The larger one, A, is fixed and insulated; the smaller, B, turns on a glass axis, which passes through a hole in the center of the fixed plate. In the plate, A, are two openings, each furnished with an *armature.* These armatures consist of a band of paper terminating in a sort of tongue, which is glued to the glass so that the tongues, *ff′*, project into the window.

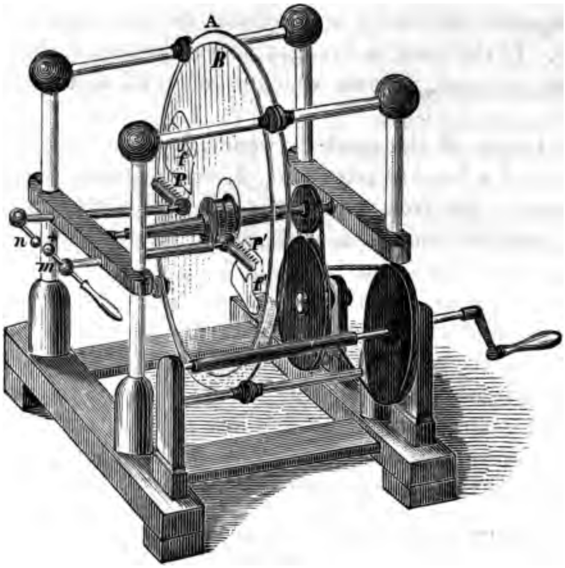

FIG. 307.

In front of the armatures, but on the other side of the movable plate, B, are two brass combs, P P′, supported by two brass rods. Through the rounded ends of these rods are inserted two smaller rods, terminating in knobs, *m* and *n*, which are called the *poles* of the machine. These poles may be inclined to each other or placed at any distance apart by means of a wooden handle attached to *m*. Finally, a very rapid rotation may be given to the plate, B, by means of the multiplying wheels shown on the right of the figure.

**682.** To obtain electricity, the poles are brought in contact and one of the armatures slightly charged. For instance, let *f* be charged negatively by touching it with an excited rod of ebonite. The armature will then act inductively on the plate, repelling negative electricity to the comb P, and leaving the nearer surface of the glass positively charged. On turning the machine, these positively charged particles will be brought in front of the armature *f'*, and a second induction takes place, viz.: the positive glass attracts negative electricity to itself, and sets free positive electricity on the armature *f'*.

After a few turns the armatures will become charged with opposite electricities, and the poles may be gradually separated, as shown in the figure. There will occur immediately a succession of sparks, which results from the reunion of the electricities of the two poles. Under the conditions indicated, *n* will be the negative and *m* the positive pole. The power of the machine increases rapidly for a short time, and then becomes constant.

Though this machine under favorable circumstances is far more powerful than the plate machine, it is less reliable, for it requires nearly perfect insulation, and is more seriously affected by the humidity of the air. Instead of the fixed plate, A, any number of insulated sectors of glass, provided with paper armatures, may be employed. By connecting one of the poles with the ground, the other may be used as a prime conductor.

**683. There is a limit** to the accumulation of the electric force on any surface. But if two conducting surfaces are separated by an insulating medium capable of being highly polarized, the intensity will be increased by reason of the reciprocal inducing action of the two surfaces. Any arrangement of this sort is said to act as a *condenser*.

**684. The Leyden jar** is the most convenient form of the condenser. This consists of a glass bottle coated both on the inner *and the outer* surface with tin foil to within three *inches of the neck.* The mouth is usually closed with a plug of varnished wood, through which passes a brass wire surmounted by a knob, and connected to the inner coating by means of a chain. If the jar be held near a machine in action, as shown in Fig. 308, the sparks will pass from the machine to the interior of the jar; but after a little while this will cease, and the jar is then said to be charged. 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.* As this shock is inconvenient and sometimes dangerous, the discharge is usually effected by means of a *discharging rod,* which consists of a jointed wire terminating in brass knobs. See Fig. 321.

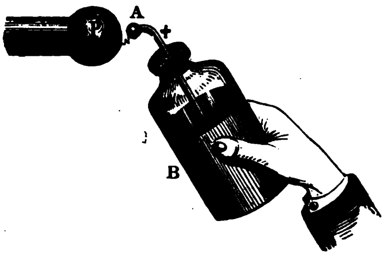

Fig. 308.

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 spark that passes into the jar, an equal spark of the same kind will pass from the outer coating to the finger. Hence, a jar contains no more of either electric force when charged than before.

Several Leyden jars, standing side by side, and having their similar coatings connected, the outer by means of tin foil and the inner by wires, constitute an *electrical battery.* Such an arrangement is shown in Fig. 321.

**685. The action of the jar** may be thus explained: when a positive spark passes to the interior of the jar, the molecules of the glass are all polarized, as shown in Fig. 309. If the jar be insulated, but little charge can be received, be cause of the repulsion of positive electricity, which accumulates on the outer coating. If, now, the outer coating be connected with the ground, the positive electricity escapes from it, and, consequently, this layer becomes charged with negative electricity, as represented in Fig. 310.

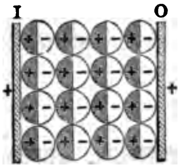

FIG. 309.

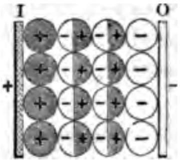

FIG. 310.

The outer surface is, therefore, charged by induction, and the negative electricity will not escape from it, because it is bound by the attraction of the positive on the inner surface. The amount of charge which a jar may receive is in proportion to the facility it has for induction. The thinner the glass the better; but if too thin, the polarization may rise high enough to cause a discharge sufficient to break the glass.

The charge is, therefore, dependent rather on the glass than on the coatings. This is shown by means of a jar with movable tin coatings, Fig. 311. If the parts be put together and the jar charged, the coatings may be removed and discharged: now, on replacing the parts, a charge may be received from the jar almost as strong as if the coatings had not been removed. So, also, the glass cup, B, may be charged separately by rotating its inner surface on a knob connected with the prime conductor, and then, after the two coatings are applied, the whole combination may be discharged by a single spark. Hence, the principal office of the coatings is that of a conductor to connect the polarized molecules of the glass.

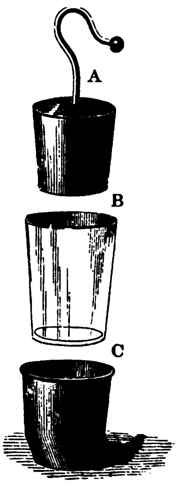

FIG. 311.

***686. If a series of jars*** be insulated *except the last,* as represented in Fig.

312, all may be charged simultaneously. The electricity repelled from the first, charges the second, and so on. This is called the *charge by cascade*. Each may be discharged singly, or they may be connected to form an electrical battery.

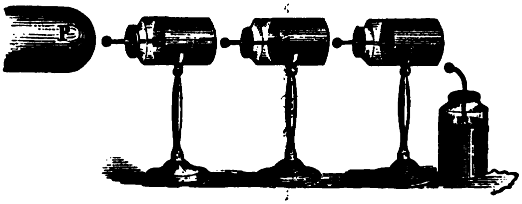

FIG. 312.

**687. A small quantity of free electricity** is usually found in a charged jar, which is due to the polarization of the air and other bodies surrounding the jar. If the jar be insulated, and the finger be brought near the knob, the free charge will pass to the finger. An equal spark may now be obtained from the outer coating. By touching alternately the inner and outer coating, an insulated jar may be gradually discharged.

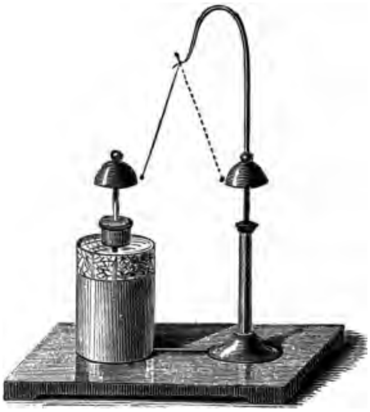

FIG. 313.

This is prettily shown by the apparatus in Fig. 313. Between the two bells, connected with the inner and outer coatings of the jar, is *suspended* a light copper ball, by means of silk thread. The ball is *attracted* first by one bell and then the other, and so on for a considerable time, receiving at each contact the free electricity of the bell, until the jar is discharged.

### ELECTRICAL PHENOMENA.

**688.** By means of the electrical machine and the Leyden jar, a great number of striking experiments may be performed, which illustrate the laws and exhibit the effects of electricity.

1. *Repulsion.* If a doll's head, with hair affixed to it, be placed on the prime conductor when the machine is in action, the hairs will stand out apart from each other, because they are charged with the same electrical force.

This experiment may be repeated by placing a person on an insulating stool. This is merely a low stool with glass legs. When the person 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.

2. *Attraction.* If a bystander place his hand near the hairs excited in the previous experiment, they will converge toward it. Negative electricity is induced in his hand, and the two bodies oppositely electrified attract each other.

3. *Attraction and repulsion. The electrical chimes,* Fig. 314, consists of two bells in metallic connection with the machine, and of a third bell insulated by a silk thread from the machine, but in communication with the ground. Between the bells are small brass balls suspended by silk threads. On working the machine, the outer bells become positively electrified, and induce negative electricity in the middle bell. The balls are, therefore, alternately attracted and repelled by the outer and inner bells, and thus a constant ringing is kept up.

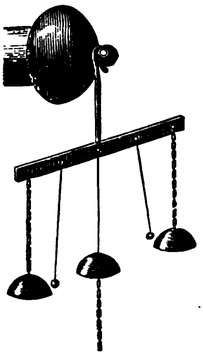

FIG. 314.

*The electrical hail* is exhibited by means of two metal plates, *one connected* with the machine, and the other with *the ground, as in* Fig. 315. If light pith balls be placed between the plates and the machine set in action, the balls will rise and fall in an irregular shower.

FIG. 315.

A variation of this experiment consists in placing grotesque figures of pith or paper between the plates.

**689. The kinds of discharge** are three: (1.) conductive, (2.) convective, (3.) disruptive.

*The conductive discharge* is effected without light, when the electricity passes through a good conductor.

*The convective discharge* is usually effected by the movement of particles of air passing away from a point on a charged surface. Solid particles may also be the medium of convective discharge, as in the case of the electrical hail. In such cases the electricity is *carried away* from the electrified body by means of these charged particles.

Quite a current of air may be detected by persons standing near the 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. 316. The reaction of the current upon the air is sufficient to move the wheel rapidly about.

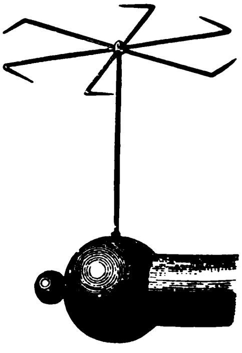

FIG. 316.

*Flames act as points.* If a candle be held near the charged conductor, the flame will be repelled, as shown in Fig. 317. If the candle be placed on the machine and a point be turned toward it, the flame will be driven in a contrary direction.

This is due to the current of air which sets out from the point, which has become negatively electrified by induction.

3. ***The disruptive charge*** is effected through a bad conductor, and is attended by the evolution of light.

**This light is not electricity, but is due to the molecular disturbance of the particles through which the electric force passes. This is proved (1.) by the actual transfer of solid particles from one conductor to another, and (2.) by the fact that the color of the light varies with the medium through which it passes.**

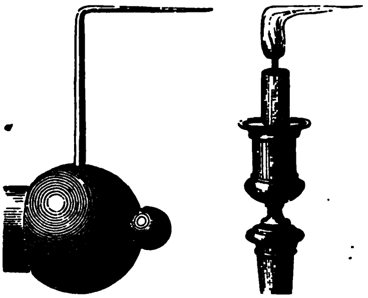

FIG. 317.

There are three varieties of the disruptive discharge: (1.) the spark, (2.) the brush, (3.) the glow.

*The spark* is the most energetic form of the discharge, and varies in form from a straight line to a zigzag line, with strongly marked lateral branches. *The brush* may be regarded as a rapid succession of feeble sparks. The brush is readily obtained when the discharge occurs between the edge of a metallic plate and a poor conductor. It has the form of a bush without leaves, and is accompanied by a low, hissing sound. When a feeble charge escapes from a point, the light is simply a quiet *glow.* This is best exhibited in the dark.

**690. 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,* Fig. 318, may be used for this purpose. It consists of a glass tube on which are pasted, in a spiral form, bits of tin foil. The *luminous pane is constructed on* the same principle on a pane of *glass.*

If the discharge is effected in rarefied gases, the effect is very beautiful. For this purpose a receiver, called the *Aurora tube*, Fig. 319, is used. In rarefied air, the light is intense and of a bluish color; in nitrogen, the sparks are more of a purple; in hydrogen, of a fine crimson color.

FIG. 318.

FIG. 319.

**691. Duration of the spark.** If Newton's wheel, Fig. 221, be set in very rapid revolution in a darkened room, and be illuminated by an electric spark, the wheel will appear stationary. This shows that the spark must be of very brief duration, inasmuch as it fails to illuminate the wheel in two successive positions. By applying this principle, it has been shown that the duration of the spark is less than one millionth part of a second.

**692. The velocity of the discharge** has been 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 of the jar. In this way three sparks were formed, which to the eye appeared simultaneous; but when they were viewed by means of a revolving mirror, they presented the appearance of three arcs of equal length, with the middle one rather behind the others Fig. 320.

FIG. 320.

*By* knowing the velocity with which the mirror revolved,

[redacted]

2, 4 8 16 32 64
4 8 16 32 64 128

32.16
4
128.64
16.08
144.72 feet traversed
5th Second

126

2

3 + (5 x 2) = 13

+128

16 16 16 16 16 16
13 11 9 7 5 3
3. 5. 7. 9. 11. 13

ccompanie... el...trica. discharge, has been t...

[redacted]

1 3 5 7 9

$1 + (4 \times 2) = 9$

$16, 8 + (4 \times 2) =$

8

2, 4 . 8 . 16. 32. 64

64. 32 16 8 4 2

$2 \quad 2\times2 . 2\times2^2 . 2\times2^3 . 2\times$

mer

showing the velocity with which the . . . or revolved the amount of retardation was found, and the velocity of the electric discharge in copper was estimated to be two hundred and eighty-eight thousand miles per second. The velocity varies with the intensity of the charge, and also with the nature of the medium.

**693. Calorific effects.** It has already been mentioned that coal gas may be ignited by a spark. Any combustible substance, as ether, alcohol, or phosphorus, is readily inflamed by a discharge from a single Leyden jar. Very thin wires may be melted by a discharge from a battery. It is noticeable, that those wires are heated most which are the worst conductors. Fig. 321 shows the arrangement employed to communicate an intense discharge. B is a battery of nine jars, J a discharging rod, furnished with two glass handles for safety, and U is called an universal discharger.

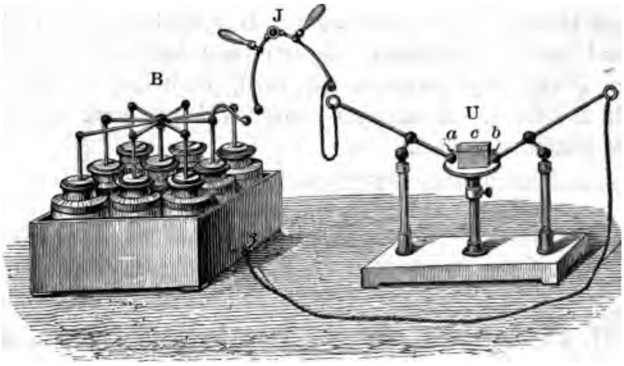

FIG. 321.

This 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 plate by a paper card, *c*, is instantly volatilized by a powerful discharge.

**694. Chemical effects.** Electricity is an efficient agent in *producing chemical* changes. The peculiar odor which *accompanies the electrical* discharge, has been traced to the formation of ozone, which is an active allotropic state of oxygen. If a succession of sparks be passed through ammonia, or through carbonic acid gas, it will be decomposed. The spark may also effect combination.


FIG. 322.

Thus, if two volumes of hydrogen and one of oxygen be mixed in the *electrical pistol*, Fig. 322, a single spark will cause them to combine with a loud explosion. To this same cause is attributed the presence of nitric acid in the air during a thunder-storm.

**695. The magnetic effects** of statical electricity are not as marked as those of dynamical electricity. Nevertheless, a steel wire may be magnetized by the discharge of a large Leyden jar.

**696. The mechanical effects** are shown when a discharge passes through a poor conductor. If a thick paper card be placed between the rods of the universal discharger, a moderate charge will perforate the card, producing a burr in both directions. A stronger charge will perforate a glass plate similarly placed.

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.

**697. Physiological effects.** A moderate discharge, sent through the human body, will produce a decided shock.

Quite a number of persons may receive the shock simultaneously. For this purpose all must join hands, the first touching the outside of a Leyden jar, and the last the knob. The Abbe Nollet communicated a shock to an entire regiment of thirteen hundred men. With large Leyden jars and batteries, the discharge is dangerous.

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, some form of dynamical electricity is *generally* employed.

## ATMOSPHERIC ELECTRICITY.

**698. Franklin demonstrated**, in 1752, that a flash of lightning is simply an enormous spark of electricity. This he proved by raising a silk kite at the approach of a storm. As soon as the rain had wetted his hempen kite string, and thereby rendered it a good conductor, he succeeded in drawing sparks from a key attached to the string, and in charging a Leyden jar.

It is now known that the atmosphere is sensibly electrical in all weathers, but that it varies both in the kind of electricity present and also in its intensity. It is more intense in summer than in winter, and, as a general rule, a little before noon than in the afternoon of each day. The development of this electricity has been attributed to the friction of the air, to combustion, to vegetation, and to the induction from the earth; and although many of these causes may contribute to the phenomena, it is now generally supposed that the principal source of atmospheric electricity is the evaporation and subsequent condensation of water.

**699. A cloud will become positively electrified** by the accumulation of the electricity which, before its formation, was disseminated through the particles of air which it contains.

The watery particles of the cloud being good conductors, permit the free discharge of the electrified particles, and thereby the electricity accumulates on the surface in considerable intensity.

**Negative clouds** may be similarly charged, but it is probable that the majority of them are due to the inductive action of a cloud more powerfully charged than themselves. By the presence of such a cloud their positive electricity will be repelled to other clouds or to the earth, and they will retain only negative electricity.

The earth beneath any cloud is subject to the same inductive action, and *will become, by consequence*, charged with electricity opposite *to that of the cloud.*

700. **Lightning.** The air between a strongly charged cloud and an oppositely charged adjacent body becomes polarized, and when the tension passes a certain limit, the two electrical forces unite with a dazzling flash of lightning. The lightning may therefore pass from cloud to cloud, from a cloud to the earth, or from the earth to a cloud.

701. **The thunder** is due to the violent commotion produced in the air by the passage of a flash of lightning. The rolling peal may be due to several reports produced by the same flash, or to the multiplied echoes reflected from the clouds and the earth, or to both causes combined.

702. **Heat lightning** is the name applied to bright flashes of light often observed in the horizon during summer evenings. This is generally due to the reflection by the atmosphere of ordinary lightning so distant that the thunder is inaudible.

703. **The distance of the lightning** may be computed by measuring the interval between the flash and the report.

The passage of light may be regarded as instantaneous, while sound moves about eleven hundred and twenty feet per second. Hence, if five seconds elapse between the flash and the thunder, the lightning must have been more than a mile distant. No danger need be anticipated in a thunder-storm, unless the quick succession of lightning and thunder indicates that electric clouds are near at hand.

704. **The position of greatest safety** during a thunderstorm is obtained, if out of doors, by taking shelter under low sheds and buildings. Tall trees or houses should be avoided, because elevated objects are most likely to receive the discharge. Within doors, a person may become insulated and, therefore, tolerably safe, by standing on a thick carpet, or by reclining on blankets and feather mattresses. It is always injudicious to stand near a good conductor that is not in free communication with the ground: hence, the chimney should be avoided because of the conducting power of soot; so, also, should bell wires, gilt moldings,

and open windows. Experience has also shown that cellars are unsafe places for refuge.

**705. Lightning conductors** are metallic rods used to protect buildings against the effects of lightning. The most available material is galvanized iron, tipped with gilded points. The rod should be continuous from top to bottom, and should terminate at the bottom in earth permanently moist.

A lightning rod affords protection in two ways: (1.) by preventing the flash. The nearer an object is to an electrified cloud, the greater will be the inductive action of the cloud on the object, and, by consequence, the greater the polarization of the air between them. Hence, if such objects are provided with a series of points extending to some distance above them, the electricity will be dissipated before it has attained sufficient tension to produce a disruptive discharge. If, however, the pointed rods are not sufficient to prevent this discharge, the rods protect the building (2.) by offering to the discharge the line of smallest resistance. The rod should be so large that it can not be melted, and should be connected with any external metallic surface, as tin roofs and gutters.

Experiment has shown that a rod protects a conical surface about it, the radius of whose base is approximately twice the height of the rod. Hence, when the building is large, it is necessary to have several points, projecting at various places from the roof, and to have all so connected as to form one or more conducting systems. If the lightning rod is badly constructed, as, for instance, if there are breaks in it, or if it terminates in dry earth, the danger is increased, because there is then greater liability to lateral discharge through the building.

**706. The Aurora Borealis**, or Northern Lights, are luminous appearances observed in the northern sky, of different colors and of variable brilliancy and forms. Similar phenomena, called the *Aurora Australis*, are witnessed in the southern hemisphere. Frequently they form great arches in the sky, more or less broken, traversed continually by great waves of light shooting across them. The brightest exhibitions are always near the poles.

*During the exhibition* of the aurora (1.) the magnetic needle is

[redacted]

disturbed, and this disturbance has been found to increase with the brilliancy and extent of the aurora. (2.) The telegraph lines are so far affected as to prevent sending intelligible dispatches. (3.) Nevertheless, telegraphs were worked without the aid of a battery during the auroras of 1859. (4.) In other ways the phenomena are so similar to those of electricity, that we are justified in assuming that auroral light is electric light.

It has not been settled whether the aurora and the effects described are not all due to magnetic currents, or whether the aurora is itself an electrical current producing these effects. Many observations indicate a maximum of brilliancy every ten years, which seems to point to some connection between the auroras, terrestrial magnetism, and solar heat. (658, 659.)

## 707. 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.
     - Glow.
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 decomposing compounds.
   - By effecting combination.
5. Magnetic ...... By affecting the magnetic needle.
6. Physiological.. In producing shocks.

## DYNAMICAL ELECTRICITY.

**708. All chemical actions** are attended by 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 has also been called *Galvanism* and *Voltaic electricity*, in honor of Galvani and Volta, who were among the first to study its phenomena.

**709. The fundamental phenomena** of dynamical electricity may be exhibited by means of the *simple Voltaic element*, Fig. 323. This generally consists of two metals plunged in a liquid which acts upon them unequally. The usual combination is 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. The chemical action takes place only between the zinc and the liquid, and may be thus explained: (1.) The water is decomposed, its hydrogen is liberated, and its oxygen combines with the zinc to form oxide of zinc. With water alone this action is very feeble, because the oxide of zinc soon forms an insoluble coating on the zinc plate.

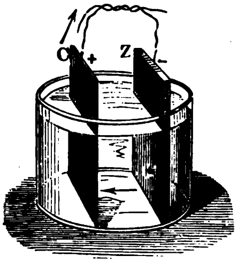

FIG. 323.

(2.) The principal use of the sulphuric acid seems to be to prevent the formation of this coating. This it does by uniting with the oxide to form sulphate of zinc, which

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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. All zinc employed in batteries requires to be frequently amalgamated. When thus treated, *commercial zinc acts* precisely as pure zinc; the amalgamation *removes from its surface* all impurities, and presents an uniform layer *of zinc dissolved in mercury* to the action of the liquid.

*N. P. 34.*

readily dissolves in the liquid and leaves the plate clean. The copper is not chemically acted upon, and serves merely as a conductor.

As soon as the plates are immersed, there is a slight disengagement of hydrogen from the surface of the zinc, 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. 324. The positive molecules are shaded to distinguish them from the negative. The outer extremity of the zinc plate is negative, while 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.

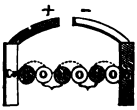


Fig. 324.

**710.** 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 is apparently 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 wires are separated. The operation of connecting the plates is called *closing the circuit,* and the separating of them is called *breaking the circuit.*

**711.** 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 a like manner, the same transference takes place throughout the whole series, until the hydrogen of the molecule of water next the copper is displaced. This hydrogen can not enter into chemical combination 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 re-combination of the opposite electricities. The current itself must be regarded as due to a constant series of polarization and discharge among all the molecules of the element, both liquid and solid, by reason of which there is a transmission of both electrical forces throughout the circuit. In confirmation of this, we find that the circuit manifests the same effects at any point where it is possible to test it. Nevertheless, it is convenient to use the term, current, to designate this transmission of force.

To avoid confusion, whenever reference is made to the direction of the current, only the positive is indicated. 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. The negative current passes in the opposite direction.

**712. The direction of the current** is dependent on the chemical action, and is, consequently, influenced both by the metals and the exciting liquid. Within the liquid, the current always sets out from the metal most easily acted upon, which is, therefore, called the *generating*, or *positive plate.* The other metal is called the *conducting*, or *negative plate.* The following table shows the electric deportment of several substances, with reference to three liquids, two of them dilute acids, and the third a solution of sulphide of potassium. Each metal is electro-positive with regard to any *one below it in the* list, and electro-negative with re*gard to any one above it.*

*Electro-motive Series.*

| Dilute Sulphuric acid. | Dilute Hydrochloric acid. | Solution of Sulphide of Potassium. |
|---|---|---|
| + | + | + |
| Zinc. | Zinc. | Zinc. |
| Lead. | Lead. | Copper. |
| Iron. | Iron. | Silver. |
| Nickel. | Copper. | Antimony. |
| Bismuth. | Bismuth. | Lead. |
| Antimony. | Nickel. | Bismuth. |
| Copper. | Silver. | Nickel. |
| Silver. | Antimony. | Iron. |
| — | — | — |

In dilute acids, iron is positive with respect to copper, in liquids containing alkaline sulphides, the order is inverted.

By dilute sulphuric acid is meant water to which from one-eighth to one-twentieth of its bulk of acid has been added. In all voltaic elements to be described, the electricity is generated by the action of this acidulated water upon amalgamated zinc. The sulphuric acid, however, may be replaced by a strong solution of common salt, or by weak hydrochloric acid, without loss of efficiency; but in such cases the chloride of zinc is formed, and hydrogen liberated.

Among the most decided electro-negative substances are silver, carbon, platinum, and iron in contact with strong nitric acid. Either of these substances, or copper, may be used for the negative plate.

**713. The electro-negative plate is protected** from chemical action, so long as it is in contact with an electro-positive plate.

Thus, if a slip of iron be placed in hydrochloric acid, it readily dissolves, but if a piece of zinc be laid on the iron, a voltaic circuit is formed, and the iron will remain untouched until all the zinc has been corroded. This accounts for the durability of "galvanized iron," which is iron coated with zinc.

Davy proposed to apply this principle for the protection of the copper sheathing of ships. The experiment was successful so far as the protection of the sheathing was concerned; but, unluckily, it was found that unless a certain amount of corrosion takes place in the copper, its surface becomes foul from the adherence of marine plants and animals, and thereby the sailing qualities of the vessel are impaired.

**714. 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 on the wire attached to the positive or zinc plate. These ends or terminals are called the *poles,* or *electrodes,* of the circuit. The name of the pole is always contrary to that of the plate to which it is attached. In most combinations zinc is used for the positive plate; the wire connected with it is the negative electrode or pole. The wire attached to the negative plate is the positive electrode or pole.

**715. The energy of the current** is proportional to the chemical activity of the element, or to the amount of zinc dissolved in a given time. It is greater the greater the difference in the affinity of the liquid for the two metals.

Thus, dilute sulphuric acid acts upon copper, when taken by itself, though to a less degree than upon zinc; hence, it tends to produce on the copper plate a current acting contrary to that developed on the zinc. The energy of the voltaic element is 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 two metals given in the series (712).

**716. The quantity of electricity** which a single voltaic element can develop, is proportional to the size of its generating plate. 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. Nevertheless, the intensity is very feeble.

The current ceases as soon as the circuit is broken, because it has not sufficient intensity to produce a discharge through the air. The enormous quantity but feeble intensity of dynamical electricity afford a striking contrast to the little *quantity but high* intensity of statical electricity. *For the reasons above* indicated, the electroscope can not be used, except in rare instances, to detect the current. The smallest current may be at once detected and measured by its effects on the magnetic needle. The galvanometer used for this purpose is described in (739).

**717. The intensity** will be increased in proportion as the resistance to polarization and discharge is increased. The resistance to the current arises (1.) from the liquid employed in the element, and (2.) from the substances used to connect the poles. The better the conducting power of a substance, the less will be the resistance to be overcome by the current.

When solids are employed, *the resistance increases with the length of the conductor, but diminishes as the area of its section increases.* Hence, the shorter and thicker the connecting wire, the less will be the resistance. The same law is approximately true of liquids; 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.

**718. The conducting power** of different substances, having equal dimensions is shown by the following table, in which silver is taken as the standard:

| 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 zinc, saturated solution... | .00000577 |
| Lead .......... | 8.3 | Sulphate of copper, saturated solution | .00000542 |
| Carbon ....... | .04 | Distilled water ............................... | .00000001 |

From this it follows, (1.) that a silver wire one hundred feet long offers less resistance to a current than an iron wire of the same thickness seventeen feet long. (2.) That if two conductors are of equal length, their conducting powers may be rendered equal by making the poorer conductor proportionally thicker. Hence, a thick bar of carbon may be even a better conductor than a thin wire of silver. (3.) That the resistances offered by liquids are enormous as compared with solids. Hence, the resistance to the current, caused by the liquid between the plates, is ordinarily far greater than in the conducting wire. If the poles are connected by short and thick copper wires, the resistance offered is practically nothing.

It will also be noticed that pure water, which is a good conductor for statical electricity, is almost a non-conductor of the current. Its conducting powers are vastly improved by the presence of foreign substances in solution. This is one reason why acidulated water is always used in these experiments.

## VOLTAIC BATTERIES.

**719. A voltaic battery** consists of several voltaic elements, 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 similar plates are connected together, as represented in Fig. 325, the effect will be the same as that of a single element having a zinc plate of six square inches, one inch distant from its copper plate. Either arrangement is called a *simple voltaic circuit.*

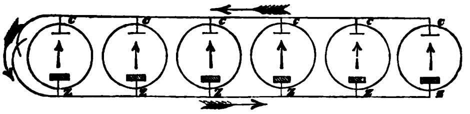


FIG. 325.

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. 326. The zinc dissolved and the electricity *generated* will be the same as in the simple *circuit, but now the* electrical force has to perform addi-

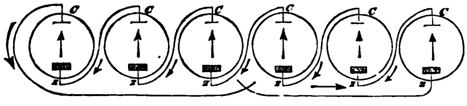


FIG. 326.

tional work because the resistance is increased. For in the simple circuit the space traversed by the current is but one thickness of the liquid, but in the compound circuit, as there is a separate starting point in each element, the current must pass through six equal thicknesses.

The discharge will not be effected until the polarization rises in proportion to the resistance offered, and, consequently, the intensity of the current will be increased. Where the plates are of equal size, the intensity of the current is proportioned to the number of elements compounded.

A simple circuit is sometimes called a *quantity* battery, and a compound circuit an *intensity* battery. As the intensity is obtained at the expense of the quantity, we can not expect to have a battery which shall at once exhibit the maximum intensity and the maximum quantity. For ordinary purposes, we require batteries having some intensity and considerable quantity. This may be obtained by first grouping the elements in simple circuits of two, three, or more, and then connecting the groups to form compound circuits. A good arrangement for six elements is represented in Fig. 327.

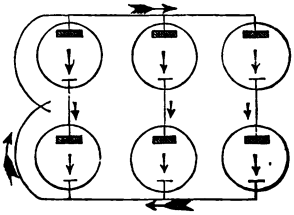


Fig. 327.

**720. Numerous batteries** have been constructed on the principle of the simple voltaic element, Fig. 323, but most of them have gone out of use, because of the rapid enfeeblement of their currents.

This may occur (1.) from the gradual consumption of the sulphuric acid and the zinc, and (2.) from *local action*. By local action is meant the production of small closed circuits on the surface of the positive plate, which are due to particles of lead and iron adhering to the zinc. All batteries are subject to these defects, which may be remedied, the former, by the renewal of the acid and the zinc; and the latter, by amalgamating the zinc. When the zinc is well amalgamated, no chemical action takes place until the circuit is closed.

(3.) Besides these defects, the older batteries were subject to *secondary currents*, acting opposite to the principal current. In the action of the simple element, the hydrogen is apparently evolved from the copper. In 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 sulphate of zinc, and thereby forms a layer of metallic zinc on the copper. Hence, the two plates become gradually less different, and the current is weakened.

**721. Constant batteries** obviate this last defect by preventing the permanent deposition of the hydrogen on the negative plate. Over fifty forms of batteries have been devised, from which the following are selected for description:

**I. One fluid batteries.**—1. An element of Smee's battery consists of a silver plate, placed between two plates of zinc, and suspended vertically in dilute sulphuric acid, Fig. 328. The silver plate is coated with platinum in the state of a fine powder. This coating renders the surface of the plate rough, and prevents the adherence of the hydrogen to the plate by its mechanical action.

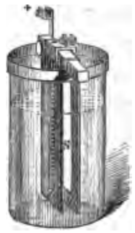


FIG. 328.

In the other batteries to be described, the hydrogen is removed from the circuit by entering into chemical combination with the liquid surrounding the negative plate.

2. *The bichromate of potassa battery* resembles Smee's in its general appearance. The liquid is a solution of ten parts of bichromate of potassa, seventeen of sulphuric acid, and one hundred of water. The negative plate is a cylinder of carbon.

Bunsen's carbon is made by calcining a mixture of coke and bituminous coal *in iron molds*. The carbon is placed either between *two plates of zinc or in the* inside of a zinc cylinder. The zinc dissolves in the acidulated water, and the liberated hydrogen combines with a portion of the oxygen of the chromic acid, reducing it to oxide of chromium.

This battery is not constant in its action, but is one of the cheapest forms. The best carbon is that which forms on the interior surface of gas retorts. Any one who can obtain fragments of this in a somewhat cylindrical form can construct a serviceable battery for himself. The connections may be made by means of the binding screws shown in the figures, or by twisting copper wires tightly about the upper portion of the plates.

3. Small but very energetic batteries have recently been constructed in a similar manner, by immersing zinc and carbon plates in a saturated solution of sulphate of mercury. The zinc decomposes the water and liberates hydrogen; the hydrogen displaces the mercury in the sulphate, forming sulphuric acid, which dissolves the oxide of zinc, while the effect of the freed mercury is to amalgamate the zinc.

**722. II. Two fluid batteries.** A simple Voltaic element may also be made of two solids and two fluids. The fluids are kept from mixing by means of a thin partition, more or less porous. The most efficient substances for this purpose are animal membranes, like thin parchment or bladder; but the most convenient form is that of a *porous cup*, made of unglazed earthen ware. The porous cup contains one liquid and one plate, and is placed in a glass vessel, which also contains the other plate and the other liquid. There is no fixed order of arrangement; but, to increase the size of the generating plate, the zinc is commonly cast in the form of a hollow cylinder, large enough to receive the porous cup within it, and is itself placed in the outer glass vessel, together with dilute sulphuric acid.

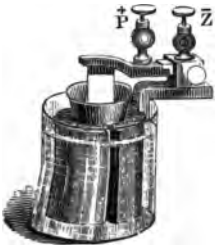


FIG. 329.

4. In *Grove's battery*, Fig. 329, the porous cup contains strong nitric acid, in which is placed a slip of platinum

to serve as the negative plate. Zinc and dilute sulphuric acid are placed in the outer vessel.

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 deep red fumes, which are tetroxide of nitrogen, an extremely offensive and poisonous gas.

5. *Bunsen's battery*, Fig. 330, 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 but less intensity than Grove's.

To avoid the production of the noxious fumes, the nitric acid is frequently replaced by the solution used in the bichromate of potassa battery. Strong brine may be used in place of the sulphuric acid.

FIG. 330.

6. *Daniell's constant battery*, Fig. 334, was the first devised, and is still in use. It is more constant in its action than either Bunsen's or Grove's, though not as powerful. It may be readily constructed by placing within a porous cup dilute sulphuric acid and a rod of zinc, and, in the outer vessel, a thin roll of copper, with a saturated solution of sulphate of copper. As the hydrogen is liberated by the action of the zinc, it enters the solution of 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 through the porous cup and replaces the acid which was neutralized by the zinc.

By placing crystals of sulphate of copper around the copper plate, to replace that which is reduced, the action of the battery may be maintained for months.

**723. III. Other batteries** have been devised containing two fluids and one metal. Grove's gas battery employs the oxygen and hydrogen liberated by the decomposition of water to produce secondary currents when the primary has ceased. These batteries are very interesting in a theoretical point of view, but as they are of little practical importance, no further description of them will be given.

### 724. Recapitulation.

I. A voltaic element consists of

| | |
|---|---|
| 1. Two metals and one liquid...................... | Smee's.<br>Bichromate.<br>Mercurial. |
| 2. Two metals and two liquids.................... | Grove's.<br>Bunsen's.<br>Daniell's. |
| 3. One metal and two fluids...................... | Gas. |

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 chemical action upon one metal.
4. To a transfer of the fluid molecules.

III. The voltaic current is characterized

1. By its enormous quantity.
2. By its feeble intensity.

| | |
|---|---|
| IV. The voltaic circuit may be......................... | Simple.<br>Compound. |

THE PHENOMENA OF DYNAMICAL ELECTRICITY.

**725. The effects of the current** are manifested either (1.) within its path, or (2.) external to its path. The *former* will be first considered.

*1.* **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. 331. 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 if one pole of a battery touches the nerves 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. The more frequently and abruptly the current is broken and closed, the greater will be the physiological effect. This remark also applies to the effects of the current on living animals.

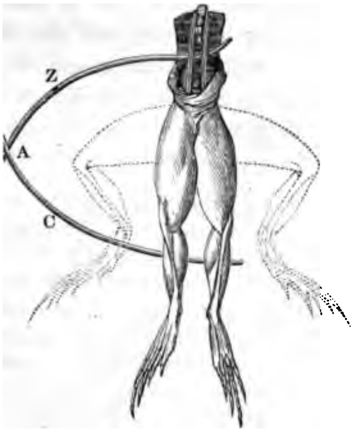


FIG. 331.

If the electrodes of a strong battery be grasped with the hands, previously moistened, a shock will be experienced, resembling that from a Leyden jar; but unless the number of elements be 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 silver plate beneath the tongue, a peculiar taste will be experienced when the two metals are made to touch. If the silver be placed between the gums and the cheek, as often as the metals are made to touch, not only will the taste be perceived, but a flash of light will appear to pass before the eye.

By means of a very powerful current, transmitted through animals recently killed, all the vital actions may be reproduced, though imperfectly. In some cases of drowning and suffocation, the current has been used with success to restore animation after it had been suspended for some time.

**726. Calorific effects.** When a voltaic current is transmitted through a metallic wire, more or less resistance is experienced, which is dependent both on the quantity of electricity and the conducting power of the wire. Heat is always developed in proportion to the amount of resistance, as in the analogous case of mechanical friction. Hence, if the current be strong, and the wire an insufficient conductor, the wire will be heated, and, if quite thin, may become incandescent, or even dissipated in vapor. All the metals have been fused in this manner, and even carbon has been so softened that it could be welded.

When other conditions are the same, the worst conductor will be the soonest 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. As this can be done at a great distance from the battery, and even under water, it has been turned to account in exploding torpedoes, and in blasting rocks. It has also been applied as a cautery in surgical operations.

**727. Luminous effects.** No spark is obtained unless the poles are first brought in contact, or nearly so. One-twentieth of an inch of air, or any other non-conductor, is sufficient to prevent the discharge of a battery containing several thousand elements. Gassiot succeeded in obtaining sparks .02 of an inch long, which continued without interruption, in rapid succession, for five weeks, but to obtain this result he constructed a battery of three thousand five hundred and twenty pairs of zinc and copper plates, insulated with every possible precaution, and charged with water only.

With a moderately strong battery, sparks may be obtained at the moment the circuit is closed or broken. If two files are fastened to the terminal wires, very brilliant sparks may be produced by rubbing the point of one over the teeth of the other. A most brilliant electric light is obtained by connecting the terminals with cylinders of dense carbon, as shown in Fig. 332. 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, which is called the *Voltaic arc.*

FIG. 332.

With forty-eight Bunsen's elements, the arc is about one-fourth of an inch long. The light is of far greater intensity than that obtained by the oxy-hydrogen blowpipe, being equal to five hundred and seventy-two wax candles. With six hundred elements, the arc is nearly eight inches long, and may be said to rival the sun in brilliancy. The presence of oxygen is not necessary to its formation, as it may be produced in highly rarefied nitrogen, or other gases, with nearly equal brilliancy as in air.

The light is not due to combustion, but to the transference of intensely heated particles of carbon from the positive to the negative electrode. In consequence of this, the positive electrode gradually wears away, and, at the same time, a deposit is formed on the negative electrode. 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, but is more effectually accomplished by regulators moved by clockwork, and constructed so as to act automatically.

This apparatus is admirably adapted for the display of optical phenomena in the class room, and for illumination in theaters, but the light is not 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 an obstacle to its use, as it throws the shadows into too strong relief, and acts injuriously upon the eye.

The most refractory substances, as platinum, quartz, and lime, when introduced within the voltaic 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. These effects are caused mainly by the dispersion of the metallic particles in vapor, although they may be heightened by the combustion of a portion of the metals.

**728. Chemical effects.** If a chemical compound, in a liquid state, be placed between the electrodes and 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. A body capable of this decomposition is called an *electrolyte*, and the process itself is called *electrolysis*.

Fig. 333 represents a very convenient apparatus to show the decomposition of water. It consists of a glass vessel having a cork bottom, through 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 the battery. Five of Grove's or of Bunsen's elements will cause a rapid decomposition of the water; bubbles of gas will collect in the tube above each pole.

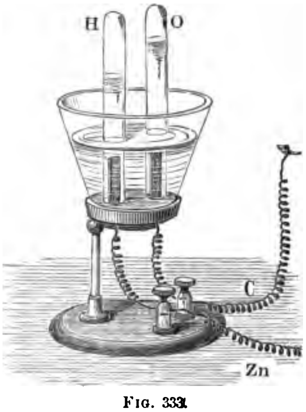


FIG. 333

On examination, it is found that hydrogen rises from the negative pole and oxygen from the positive. About twice as much hydrogen is liberated as oxygen, and hence this experiment serves both as a qualitative and quantitative analysis of water.

If the water were perfectly pure, very little decomposition would be effected, because of the non-conducting properties of pure water. If the conduction were perfect, the same amount of oxygen should be set free in the tube as combines with the zinc in the battery. By employing the same conductors, but varying the number of elements, it will be found that the gases evolved are in proportion to the amount of zinc consumed; hence, the strength of a battery may be measured by the amount of water it can decompose in a given time. An apparatus used for this purpose is called a *Voltameter.*

**729. The decomposition of other bodies** may be effected by a similar apparatus, provided care be taken to make the electrodes of some conductor that is not attacked by the compound or by any of its constituents. Hydrochloric acid, for instance, consists of equal volumes of hydrogen and chlorine; but as chlorine attacks all the metals, the electrodes must be of gas carbon.

If the electrodes be plunged in solutions of binary compounds, like chloride of copper, iodide of potassium, the metals will 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. An electro-chemical series has been arranged, in which any one in the list is electro-negative to any following it, but electro-positive to any preceding it.

The following is a portion of *Berzelius' electro-chemical series:*

| — | + |
|---|---|
| Oxygen, | Rubidium, |
| Sulphur, | Potassium, |
| Chlorine, | Zinc, |
| Iodine, | Iron, |
| Phosphorus, | Copper, |
| Arsenic, | Silver, |
| Carbon, | Platinum, |
| Antimony, | Gold, |

Hydrogen.

±

**730. Ternary salts** are also decomposed by the current, the metal going to the negative pole, and the acid, or the body *which is chemically* equivalent to it, going to the pos*itive pole.*

If a solution of sulphate of copper is decomposed by two copper electrodes, metallic copper will be deposited on the negative pole, while the positive pole will be dissolved to an equal amount, but no gas will be liberated. If the positive electrode be of platinum, bubbles of oxygen will be liberated from it, but copper will be deposited on the negative electrode as before. To explain this action, it is convenient to represent the composition of sulphate of copper by the formula $CuSO^4$. By electrolysis, this is supposed to divide into an electro-positive constituent, copper, and an electro-negative constituent, $SO^4$, to which the name *sulphion* has been given. This sulphion can not exist in a free state, and when it arrives at the positive electrode, a *secondary action* takes place, which is purely chemical. The $SO^4$ decomposes into anhydrous sulphuric acid, $SO^3$, and into oxygen.

If the oxygen can enter into combination with the electrode, an oxide is formed which immediately unites with the liberated acid and dissolves in the liquid; but if the electrode can not be oxidized, the oxygen is liberated as free gas, while the $SO^3$ combines with water to form ordinary sulphuric acid $H^2O, SO^3$.

Thus, in the case supposed, if the positive electrode be of copper, it is first oxidized and then dissolved as sulphate of copper. The solution, therefore, remains of the same strength, for as fast as it is decomposed in one part of the circuit, it is reproduced at another. If the electrode be of platinum or carbon, oxygen and the free acid collect at the positive pole, and the solution becomes gradually weaker, from the abstraction of the copper.

The decomposition of other salts, as nitrate of silver, $AgNO^3$, cyanide of gold, $AuCy^3$, or the cyanide of silver, $AgCy$, will be understood from these examples.

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 to a considerable degree 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.

**731. Electro-metallurgy** is the art of depositing the metals from solutions of their salts, by means of the electric current. The principles on which this art is founded have already been explained.

The solution is decomposed and the pure metal is deposited on the negative electrode. This may consist of any article whatever that possesses a conducting surface. If the material is non-conducting, the surface may be rendered conducting by covering it with finely powdered graphite, applied by means of a brush of camel's hair. The positive electrode, C, Fig. 334, should be a plate of the same metal as that to be deposited, in order that it may be dissolved by the acid which is liberated, and thus maintain the strength of the solution.

**732. The processes of electro-metallurgy** may be arranged in two divisions: (1.) those in which the deposit remains permanently fixed on the electrode; (2.) those in which the deposit is intended to be removed. The first may be represented by *electroplating*, and the second by *electrotyping*.

**Electroplating.** The apparatus employed in electroplating is represented in Fig. 334. 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 polishing* and burnishing.

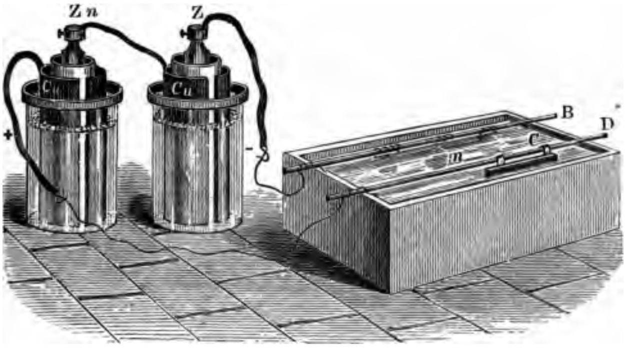


FIG. 334.

By a similar process, articles may be electro-gilded, or coated with copper, nickel, and several other metals. When iron, tin, zinc, or Britannia metal are to be electroplated or gilded, the articles must first be electro-coppered in order to secure the adhesion of the silver or the gold. All solutions do not deposit equally well; the soluble chlorides are generally employed; gold and silver are deposited from their cyanides; copper, as a general thing, from its sulphate.

**733. Electrotyping.** When a medal has been electro-coppered, the coating, if sufficiently thick to be stripped off whole, will give a surface the exact reverse of the medal, even to the finest lines. If this reversed copy, or mold, be attached to the negative electrode, a second copy may be formed which will exactly resemble the original. Any object may be copied in this manner, but, in the ordinary processes of electrotyping, it is usual (1.) to form a mold of the object in wax, gutta-percha, or plaster, and (2.) then to deposit within this a sufficiently thick coating of some metal, which is usually copper.

Thus, suppose we desire to copy a medal in copper. It is first rubbed over with graphite, and the excess of graphite blown off; then (2.) an impression 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.) it 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 by this process.

**734.** The student may easily copy seals, coins, and other small articles, without the aid of a battery, by the simple means shown in Fig. 335. 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 combination is evidently equivalent to a single element of

Daniell's battery. The connecting wire, and any part of the object which it is not desired to copy, must be carefully coated with wax or some resinous varnish.

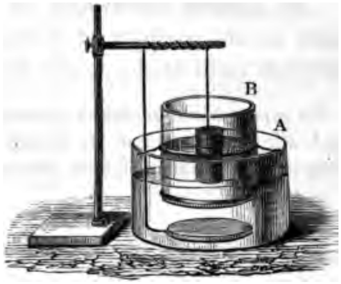


Fig. 335.

The applications of electrotyping are very numerous. By means of it engraved plates, wood cuts, seals, bas reliefs, and other objects may be reproduced in copper, and an unlimited number of copies obtained without injuring the original in the least.

### 735. Recapitulation.

The effects of the current within its path are:

| | |
|---|---|
| 1. Physiological | Applied in disease. |
| 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.

**736. 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.

**It is also found** that permanent magnets may act inductively on conducting wires, and thereby give rise to electrical currents *without the aid* of a battery. The study of these *phenomena belongs to magneto-electricity.*

## ELECTRO-MAGNETISM.

**737. 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.

To repeat his experiment, a magnetic needle is placed on a pivot and allowed to assume its natural position in the direction of the magnetic meridian. If, now, the conducting wire of a voltaic current be held parallel to the needle; the needle will be deflected and ultimately assume a position which is more nearly at right angles to the magnetic meridian, as the current is more intense.

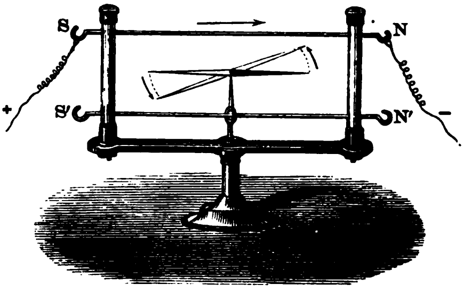


FIG. 336.

**738. The direction** in which the needle should turn, may be remembered by the following rule, devised by Ampère:

*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 always 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 be deflected toward the west. The same deflection will take place if the current passes below the needle from north to south.

*Hence*, if the wires, N S, N′ S′, be connected so that the current shall pass around the needle, the deflecting power of the current will be doubled. By coiling the wire several times around the needle, provided that the coils are insulated from each other, the deflecting

**power of the current will be so multiplied that the needle 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 termed a *galvanometer*.**

**739. The sensibility of the galvanometer** may also be increased by the use of an *astatic needle*. This consists of two magnetic needles, Fig. 337, fastened in the same axis of suspension, but with their poles reversed. If these are suspended by a silk thread, so that one needle swings freely within the coil and the other above it, they constitute the *astatic galvanometer*, shown in Fig. 338. The advantages of this instrument are: (1.) the directive force of the earth on the needle may be almost neutralized, because the poles of th

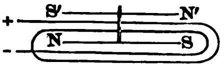


FIG. 337.

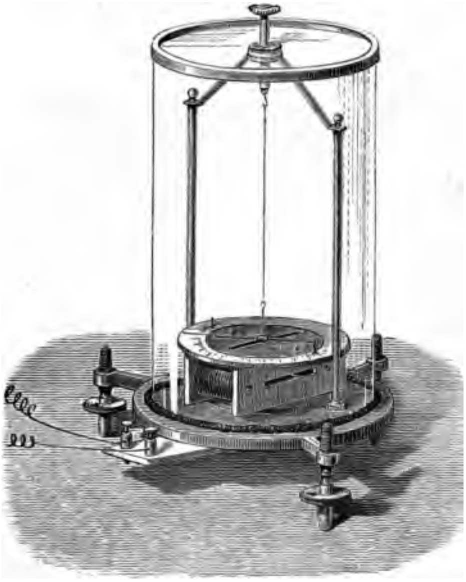


FIG. 338.

needles lie in opposite directions. (2.) The force of the coil is exerted in the same direction upon two needles instead of one. For, although the upper needle is subject to the action of two opposite currents, yet as that in the upper part of the coil is much the nearer, its action preponderates, and, because the needles are reversed, both are deflected in the same direction.

The wire used in this, and in other coils, should be carefully insulated, by being covered with white silk thread. A coil having a few hundred turns of moderately thick copper wire is well adapted for ordinary experiments; but, for very delicate investigations, as many as thirty thousand turns of fine wire have been used.

**740. 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.

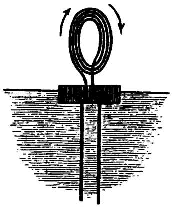


Fig. 339.

De la Rive's floating battery, Fig. 339, will enable us to verify this fact, as well as to exhibit other properties of the current. It consists of a small voltaic element, which is floated in acidulated water by means of a cork attached to its upper end. The conducting wire may be made straight, rectangular, or coiled. The spiral coil shown in the figure is technically called a *helix*. An elongated helix, with its conducting wire returned through the axis of the coil, is a *solenoid*, Fig. 341. The coil is *right-handed*, when its spire winds to the right, like a corkscrew, and is *left-handed* when its spire winds in the opposite direction.

**741. By means of this apparatus,** it may be shown that when a current is passing through the wire, it exhibits all the properties of a magnet.

1. If a permanent magnet be held near the helix, one face of the coil will be attracted by the north pole of the magnet, and the other repelled.

2. Each side of the helix will attract iron filings.

3. If a helix or solenoid be free to move, it will swing so that its axis points north and south. If the coil be

right-handed, the south pole will be the end at which the current enters; but if the coil be left-handed, the north pole will be the end at which the current enters.

4. If the conducting wire of the 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 contrary directions.*

The attraction of similar currents may be shown by means of a spiral of fine copper wire, connected at its upper end with the positive pole of a battery, and slightly dipping, at its lower extremity, in a cup of mercury, which is in connection with the negative pole. When the current passes, each turn of the spiral attracts the next, thereby shortening the spiral, and breaking the current with a spark. The weight of the wire then restores the connection, and thus a continuous oscillation is sustained.

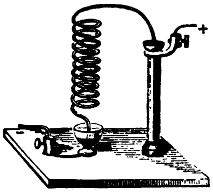


FIG. 340.

5. If two solenoids are brought near each other, Fig. 341, *with their similar* ends adjacent, they will repel each *other, because the* currents of the two coils are in opposite

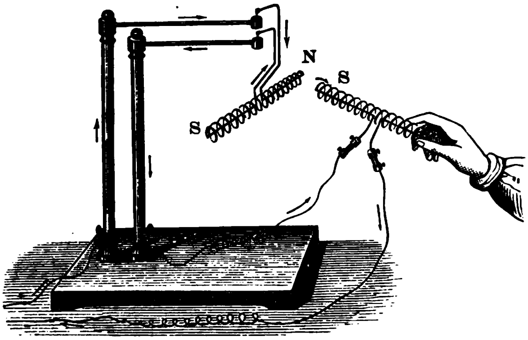


FIG. 341.

directions. Conversely, the dissimilar ends will attract each other.

**742. Electro-magnetic rotation.** We have seen that the current acts at right angles to a magnet, and tends to urge the north pole of a magnet always toward the left. Hence, it is possible so to arrange the connecting wire and the magnet, that one shall revolve about the other. There are many contrivances for accomplishing this, one of which is shown in Fig. 342.

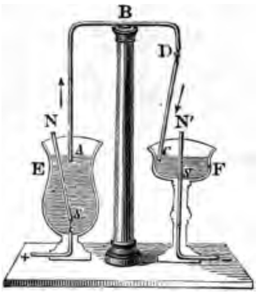


FIG. 342.

E and F are two glass cups containing mercury. A B C is a conducting wire, jointed at D, and dipping at each end in the mercury. N S, N′ S′, are two bar magnets, one fixed and the other attached by a thread to the bottom of its cup. If, now, a current is passed through the mercury and the conducting wire, there will be a mutual repulsion between the ends of the magnets and the conducting wire. The magnet, N S, being free, will revolve about the end, A, of the wire; but in the other cup, as the magnet is fixed and the wire free, the wire will revolve about the magnet, N′ S′. When the current passes in the direction of the arrows, both rotations will be to the left; but if the current is passed in the opposite direction, the rotations will be to the right.

**743. The voltaic current** may also induce magnetism in magnetic substances. If a bar of soft iron, N S, be placed in the axis of a helix, so that the current may pass at right angles to its length, the bar will be instantly magnetized, but will lose its magnetism as soon as the current ceases. If the helix is held vertically while the current is passing, 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. With a powerful current and a

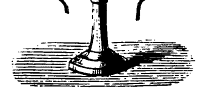
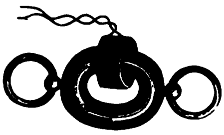


FIG. 343.

large coil, a weight of several hundred pounds may be suspended from the bar, and the whole sustained without any visible support.

A pleasing modification of the same experiment may be had by joining the ends of two semicircular pieces of soft iron, with one pair of the ends within the helix, as shown in Fig. 344. While the current is passing they will adhere with considerable force.



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**744. 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 coils of insulated copper wire. When a strong current is passed through the wire, 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. 345.

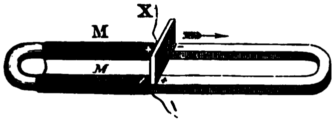
The polarity of an electro-magnet depends upon the direction in which the current moves in the helix. If the direction be reversed the polarity will be reversed. If the current is broken the magnetism almost instantly ceases.

**745. Permanent magnets.** If the iron employed in electro-magnets is not quite pure, it will retain traces of magnetism for some time after the circuit is broken. A steel bar placed in the helix, Fig. 343, will become permanently magnetized.

It is sufficient to move the bar once nearly through the coil, then backward *till it lies in the* center of the coil; the current is then *stopped and the bar taken* out. A better result will be attained, if

the bar be previously armed with short cores of soft iron, which just fit the ends of the helix. This method may also be applied to horse-shoe magnets of steel.

**Permanent horse-shoe magnets** may be made of steel wrought in the proper shape, by connecting their open ends with a keeper of soft iron, while an electro-magnet is passed along a few times from the poles to the bend.



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A better method is that shown in Fig. 346. The steel horse-shoe is applied to the 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 repeated. Both magnets are then turned over without separating the poles, and the other side treated in the same way. Magnets have been made in this manner so as to be capable of sustaining twenty-six times their own weight.

**746. Ampere's theory of magnetism.** In view of these various magnetic properties of the current, Ampère assumes that all bodies which exhibit polarity derive this polarity from electrical currents, which are perpetually traversing each molecule of a magnetic substance. Magnetization consists in giving to these individual currents a parallel direction. When all the currents are parallel, the magnet is said to be *saturated.*

The resultant of these parallel currents is equal to a single current which traverses the outside of a magnet as if it were a solenoid. At the north end of a magnet, the

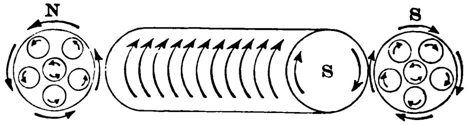


FIG. 347.

direction of these currents is opposite to that of the hands of a watch, and at the south end the direction is the same

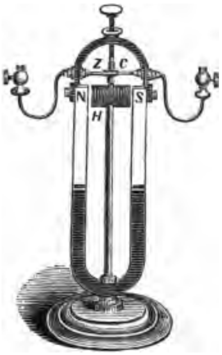
as that of the hands. In this view of the subject, magnetism is a branch of dynamic electricity.

This theory does not assign a reason for the persistence of currents in permanent magnets, but in other respects affords a satisfactory explanation of all magnetic phenomena. For instance, it explains why like poles attract and unlike repel. If two south poles are brought near each other, they have opposite currents on their adjoining sides, and hence repel. A north and south pole have similar currents on their adjoining sides, and attract.

## ELECTRO-MAGNETIC MACHINES.

**747. Various machines** have been devised in the hope of employing the prodigious force of electro-magnets as a motive power. All of these take advantage of the facility with which the polarity of an electro-magnet may be annulled or reversed, by which attractions and repulsions may be so arranged with another magnet as to produce a rotary or alternating motion.

The action of the first class may be illustrated by Page's revolving electro-magnet, Fig. 348.



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A small electro-magnet, H, is fixed to a vertical shaft so as to revolve between the poles of a permanent horse-shoe magnet. The ends of the wires of the helix are soldered to two strips of silver on opposite sides of the shaft, insulated from each other and from the shaft. Two metallic springs, Z, C, connecting with the battery, are so placed that when the shaft makes half a revolution, the silver strips pass from one spring to the other. This reverses the direction of the current in the helix, and thereby causes the poles of the electro-magnet to be changed twice in each revolution.

The position of the two magnets is such that, during the first quarter of a revolution, their like poles are adjacent and repel; during the second quarter, their unlike poles approach and *attract.* The current is then reversed, like poles again face each other and are repelled. The shaft is thus made to rotate,

By a similar process, articles may be electro-gilded, or coated with copper, nickel, and several other metals. When iron, tin, zinc, or Britannia metal are to be electroplated or gilded, the articles must first be electro-coppered in order to secure the adhesion of the silver or the gold. All solutions do not deposit equally well; the soluble chlorides are generally employed; gold and silver are deposited from their cyanides; copper, as a general thing, from its sulphate.

**733. Electrotyping.** When a medal has been electro-coppered, the coating, if sufficiently thick to be stripped off whole, will give a surface the exact reverse of the medal, even to the finest lines. If this reversed copy, or mold, be attached to the negative electrode, a second copy may be formed which will exactly resemble the original. Any object may be copied in this manner, but, in the ordinary processes of electrotyping, it is usual (1.) to form a mold of the object in wax, gutta-percha, or plaster, and (2.) then to deposit within this a sufficiently thick coating of some metal, which is usually copper.

Thus, suppose we desire to copy a medal in copper. It is first rubbed over with graphite, and the excess of graphite blown off; then (2.) an impression 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.) it 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 by this process.

**734.** The student may easily copy seals, coins, and other small articles, without the aid of a battery, by the simple means shown in Fig. 335. 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 combination is evidently equivalent to a single element of

Daniell's battery. The connecting wire, and any part of the object which it is not desired to copy, must be carefully coated with wax or some resinous varnish.

The applications of electrotyping are very numerous. By means of it engraved plates, wood cuts, seals, bas reliefs, and other objects may be reproduced in copper, and an unlimited number of copies obtained without injuring the original in the least.

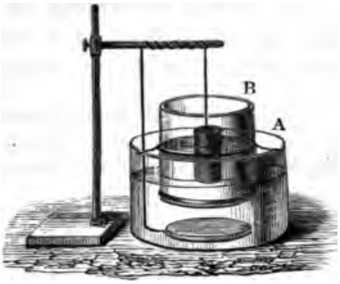

FIG. 335.

### 735. Recapitulation.

The effects of the current within its path are:

1. Physiological............Applied in disease.
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PHENOMENA EXTERNAL TO THE PATH OF THE CURRENT.

**736. 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.

**It is also found** that permanent magnets may act inductively on conducting wires, and thereby give rise to electrical currents *without the aid* of a battery. The study of these *phenomena belongs to magneto-electricity*.

## ELECTRO-MAGNETISM.

**737. 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.

To repeat his experiment, a magnetic needle is placed on a pivot and allowed to assume its natural position in the direction of the magnetic meridian. If, now, the conducting wire of a voltaic current be held parallel to the needle; the needle will be deflected and ultimately assume a position which is more nearly at right angles to the magnetic meridian, as the current is more intense.

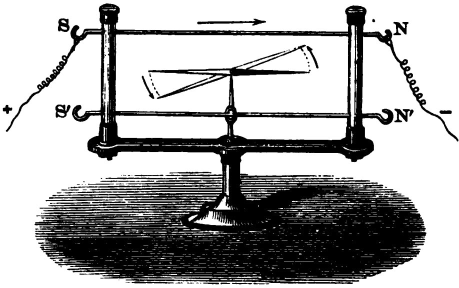


FIG. 336.

**738. The direction** in which the needle should turn, may be remembered by the following rule, devised by Ampère:

*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 always 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 be deflected toward the west. The same deflection will take place if the current passes below the needle from north to south.

*Hence,* if the wires, N S, N′ S′, be connected so that the current *shall* pass around the needle, the deflecting power of the current will *be doubled.* By coiling the wire several times around the needle, *provided* that the coils are insulated from each other, the deflecting power of the current will be so multiplied that the needle 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 termed a *galvanometer.*

**739. The sensibility of the galvanometer** may also be increased by the use of an *astatic needle.* This consists of two magnetic needles, Fig. 337, fastened in the same axis of suspension, but with their poles reversed. If these are suspended by a silk thread, so that one needle swings freely within the coil and the other above it, they constitute the *astatic galvanometer,* shown in Fig. 338. The advantages of this instrument are: (1.) the directive force of the earth on the needle may be almost neutralized, because the poles of the

FIG. 337.

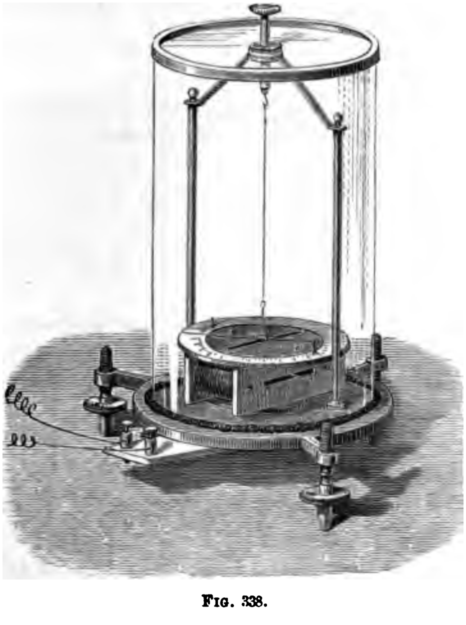


FIG. 338.

needles lie in opposite directions. (2.) The force of the coil is exerted in the same direction upon two needles instead of one. For, although the upper needle is subject to the action of two opposite currents, yet as that in the upper part of the coil is much the nearer, its action preponderates, and, because the needles are reversed, both are deflected in the same direction.

The wire used in this, and in other coils, should be carefully insulated, by being covered with white silk thread. A coil having a few hundred turns of moderately thick copper wire is well adapted for ordinary experiments; but, for very delicate investigations, as many as thirty thousand turns of fine wire have been used.

**740. 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. 339, will enable us to verify this fact, as well as to exhibit other properties of the current. It consists of a small voltaic element, which is floated in acidulated water by means of a cork attached to its upper end. The conducting wire may be made straight, rectangular, or coiled. The spiral coil shown in the figure is technically called a *helix*. An elongated helix, with its conducting wire returned through the axis of the coil, is a *solenoid*, Fig. 341. The coil is *right-handed*, when its spire winds to the right, like a corkscrew, and is *left-handed* when its spire winds in the opposite direction.

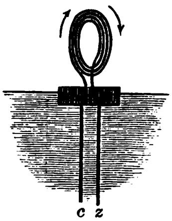


FIG. 339.

**741. By means of this apparatus,** it may be shown that when a current is passing through the wire, it exhibits all the properties of a magnet.

1. If a permanent magnet be held near the helix, one face of the coil will be attracted by the north pole of the magnet, and the other repelled.

2. Each side of the helix will attract iron filings.

3. If a helix or solenoid be free to move, it will swing so that its axis points north and south. If the coil be

right-handed, the south pole will be the end at which the current enters; but if the coil be left-handed, the north pole will be the end at which the current enters.

4. If the conducting wire of the 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 contrary directions.*

The attraction of similar currents may be shown by means of a spiral of fine copper wire, connected at its upper end with the positive pole of a battery, and slightly dipping, at its lower extremity, in a cup of mercury, which is in connection with the negative pole. When the current passes, each turn of the spiral attracts the next, thereby shortening the spiral, and breaking the current with a spark. The weight of the wire then restores the connection, and thus a continuous oscillation is sustained.

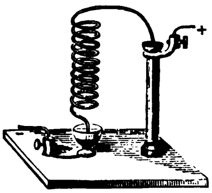


FIG. 340.

5. If two solenoids are brought near each other, Fig.

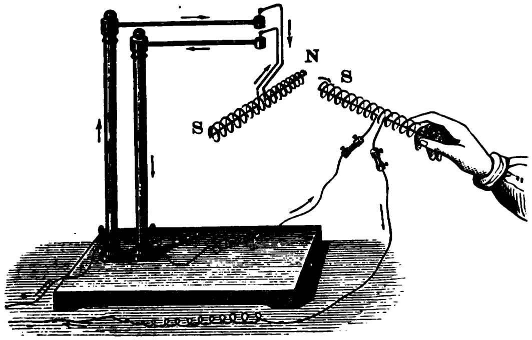


FIG. 341.

341, *with their similar ends adjacent,* they will repel each *other, because the* currents of the two coils are in opposite

directions. Conversely, the dissimilar ends will attract each other.

**742. Electro-magnetic rotation.** We have seen that the current acts at right angles to a magnet, and tends to urge the north pole of a magnet always toward the left. Hence, it is possible so to arrange the connecting wire and the magnet, that one shall revolve about the other. There are many contrivances for accomplishing this, one of which is shown in Fig. 342.

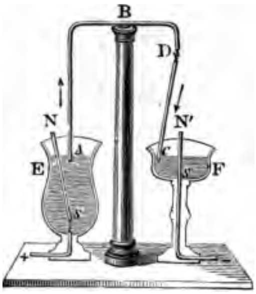
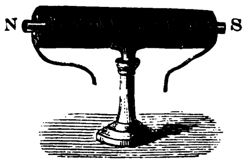


FIG. 342.

E and F are two glass cups containing mercury. A B C is a conducting wire, jointed at D, and dipping at each end in the mercury. N S, N′ S′, are two bar magnets, one fixed and the other attached by a thread to the bottom of its cup. If, now, a current is passed through the mercury and the conducting wire, there will be a mutual repulsion between the ends of the magnets and the conducting wire. The magnet, N S, being free, will revolve about the end, A, of the wire; but in the other cup, as the magnet is fixed and the wire free, the wire will revolve about the magnet, N′ S′. When the current passes in the direction of the arrows, both rotations will be to the left; but if the current is passed in the opposite direction, the rotations will be to the right.

**743. The voltaic current** may also induce magnetism in magnetic substances. If a bar of soft iron, N S, be placed in the axis of a helix, so that the current may pass at right angles to its length, the bar will be instantly magnetized, but will lose its magnetism as soon as the current ceases. If the helix is held vertically while the current is passing, 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. With a powerful current and a



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large coil, a weight of several hundred pounds may be suspended from the bar, and the whole sustained without any visible support.

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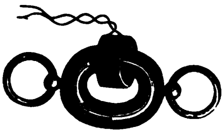

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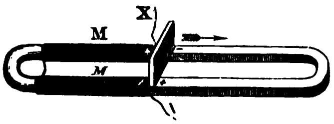

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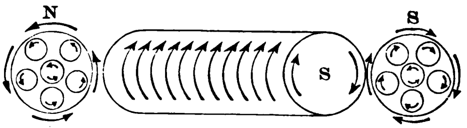

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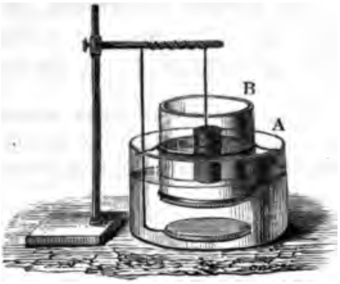

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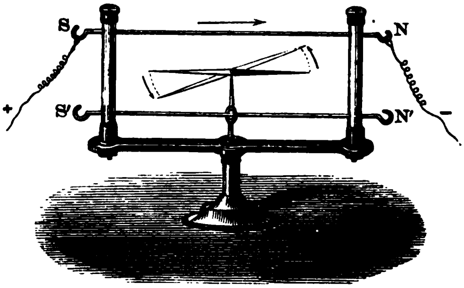

FIG. 336.

**738. The direction** in which the needle should turn, may be remembered by the following rule, devised by Ampère:

*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 always 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 be deflected toward the west. The same deflection will take place if the current passes below the needle from north to south.

*Hence*, if the wires, N S, N′ S′, be connected so that the current shall pass around the needle, the deflecting power of the current will be doubled. By coiling the wire several times around the needle, provided that the coils are insulated from each other, the deflecting

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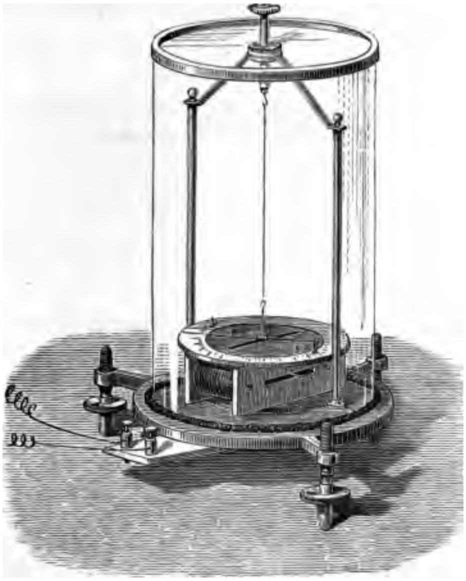

FIG. 338.

needles lie in opposite directions. (2.) The force of the coil is exerted in the same direction upon two needles instead of one. For, although the upper needle is subject to the action of two opposite currents, yet as that in the upper part of the coil is much the nearer, its action preponderates, and, because the needles are reversed, both are deflected in the same direction.

The wire used in this, and in other coils, should be carefully insulated, by being covered with white silk thread. A coil having a few hundred turns of moderately thick copper wire is well adapted for ordinary experiments; but, for very delicate investigations, as many as thirty thousand turns of fine wire have been used.

**740. 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. 339, will enable us to verify this fact, as well as to exhibit other properties of the current. It consists of a small voltaic element, which is floated in acidulated water by means of a cork attached to its upper end. The conducting wire may be made straight, rectangular, or coiled. The spiral coil shown in the figure is technically called a *helix*. An elongated helix, with its conducting wire returned through the axis of the coil, is a *solenoid*, Fig. 341. The coil is *right-handed*, when its spire winds to the right, like a corkscrew, and is *left-handed* when its spire winds in the opposite direction.

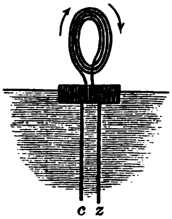

FIG. 339.

**741. By means of this apparatus,** it may be shown that when a current is passing through the wire, it exhibits all the properties of a magnet.

1. If a permanent magnet be held near the helix, one face of the coil will be attracted by the north pole of the magnet, and the other repelled.

2. Each side of the helix will attract iron filings.

3. If a helix or solenoid be free to move, it will swing so that its axis points north and south. If the coil be

right-handed, the south pole will be the end at which the current enters; but if the coil be left-handed, the north pole will be the end at which the current enters.

4. If the conducting wire of the 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 contrary directions.*

The attraction of similar currents may be shown by means of a spiral of fine copper wire, connected at its upper end with the positive pole of a battery, and slightly dipping, at its lower extremity, in a cup of mercury, which is in connection with the negative pole. When the current passes, each turn of the spiral attracts the next, thereby shortening the spiral, and breaking the current with a spark. The weight of the wire then restores the connection, and thus a continuous oscillation is sustained.

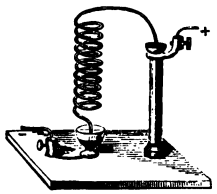

Fig. 340.

5. If two solenoids are brought near each other, Fig. 341, *with their similar* ends adjacent, they will repel each *other, because the* currents of the two coils are in opposite

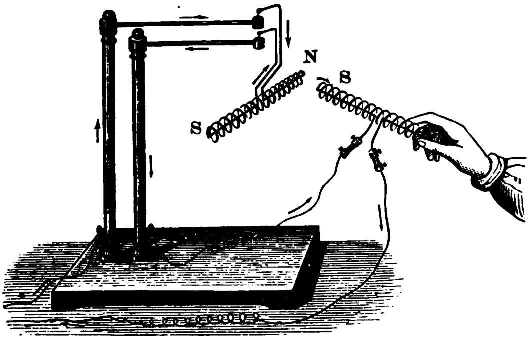

Fig. 341.

directions. Conversely, the dissimilar ends will attract each other.

**742. Electro-magnetic rotation.** We have seen that the current acts at right angles to a magnet, and tends to urge the north pole of a magnet always toward the left. Hence, it is possible so to arrange the connecting wire and the magnet, that one shall revolve about the other. There are many contrivances for accomplishing this, one of which is shown in Fig. 342.

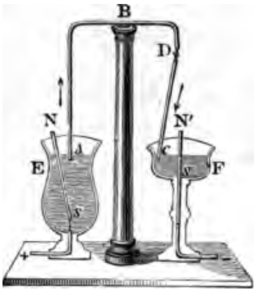

FIG. 342.

E and F are two glass cups containing mercury. A B C is a conducting wire, jointed at D, and dipping at each end in the mercury. N S, N′ S′, are two bar magnets, one fixed and the other attached by a thread to the bottom of its cup. If, now, a current is passed through the mercury and the conducting wire, there will be a mutual repulsion between the ends of the magnets and the conducting wire. The magnet, N S, being free, will revolve about the end, A, of the wire; but in the other cup, as the magnet is fixed and the wire free, the wire will revolve about the magnet, N′ S′. When the current passes in the direction of the arrows, both rotations will be to the left; but if the current is passed in the opposite direction, the rotations will be to the right.

**743. The voltaic current** may also induce magnetism in magnetic substances. If a bar of soft iron, N S, be placed in the axis of a helix, so that the current may pass at right angles to its length, the bar will be instantly magnetized, but will lose its magnetism as soon as the current ceases. If the helix is held vertically while the current is passing, 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. With a powerful current and a

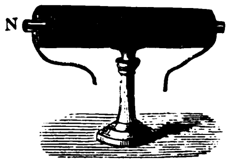

FIG. 343.

large coil, a weight of several hundred pounds may be suspended from the bar, and the whole sustained without any visible support.

A pleasing modification of the same experiment may be had by joining the ends of two semicircular pieces of soft iron, with one pair of the ends within the helix, as shown in Fig. 344. While the current is passing they will adhere with considerable force.

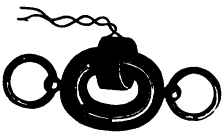

FIG. 344.

**744. 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 coils of insulated copper wire. When a strong current is passed through the wire, 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. 345.

The polarity of an electro-magnet depends upon the direction in which the current moves in the helix. If the direction be reversed the polarity will be reversed. If the current is broken the magnetism almost instantly ceases.

**745. Permanent magnets.** If the iron employed in electro-magnets is not quite pure, it will retain traces of magnetism for some time after the circuit is broken. A steel bar placed in the helix, Fig. 343, will become permanently magnetized.

It is sufficient to move the bar once nearly through the coil, then backward till it lies in the center of the coil; the current is then stopped and the bar taken out. A better result will be attained, if

the bar be previously armed with short cores of soft iron, which just fit the ends of the helix. This method may also be applied to horse-shoe magnets of steel.

**Permanent horse-shoe magnets** may be made of steel wrought in the proper shape, by connecting their open ends with a keeper of soft iron, while an electro-magnet is passed along a few times from the poles to the bend.

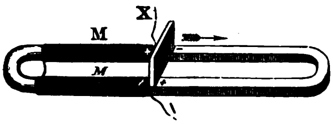

FIG. 346.

A better method is that shown in Fig. 346. The steel horse-shoe is applied to the 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 repeated. Both magnets are then turned over without separating the poles, and the other side treated in the same way. Magnets have been made in this manner so as to be capable of sustaining twenty-six times their own weight.

**746. Ampere's theory of magnetism.** In view of these various magnetic properties of the current, Ampère assumes that all bodies which exhibit polarity derive this polarity from electrical currents, which are perpetually traversing each molecule of a magnetic substance. Magnetization consists in giving to these individual currents a parallel direction. When all the currents are parallel, the magnet is said to be *saturated.*

The resultant of these parallel currents is equal to a single current which traverses the outside of a magnet as if it were a solenoid. At the north end of a magnet, the

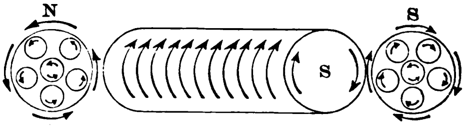

FIG. 347.

direction of these currents is opposite to that of the hands of a watch, and at the south end the direction is the same

as that of the hands. In this view of the subject, magnetism is a branch of dynamic electricity.

This theory does not assign a reason for the persistence of currents in permanent magnets, but in other respects affords a satisfactory explanation of all magnetic phenomena. For instance, it explains why like poles attract and unlike repel. If two south poles are brought near each other, they have opposite currents on their adjoining sides, and hence repel. A north and south pole have similar currents on their adjoining sides, and attract.

## ELECTRO-MAGNETIC MACHINES.

**747. Various machines** have been devised in the hope of employing the prodigious force of electro-magnets as a motive power. All of these take advantage of the facility with which the polarity of an electro-magnet may be annulled or reversed, by which attractions and repulsions may be so arranged with another magnet as to produce a rotary or alternating motion.

The action of the first class may be illustrated by Page's revolving electro-magnet, Fig. 348.

A small electro-magnet, H, is fixed to a vertical shaft so as to revolve between the poles of a permanent horse-shoe magnet. The ends of the wires of the helix are soldered to two strips of silver on opposite sides of the shaft, insulated from each other and from the shaft. Two metallic springs, Z, C, connecting with the battery, are so placed that when the shaft makes half a revolution, the silver strips pass from one spring to the other. This reverses the direction of the current in the helix, and thereby causes the poles of the electro-magnet to be changed twice in each revolution.

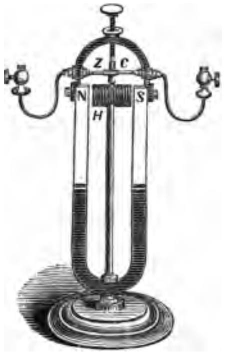

Fig. 348.

The position of the two magnets is such that, during the first quarter of a revolution, their like poles are adjacent and repel; during the second quarter, their unlike poles approach and attract. The current is then reversed, like poles again face each other and are repelled. The shaft is thus made to rotate, and may be made to communicate motion to a train of wheels, so that the rate of motion may be accurately determined. The velocity attained by this machine has reached as high as 2500 revolutions per minute.

No electro-magnetic engines have been or can be devised which can compete with steam engines in economy, because the expense of the zinc and the acid consumed in the battery far exceeds that of the coal burned in steam boilers of the same power. Nevertheless, small electro-magnetic engines have been employed successfully in cases where economy is of less consequence than convenience and facility of application.

**748. The electric telegraph** is by far the most important application of electricity to the practical affairs of life. Very many forms of this telegraph have been invented, but 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 the one station, and (4.) an instrument for receiving signals at the other station.

Any constant battery may be used for generating electricity. In this country, Grove's and Daniell's are both in use. Twenty-five Grove's elements are required for a line of one hundred miles.

**The line circuit.** Two stations must be connected by at least one insulated metallic wire. Generally speaking, this is done by passing galvanized iron wires over glass insulators attached to a series of tall wooden posts. When the wire is to be laid in the sea, or under ground, it is insulated by being coated with gutta-percha.

**749. The earth circuit.** 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 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 itself might be used for the return conductor. To effect this, large copper 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.

**750. Wheatstone's needle telegraph,** which is extensively used in England, consists essentially of a delicate galvanometer placed at the receiving station, and a pole changer placed at the other station. By means of this pole changer, or key, the direction of the current is reversed, and the needle of the galvanometer made to deflect to the right or to the left at the pleasure of the operator. A set of signals may in this manner be transmitted from one station to the other. With this system, two deflections of the needle to the left represent A; two to the right, N; one to the right and two to the left, E; and so on for other letters and figures.

A modification of this telegraph is used with the Atlantic submarine cable. Although its sensitiveness makes it a necessity on very long circuits, yet it affords no means of registering the dispatches sent, nor of detecting errors in copying the signals.

**751. Morse's telegraph,** which is more extensively used than any other, prints the signals on a strip of paper. This instrument requires at least two distinct parts: (1.) a *signal key;* (2.) a *recording apparatus,* or *receiver.* (3.) Besides these, a third part, called a *relay,* is necessary on long circuits, as an adjunct to the receiver. These parts are all shown in Fig. 351. If messages are to be received and answered, each station will require both a key and a receiver.

**752. The signal key** is used for breaking and closing the *circuit at the transmitting* station. This may be effected by cutting the line wire, and alternately joining and separating the two ends thus formed; but for the sake of convenience it usually has the form represented in Fig. 351.

This consists of a brass lever, *a d*, which works on an axis, K, supported by 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 the receiver at R′ is in condition to receive a dispatch from a distant station. (2.) When a dispatch is to be transmitted, the end, *d*, is depressed by applying the finger to an ebonite button, *f*, and the current passes from the battery up the point, *d*, through the lever to K, and along the line 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 end, *d*.

**753. The receiver,** Fig. 349, consists (1.) of an electro-magnet whose helices form a part of the line circuit, and (2.) of a lever which is operated by the joint action of the electro-magnet and an adjustable spring.

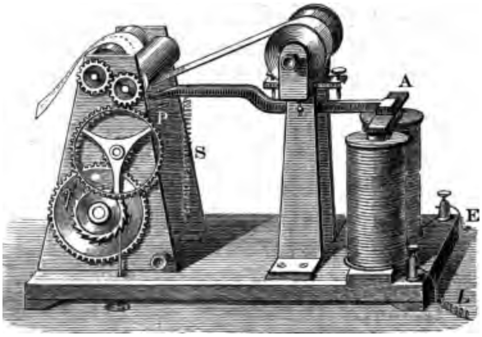

FIG. 349.

*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 left blank. Hence, by varying the time of contact at the sending station, a series of signals, formed by dots and lines, can be produced at the receiving station.

The following is the modified Morse's alphabet, now in general use throughout the world:

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| ·— | —··· | ·· · | —·· | · | ·—· | ——· | ···· | ·· | —·—· |
| *a* | *b* | *c* | *d* | *e* | *f* | *g* | *h* | *i* | *j* |
| —·— | ⸻ | —— | —· | · · | ····· | ··—· | · ·· | ··· | — |
| *k* | *l* | *m* | *n* | *o* | *p* | *q* | *r* | *s* | *t* |
| ··— | ···— | ·—— | ·—·· | ·· ·· | ··· · | · ··· | ·——· | ··—·· | |
| *u* | *v* | *w* | *x* | *y* | *z* | *&* | 1 | 2 | |
| · · — | ····— | ——— | ······ | ——·· | — · · · | —··— | ⸻ | | |
| 3 | 4 | 5 | 6 | 7 | 8 | 9 | 0 | | |
| ·—·— | ·—·—· | ··——·· | —··—· | ———· | | | | | |
| , | ; | . | ? | ! | | | | | |

**754. 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, but reads only by sound.

**755. 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, generally not exceeding fifty miles. In longer circuits, 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 effected will be rendered evident by an inspection of Fig. 350. The line current passes from the positive pole of the battery, 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 zinc pole of the battery.

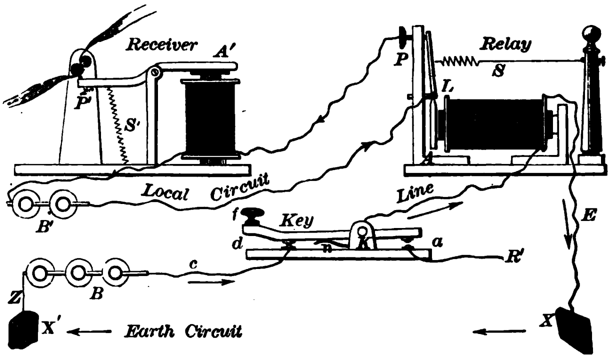

FIG. 350.

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 time the upper end of the lever strikes against the screw, P. At this moment 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 another station further on.

**756. The electric fire alarms** now extensively used in large cities for indicating the locality of fires, are modifications of the Morse instrument.

**757. 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.

**758. Various other telegraphs** have been devised, of greater or less merit. Two of these, invented by R. E. House, in 1848, and by D. E. Hughes, in 1855, print the message as received, in plain Roman letters.

**In Caseli's pantelegraph,** the message is written on tin foil with wax varnish, and, by a very ingenious apparatus, is reproduced in exact counterpart at the distant station, on paper chemically prepared. By this means, not only may autographic messages be transmitted, but even engravings may be copied.

**759. Telephone.** The most remarkable improvement in the telegraph is the *telephone.* Fig. 351.

A is a permanent magnet, about the end of which is a coil of fine wire, B, connected with the binding posts, DD. Just above the magnet, A, is a thin iron diaphragm, E, the central portion of which is free to move, not quite touching the magnet. This diaphragm is held in its place by a cup-shaped cover, to which the ear is applied in receiving, or the mouth in sending. One of the wires from D is connected with the line, and the other with the earth. No battery is used. The operation of the telephone is as follows — A sound produced in front of the diaphragm causes it to vibrate. Every movement of this iron plate near the magnet alters its magnetic condition, and every change in this, in turn, induces a current in the surrounding coil (§763), which goes through the line to an exactly similar instrument at the remote station. There the current produces corresponding changes in the condition of the pole of the magnet of the receiving instrument, every change being accompanied by a movement of the iron diaphragm. Thus the vibrations produced by the sound at the sending station are reproduced at the receiving, and again produce audible sounds, which resemble, in pitch, intensity, and quality, those which give rise to the current at the other end. In this way music, conversation, etc., can be transmitted over many miles of wire. So perfect is the reproduction of vibrations that it is even possible to distinguish voices of different individuals.

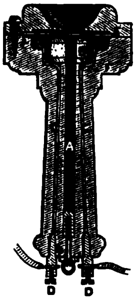

FIG. 351.

### ELECTRO-DYNAMIC INDUCTION.

**760. The phenomena of current induction** may be shown by the apparatus represented in Fig. 352. Let P and I be two helices of insulated wire, the first connected with a voltaic battery, and the other with a galvanometer. If, when the current is passing through P, it be brought near the helix, I, a momentary current, in the opposite direction, will be induced in I, and will be manifested by the deflection of the needle in the galvanometer. The first current is called the *primary,* or *inducing,* current, and the other, the *secondary,* or *induced,* current.

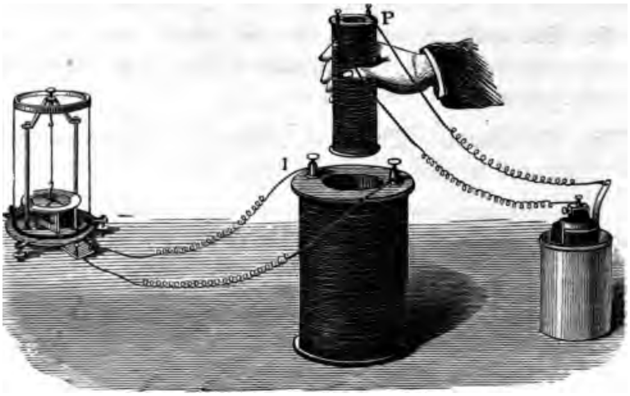

FIG. 352.

A current in the same direction as the primary, is said to be *direct;* but if in the opposite direction, *inverse.* If the two helices are held in the same relative position, the induced current soon ceases, and the needle falls back to its old position. If the primary coil is placed within the other, another momentary *inverse* current is produced. This will also be the case, if the intensity of the battery be increased. If, however, the primary current be weakened, the circuit broken, or the coil withdrawn, a momentary current will be induced, which in each of these cases will be *direct.*

Hence, (1.) *An inverse momentary current will be induced in a neighboring circuit by a primary current on starting, approaching, or increasing in intensity.* (2.) *A direct momentary current will be induced by a primary current which decreases in intensity, or which is removed or stopped;* but (3.) *A continuous and constant current does not induce any current in a neighboring conductor.*

**761.** The induced currents are, therefore, but momentary in their action; nevertheless, they have all the properties of the primary currents. For instance, they may induce other currents on adjacent circuits, and thus currents of the third, fourth, and even of the seventh orders have been obtained.

The direct induced and the inverse induced currents of the same order are equal in quantity, and, therefore, have the same effect on the galvanometer. The direct induced current has greater intensity than the inverse, and will, therefore, give rise to a more powerful shock. The direct induced current also magnetizes to saturation, while the inverse does not magnetize.

The intensity of the direct induced current is always high, even when excited by a feeble primary current, but increases with the intensity of the primary. The more rapid its action, the greater will be its intensity, and hence the more instantaneously the primary circuit is demagnetized, the more intense will be the induced current.

**762. A primary current** may also act inductively on itself, and thus give rise to what is called the *extra current.*

It is this which produces the spark on breaking the circuit. This is particularly observable when the conducting wire has the form of a helix, because then each spire acts inductively on the next succeeding one. The effect of the extra current is to prolong the duration of the primary current when the circuit is broken, and it, therefore, reduces the tension of the induced currents, by retarding the suddenness of the change.

**763. Magneto-electrical induction.** Since a helix, through which a current is passing, is essentially a magnet, we ought to *expect that* a permanent magnet would, like it, *induce electrical* currents. In fact, if we substitute for the

**primary coil, P, in Fig. 352, a permanent magnet, we shall obtain almost identical effects.**

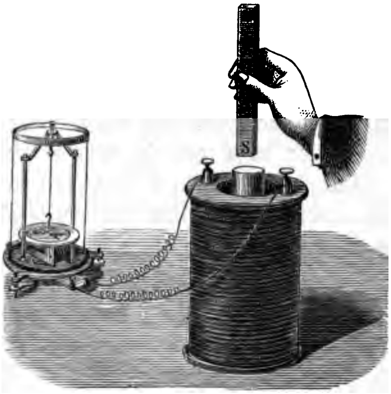

FIG. 353.

The same phenomenon may be studied by placing a bar of soft iron within a helix, as shown in Fig. 353, and bringing above it a strong permanent magnet. The core of soft iron becomes magnetized by induction, and induces an electrical current in the helix, by reason of which the needle of the galvanometer is deflected for a moment, and then returns to its normal position. On removing the magnet, the needle is deflected in the opposite direction. The direction of the currents depends upon the pole of the magnet presented, and is in accordance with Ampère's law, (738).

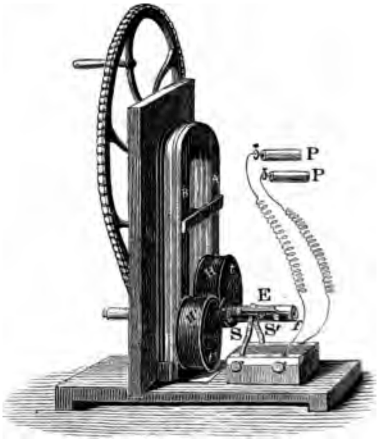

FIG. 354.

**764. The magneto-electrical machine** is constructed on this principle. Fig. 354.

This consists of a permanent magnetic battery, A B, in front of which two helices of fine copper wire, carefully insulated, are made to revolve on an axis, *f*, by means of a wheel and winch. The cores of the helices are made of two pieces of soft iron, joined by a soft iron, *t t'*. The same wire is coiled about the two cores, but in different directions, in order that the currents induced by the opposite poles may be in the same direction. The two ends of this wire terminate in two metallic plates insulated from the axis and from each other by ivory, and are connected alternately with the springs, S S′. On turning the wheel, a current of electricity is induced in each helix, the direction of which changes twice at each revolution.

**765. This instrument** is capable of producing sparks, decomposing water, and igniting wires, and of producing other effects of dynamical electricity. If a break piece, not shown in the figure, be added, an extra current of great tension will be induced, which is capable of producing very powerful shocks, if the handles, P P′, be grasped with the hands slightly moistened. With a good apparatus, the muscles contract with such force that they no longer obey the will, and the handles can not be dropped. From its convenience and neatness, this is a very common apparatus for applying the effects of induced currents in therapeutical operations.

**766. Other magneto-electrical machines**, on the same principle, have been constructed, some of which are of remarkable power.

They have been used for electroplating, for telegraphing, and other practical applications of electricity. By Wilde's machine, which is driven by a steam engine, an electric light of surpassing brilliancy is obtained, which casts shadows from the flames of street lamps a quarter of a mile distant, darkens sensitized photographic paper in less time than the noon-day sun, and evolves sufficient heat to melt iron rods fifteen inches long and one-fourth of an inch thick.

**767. Induction coils** are instruments which employ both magnetic and electric induction. One form in which the helices are separable is shown in Fig. 355.

The primary coil, P, is, of coarse, insulated copper wire, connected by the screw cups, + and —, with the battery. I is the secondary coil, of very fine, insulated copper wire, to which handles may be attached. M is a bundle of iron wires, which are sufficiently insulated from each other by *the rust which* 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.

As soon as the coil of B receives the current, the armature is drawn down and the circuit is broken. At every interruption of the primary current, the iron wires, M, become magnetized and demagnetized, and react upon the secondary coil. The intensity of the induced currents is thereby much increased, and may even become of so high tension as to produce all the effects of statical electricity. The form shown in Fig. 355 is frequently used for giving shocks, and for medical purposes.

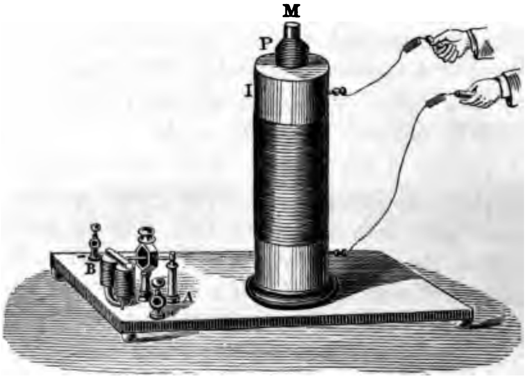

FIG. 355.

**768. Ruhmkorff's coil** is made on the same principle as that already described. The utmost care is taken in insulating the wire used. The secondary helix contains from three to thirty miles of fine wire. To avoid the effect of the extra current of the primary coil, a *condenser* of tin foil is placed in the base of the instrument and is connected with the interrupter. This is ordinarily a ratchet wheel, turned by the hand, which breaks and closes the current every time its spring passes from one tooth to another.

With three or four Bunsen's elements and a large coil the induced current becomes of amazing tension, although of inconsiderable quantity. Some of the effects of the coil are as follows:

1. **Physiological.** The shocks are so violent as to be dangerous, and incautious experimenters have been prostrated by them.

2. **Calorific.** Fine iron wires brought between the ends of the induced wire are melted and burned.

3. **Luminous.** Sparks have been obtained nineteen inches in length. When the discharge is passed into rarefied air or gases, the phenomena of auroral light is produced in a most beautiful and varied manner.

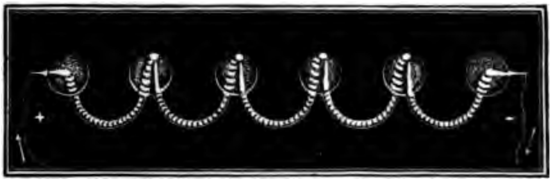

FIG. 356.

These experiments are performed with sealed glass tubes, known as Geisler's tubes, one of which is shown in Fig. 356. 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. To produce these effects with the primary current would require a battery of over fifty elements.

4. Leyden jars may be charged and discharged by means of the coil with an almost continuous spark, of great brilliancy and accompanied by an almost deafening sound.

These, as well as the mechanical and chemical effects of the coil, are similar to those produced by statical electricity.

### THERMO-ELECTRICITY.

**769. If any two metals** are soldered together and heated at their junction, an electrical current is evolved which is *capable of deflecting* the needle of the galvanometer. On the other hand, if their junction be cooled, the needle will be deflected in the opposite direction. These currents are called *thermo-electric currents*, but they differ in no respect from those already studied.

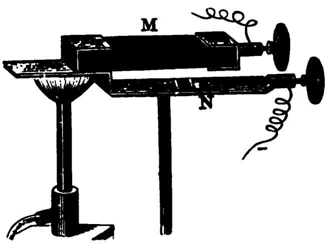

Fig. 357.

**770. The direction of the current** within the pair 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. −

**771. The most efficient electro-thermal couple** is said to be formed of artificial sulphide of copper and metallic copper. Fig. 357. The usual combination is bars of antimony and bismuth.

Fig. 358 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 attain the same results as the voltaic battery.

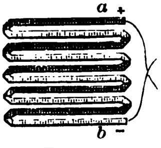

Fig. 358.

Since in combining the pairs it is necessary to join both ends of all except the outer bars, the effect of the current will be due to the difference in the temperature of the two ends.

This fact is utilized in the *thermo-multiplier* shown at T in Fig. 359. This 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 tolerably thick wire. This apparatus is so sensitive that

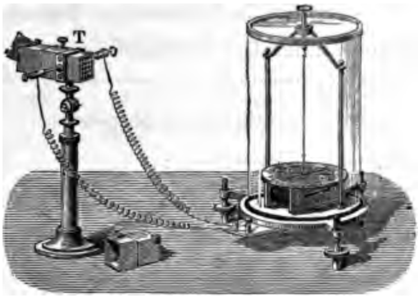

FIG. 359.

even the radiant heat emitted by insects may be estimated by it. It is therefore used in all delicate investigations on the subject of radiant heat.

## ANIMAL ELECTRICITY.

**772. We have already seen** 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.

**773. 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.

It is thought by some philosophers that electrical currents are evolved and consumed in all animals during the various vital processes, like *secretion, digestion*, and the like. None of these theories are *sufficiently well established* to be introduced here.

## 774. Recapitulation.

I. 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 Ampèrean 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.

Induced currents are applied

1. For physiological and therapeutical purposes.
2. For evolving light and heat of great intensity.
3. For effecting chemical changes.
4. For making temporary and permanent magnets, which are employed to produce mechanical action in engines, telegraphs, clocks, etc.

# PROBLEMS.

THE object sought in these problems is rather to enforce the principles of Physics than to afford practice in arithmetic. They are therefore as easy as circumstances will permit. In their solution it will not be necessary, as a general thing, to employ more than two places of decimals. The student will understand that they are to be solved only in view of the principle involved, and that circumstances modifying the application of the theory in actual practice are excluded. The solutions should be preserved for reference and comparison.

### USEFUL FACTORS.

$\pi = 3.1416$ ........................................ $\pi^2 = 9.87$.

Circumference of a circle...................... $2\pi r = \pi d = 3.1416d$.

Area of a circle.................................. $\pi r^2 = \frac{1}{4}\pi d^2 = .7854d^2$.

Surface of a sphere.............................. $4\pi r^2 = \pi d^2 = 3.1416d^2$.

Volume of a sphere.............................. $\frac{4}{3}\pi r^3 = \frac{1}{6}\pi d^3 = 0.5236d^3$.

### SOMATOLOGY.

**Art. 17.** 1. How many metres in an English mile? How many miles in a kilometre? What part of an inch is a millimetre? How many inches in 776 millimetres?

2. The radius of the earth is 3963 miles; find its circumference.

3. The distance of the earth from the sun is 91430000 miles; find the circumference of its orbit, supposing it to be an exact circle.

4. If the radii of two circles are given, what is the ratio between their circumferences? Between their areas?

5. Find the area of a circle whose radius is 1 inch; 10 inches; $\frac{1}{10}$ *of an inch.*

6. How much more water will flow through a 2 inch pipe than through a 1 inch pipe?

7. What is the ratio between the surfaces of two spheres whose radii are given? Between their volumes?

8. Find the spherical surface of an inch ball; a 10 inch ball; $\frac{1}{10}$ of an inch ball.

9. Find the volume of an inch ball; a 10 inch ball; a $\frac{1}{10}$ of an inch ball.

10. Find the cubic inches in a pint. Find the litres in a gallon. How many gallons in a cubic foot? How many cubic feet in 10 gallons? How many litres in a cubic foot?

**Art. 19.** 11. How many grammes in a pound?

12. What is the volume of a pound of water? What is the weight of a pint of water? What is the weight of a cubic inch of mercury? How many grains in a cubic foot of hydrogen? What is the volume of a pound of hydrogen?

**Art. 24.** 13. Calculate, from Example 2, the velocity per minute of a point on the equator.

14. Calculate, from Example 3, the velocity per minute of the earth in its orbit.

15. Find the time required for electricity to pass around the equator. For sound to traverse the same distance.

16. Find the space that light will traverse in 8 minutes and 13 seconds. How far will a rifle ball go in 3 seconds?

17. How long would it take a railway train to reach the sun?

**Art. 29.** 18. An ounce of water contains 360 drops: if a grain of nitrate of copper be dissolved in a gallon of water, how much nitrate of copper will there be in a single drop?

**Art. 30.** 19. Suppose a grain of water be blown into a soap bubble 10 inches in diameter, what will be the weight of the water in each square inch of the film?

**Art. 38.** 20. Find the weight of a cubic foot of cork; of ice; of a ball of silver 10 inches in diameter. Of a pint of alcohol.

21. Find the weight of a gallon of ammonia in both the liquid and *aëriform* states.

22. How many times heavier is a cubic inch of platinum than of hydrogen?

**Art. 42.** 23. How deep must water be at 39°.2 F. to equal the pressure of one atmosphere? at 62°?

24. What is the pressure in pounds indicated by a column of mercury at 62° F. and eighteen inches high?

25. How many feet of air are required to produce the same pressure as 30 inches of mercury at 32° F.

26. Suppose a boy has a surface of 8¾ square feet, what is the atmospheric pressure he sustains?

**Art. 62.** 27. How much will a rod of steel, 1 inch in section and 10 feet long, be stretched by a weight of 100000 pounds?

28. How much force is required to crush a cubic foot of oak? Of cast iron?

29. How much force is required to overcome the tenacity of a steel wire $\frac{1}{10}$ of an inch in diameter?

**Art. 74.** 30. What is the weight of the finest platinum wire a mile long? What is the weight of a square inch of finest gold leaf?

**Art. 93.** 31. How many gallons of ammonia may be absorbed by a pint of water? What will the solution weigh?

**Art. 95.** 32. How many gallons of ammonia may be absorbed by a cubic foot of charcoal?

33. What weight of carbonic acid may be absorbed by a cubic foot of charcoal?

## MECHANICS.

**Art. 114.** 34. Find the momentum of a glacier 300 feet high, 5 miles long, and 1 mile wide, moving at the rate of 1 mile a month.

35. Find the momentum of a locomotive weighing 25 tons, and having a velocity of 30 miles per hour.

36. Find the velocity of a cannon ball weighing 60 pounds, and having a momentum of 30000 pounds. Find the weight of a ball that has the same momentum and a velocity of 1200 feet per second.

**Art. 120.** 37. Two forces, A and B, act on the same point; A with a force of 90 pounds, B with 120; what will be their resultant if they lie in the same direction? If in opposite directions? If at right angles to each other?

**Art. 123.** 38. The resultant of two forces acting at right angles is *10; one of the forces is 8*; what is the other?

**Art. 125.** 39. Suppose two equal forces act at an angle of 60 degrees; what will be the direction and force of their resultant? If one force be double that of the other? Apply the method by construction.

**Art. 128.** 40. If two inelastic bodies—A having a weight of 3 pounds and a velocity of 5 feet per second, B having a weight of 4 pounds and a velocity of 3 feet per second—collide from opposite directions, what will be the resulting momentum, velocity, and direction? If they move in the same direction, and A strikes against B, what will be the resulting momentum and velocity?

**Art. 129.** 41. In the last example, what would have been the result if the bodies had been perfectly elastic?

**Art. 134.** 42. Calculate the striking force in examples 34 and 35.

43. If light were matter, and one-millionth part of a grain entered the eye in a second, what would be its striking force as compared with an ounce rifle ball with a velocity of 1200 feet per second?

44. How fast must a battering ram weighing 3 tons be propelled in order to have the same striking force as a 30 pound cannon ball with a velocity of 1200 feet per second? With equal *vis viva*, how would their momenta compare?

**Art. 143.** 45. If two cannon balls, weighing respectively 30 and 80 pounds, be connected by a rigid bar, where will the common center of gravity be?

46. If the mass of the moon is $\frac{1}{81}$ that of the earth, where is their common center of gravity?

**Art. 154.** 47. What is the work, expressed in foot-pounds, that is required to raise 193 pounds 4 feet high? To raise 10000 gallons of water from the bottom of a mine 600 feet deep?

**Art. 155.** 48. How many horse powers are required to fill every day a reservoir, having a capacity of a million cubic feet, with water from a lake 400 feet below the reservoir?

**Art. 157.** 49. 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?

**Art. 162.** 50. 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?

51. 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 one foot?

52. 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?

53. 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?

**Art. 166.** 54. 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?

**Art. 167.** 55. 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?

How far from B must a power of 10 pounds be placed to balance a load of 300 pounds at L.

**Art. 171.** 56. 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.

**Art. 175.** 57. 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?

**Art. 176.** 58. With the same machine, what will be the length of the rope unwound from the wheel, when the load has been lifted 10 feet?

**Art. 177.** 59. A capstan has an axle 1 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 4000 pounds?

**Art. 178.** 60. In a differential wheel and axle, the two parts of the axle are respectively 8 and 10 inches in diameter; what is the load that may be lifted by this machine by a power of 100 pounds, applied at a winch of 2 feet radius?

**Art. 179.** 61. In a train of three 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? How many times must the first wheel revolve, in order that the third pinion may be turned around once?

62. In Fig. 176, the cord, D, passes from the wheel, A, 5 feet in diameter, to the axle of the second wheel, B, 2 inches in diameter; how many times faster will B revolve than A? B has 100 teeth which strike against a card, E; how many teeth will strike the card when A has revolved once?

**Art. 185.** 63. In a system of 2 movable pulleys, with a continuous cord, the power is 100 pounds; required the load.

64. What power will be required to raise 2000 pounds with a system of 4 movable pulleys?

**Art. 187.** 65. In the Spanish burton, shown in Fig. 64, what power will be required to lift one ton?

**Art. 189.** 66. On a road rising 1 foot in 25, what power will be required to sustain a wagon weighing 1000 pounds?

67. A plank 16 feet long extends from the ground to a wagon 4 feet high; required the power necessary to roll a cask weighing 500 pounds into the wagon. What would be the power required if applied parallel with the ground?

68. Apply the method by construction to find the power required when applied at an angle of 40°.

**Art. 198.** 69. 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?

70. In the differential screw, the threads of the two screws are respectively $\frac{1}{8}$ and $\frac{1}{9}$ of an inch apart; through what space will the plate move when the lever is turned 90°?

**Art. 201.** 71. In the crane, Fig. 75, 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 4 movable pulleys?

**Art. 202.** 72. In Fig. 76, suppose the muscle to be applied 1 inch from the joint, and the length of the fore-arm to be 15 inches; required the power necessary to raise a weight of 10 pounds.

**Art. 207.** 73. Suppose an oak block weighing 100 pounds rest upon an oak plank, with their fibers parallel. What will be the force required (1.) to start and (2.) to keep the block in motion, if no unguents are used?

[redacted]

**Art. 208.** 74. A wagon weighs 2000 pounds. What will be the power required to draw it over a well paved, level road? Over a dry highway? Suppose the road to rise 1 foot in 30, what will be the power necessary in each case?

**Art. 210.** 75. What force will be required to draw a scow with blunt bow, having a submerged area of 8 feet broad and 2 deep, through water at the rate of 1 foot per second? Of 1 foot per minute?

**Art. 211.** 76. In the problems already detailed for machines, what allowance must be made for friction?

**Art. 219.** 77. A body falls freely through the air. What will be the space described in the fifth second? The velocity at the end of the sixth second? The total space described in 8 seconds?

**Art. 220.** 78. What will be the velocity attained by a body falling from a vertical cliff 784 feet high? In what time will it fall?

**Art. 221.** 79. Suppose a smooth plane to extend 10000 feet up a mountain side, with an inclination of 1 foot in 10, and that a smooth ball rolls from the top to the bottom. What will be the time required for the descent? What will be the velocity attained?

**Art. 223.** 80. In the case supposed, what will be the space passed over in 5 seconds if the ball is started with a velocity of 100 feet per second?

**Art. 224.** 81. With what velocity must a ball be thrown to strike the top of a flag-staff 257.32 feet high? What will be the time required for its flight?

**Art. 226.** 82. Suppose a rifle ball is shot horizontally, with a velocity of 1200 feet per second. What will be its range if shot from a rest 4 feet high? From a rest 64 feet high?

**Art. 229.** 83. Suppose the radius of the moon were the same as that of the earth, what would be the weight of a terrestrial pound when taken to its surface? Assuming the lunar radius to be ¼ that of the earth, what would be the weight of a terrestrial pound taken to the surface of the moon if its mass were the same as that of the earth?

84. If the moon's mass be assumed as .0128 and its radius as .24, what would be the weight of a terrestrial pound taken to its surface?

85. If the mass of the sun be 314760 and its radius 110 times that of the earth, what would be the weight of a terrestrial pound on its surface? What would be the space passed over in the first second by a falling body?

**Art. 230.** 86. If a body were dropped from a distance of 12000 miles from the earth's center, how far would it fall in 10 seconds?

**Art. 232.** 87. What would be the weight of a cubic foot of iron 500 miles below the surface of the earth?

**Art. 238.** 88. What is the length of a pendulum at New York that vibrates in $\frac{1}{3}$ of a second? In 3 seconds? What is the ratio between the lengths of these two pendulums? How long should a pendulum be to vibrate 100000 times in a day?

**Art. 239.** 89. Find the increment of velocity due to gravity at Spitzbergen from the length of the seconds pendulum = 39.21614 inches.

**Art. 257.** 90. What will be the centrifugal force of a wheel 10 feet in radius, whose weight may be considered as concentrated in a rim weighing 1000 pounds, when the wheel makes 1 revolution in a second? 5 revolutions in a second?

91. With what speed must a pail of water be whirled over the head to prevent the water from falling out, granting that the radius of the circle in which the pail revolves is 3 feet?

## HYDROSTATICS.

**Art. 274.** 92. Find the pressure on the bottom of a reservoir 120 feet long and 40 feet wide, when the water is at a depth of 10 feet.

93. A pipe leading from the reservoir descends 100 feet into a valley. What is the pressure on each square foot at the bottom of the valley?

**Art. 275.** 94. What is the pressure on each side of the reservoir? What is the total pressure at the sides and the bottom? What is the weight of the water contained in the reservoir?

**Art. 276.** 95. What is the pressure on a cubic foot of iron sunk in water to the depth of a mile?

**Art. 277.** 96. In Pascal's experiment, suppose the pipe to have had an area of 5 square inches, what would have been the weight of water in the tube? What would have been the pressure on each square inch?

**Art. 278.** 97. 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?

**Art. 280.** 98. In Bramah's press, suppose a power of 1000 pounds to be applied at one end of a lever of the second class 10 feet long, whose weight is 3 inches from the other end, and suppose the larger cylinder to have 1000 times the area of the smaller: what will be the pressure on the ram?

99. If the larger cylinder have an area of 200 inches, what will be the pressure on each square inch? How high a column of water would this pressure support?

**Art. 284.** 100. If the discharge pipe of an Artesian well is 200 feet above the surface, what is the least elevation possible for its distant source?

**Art. 286.** 101. At what distance can a mountain 5 miles high be seen from the sea-level?

**Art. 289.** 102. What will be the buoyant effort of water on a cubic foot of iron immersed in it? How much weight will a cubic foot of iron lose when immersed in water? Of lead?

**Art. 291.** 103. What is the volume of water displaced by a cubic foot of cork? Of ice?

**Art. 293.** 104. How many cubic feet of water must an iron boat weighing 480 pounds displace in order that it may float? If it displaces twice this volume, how many pounds will it carry?

**Art. 301.** 105. From the table on page 16 calculate the specific gravity of iron: of copper. From the tables on pages 24 and 25 find the weight of a cubic inch of oak: of glass: of lead.

106. How much weight will a pound of iron lose when immersed in water? How much will a pound of lead lose?

107. Find the volume of a pound of lead. Of a pound of iron.

108. If a pound of lead be in a cubical shape, what will be the length of each side?

**Art. 302.** 109. A mass of iron pyrites weighs 6 ounces in air and 4.8 ounces in water. What is its specific gravity?

**Art. 303.** *110. The* same mass attached to an ounce of cork weighs *in water 4.7 ounces.* What is the specific gravity of the cork?

**Art. 304.** 111. 480 grains of carbonate of potassa weighs in alcohol 270 grains. The specific gravity of the alcohol being .85, required the specific gravity of the carbonate of potassa.

**Art. 305.** 112. A small flask contains 900 grains of water, 800 grains of alcohol, or 1350 grains of sulphuric acid. Required the specific gravity of the alcohol and sulphuric acid.

113. A boy's marble weighs in air 450 grains, in water 300 grains, in naphtha 350 grains. Required the specific gravity of the naphtha.

**Art. 306.** 114. If 1500 grains are required to sink a Nicholson's hydrometer to the mark on the stem, what will be the specific gravity of a solid that requires 1000 grains to be added to the pan when the body is on the scale pan, and 1100 grains when the body is in the basket?

**Art. 308.** 115. What is the specific gravity of a liquid corresponding to 30° Beaume? For heavier liquids? For lighter liquids?

**Art. 309.** 116. A flask full of air weighs 131 grains; when full of carbonic acid, 146 grains; the flask weighs 100 grains. What is the specific gravity of the carbonic acid?

**Art. 311.** 117. A nugget of quartz and gold weighs in air 10 ounces, and loses 2 ounces in water; the specific gravity of the quartz being 2.5. How much gold does the nugget contain?

## HYDRODYNAMICS.

**Art. 314.** 118. With what velocity will water flow from an orifice 25 feet below the surface? What will be the relative velocities of two streams respectively 9 and 16 feet below the surface?

**Art. 315.** 119. What will be the range of a stream escaping from the center of a reservoir 72 feet high?

**Art. 316.** 120. What will be the theoretical volume discharged per minute from each orifice, in the above examples, supposing the head to be constant, and the diameter of the stream 1 inch?

**Art. 318.** 121. What will be the volume if allowance is made for the *vena contracta* without adjutage? What with a good adjutage?

**Art. 322.** 122. If the flow of the Mississippi were not retarded by the shape of its bed, etc., what would be its velocity at its mouth, which is 1572 feet below its source?

**Art. 323.** 123. What is the gross power of a stream flowing through a weir having a section of 4 square feet and a fall of 9 feet?

**Art. 326.** 124. What will be the effective power of the same stream when applied to an overshot wheel? To a turbine?

### PNEUMATICS.

**Art. 338.** 125. How high must a barometer tube be if filled with sulphuric acid, having a density of 1.84?

**Art. 339.** 126. How heavy a brick may be raised by a boy's sucker, whose effective diameter is 2 inches?

**Art. 340.** 127. What is the pressure on each square inch required to condense air to $\frac{1}{10}$ of its original volume?

**Art. 344.** 128. If an air pump exhausts $\frac{1}{10}$ of the air from a receiver at each stroke, what will be the tension of the air remaining at the fifth stroke?

**Art. 345.** 129. What will be the pressure on a pair of Magdeburg hemispheres 2 inches in diameter when the gauge of the pump stands at 24 inches?

130. How heavy a load may be raised by a weight lifter whose diameter is 3 inches?

131. How much weight will be gained respectively by 10 pounds of lead and of cork when transferred to a vacuum?

132. What is the ascensional power of a spherical balloon 100 feet in diameter, and filled with coal gas of a specific gravity of 0.5?

**Art. 346.** 133. If the cylinder of a condensing pump is $\frac{1}{10}$ the volume of its receiver, what will be the tension of the condensed air after 50 strokes of the piston?

**Art. 351.** 134. What will be the variations in atmospheric pressure due to a range of 3 inches in the barometer?

**Art. 354.** 135. What will be the difference in pressure on the body of an average sized man?

**Art. 355.** 136. On the same man, when he has descended in a diving bell 17 feet?

**Art. 359.** 137. What is the pressure required to force a stream of water 75 feet high?

**Art. 361.** 138. What is the greatest vertical height possible for a siphon used for transferring alcohol?

## ACOUSTICS.

**Art. 397.** 139. What is the relative intensity of two sounds from the same source heard at the distances of 10 and 250 feet?

**Art. 406.** 140. With air at 32° F., how long will it take sound to travel 1 mile? How long with air at 90° F.?

141. A stone dropped into a deep well returns the sound in 3 seconds; required the depth of the well.

**Art. 409.** 142. An iron gas pipe is 5 miles long; required the time for a blow struck at one end to be heard at the other, through the iron and through the air. (The velocity of sound in iron may be taken as the same as in steel.)

**Art. 421.** 143. A string which sounds $C_1$ is 2 feet long; what must be the length of the same string to sound $C_{-1}$, $A_2$, $G_3$?

144. If the same string is made 8 inches long, what will be the sound that may be emitted by it? With what relative force must the original string be stretched to sound $G_2$?

145. Suppose a string of the same material, but of quadruple the relative weight, sounds $C_1$, what is its length?

**Art. 422.** 146. What is the absolute number of vibrations corresponding to $G_{-3}$, $G_5$?

**Art. 423.** 147. What is the length of the sonorous wave corresponding to G , $G^{-2}$?

**Art. 428.** 148. What is the relative number of vibrations corresponding to $F_1$, $F_1\sharp$, $G_1\flat$, G? The absolute number?

**Art. 429.** 149. In the key of A what notes are sharped?

**Art. 434.** 150. What is the length of the sonorous wave corresponding to $C_2$ when made in carbonic acid gas? (Compare 408.)

## OPTICS.

**Art. 441.** 151. It is calculated that the light from the polar star requires 3½ years to reach the earth; what is its distance?

**Art. 446.** 152. What are the relative intensities of two lights that cast equal shadows at distances from an opaque rod respectively 6 inches and 6 feet?

153. 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"?

**Art. 473.** 154. What will be the index of refraction when light passes from crown glass into bisulphide of carbon? When it passes in the other direction?

**Art. 495.** 155. What will be the relative lengths of two solar spectra produced under the same circumstances by prisms of quartz and of bisulphide of carbon?

**Art. 506.** 156. 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 sonorous waves in an octave. Will the comparison warrant any analogy between vibrations of light and of sound?

**Art. 524.** 157. What is the magnifying power of a lens whose focal length is $\frac{1}{120}$ of an inch?

**Art. 527.** 158. With this lens as an objective and an eye piece of 5 inches focal length, how powerful a compound microscope can be constructed?

-10°C to 10°C [illegible]

## PYRONOMICS.

**Art. 552.** 159. Construct a table showing the equivalence between the Fahrenheit and Centigrade scales for every 10 degrees between the freezing and boiling points of water.

160. Reduce — 220° F. to Centigrade. Reduce 142°.65 F. to Centigrade. Reduce + 273° C. to F.

**Art. 554.** 161. What is the linear co-efficient of expansion for iron? For steel? For brass? What is the ratio been the two last?

162. How much will a railway track 100 miles long expand on being heated from 0° F. to 110° F.?

**Art. 557.** 163. How many thermal units are required to raise 1 pound of water from 0° C. to 1° C.? One kilogramme of water?

164. 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 from — 37°.9 F. to 662° F.? How many pounds *of iron would it raise from* 32° F. to 2132° F.?

**Art. 561.** 165. How many pounds of lead would it raise from 32° F. to the melting point of lead?

**Art. 566.** 166. How much ice at 32° F. will the same fuel melt?

167. How many thermal units will be evolved by the freezing of 100 cubic feet of water?

168. If this freezing takes place in a cellar containing 10000 cubic feet of air, how much will the air be heated if all the effect is expended on it?

**Art. 572.** 169. How many thermal units are required to raise 10 pounds of alcohol from 32° F. to its boiling point?

**Art. 574.** 170. What is the altitude of a station at which water boils at 180° F.?

**Art. 579.** 171. How many thermal units are required to evaporate 10 pounds of boiling alcohol?

**Art. 584.** 172. What will be the bulk of steam formed from 10 pounds of water at 212° F.? At 249°.5 F.? At 306° F.?

**Art. 588.** 173. How much faster will a rod of copper conduct heat than an equal rod of iron?

**Art. 619.** 174. How many pounds of ice may be changed to steam by the burning of 10 pounds of coal? By 10 pounds of alcohol?

**Art. 624.** 175. What is the mechanical equivalent of the heat produced by the burning of 1 pound of coal?

176. How many thermal units are evolved in an hour by a stream of water with a section 1 foot square and a fall of 60 feet?

**Art. 626.** 177. To what temperature would a cannon ball moving at the rate of 960 feet per second be raised if suddenly stopped? How many thermal units would be evolved if the ball weighed 60 pounds?

**Art. 637.** 178. What is the efficiency of a boiler capable of evaporating 10 cubic feet of water each minute? How much anthracite coal will be required in an hour?

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