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PRACTICAL
LESSONS IN SCIENCE

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PRACTICAL

LESSONS IN SCIENCE

BY

JOSIAH T. SCOVELL, M. A., M. D.,

FOR TEN YEARS PROFESSOR OF NATURAL SCIENCE IN THE INDIANA STATE
NORMAL SCHOOL.

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PREFACE.

THE question before each one of us is how to use all our faculties to the highest advantage of ourselves and others. This is the great thing to learn, the great thing to teach. If we would be strong in body and mind we must obey nature's laws. If the farmer would succeed, he must work in accordance with the laws that govern the phenomena of vegetable and animal life. The miner and quarryman must recognize the laws of the mineral world; the machinist and mechanic the laws of mathematics and physics, and the manufacturer the laws of chemistry; while the work of the artist, poet and musician must conform to and interpret nature; so that from every economic standpoint the study of science is of the widest importance. Nature is the field of *observation*, the primary source of our ideas. Here we find objects for comparison, material for the exercise of the memory and data for the formation of judgments. The study of nature promotes respect for law, developing honesty, self-reliance and reverence, so that the careful study of nature's laws is of the highest educational value.

It is the recognition of these truths that has given science a prominent place in every university, college and high school, and their wider appreciation has given rise to the demand for its introduction into the common schools.

While admitting the great value of scientific training it did not seem desirable in this case to write a formal text-book, or an

exhaustive discussion of science, but rather to set forth in a clear and concise manner the general principles of this important branch of study. The plan has been to consider briefly the fundamental ideas of the different departments of science, illustrating them by examples of their practical application, and also to consider the relation of these branches to each other as constituent parts of one great organic whole—the earth, the home of man. The writer has aimed to open up the fascinating field of science in such a manner as to awaken and develop the spirit of scientific inquiry, and the desire for scientific work. Such experiments have been suggested as can easily be performed anywhere without costly or complicated apparatus, and lines of work have been mapped out in each division that may be pursued with pleasure and profit in almost any locality.

It is hoped that the work will stimulate many to study nature for themselves, to observe the phenomena of climate, to notice the surface changes of the earth, to study plants and animals as living things, to observe them in their homes, amid their natural surroundings—in fact, to study nature as the great fountain of knowledge. Numbers may thus be encouraged to go beyond the limits of these discussions, into special fields to which they may have served as an introduction; yet if the book only helps to bring our teachers and school children into closer sympathy with nature, the purpose of the author will be well accomplished.

JOSIAH T. SCOVELL.

TERRE HAUTE, IND., January 10, 1894.

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PRACTICAL LESSONS IN SCIENCE.

CHAPTER I.

INTRODUCTION—GENERAL PRINCIPLES OF SCIENCE.

SCIENCE is scarcely more than a century old. In fact the investigations, discoveries and generalizations, which have given science a standing before the intellectual world, were for the most part made within the present century. The growth and development of that great body of systematic knowledge, which we call science, has been interesting from many points of view. The scientific investigator, penetrating the hidden realms of nature, has set forth new ideas. These ideas excited opposition, so that there has been a constant conflict between the new and the old, between the conservative and the progressive. Every advancement in science has been opposed by those who thought its tendencies were atheistic, leading toward the subversion of religion and the church; by those who considered the reasoning and conclusions of science unphilosophical; by those who considered the processes and results unpractical, and by those who were willing to leave well enough alone, being hostile to every change. Science has been looked upon with distrust by the learned professions, has been sneered at by practical men, and shunned as something uncanny by the illiterate.

The wide dissemination of information, the growth of intelligence, the continued stability of the essentials of religion, the immense economical value of many of the results of scientific investigation and discovery, have happily dispelled nearly every form of distrust and opposition. And the unanimity of opinion among scientific men, on all the important conclusions and gen-

eralizations of science, and the wide application and continued stability of these conclusions, is leading even philosophers and metaphysicians to accord science some degree of respect.

While at the present time there is little active opposition to science, there are still many people who, through lack of information, think of science as something peculiar and difficult, which only persons of superior ability and intelligence can understand and appreciate. There are many people who have no idea that scientific investigations are of any interest or value to them, who have no idea that they suffer less pain, will live longer, are surrounded on every hand by comforts and conveniences, and means for enjoying life, all as the direct results of scientific work.

Science is neither strange nor peculiar. It deals in a business way with those common facts and phenomena which are the familiar events of our every-day experience. The earth on which we live, the air we breathe, the water we drink, the food we eat, the clothes we wear, the dwellings which afford us shelter, the tools we use, the soil we cultivate, the sun that rules our day, the moon and stars that cheer the night, and the myriad forms of vegetable and animal life that swarm around us everywhere, constitute the subject matter of science.

The discovery of facts, the arrangement of these facts in accordance with their relations, and the formation of judgments from these facts, which shall be free from personal feeling or bias, is scientific work. Through this kind of work science attempts to explain in a rational way the facts and phenomena of the world. Such work results in the discovery of important laws and principles, which lead the way to valuable inventions, and to the development of new processes, that enable us more fully to utilize the vast and varied resources of nature. Knowledge gained in this way underlies the success of every industry, has been potent in every wave of progress made by the human race.

The observations of Sir Isaac Newton on the relation between the motions of a falling apple and the moon, gave the world clearer ideas of the order that pervades the universe. The con-

vulsive movements of a frog's legs when in contact with iron and copper, started in the mind of Galvani a train of thought which grew and developed into the telegraph, telephone, ocean cables, electric motors, electric light, etc. From other ideas, suggested by the bobbing lid of a kettle partly filled with boiling water, have resulted the steam engine and our modern steamship and railway systems, which have revolutionized every form of industry.

But the chief value of science is not in its practical applications, valuable as they may be, but rather in the development of the scientific method of thought and investigation. That training of the mind, which grows out of the nature of scientific work, is of the highest educational value. The collection of facts, the study of their varied relations, the testing of conclusions by comparison and experiment, result in habits of thought that are valuable in any field of human endeavor. Such work tends to make man a self-reliant, independent thinker. The field of science is the universe of matter. As more and more of this field was opened by investigators, it was gradually divided into departments and sub-departments until there are as many as fifty separate lines of scientific inquiry, either one of which would furnish material enough to employ the life-time of an industrious student.

The boundaries of these departments are, in many cases, not sharply defined. The different parts of the universe are so intimately related that any scheme of classification must be largely artificial.

Of these departments, physics and chemistry seem to be fundamental. Physics deals with those phenomena of matter that do not involve a change of substance, but simply change of position, form or condition. Chemistry deals with those phenomena which do involve a change of substance, as the various kinds of combustion and decay. But the distinction between these branches of science is not very exact. In fact there is a wide field of common ground between them.

Every body, whether mineral, vegetable or animal, whatever

its form or substance, comes under the domain of physics and chemistry. Some knowledge of these subjects is therefore necessary to intelligent work in any other department of science.

Botany treats of the vegetable kingdom, including trees, flowering plants, ferns, mosses, fungi, molds, algæ, etc., considering their form and structure, the conditions of their growth, and their relation on one side to minerals and on the other to animals. Zoölogy and its sub-departments deals with animal life, including birds, fish, insects, reptiles, mammals, etc., in much the same way that botany deals with vegetation.

Geology, drawing largely from other branches of science, considers the earth as a working organism, giving special attention to climate and those relations between the mineral, vegetable and animal worlds which have so largely determined the past and present conditions of our earth. Geology covers much of the field usually treated in physical geography, taking a general view of the earth as a whole.

Von Humboldt, at the beginning of the century, was able to master the whole domain of science as known at that time. No student of to-day could survey the whole field of science; in fact, few can master the whole work of any one of its departments. The growth of scientific knowledge during the present century has been wonderful, not only as to quantity but as to quality. It is as if workers from all parts of the world, bringing the products of their investigations, as bricks and stones, had laid them somewhat haphazard into an edifice; these workers, following the lead of a few master builders, have laid a structure of giant proportions, rugged in form, incomplete in detail, but broad of foundation, showing few lines of weakness and possessing a unity and symmetry surpassing the work done by man in any other field of human endeavor. The strength, unity and symmetry of this body of knowledge depends mainly upon the scientific method.

The great body of scientific knowledge may well discourage us from attempting to master the whole, but should not turn us aside from this important study. Careful scientific work in any

department of science, however limited, will be of greater educational value to the individual and will make him more helpful to his fellows, than less careful work over a wider range of the subject. And so intimate are the relations of the different parts of the scientific field, that a thorough knowledge of one portion gives one a better view of the whole than does the mere superficial knowledge of even several branches.

Time is an important element in scientific investigations. It takes time, often a long time, to gather sufficient facts, time to arrange these facts according to their relations, time to draw conclusions and form judgments. Many would-be scientific men fail because they are over-anxious to reach conclusions. It was a long time from Galvani's observations of the muscles of a frog to the laying of the Atlantic cable, and yet they were related as cause and effect. While time is necessary to reach scientific conclusions, some of the best scientific work the world has known was done at odd moments, between the hours of regular employment.

The term law, as used in scientific discussions, means simply a statement of the observed order, sequence or relation observed among natural phenomena. The law of gravitation merely explains to us how every particle of matter in the universe is, or appears to be, altering its motion with reference to every other particle. It does not tell why the particles move as they do; it does not tell why the moon moves in a certain curve about the earth. It simply gives in a few brief words the relationships observed between a vast range of phenomena. This is the nature of all scientific law. Men gather facts, classify them, analyze them, discover their relationships, and then describe in simple terms the widest possible range of phenomena. A scientific law is always liable to be replaced or reformed as knowledge increases. Newton's law of gravitation has stood the test of human experience for over 200 years without necessity of change.

An hypothesis or theory is the supposition assumed to account for that which is only partially known. Such suppositions have been based on a larger or smaller knowledge of facts. They may

be more or less in harmony with natural phenomena, and they may more or less fully agree with accepted ideas in science, but they differ from natural laws, in that they attempt to explain how a given order of phenomena might have been produced. They are made by men who are fully acquainted with what is known of the subject and whose gifts are often higher than knowledge. Call it genius, call it intuition, or by whatever name, there is an element which we all recognize in such creative minds that enables them to apprehend truth in a manner and to an extent which ordinary men cannot appreciate or understand. Such theories are inductions and the whole history of science is simply the story of verified inductions.

Many theories have failed when tested by experiment and experience, others have been verified and are permanent landmarks in the field of science. The theories of Ptolemy and Aristotle dominated the intellectual world for more than a thousand years. Those theories were good working propositions, the best the world then had, and it was hundreds of years before advancing knowledge began to find out their weakness. To us they may seem fanciful and crude, but considering the amount of knowledge possessed by man those theories, for their time, were creditable. If, without telescope, charts, or higher mathematics, one should attempt to formulate some scheme to account for the motions of the sun, moon, planets and stars, his respect for the old Egyptian astronomers would be greatly enhanced.

At the present time, besides many lesser theories, there are four great systems of science under whose guidance most of the scientific work of to-day is being done. These are the theory of universal gravity, the undulatory theory of light and heat, the molecular theory of matter, and the theory of organic development. These may or may not stand the test of progressive investigations, but they are good working theories and the best and only ones we have regarding their subject-matter. Their value and bearings will be developed in our treatment of the various branches of science.

CHAPTER II.

PHYSICS—MATTER AND THE ATTRACTIVE FORCES.

PHYSICS deals with matter and energy. It treats of the properties and phenomena of matter due to the action of the different forms of energy. We know many things about how matter appears, and many things about how energy acts, but we know very little about what matter really is and very little about the true nature of energy.

A rod of iron may be heated, may be melted, may be molded or worked into any form, it may be made a magnet, all without change of substance. But if the rod of iron is exposed to moist air it soon begins to change into a reddish substance called rust, or if we expose it to the action of strong acids other changes occur and other products are formed. Experiments with other substances show that matter is subject to two groups of changes or phenomena, one resulting in change of substance, the other resulting merely in change of form or structure without change of substance.

Chemistry treats of those phenomena which result in change of substance or composition, while physics treats of those phenomena which do not result in change of substance. While this is the distinction usually made between physics and chemistry it scarcely exists in nature. There is a wide field of common ground between these branches of science called chemical physics, which considers heat, light and electricity in some of their phases, and discusses some of the phenomena of gases and other subjects which seem to involve both groups of changes.

The earth, air and water, plants and animals, are composed of *matter*. Matter occupies space, it extends in three directions—that is, it has length, breadth and thickness, and as far as known matter is indestructible.

The property of matter, by virtue of which it occupies space, is called *extension*. Most arithmetics contain tables of the English and French systems of linear, square and cubical measures, and they need not be given or discussed here.

Under ordinary circumstances, matter exists in three forms or conditions: *Solids*, as wood and stone; *liquids*, as water and oil; *gases*, as air and illuminating gas.

Impenetrability is a property of matter which depends upon extension, illustrating and emphasizing that property. By impenetrability is meant that property by which one body of matter occupies space to the exclusion of all other bodies of matter, or that two bodies of matter cannot occupy the same space at the same time.

The truth of the above statement may be shown by trying to put two solids, as a stone and a block of wood, or two stones or any other two solids, in the same place at the same time. The nail in the board separates the particles of wood; does not occupy the same place with them. Take a cup or glass partly filled with water, and put into it a piece of lead, a little stone, or thrust into it a piece of wood, and in each case the rising of the water in the glass shows that the solid does not occupy the same place as the liquid water; and again, if we pour more water or some other liquid into the glass, it is manifest that the two liquids do not occupy the same space at the same time. Fill a deep pan, holding four or five quarts, nearly full of water, and put a common tumbler into it; the water will force the air out of the tumbler and take its place. Invert the tumbler and raise it partly out of the water, being careful not to let any air enter it; then through a straw or some kind of a tube blow a little air under the tumbler; the air rising drives out some of the water, showing that air and water can not occupy the same place at the same time. The diving bell, formerly much used for work under water, illustrates this principle. If another portion of air is forced into the tumbler more water is forced out, showing that two bodies of air can not occupy the same space at the same time. When the glass is partly filled with air, if a piece of cork or light wood is

pushed under the rim of the glass it rises to the surface of the water inside the glass, pushing out a bubble of air, showing that air and wood or cork can not occupy the same place at the same time. These experiments may be varied in many ways with profit and pleasure, and will fully satisfy the experimenter of the fact that matter occupies space and possesses the properties of extension and impenetrability.

The property of matter, which allows it to be divided into small particles, is called *divisibility*. We may crush a piece of common salt to powder, and dissolve the powder in water, when the particles become so small as to escape the sense of sight, even when aided by the most powerful microscope, and only the sense of taste or the chemist's art can detect the salt. Again, take a piece of aniline (magenta) about the size of a pin-head, dissolve in a few drops of alcohol, then stir into a gallon of clear water, and the little particles or divisions of aniline will tinge every drop of the whole mass of water. Experiments with other substances show that matter may be divided into particles that are exceedingly small, without changing its composition.

When we have crushed and dissolved the salt the particles are so small that we can divide them no further without changing their nature. But the chemist can divide the smallest particle of salt into two substances, one a silvery-white metal called sodium, the other a greenish-yellow gas called chlorine, while the aniline may be divided into the gases hydrogen and nitrogen, and the solid, carbon. Those who have experimented with great numbers of substances tell us that most bodies, mineral, vegetable or animal, are compound bodies, like the salt or aniline, made up of two or more simpler bodies, which are called *elements*.

The smallest division that can be made of a compound body, without breaking it up into its component parts, is called a *molecule*, and the particles that unite to form the molecule, whether of the same or different kinds of matter, are called *atoms*. The atom is the smallest division that we can make of matter. We may in the future learn to divide atoms, but at present they seem

to be indivisible, absolutely hard, inelastic, unchangeable—as bright, sharp-angled and perfect as when they left the creative hand. They are the bricks of the material world. They have combined with each other to form millions of compounds; these compounds have been broken up and new combinations formed over and over again, and yet these particles of matter show no marks of abrasion or signs of decay.

In general the molecules composing bodies are arranged in some definite way, as the crystals so common among minerals, and the various structural forms in plants and animals, leaving many spaces unoccupied, which may be called structural spaces; and it is supposed that the atoms and molecules which make up even the most compact bodies, as the metals, do not touch each other, so that even in a piece of gold there is more vacant than occupied space. These spaces between the particles which make up a body are called pores, and the property of matter depending upon the existence of pores is called *porosity*. Porosity suggests the idea and possibility of the properties of *compressibility* and *expansibility*. The porosity of water may be shown by filling a glass with water and then sprinkling into the water fine salt or sugar. The particles of salt seem to be smaller than the particles of water, and to run down among them as wheat may be shaken into a barrel of apples or potatoes. Again, water penetrates the pores of wood, cloth, paper, some kinds of rock, etc., by a process called absorption, showing the existence of pores in all such bodies.

Rest is that condition of a body when it is not changing its position in regard to other bodies around it, while *motion* is that condition of a body when it is changing its position in regard to other bodies around it.

That which changes the condition of a body as regards rest or motion is called *force*.

Bodies have no control over their conditions of rest or motion. They can not move themselves if at rest, and can not stop themselves if in motion. It requires force to put a body, as a wheel, in motion, and it requires force to stop the wheel when in

motion. *Inertia* is the property of matter which does not allow a body to change its condition of rest or motion.

Leaves and fruit fall to the earth; force is necessary to lift a body from the earth; in short, all our experience seems to indicate the existence of a force which draws or tends to draw all things together into one mass. This force is called *attraction*. It is known by different names from its different modes of action.

Gravitation is that form of attraction which acts on all bodies and throughout all distances. Every body or particle of matter in the universe attracts every other body or particle of matter. The rain, the snow, the dead branch, or loosened rock, falls under the action of gravitation; and it also holds the heavenly bodies in their accustomed orbits. The action of gravity, as manifested on the earth, is to bring all bodies as near the center of the earth as possible and hold them there.

The force of gravity is found to vary in accordance with two laws.

If two bodies, one containing twice as much matter as the other, are attracting a third body, equally distant from the others, the force exerted by the larger one will be twice as great as that exerted by the other. If one contained three times as much matter as the other it would exert three times as much force, etc., illustrating the first law of gravity, that the force of gravitation varies directly as the quantity of matter exerting it; that is, the greater the quantity of matter the greater the force of attraction.

Suppose a body to be twice as far from a source of attraction at one time as at another. In the first position the force of attraction will be only one-fourth as strong as in the second. If the distance be three times as great the attraction will be one-ninth as strong, etc., illustrating the second law of gravity, that the force of gravitation varies inversely as the square of the distance through which it acts. In discussing gravity, the center of gravity is considered as the center of the mass of matter exerting the force, and the distances are estimated from the center of gravity in each case. In the case of a sphere

or cube of uniform density the center of gravity is at the center of the body, while in a pyramid or cone it is below the center of the body. The lower the center of gravity the more stable the body. A load of hay may be overturned more easily than a load of stone, as the center of gravity is lower in the load of stone. A body will stand up as long as a vertical line from its center of gravity falls within the base of the body. It is easier to stand on our feet than on a pair of stilts, because, in the latter case, the slightest motion will throw the vertical line outside the supporting base.

It is difficult to illustrate the second law of gravity, but the intensity of light and heat vary according to the same law, and it can be more easily illustrated when treating of those subjects.

The *weight* of a body is the downward pressure which it can exert, and this pressure or weight is due to the action of gravitation exerted by the earth. Weight depends upon gravity, measures gravity, and varies according to the laws of gravity. On the surface of the earth the variations of gravity are so slight that weight is usually considered as a good measure of the mass or quantity of matter in a body as well as of the force of gravitation. As the earth is somewhat flattened at the poles, the distance to the center of gravity of the earth is less at the poles than at the equator, consequently the force of gravity is greater and a body will weigh more at or near the poles than at or near the equator. Water, dirt or mud is thrown from a rapidly turning wheel; the earth as a rotating body tends to throw off matter from the equatorial regions; this tendency also lessens the force of gravity and consequently the weight of bodies at the equator. The combined effect of these two causes is to make gravitation at the equator less by about 1-192 part of its value at the poles. Conversely, the increase of the force of gravity from the equator north and south, as shown by the vibrations of the pendulum, indicates a flattening of the earth toward the poles.

The quantity of space a body of matter occupies is its *volume*, and is expressed in cubic inches or feet. The quantity of matter

in a body is its *mass*, and is expressed in ounces, pounds, etc. If you cut blocks of wood, cheese and lead of the same size you will find their weights to be different; that is, bodies of the same volume may contain unequal quantities of matter. Those bodies which contain more matter in the same volume than others are said to be more *dense* than the others. *Density* refers to the quantity of matter in a given volume as compared with some standard. Lead is more dense than iron, because a cubic inch of lead contains more matter than a cubic inch of iron.

Cohesion is that form of attraction which acts between the molecules of a body, and which resists dividing, breaking, or tearing forces, differing from gravity in that it only acts through small distances and between molecules of the same kind, making the diamond hard, copper tenacious, and iron strong.

Cohesion varies with the kind of matter, being stronger in some kinds than in others, and it varies on account of what seems to be a different arrangement of molecules in the same kind of matter, as in the case of tempered and untempered steel. In welding iron the pieces must be heated, at least to the plastic state, before the particles can be hammered together so that cohesion will act.

Adhesion is that form of attraction which holds together molecules of different kinds of matter. It is this form of attraction that makes glue, paint, mucilage and varnish valuable, and is more marked between solids and liquids.

While adhesion is more marked between solids and liquids it does exist between solids and solids, as in the case of dust adhering to a wall, and between liquids and gases as well. This may be shown by pouring water from one vessel into another; air adhering to the descending stream is carried with it, as shown by the bubbles of air formed in the water of the receiving vessel. Gases sometimes adhere to solids. If a piece of glass be immersed in water, bubbles will often appear on its surface. Dust, even iron filings, gently spread over the surface of water, will float,

though much heavier than water. A layer of air adhering to the particles of iron, serves as a boat in which the iron floats.

If a tumbler be placed on the surface of water and then lifted slowly upward, it will draw up the water, forming a little hill. After it has been raised from the water, the film of water on the bottom of the tumbler shows that the force of adhesion between the glass and the water was stronger than the force of cohesion between the molecules of water. This can be measured by letting one pan of a balance rest on the surface of water and then adding weights to the other pan till the force of cohesion is overcome.

Capillary attraction is a kind of adhesion which causes some liquids to rise along the sides of solids partly immersed in them and to rise in narrow tubes, or between plates that are brought near each other. By capillary attraction the blotter absorbs ink, the oil rises in the lamp-wick, and doubtless, in the case of paint and glue, these substances actually penetrate the solid by capillary attraction, and when hardened, mechanical interlocking of the particles aids the force of adhesion in making the union firm. This form of attraction does not act the same in all cases. If a glass tube be partly immersed in mercury, the mercury sinks instead of rising in the tube; in general, those liquids which wet the solid will rise, those that do not will be pushed down, and the smaller the tube the higher the liquid will be raised or the farther it will be pushed down. Experiments with two pieces of glass three or four inches square, separated by different distances, shows that capillary force is manifested between plates in the same manner as within tubes.

The surface of a solid or liquid, is in a state of tension. It is explained as follows: In the interior of bodies, each molecule is attracted equally in all direction, and no tension exists, while at the surface the molecules are attracted laterally and inward, but not outward, so that there is strain on the surface molecules. It is through this surface strain that cohesion causes small bodies of liquids to assume a spherical form, as drops of water or mercury. When a soap bubble is formed at the mouth of a pipe, and the stem left open, the bubble soon shrinks and expels the

air, which indicates tension in the surfaces of the bubble. Pure water has the highest surface tension of any ordinary liquid except mercury. It is the surface tension of water that causes oil, dust, or any impurities that may settle on it, to spread out over the whole surface. The interesting phenomena observed when trying to spread a small quantity of water over an oily surface, or when a drop of oil and a drop of alcohol are made to touch each other on a plate of glass, or when small quantities of water and alcohol or water and ether are brought together on a plate or piece of glass, are all explained by the action of surface tension. Surface tension explains capillarity. The force of adhesion between glass and water is stronger than the force of cohesion between the molecules of water, and the water rises along the sides of the tube, making the surface of the water inside the tube concave like a cup. The effect of this action is to lessen the pressure on the water in the tube, and the air pressure on the outside forces the water up in the tube until the weight of the column of water equals the difference between the forces of adhesion and cohesion. In the case of an oiled tube and water, or a glass tube and mercury, no cohesion is manifested, and surface tension causes an increased pressure inside the tube, and the liquid is depressed.

Magnetic attraction is that form of attraction which acts between a lodestone or a magnet and iron, drawing the bodies towards each other and causing them to assume some particular position in reference to each other. The compass, so important in navigation and in surveying, owes its value to this form of attraction.

Electrical attraction is shown in lightning, and often results from chemical action. Through the action of magnetic and electrical forces we have the telegraph, telephone, dynamo, electric motor, etc., which will be more fully discussed under the subjects of magnetism and electricity.

Chemical attraction or *affinity* acts between the atoms or molecules of elementary bodies, binding them together into molecules of compound bodies, whose molecules are held together by the force of cohesion.

CHAPTER III.

HEAT: ITS SOURCES, EFFECTS AND MODES OF TRANSMISSION.

HEAT and the different forms of attraction are called physical agents, forces, or forms of energy. They are known to us chiefly by their effects.

Heat was once called an element; later it was regarded as a subtile form of matter contained in bodies, and manifesting itself with more or less intensity. Now it is thought to be the vibratory motion of the molecules of bodies, which may be increased or diminished in various ways. When this motion is increased the body becomes hot, the molecules are separated and the body expands. When the motion is diminished the body grows cold, the molecules approach each other and the body contracts. Concerning the ultimate source of this motion which affects us as heat, science as yet has no suggestions to make.

The process by which the blacksmith sets the tire of a wheel shows that heat causes iron to expand and that when the heat is removed or its intensity lessened, the iron contracts. Lay a rod of iron or copper, ten or twelve inches long, on a board, and drive a nail at each end so that the rod just touches the nails; then place the rod in the fire and when red-hot test its length by the nails. A few experiments with different solids will show that heat causes them to expand and that some expand more than others. Purchase from the druggist an alcohol lamp, some test tubes fitted with corks, and a few pieces of narrow glass tubing, and have holes cut in some of the corks of such size that the glass tubing will fit them closely. If a lamp seems too costly, one can be made with little trouble. Get a bottle holding from two to four ounces, with a wide mouth, fit it with a cork, bore the cork for a small tube made of tin, or the

ferrule of an old penholder; then a little candle wicking and an extinguisher, which may be made of cork, completes the lamp. Take a piece of glass tubing, from eight to ten inches long, soften it near the middle in the alcohol flame and bend it to an angle of about 60 degrees, and, when cold, fit it in one of the perforated corks. Fill a test tube with water and force in the cork, carrying the glass tube so that the water rises in the tube through the cork; then wipe dry, place the lower end of the test tube in the alcohol flame, and notice the water in the smaller tube; withdraw the heat and again observe the effect. The experiment may be more interesting if colored water is used. If a vessel be filled with cold water and heat applied, the water will expand and overflow before it is hot enough to boil; this is a common occurrence in the cook room. Empty the water from the test tube, used in showing the expansion of water, and when dry, close it with the cork carrying the delivery tube; then dip the free end of the tube under water and apply the flame to the test tube. The bubbles formed indicate that the air in the tube is expanding; that some of it has been forced out. Remove the flame, keeping the end of the delivery tube under the water, and soon the water will be seen rising in the carrying tube; showing that the air is contracting. These and other experiments indicate that heat causes solids, liquids and gases to expand, and that when heat is removed they contract, the attractive forces drawing the molecules closer together.

The forces of heat and cohesive attraction, acting upon the molecules of bodies, are called molecular forces, and from the direction of their action are called attractive or repellant forces. They are constantly struggling between the molecules of bodies, and as the one or the other prevails the body is hot or cold, is a solid, a liquid, or a gas. In a solid body the attractive forces prevail, and its molecules are firmly bound together, so that solid bodies tend to retain the form given them by nature or art. In a liquid body the attractive and repellant forces are nearly equal, and the molecules are free to move easily among themselves, so that the form of liquids depends on the form of

some solid in which they are inclosed. In a gaseous body the repellant forces prevail and the molecules are driven away from each other to the greatest possible distance; consequently gases have no independent form or volume. In the firmest solid the repellant force is still active, and some degree of mobility still exists, even in the hardest body. But in the case of gases the particles seem to have been separated so far as to be beyond the influence of cohesive attraction, so that if they ever become liquids it must be through the action of some other force than cohesion.

If we apply heat to a solid, as ice, it soon becomes a liquid; and if the heat continues to increase, the liquid expands into a gas. If heat is removed the pressure of the air and the force of gravity bring the molecules together into a liquid form, and finally the cohesive force draws them into the solid form again. In common language, the gas cools and condenses into a liquid and the liquid cools to a solid; that is, cold is often spoken of as an active force, while it is simply a condition of a body due to the diminished action of heat; as heat diminishes, the body becomes cooler, and the attractive forces prevail more and more fully.

By *temperature* is meant the warmth or intensity of heat in a body as compared with some standard. Temperature is not the same as quantity of heat; that is, a pond of water at a temperature of 40 degrees would contain more heat than a pail of water at a temperature of 100 degrees.

We can tell by touch that one body is warmer than another if the difference is considerable, but the touch does not give us an accurate knowledge of the difference. In some substances there is a definite amount of expansion or contraction for a definite increase or diminution of the intensity of heat. This makes it possible to construct an instrument called a thermometer, or heat measurer, which, by the expansion or contraction of some substance, enables us to get an accurate idea of the relative temperature of bodies. In the thermometer for ordinary use the temperature is indicated by the expansion or contraction of

mercury which has been confined in a glass tube. A scale of degrees is attached to the tube, of which the following are the most important points: 212 degrees, which indicates the temperature of boiling water; 32 degrees, which indicates the temperature of freezing water; and zero, indicating a temperature 32 degrees below that of freezing water. At 39 degrees below zero mercury freezes, and to indicate lower temperatures alcohol thermometers are commonly used.

The above are the figures on the Fahrenheit scale. On the Centigrade scale, zero marks the freezing point, and 100 the boiling point. Other scales are sometimes used.

To measure higher temperatures, an instrument called a pyrometer is used, in which some metal or one of the permanent gases serves to indicate the intensity of the heat. To measure delicate changes in temperature an air thermometer is sometimes used. In our experiments for showing the expansion of water and air by heat, the tubes, with the water in one case and the air in the other, formed a thermometer, needing only a scale for completion.

The principal sources of heat for the earth are the sun and stars. Chemical action, as combustion, fermentation, and the vital processes, is a source of heat; so is mechanical action, as friction, percussion, etc. Illustrations of heat from these various sources will be familiar to everyone.

Heat is assumed to be the motion of the molecules of bodies. An imponderable but highly elastic substance, called ether, is supposed to fill the spaces between the molecules of bodies and all spaces throughout the universe not otherwise occupied. The vibrating molecules of the heated body cause vibrations or waves in this ether. These waves spreading out in all directions cause a more rapid movement of the particles of bodies which they meet, thus causing more intense heat. In fact, heat does not pass from point to point as heat, but rather as energy which becomes heat in the bodies acted upon by the waves of ether. This transference of heat through waves of ether is called *radiation*. The intensity of heat by radiation varies; first, as the intensity of heat in the source; second, inversely, as the square of the distance

from the source. The first law needs no illustration, and our experience leads us to believe that the other may be true also, but its truth can be better illustrated in the discussion on the subject of light, which varies according to the same law.

Radiant heat or energy moves in straight lines, as can be shown by arranging screens about the source of heat. A body with a rough surface will radiate heat more readily than a similar body with a smooth surface. The teapot is given a polished surface because such surfaces retain heat better than rough ones do.

Suppose one end of an iron rod is held in the flame of a lamp, the molecules in contact with the flame are made to vibrate more rapidly. They swing against their neighbors and put them also in more rapid motion; they in turn give motion to the next, and so on until those at the end of the rod are in more rapid motion, and can put in more rapid motion molecules of other bodies in contact with them, thereby increasing their temperature. This method of transferring heat from molecule to molecule, through a body, is called *conduction*. The metals are, in general, the best conductors of heat. Liquids and gases are poor conductors of heat. If we take a test tube and put a piece of ice in the bottom, weighted by a piece of iron or lead, and then fill the tube with water, the water at the top of the test tube may be boiled without melting the ice, showing that water does not conduct heat as rapidly as some solids do.

The heat applied to a body is divided by it into two parts, one part is used to increase the temperature of the body, another part is used to expand the body. The first can be appreciated by the touch, and is called sensible heat; the second can not be appreciated by the touch or by the thermometer, and is called latent heat. The latent heat has not been lost, but it has simply been used up in doing the work of expansion. Different substances do not divide heat in the same proportion. Let equal parts of water and mercury be placed over the same source of heat. Each divides the heat it receives into two parts as above; but the heat devoted to temperature is more in the

mercury than in the water, while that devoted to expansion is less. We find that the temperature of mercury rises much faster than that of water. It takes thirty times as long to raise water to a given temperature as it does mercury, which means that there must be thirty times as much heat in the water as in the mercury when the same temperature is reached by both. We see, then, that at the same temperature different substances may have different quantities of heat in them. The relative quantities of heat in different bodies at the same temperature is called specific heat. Water is the standard of specific heat. At a given temperature water contains more heat than any other known substance, its specific heat being 1, when the specific heat of mercury is .03. By this is meant that when equal weights of water and mercury are at the same temperature mercury will contain only .03 as much heat as the water.

The expansion of a solid body continues nearly uniform until its temperature has reached the melting point; the temperature then stops rising while the expansion increases, and continues until the solid is melted, the liquid resulting having the same temperature as the melting point of the solid; that is, after the body reaches the melting point all the heat applied is used in expansion, and none is used to increase temperature.

The melting points of different substances is not the same. Ice melts at 32° F., mercury at -39° , iron at about $3,000^{\circ}$, platinum at about $5,000^{\circ}$. Melting ice contracts while most other bodies expand in melting. The expansion of a liquid continues gradually until the boiling point is reached; at the boiling point the temperature stops rising, while the expansion increases and continues until the liquid is vaporized or becomes a gas. The temperature at which a liquid begins to boil is called its boiling point. Liquids change to vapor slowly at all temperatures, the change being called *evaporation*, but at the boiling point the body changes rapidly into vapor, and the change is called *vaporization*. The temperature of the boiling point depends upon the purity of the liquid; the presence of some impurities raises the boiling point, while the presence of others lowers it. Salt water,

for example, boils at a higher temperature than pure water, while that which contains air boils at a much lower temperature than that which contains none. In the salt water the attractive force is stronger than in the fresh water, and more heat is necessary to overcome this force, while in the water containing air the attractive force is less, and less heat is necessary to raise it to the boiling point. The temperature of the boiling point also depends upon the nature of the vessel in which the water is boiled. If the adhesion between the water and the vessel is strong it requires more heat to overcome it, and *vice versa*. Thus, water will boil at a lower temperature in an iron vessel than in a glass vessel, because the force of adhesion is stronger between water and glass than between water and iron. The temperature of the boiling point of water also depends upon the pressure. This pressure may be due to the atmosphere, or to some force which may be brought to bear upon it by artificial means. Whatever may be the cause of pressure the effect is to raise the boiling point. Whatever serves to decrease the pressure lowers the temperature of the boiling point. It is well known that water boils at a lower temperature on the top of a mountain than at its base. It does so because the pressure of the air upon it is less. At some high mountain stations the temperature of boiling water is so low that it is of little value for cooking purposes.

When heat falls upon a body a portion is thrown back, or reflected, from the surface. Dense bodies, as the metals, with smooth surfaces, are the best reflectors of heat as well as light. About midday in summer, when the sun is shining, it is warmer on the south side of a building than in an open field, showing that even rough surfaces will reflect heat. Heat is reflected according to the same laws observed in the reflection of light, but they can be illustrated more easily in connection with the study of light.

When heat falls on the surface of a body from any source, one portion is reflected, while another portion penetrates the body, passing from molecule to molecule, as in the case of conduction.

While this process is called *absorption*, it is practically the same as conduction.

Convection is the process by which one body carries heat from its source to another body. Air receives heat from the stove, moves to other parts of the room and gives up the heat to other bodies. Liquids and gases are good conveyers of heat.

Experiment: Take a test tube and fill it nearly full of dirty water, and, inclining it slightly, apply heat to the bottom and very soon currents will be observed in the tube, and if we test with the finger the temperature of this water, we shall find that there is a warm current on the upper side of the tube and a cooler current on the lower side; now remove the heat and hold the tube in a vertical position and it will be found that the water at the top is warmer than the water at the bottom of the tube. The water has conveyed the heat from the bottom of the tube to the top by the process of convection.

Heat from the sun will pass through the air and window glass, and warm the window sill or the hand much more than it warms the glass or the air. The property by which some bodies allow heat to pass through them without themselves being much warmed, is called *diathermancy*. Such bodies are called *diathermic* bodies. They are transparent to heat as some bodies are transparent to light.

CHAPTER IV.

PROPERTIES OF SOLIDS, LIQUIDS AND GASES.

THE resistance which a substance offers to the separation of its parts by pulling is called *tenacity*. This property varies greatly in different substances, cast steel being the most tenacious substance known. Tenacity differs from *toughness*; the cast steel will bear a pulling strain but will not bear much twisting or bending backward and forward, while copper, which is not as tenacious as the steel, will bear twisting and bending many times before breaking, having the property of toughness in a higher degree. Cast steel does not stretch. Other substances, as copper, soft steel and iron, gold, silver, etc., yield to the pulling force and may be drawn into wire, thus exhibiting the property of *ductility*. This property varies greatly in different substances, and many substances which are but slightly ductile when cold possess that property in a high degree when heated, as glass and iron. The tenacity of a substance is increased by drawing it out into wire. Thus the cables of suspension bridges are made of fine wire twisted together, not only because such form makes them flexible, but because the steel, in that form, possesses more tenacity. Platinum is the most ductile of metals. Gold and silver also possess this property in a high degree, while lead and tin are only slightly ductile.

Malleability is a property similar to ductility, which allows a body to be rolled or hammered into plates or thin sheets. Gold is the most malleable substance known. Most of the metals possess this group of properties in some degree.

Hardness is that property of solids which enables them to resist any action which tends to abrade or scratch them. Hardness does not mean strength, indeed hard substances usually possess the property of *brittleness* as well, yielding easily to a

sudden blow, as glass or the diamond. The relative hardness of two bodies is ascertained by trying which will scratch the other. This test shows the diamond to be hardest of all substances and the mineral, talc, to possess the property of hardness in the least degree, or the property of *softness* in the highest degree. Many substances after having been raised to a high temperature may be tempered to almost any degree of hardness, and other substances, as glass, may be greatly toughened by the process of annealing.

In many cases when substances pass from the liquid or gaseous state into the solid form, their molecules arrange themselves in regular geometrical forms called crystals, as ice, common salt, sugar and quartz. The greater portion of the older rocks are of a crystalline structure, and most of the metallic ores and minerals have distinctive crystalline forms. Metals, by jarring, often become crystalline, losing their ductility and tenacity. From this cause, bells long rung change their tone; cannon, after long use, lose their strength; and the perpetual jar of bridges, shafts of machinery, car axles, etc., gradually changes the tough, fibrous iron into the weaker crystalline form, which explains many accidents.

Most substances expand as they are heated, and contract as they cool. In many cases the contraction and expansion is somewhat uniform; but those substances which crystallize when cooling usually expand slightly as their temperature approaches the point of solidification. Most crystalline structures occupy more space than the same matter in a liquid form. Water contracts as its temperature falls from the boiling point to 39° F., and then it expands, so that the volume at 32° F. is the same as it was at 48° F. If water continued to contract to the freezing point, it would be denser and heavier than the warmer water below, and would sink. Lakes, rivers and other bodies of water would begin to freeze at the bottom, and would soon become solid ice. But as the surface stratum of water approaches the freezing point, it expands, and, becoming lighter, floats, and thus the cooler water and ice remain at the surface. Similar phenomena occur in the cooling of some other substances. In freez-

ing, water expands with such force as to burst the strongest vessels, and break up the most tenacious rocks. The molecular force seems irresistible. The cohesive force is also very strong, and is frequently made use of in mechanical operations, as in setting the tires of wheels, in riveting the plates of boilers, etc. In the building of iron bridges and similar structures provision must be made for the expansion and contraction due to ordinary changes of climate, or the structures would soon go to ruin from the constantly recurring strains due to these forces.

Glass is a poor conductor of heat; so that if hot water is poured into a thick glass bottle the inner part becomes hot and expands before the outer part gets warm, and the glass is liable to break from the sudden strain. Hence, glass vessels which are to be subjected to extremes of temperature should be thin, so that there may be less chance for unequal expansion.

Most solid bodies may be changed in form by compressing, stretching, bending, or twisting forces, but when the forces cease to act, in most cases, the body tends to resume its original form. If the body has been compressed, the repellant force corrects the form, while if the body has been stretched, it is the attractive force that does the work of correction. After bending and twisting, the same forces attempt to restore the original form. This property of matter by which it assumes its original form after distortion is called *elasticity*. Many bodies are elastic only within certain limits—that is, a body may be strained beyond the limit of recovery—the particles may be separated so far that cohesion can not assert its power again. Vegetable and animal substances decay, metals become crystalline and the properties of tenacity, elasticity and strength are gradually lost.

Liquids are elastic and have other properties in common with solids, but the characteristic property of liquids is *mobility*. The attractive and repellant forces are so nearly balanced in liquids, that the molecules are allowed to move freely among themselves. Liquids under the action of gravity press downward, but their mobility allows them to press sidewise as well as downwards, so that water will pass out through holes in the sides

of a pail or barrel filled with water, as well as through holes in the bottom. And the fact that objects float on liquids, shows that they press upward; hence, it seems clear that liquids press in all directions downward, sidewise and upward. Careful experiments show that in a body of water, at rest, pressure is equal in all these directions. The rigid mountain seeks its level as eagerly as a body of water but the mobility of the water enables it to find its level more easily and quickly than the mountain can. Every body of liquid when at rest has a level surface, that is, every part of the surface is equally distant from the center of the earth, and this is true however irregular the body of water may be. If a tube or pipe, even miles in length, be connected with a pond, lake, or other body of water, it becomes a part of the pond or lake and the water rises to the same level in the pipe as in the pond. This accounts for many springs and artesian wells, and on this principal many cities and towns are supplied with water from ponds or lakes, often miles away among the hills above them, the main pipe being divided and subdivided into thousands of service pipes in each of which the water rises to any level not above the level of the reservoir. In practice it will not rise quite as high as the source, on account of friction in pipes. The liquid water weighs about $62\frac{1}{2}$ pounds or 1,000 ounces per cubic foot, or about .577 of an ounce per cubic inch. Water is heavy and when urged down a steep slope by the force of gravity exhibits a terrific power; even when the slope is only moderately steep its destructive power is immense, as shown in the case of the disaster from the breaking of the dam at Johnstown, Pennsylvania, and as manifested everywhere in the work of torrents and rivers. This force is sometimes utilized in placer mining, by bringing the water down a steep slope in pipes, using it to move soil, gravel and rocks, much as a garden hose is sometimes used for cleaning walks, etc. It is also used for driving various kinds of machinery.

The fact that liquids press upwards may be shown as follows: Suspend a solid, as a stone, by a wire from one end of a scale beam, so that it hangs near the bottom of a pail or tub. After

noting the weight, fill the pail with water, so that the stone is covered, and again note the weight. The water seems to have pushed upward against the stone, with a force equal to the difference of weight in the two cases. Experiments show that this difference between the weight of the stone in the air, and its weight in water, is equal to the weight of a volume of water which is equal to the volume of the stone. Now, if we divide the weight of this volume of water by .577, the weight of a cubic inch of water, in ounces, we get the volume of the water in cubic inches, and the volume of the stone as well, however irregular the stone may be. In this way the volume of any substance heavier than water may be found.

Now, if we divide the weight of the stone, in air, by the weight of an equal volume of water, which is equal to the difference between the weight of the stone, in air, and its weight in water, we find what is called the *specific gravity* of the stone.

Suppose a piece of marble weighs in the air 10 ounces; in water it weighs 6.3 ounces; the difference of weight in air and in water, or the weight of an equal volume of water, is 3.7 ounces; then $10 \div 3.7 = 2.7$, the specific gravity of the piece of marble. Now, if the specific gravity of all the more valuable substances be carefully determined, we have at hand an easy method of testing the purity of articles supposed to be made of gold or silver, of jewels supposed to be diamonds or other precious stones, and for determining the identity of many doubtful substances. The process of finding the specific gravity of solids heavier than water is simple, but in the case of solids lighter than water, the process is more complicated, though not difficult.

In case we wish to find the specific gravity of a body lighter than water, it will be necessary to attach some heavier substance, as lead, to it, in order to make it sink in the water, and then we need to consider the volume of water displaced by the lead. This may be illustrated by the following experiment: A body lighter than water weighs in air 200 grains. When attached to a piece of lead weighing 1,736 grains, they both weigh in the air 1,936 grains; in water they together weighed 1,460, the loss in weight

of the two being 476 grains, which is the weight of a volume of water equal to the volume of both bodies. Then weighing the lead by itself in water, it is found to lose 152 grains, and this subtracted from 476, the loss of both, gives 324 grains as the weight of the water displaced by the lighter body. Then dividing the weight of the lighter body in air (200 gr.) by the weight of an equal bulk of water (324 gr.) gives the specific gravity of the lighter body. From this data the volume of the lighter body may be found as before.

To do this kind of work accurately, delicate scales and pure water of definite temperature, are necessary; but with a home-made balance, using bird-shot for weights, results of great accuracy may be obtained. Water is the standard in finding the specific gravity of liquids as well as solids. We may find the specific gravity of a liquid by weighing a given volume of the liquid and dividing that weight by the weight of an equal volume of water. To facilitate such operations specific gravity bottles are made, holding 1,000 grains of pure water, so that one has only to fill the bottle with the liquid he wishes to test, and weigh it and divide the result by 1,000, to get the specific gravity. In this way we compare the weight of a volume of the liquid to be tested and the weight of an equal volume of the standard—that is, we compare *weights* of equal *volumes*—but the same result may be reached by comparing the *volumes* of equal *weights*, which is the principle of the hydrometer, lactometer, alcohol-meter, etc. These instruments are made so as to sink to a given depth in pure water, milk, or alcohol. If the liquid tested is lighter than the standard the instrument sinks deeper—if heavier it does not sink as far—and the difference is read from the scale. This principle may be illustrated by using a piece of wood about an inch square by 6 or 8 inches long, into one end of which a nail has been driven so that it will stand erect in a liquid. Place the stick in a jar of water and note how far it sinks—then put it in a jar of milk, kerosene oil, or any other liquid, and note how far it sinks, and the principle of the hydrometer is easily understood.

Again, if a heavier body, as glass or iron, of known weight in air, be weighed in water, the loss of weight shows the volume of an equal weight of water. If the same body be weighed in alcohol or milk, the loss of weight shows the volume of an equal weight of the milk or alcohol, which may be compared with that of water and the specific gravity found. It is said that the principle on which the whole subject of specific gravity is based was accidentally discovered by Archimedes, an eminent philosopher, who lived in the third century B. C., who used it to test the purity of a crown, supposed to have been made of gold.

Liquids not only press in all directions, but they transmit pressure in all directions. Fill a bottle with water, fit it with a good cork, so that the cork touches the water in the bottle; now pressure on the cork will be distributed to every part of the bottle. Insert a pipe into the bottom of a cask and bend it so that the free end is about as high as the cask, then fill the cask with water, and the water will be found as high in the pipe as in the cask. If you pour water into the tube, the water level rises in the cask. If we fit a piston in the pipe and press down upon the water, that force is transmitted to the whole mass in the cask, as the whole mass rises to a higher level. The law may be stated as follows: Pressure exerted on any given area of a fluid, inclosed in a vessel, is transmitted without loss to every equal area of the interior of that vessel. This principle has been fully established by experiment and is utilized in the construction of the hydraulic press. Presses have been made that are capable of lifting as much as 3,000 tons.

Gases have weight and elasticity, and they surpass liquids in mobility, but they are distinguished for their high degree of compressibility and expansibility. Take a test tube fitted with a cork and a delivery tube of about twelve inches in length. Insert the free end of the delivery tube in water or some colored liquid, and apply the flame of the lamp to the test tube until some of the air is forced out; then remove the heat, keeping the delivery tube under the liquid till about one-fourth of it is filled with the liquid; then we have an air thermometer, with which can

he illustrated the compressibility and expansibility of air. Blow gently into the end of the delivery tube and the air will be compressed; apply the hand to the test tube and the air will expand as shown by the movement of the fluid in the delivery tube. The elasticity of the air may also be shown when illustrating its compressibility. Experiments with other gases show that they possess these properties in common with air.

Gases press in all directions. Fill a common tumbler with water and cover it with a piece of paper a little larger than the top of the glass; then, holding the paper in place with the fingers, invert the glass, and the pressure of the air on the paper will hold the water in the glass. It will do the same when the glass is turned sidewise. This experiment shows that air presses upward and sidewise, and surely it must press downward, must have weight. The specific gravity of gases is usually found by comparing them with the weight of an equal bulk of hydrogen or air. Objects floating in the air, as leaves, feathers, birds, balloons, etc., show that air is buoyant, behaving much as liquids do, and the destructive force of winds indicates that it must have weight and other properties like liquids and solids.

Invert a tumbler under water, as in the experiment for impenetrability, and raising it partly out of the water, notice that the water is higher inside the glass than on the outside. The air can not press on the water inside the tumbler, but the pressure of the air on the water outside keeps the water up on the inside. This experiment shows the downward pressure of the air and illustrates the principle of the common pump and the barometer.

Take a glass tube a little more than thirty inches long, closed at one end, and fill it with mercury; then, closing the open end with the finger, invert the tube, and place the end closed by the finger in a cup of mercury; then withdraw the finger. The pressure of the air on the surface of the mercury in the cup will sustain a column of mercury nearly thirty inches high in the tube. Experiments of this kind show that the pressure of the air at the level of the sea is about 15 pounds to the square inch, sustaining a column of mercury about 30 inches high, or a column of water

about 33 feet high, varying somewhat with the condition of the air, as to temperature, as to the presence of water vapor, etc. At higher elevations some of the air is below the experimenter, so that the pressure is less and the barometer column is shorter. In this way elevations may be measured with considerable accuracy. The mercurial barometer consists of a tube filled with mercury inverted in an open cup of mercury, fitted with a scale, an arrangement for making corrections, etc., the whole provided with a case of wood or metal for protection. It is used for measuring elevations, but its most important use is in connection with navigation as a weather glass. It shows the varying pressure of the atmosphere, from which one may gain some idea of what weather to expect. In general, a rising column, or increasing pressure, indicates fair weather, while a falling column, or diminishing pressure, indicates foul weather. An instrument called an aneroid barometer is much used because of its portability—a good one need not be much larger than a watch. Atmospheric pressure is indicated by its effect on an elastic box containing slightly rarefied air. The aneroid is not as reliable as the mercurial, and should be adjusted frequently by a standard mercurial, if one expects to get reliable indications. The upward pressure or buoyancy of the air interferes somewhat with the accuracy of weighing operations.

The molecules of gases are so far apart that one gas does not hinder the expansibility of another. If a number of gases are mixed in a limited space, each will be diffused throughout the whole space, gases acting as vacuums to each other. In this way poisonous gases, the products of respiration, combustion and decay, and of various manufacturing operations, instead of accumulating in one place are continually dissolved away and dispersed in the great atmospheric ocean.

The *siphon* is an instrument by which liquids may be transferred from one vessel to another by atmospheric pressure. It consists of a bent tube, one arm of which is longer than the other. Take a piece of glass tubing about twelve inches long and bend it into a U shape at five inches from one end. Fill the

tube with water, then closing the end of the longer arm with the finger, place the end of the short arm in a glass of water and open the end of the long arm, when the water will flow from the glass through the tube. If the water be allowed to run into another glass it will flow until the water is at the same level in the two glasses. If we take a glass in each hand, by changing the level slightly the water may be made to run either way. Almost any substance may be used for a tube. The first siphon the writer ever saw was made of dandelion stems. In studying the barometer we learned that the pressure of the air would sustain a column of water that was over thirty feet high, in case the air pressure was removed from the column. In the case of the barometer the air pressure was removed by closing the end of the tube. In the siphon the air pressure is removed by bending the tube, so that both ends are under water. When both arms are of the same length, that is when the water in each glass is at the same level, the air pressure sustains equal columns of water, and there is no motion; but if we change the level of the two glasses of water the pressure on the water in the lower glass has a longer column of water to sustain than is sustained in the upper glass, and water is pushed over into the lower glass to establish an equilibrium. The long arm and short arm means the perpendicular distance from the arch of the siphon to the surface of the water on either side.

The common pump depends upon atmospheric pressure for its usefulness. It consists of two barrels separated by a valve opening upward. In the upper barrel there is a piston with a valve opening upward. When the piston is raised the pressure of the air is removed from the water in the lower barrel, and the pressure of the air on the water outside forces it up the barrel through the lower valve. When the piston is pushed down the lower valve closes and the valve in the piston opens so that the water rises above the upper valve; as the piston is raised again it lifts the water above the upper valve and allows water to be forced through the lower, and so on. In the ordinary force pump the piston is solid, and a valve, opening outward in the side of the

upper barrel, near its lower end, allows the downward stroke of the piston to force the water into an air chamber, compressing the air, and the elasticity of the air forces the water forward in a steady stream.

The volume of a given weight of air or other gas varies inversely as the pressure upon it; that is, the more pressure the less the volume and *vice versa*. We have already learned that air can be compressed, but careful experiments show that if we double the pressure on a given body of air or other gas its volume will be reduced one-half, and if we lessen the pressure by one-half the volume will be doubled. This is called Boyle's or Mariotte's law, from the names of its discoverers. If the volume of gas is decreased by pressure the density is increased, so that the density of air or other gases varies directly as the pressure. The density of the air is greatest at the sea level, while on high mountains the density is much less.

We have already learned that gases expand and contract as they are heated or cooled, but careful experiments show that this expansion and contraction is somewhat uniform. If we have 491 cubic inches of air at the temperature of 32° F. it will have a volume of 492 cubic inches when heated to a temperature of 33° F.; that is, it expands $\frac{1}{491}$ of the volume at 32° F. for each additional degree of heat. If the law holds good for lower temperatures we should find absolute zero at about 495° F. below the present Fahrenheit zero.

CHAPTER V.

FORCES AND MOTION.

THE *forces* which cause all the variety of *motions* in nature are but different forms of attraction and repulsion. A *constant* force is one that acts continually, as the force of gravity, while an *impulsive* force is one that acts for a time, then ceases, as the blow of a hammer, or the stroke of a bat that drives the ball.

A *unit of time* is a measured portion of time, as a second, a minute, or an hour, and *velocity* is the distance passed over by a body in a unit of time, as the train moves 40 miles an hour. The velocity of a body may be uniform, increasing, decreasing, or variable.

Space is the whole distance passed over by a body while in motion. It equals velocity multiplied by the units of time, as the velocity of a train is 40 miles an hour, units of time are 10 hours, then space equals 400 miles, the distance passed over by the train. Motion will be uniform when the velocity of the body is the same in successive units of time, and will be accelerated when the velocity increases in successive units of time, and retarded when the velocity decreases. Accelerated and retarded motions may be uniform or variable.

The first law of motion is that a body at rest will remain at rest, or if in motion, will continue in motion, unless acted upon by some force to change its condition. This is practically the law of inertia. The second law is that a given force will produce the same amount of motion whether it acts upon a body at rest or upon a body in motion. This law is illustrated by the motion of a boat in crossing a river; the steam drives the boat across the river while the current carries it down the river, and under the action of both forces the boat moves across the stream in a diagonal course.

The third law is that action and reaction are equal and in opposite directions. If the hand strikes the wall, the wall reacts on the hand and the hand is bruised; the bullet that shatters the bone is itself bruised and flattened. The fact of reaction seems evident, but careful experiments are necessary to show that action and reaction are equal.

A constant force acting alone causes uniformly accelerated motion, in a straight line, as the motion of a body falling by the force of gravity. Experiments show that a falling body passes over a space of about $16\frac{1}{2}$ feet in the first second, over three such spaces in the next second, over five the third, and so on. The distance a body falls in a given number of seconds, equals the square of the number of seconds multiplied by $16\frac{1}{2}$ feet. The distance a body will fall in four seconds may be shown as follows: $4 \times 4 = 16 \times 16\frac{1}{2} = 257.25$ feet. In the case of falling bodies the motion is due to the action of the one force of gravity retarded somewhat by the resistance of the air, but most of the motions met with in nature are the result of the combined action of several forces.

If we represent the intensity and direction of forces by lines, we can more easily solve some of the problems of motion. Suppose

Fig. 1

a body at A (see Fig. 1) is acted upon by a force, whose intensity and direction is represented by the line AB, sufficient to carry the body to B. At B the body is acted upon by a force, represented by the line BC, sufficient to carry the body to C. The forces AB and BC, acting separately, have carried the body to C over the lines AB and BC. But if the two forces AB and AD, which equals BC, should act together on the body at A, they would carry it to C, as before, but along the line AC, not along the lines AB and BC, as in the former case. This illustrates the truth of the second law of motion, and shows that one force whose intensity and direction is represented by the line AC would

carry the body to the same point as the two forces AB and BC, acting separately or together. The separate forces, represented by the lines AB and BC or AD, are called *components* and the single force, represented by the line AC, their equivalent, is called the *resultant*. The process of finding the resultant of two or more forces is called the *composition* of forces. A resultant may be made up of, and equivalent to, more than two forces. Suppose that when the body is at C it is acted on by a force represented by CF sufficient to carry the body to F. The forces AB, BC and EF, acting successively, have carried the body to F. In the former case we found that the force represented by AC equaled the forces represented by the lines AB and BC; now if we complete the parallelogram on AC and CF we find that a force represented by AF will carry the body to the same point as the forces represented by AC and CF, acting separately, and consequently to the same point as all three forces represented by AB, BC and CF would carry it if acting separately, or as AB, AD, which equals BC, and AE, which equals CF, would carry it if acting together. In this way a resultant may be found for any number of component forces.

If two or more parallel forces act on a body, at the same time, and in the same direction, their resultant would be a force equal to the sum of the component forces, and the motion would be in the same direction. A span of horses drawing a wagon illustrates this principle. If two parallel forces act on a body at different points, and in opposite directions, they will produce rotary motion. No single force can replace two such forces.

If we have a force represented by AF (Fig. 1), we may find other forces that would produce the same effect. AC and CF together would equal AF. AB and BC would equal AC, and AB and BC and CF together equaling AF, reversing the process of composition of forces. This process of finding two or more forces that are equivalent to one force, is called the *resolution* of forces.

The study of motions in straight lines is interesting and important, but most of the motions in nature are along curved lines; so that the study of motion in curved lines will be as prac-

tical, and perhaps more interesting than the other. Every ripple and wave, every swaying branch and rustling leaf, each nodding flower, each bird and beast moves in ever varying curves.

Curved motion is produced by the action of at least two forces, one of which must be a constant force. The motion of a ball, when fastened to a string and whirled around the hand, is an example of curved motion. The string represents a constant force, and the muscles of the arm an impulsive force. An impulsive force, acting alone, or any number of impulsive forces acting together, tend to cause motion in a straight line, but one or more impulsive forces acting with a constant force, gives motion in a curved line. The forces which cause circular motion are called central forces; one acts toward the center, from which the curve is described, while the other acts in the direction of a tangent to the curve. The one is called the centripetal force, and the other the centrifugal force. The grandest examples of the actions of these forces are found in the motions of the heavenly bodies, gravitation acting as the centripetal force.

The centrifugal force varies as the quantity of matter in the moving body; that is, the more matter there is in the body the greater will be the reaction against the centripetal force. It also varies as the square of the velocity of the body in motion. These laws are illustrated in a general way by the use of a sling; the heavier the stone the greater the reaction or pull, and the greater the velocity the greater the pull. When a wagon moves slowly along the road no mud is thrown from the wheels, but as the motion is increased the centrifugal force overcomes the force of adhesion between the mud and the wheel, and the mud is thrown off. This principle is made use of in the centrifugal machines employed in laundries for drying clothes, in sugar refineries for removing molasses from the sugar, and in apiaries for extracting honey from the comb. It accounts for the action of the governor on a steam engine; for bursting grindstones and balance wheels; and the increased size of the earth at the equator was undoubtedly caused by centrifugal force when the earth was cooling from the liquid state. The effect of centrifugal forces may be

illustrated by swinging a pail partly filled with water over the head or in any direction; the centrifugal force so overcomes the force of gravity that not a drop of water falls. Race tracks and railroad tracks are raised on the outside of a curve to prevent overturning from the centrifugal force exerted when passing the curve.

The ball from the bat, the arrow from the bow, the bullet from the gun, are projectiles, and all move in curved lines. An impulsive force in each case gives the body motion, which would be in a straight line but for the action of the constant force of gravity. The range of a projectile is the horizontal distance through which it moves. This distance depends upon the energy of the impulsive force, the angle at which the body starts and on the resistance of the air. Theoretically an angle of 45 degrees would give the greatest range; but in practice an angle of about 30 degrees is found to be best for a bullet, and about 35 degrees for an arrow.

Motions in liquids may be waves caused by winds; may be tidal waves caused by the attraction of the sun and moon; may be currents caused by gravity, by winds or unequal heating; or they may be vibrations arising from an endless variety of causes. In either case the motions vary greatly, and are useful and interesting in various ways. Examples of these motions and their effects are so common and well known that they need only be mentioned here. But water is often conveyed from reservoirs through pipes for use in various ways, and it is interesting to notice that the results in practice differ so widely from theoretical deductions that most calculations are made from arbitrary rules. If we examine a jet of water flowing from an orifice in a vessel we shall see that it grows rapidly smaller, so that at a little distance its size is only about two-thirds as great as at the orifice. Beyond this point the contraction of the jet is gradual. The rapid contraction near the orifice is due to cross currents, caused by the water flowing toward the orifice from different directions. The effect of these cross currents can be diminished somewhat by the use of short tubes; but when all is done scarcely more than 80 per cent. of theoretical flow can be secured. The flow of water

is greatly retarded by friction in the pipes, so that much larger pipes should be used than might at first seem necessary.

Motions in the air and other gases are very common, in fact the air is seldom or never at rest. The differences in temperature between day and night, between the sea and land, between forest and plain, all tend to cause inequalities of pressure which result in more or less extensive motions, which vary from gentle, almost imperceptible, breezes of two or three miles per hour, to the fierce and destructive tornado in which the velocity of the air is as great as 50, 75, or even 100 miles per hour. The difference of temperature between the equatorial and polar regions is perhaps the main cause of the general system of winds of the globe, the rotation of the earth influencing the direction of the air movement. If a fire is built, the air near it is heated, and expanding becomes less dense than the surrounding air. The heavier air crowding in from all directions forces the lighter air upward, giving rise to currents of air from all directions toward the fire, all of which unite in an upward current from the fire. The great heat of the equatorial regions causes the air of those regions to be less dense than that of regions north or south. This gives rise to a movement of air from both directions toward the equatorial regions, forming there an upward current, which, spreading out, flows back toward the polar regions as counter-currents, so that the air of the earth is in constant circulation in a general way, besides the thousands of minor movements due to local causes. If the earth did not rotate we might expect these currents to move directly north and south; but the spherical form and rotary motion of the earth change the directions somewhat. On account of the form and rotation of the earth, those places near the equator move more rapidly than those either north or south of the equator. Places on the equator have a motion of 1,042 miles per hour, while those at 20° N. or S. have a motion of only 975 miles per hour. Air, moving toward the equator, having the slower motion of places north and south, falls behind places at the equator having the same longitude as those from which it started, so that these currents

instead of being north and south winds, are northeast winds north of the equator, and southeast winds south of the equator. Those currents going from the equator, having the more rapid motion of places near the equator, are constantly getting in advance of places having the same longitude as those from which they started, so that north of the equator they are southwest winds instead of south winds, and south of the equator they are northwest winds instead of north winds. Numerous observations show that the winds between 32° N. and 25° S. have the directions given above.

As the land is a better absorber of heat than the water, in the torrid zones and during summer in the temperate zones, it becomes hotter than the water during the day, and the air over the land becomes hotter and lighter than that over the water, which gives rise to a wind from the sea toward the land, called the sea breeze. The land is also a better radiator than the water, so that during the night the land becomes cooler than the water, and the air over the land becomes heavier than that over the water, which gives rise to a wind from the land toward the sea, called the land breeze. The land and the sea breeze illustrate how variations in the surface of the earth serve to promote motions in the air.

CHAPTER VI.

VIBRATIONS.

VIBRATIONS are alternate movements backward and forward. If with the finger we depress one scale-pan of a balance, it will continue to move alternately up and down over the same path for a long time after the finger is removed, or if we pull the scale-pan to one side and then release it, it will swing backward and forward for a time; or suppose a ball, hung by a fine wire, be twirled by the finger so as to twist the wire; let go of it, and, speedily untwisting the wire, it will go on for a time twisting it up the other way; these alternate motions are vibrations.

The pendulum is a body hanging from a fixed point upon which it can swing freely. The fixed point is called the point of suspension, and the point in the pendulum which vibrates as if only under the influence of its own gravitation and inertia, is called the center of oscillation, and the length of the pendulum is the distance between the point of suspension and the center of oscillation. The center of oscillation is generally a little below the center of gravity of the pendulum ball.

The pendulum vibrates under the influence of gravitation and inertia. Suppose a ball at M (see Fig. 2) to represent a pendulum hung from the fixed point, C, by a cord MC. Now, if this ball be lifted to the point A and for a moment held there, the force of gravity will act upon it in a vertical direction. We will represent this force by the line AB, and resolve it into two components, shown by the lines AD and AE. The force, AD, acts lengthwise of the string without effect to move the ball; the other force,

AE, acting at right angles to AD, will pull the ball toward the point M. If the ball is allowed to fall to M, its inertia will carry it beyond that point; but when it passes the point M, gravitation begins to pull backward, with just the same power it exerted to pull the ball from A to M. The ball will rise from M to N, a distance just as far beyond M as it has fallen to reach M. It will there stop and gravitation will bring it back to M, while its inertia will carry it up to A again. The resistance of the air and friction of the cord will finally make it stop at M.

The time of one vibration at any given place varies as the square root of the length of the pendulum, and varies inversely as the square root of the force of gravity. In general, the amplitude or extent of vibration does not affect the time. The truth of the first law may be shown by experiments with pendulums of different lengths, when it will be found that a pendulum one foot long vibrates twice, while a pendulum four feet long vibrates once. The pendulum is used to measure time. If the wire suspending the pendulum ball is of steel or any single substance, it varies in length with the temperature during the year, so that the pendulum will vibrate more rapidly in some seasons of the year than in others; usually the movement will be more rapid in winter and slower in summer. Compensation pendulums are sometimes made by using different metals, so that the contraction of one balances the expansion of the other.

The pendulum is also used to determine the figure of the earth. The rate of the vibrations of the pendulum depends upon the force of gravity. If at any place the pendulum vibrates more rapidly, other conditions being the same, it shows an increase of the force of gravity. If it vibrates more slowly, then the force of gravitation must be less, indicating that in the one case the pendulum was nearer the center of gravity of the earth than in the other, which would indicate variations from a true spherical form. The vibrations of the pendulum are more rapid toward the poles, and vary somewhat in other directions.

Let a stone be thrown into the water of a lake or pond and the tranquil surface will be carved into a series of circular ridges

and furrows called waves, which extend onward and onward, finally breaking against the shore. The ridges and furrows move outward from the point of disturbance, but the water only moves upward and downward; that is, it vibrates. Another stone dropped into the water a little distance from the first sets up another series of waves. These waves interfere with the waves caused by the first stone, breaking up the symmetry of each, cutting the surface of the water into curious shaped elevations and depressions having no semblance to uniformity. Sometimes the elevation of one group of waves is piled upon the elevation of the other group, making waves nearly twice as high as a single wave of either group; and sometimes the furrows of one group correspond with the furrows of the other, making a much deeper furrow than a single wave of either group; and again, a ridge of one set will correspond with the furrow of another set, and a level surface will result.

Waves may be caused in the air as in the water, but they differ in form. The waves of water are circular, while the air waves are like spherical shells, spreading out in every direction. The air particles simply move backward and forward, as the water particles move upward and downward. Sometimes the vibrations of the air are intense enough, so that, acting on the organs of hearing, they give rise to sensation of sound. Single intense air waves cause a sound called a report; a series of such sounds in irregular succession makes a noise, and when the waves succeed each other so rapidly and regularly that there seems to be no interval between them, the result is a musical sound or tone. In general, less than from thirty-two to forty vibrations in a second give rise to reports or noises, but vibrations, varying in number from 40 to 40,000 per second, can ordinarily be appreciated as musical tones.

The tones of the voice and of many musical instruments depend upon the vibrations of chords that are subject to more or less tension. Lay a brick or a piece of wood about the size of a brick upon each end of a table. Tie a string to one leg of the table, pass it over the bricks, and tie it to another brick as a

weight; strike the cord near the center and notice the vibrations. Add another brick as a weight and strike it again, and compare the vibrations in the two cases. Stretch a heavier cord and compare the vibrations of the two cords when stretched with the same weight. Stretch a light wire and experiment with it, and compare the vibrations of the wire with vibrations of the cords. Shorten the strings, by putting a brick in the middle, and then test the vibrations again; then shift the brick either way, so that one end of the cord is longer than the other, and again test the vibrations. Vary the weights, causing tension in different ways, and notice and compare the vibrations in each case. The result of these experiments will convince one that the shorter the string, the cord or wire, the more rapid the vibrations; and second, that the greater the weight or tension the more rapid the vibrations; and that the heavier the cord or wire the slower the vibrations. Experiments with more delicate apparatus show that in the second case the vibrations vary as the square root of the weight producing tension; and in the third case that they vary inversely as the square root of the weight of the cord.

Musical sounds differ in pitch; the pitch of sounds is that which distinguishes them as being high or low. It depends entirely upon the rapidity of vibrations; the more rapid the vibrations the higher the sound produced. Two sounds made by the same number of vibrations per second, however they may differ in other respects, will have the same pitch. With pitch as a guide, test the laws of vibrating cords just given. When the number of vibrations which produce one sound is twice as great as that which produces another, we do not say that the sound is twice as high, but rather that it is an octave higher. The term octave is used to designate the tone which is made by twice the number of vibrations needed to produce the lower tone, called the fundamental. The difference in pitch between a fundamental note and its octave is very great. To fill up this interval sounds have been chosen which blend and harmonize most perfectly with the fundamental or with each other. These placed between the fun-

damental and its octave form a series of eight tones called the natural or diatonic scale. Sounds resulting from the same number of vibrations are said to be in unison. When two notes differ in pitch, but their combination is agreeable to the ear, they are said to be consonant; when disagreeable, dissonant. This scale repeated eleven times includes all sounds within the range of the human ear. The capacity of the ear to appreciate vibrations varies greatly. Some cannot appreciate one-half as many as others can. Only about seven octaves are used in music. By the English standard of pitch the note A of the treble clef is made up of 400 vibrations in a second; by the French standard the rate for the same note is 435 vibrations per second. The tones in the scale have definite relations to each other. If we represent the number of vibrations for a fundamental note by one, then the several notes of the scale will be made by the following ratios: C 1, D 9-8, E 5-4, F 4-3, G 3-2, A 5-3, B 15-8, C 2. Now, from this scale of fractions, and the fact that A is made up of 440 vibrations, the number for the others may be found; as, for example, the number of vibrations to give the fundamental C would be $3 \cdot 5$ of 440, equal to 264.

The intensity of sound is that which distinguishes it as being loud or soft. It depends entirely upon the amplitude or width of the vibrations which produce it. The greater the amplitude the louder the sound will be.

Whenever a piano wire, or the cord of any stringed instrument is struck, it vibrates as a whole and in segments at the same time. The vibrations as a whole yield the fundamental note of the cord; the vibrations in segments yield higher tones called *overtones* or sometimes harmonics.

By quality we refer to that peculiarity of sound by which we may distinguish notes of the same pitch and intensity made on different instruments. The pitch or intensity of tones made on a violin and on a piano may not differ and yet how easy to tell the sounds apart. We recognize the voices of friends, not by their pitch or intensity but by their quality. The various stringed instruments, as the piano, harp, violin, depend for their value

upon the vibrations of cords, in accordance with the laws already discussed. Vibrations of the air, giving musical sounds, may arise from the vibrations of strips of metal, wood, or other substances, and on this principle the construction of organs, horns, trumpets, and other reed and wind instruments depends. In an organ sounds are made by vibrating columns of air in pipes, sometimes aided by the vibrations of a slender and elastic tongue called a reed. The pitch of sound in pipes depends upon the length of the pipes, or in case of reed pipes on the length and weight of the reed. The air in the pipes of an organ vibrates as a whole and in segments as well, so that there are overtones or harmonics in pipe instruments as well as in stringed instruments. In the case of the horn the sounds are made by vibrating columns of air, the lips aiding the vibrations, as the reed aids the vibrations in the organ pipes.

The human voice is regarded by the best authorities as being analogous to a reed-pipe, the vocal chords forming the reed, and the cavity of the mouth the pipe; like the reed, it is rich in harmonics, as many as sixteen having been detected in some voices. But their number and relative intensities differ much in different individuals, or even in the same person at different times; and it is on this variety that the peculiarities depend by which any one voice may be unmistakably distinguished from every other. Voices in which overtones abound are sharp, and even rough; those in which they are few or faint, are soft and sweet.

Sound waves move through all elastic media, as wood, iron, the earth, water, air, etc. The velocity of sound waves varies inversely as the square root of the density of the substance, and directly as the square root of its elasticity. These laws are doubtless true for gases whose structure is uniform throughout, but are not true for the air. Through the air at ordinary temperature sound waves move with a velocity of about 1,118 ft. per second, varying somewhat with temperature and with the amounts of water vapor in the air, etc. One great danger to commerce is the difficulty of locating rocks, shoals, and other

dangerous places during fogs and thick weather, which make the sense of sight of no value. All the maritime nations have been experimenting for years on various kinds of sound signals. These experiments have resulted in some interesting facts about the air and some of its peculiarities in transmitting sound waves. Prof. Tyndall found the capacity of the air to transmit sound waves vary so much that no laws could be discovered. He experimented with guns, fog horns, steam whistles, and a steam syren. He found that frequently, under a clear sky, when the air seemed especially transparent to the sense of sight, it was especially opaque to sound waves. These acoustic clouds so filled the transparent air, that guns, fog horns, whistles and syrens which had been heard from 10 to 13 miles, could not be heard at a distance of three miles. The interrupted sound waves seemed to be wasted by repeated reflections from streams of air differently heated or saturated in different degrees with water vapor. Neither rain, hail, snow, or fog seem to have any power to obstruct sound waves. In fact, air that is filled with water vapor, in some form, is in a highly favorable state for the transmission of sound waves. Sometimes the guns could be heard more clearly, sometimes the whistles, and sometimes the syrens; sometimes low pitched, long-waved sounds could be heard more distinctly, and again the high tones penetrated farthest. Prof. Tyndall thought the steam syren the best instrument, considering it reliable for two miles, and generally for three and three and one-half miles. In general, when it could not be heard at least four miles, the sky would be optically clear so that the sound signal would not be as necessary as in thick weather. Other things being equal, sound waves travel better with the wind than against it. The velocity of sound in water is given by some authorities as about 4,700 ft. per second; in caoutchouc, as 197 ft. per second; in lead, as 4,030 ft.; in copper, as 11,666 ft.; in oak timber, along the grain or fiber, 12,622 ft.; in iron, as 16,800 ft. per second. In wet sand, as 825 ft.; and in solid granite, as 1,664 ft. in a second. Sound waves are often reflected from plane or curved surfaces, causing echoes. At Woodstock, England, an echo returns 14

syllables, and many other localities furnish interesting echoes. Echoes are sometimes interesting; but sometimes they are annoying, and the usefulness of many large halls or assembly rooms is much diminished by conflicting echoes. The ceilings and walls of such rooms should be so broken up by arches, balconies, beveled angles, etc., that no large areas of plane surface appear; drapery, furniture, etc., tend to break up and disperse the sound waves so as to lessen the effect of reflections. People do not intentionally build whispering galleries, but there are many rooms in which at certain points the slightest noise is conveyed with great intensity to certain other points, while it may not be heard at all at intermediate points. The Mormon Tabernacle, and the dome of St. Paul's Cathedral, London, are illustrations. Sounds or vibrations are not only reflected, but are also refracted. The laws of reflection and refraction of vibrations causing sound are similar to those of vibrations causing light, and may be considered in connection with the study of light.

CHAPTER VII.

FORCE AND ENERGY.

FORCE is that which causes motion or changes motion. While this definition conveys no idea of what force is, it does give us some idea of what force does. Force may be measured by an instrument called a dynamometer, of which the common draw scale is an illustration. When a body is moved by the action of force upon it, the force is said to do work on the body. For example, steam exerts pressure on the piston of a cylinder of an engine, causing it to move. The expansive force of the steam does work on the piston in overcoming resistance and putting it in motion. If there had been no motion of the piston no work would have been done. In merely supporting a body no work is done, since no motion is produced. The force of gravity does no work on the stone resting on the ground, yet it causes a pressure between the stone and the earth. Force and space are essential elements of work. A force acting through a space of one foot in raising a weight does a certain amount of work. The same force acting through a space of two feet would do twice as much work. That is, in general, force multiplied by the space through which it acts equals the work done. Formula: Force, F . $\times$ Space, S . = work, W .

Every moving body can impart motion; can do work on any other body, and is said to possess *energy*. The energy of a body is its capacity to do work. For example, the moving bat in the hands of a ball player imparts motion to the ball; it does work on the ball. The energy which a body, as the bat, possesses, in consequence of its *motion*, is called *kinetic* energy. A stone lying on the ground is devoid of energy. Do work upon the stone by lifting it up to a shelf, or other support, and it seems as devoid of energy as when lying on the earth. Attach one end of

a cord to the stone, pass the cord over a pulley and wind a portion of it around a shaft connected with a sewing machine, coffee mill, or other convenient machine. Suddenly withdraw the shelf from beneath the stone, the stone falling communicates motion to the machinery and you may sew, grind coffee, etc., with the energy given to the machinery by the stone. The work done on the stone in raising it was not lost. The stone gives it back while descending to the earth. There is a very important difference between the stone lying on the ground and the stone lying on the shelf. The former is powerless to do work, the latter can do work. Both are alike motionless, and you can see no difference excepting the advantage which the latter has over the former in having a position such that it can move. The work done in raising it to its place on the shelf gave it this advantage. A body thus may possess energy due merely to the advantage of its position derived always from work bestowed upon it. Energy due to *advantage of position* is called *potential energy*. We see, therefore, that energy may exist in either of two widely different states. It may exist as actual motion in the case of the bat, or it may exist in a stored-up condition, as in the case of the stone lying on the shelf. The energy which the stone on the shelf possesses is due to the fact that its position is such that it can move, and that there is stress between it and the earth which will cause it to move. The force of gravity is employed to do work as when mills are driven by falling water; but the water must first be raised from the ocean bed to the hill side by the work of the sun's heat. The elastic force of springs is employed as a motive power; but this power is due to the advantage of position, which the molecules of the springs have acquired by work done upon them. We are as much accustomed to storing energy for future use as provisions for winter's consumption. We store it when we wind up the spring or weight of a clock to be doled out gradually in the movements of the machinery. We store it when we bend the bow, raise the hammer or any body above the earth's surface.

The energy of a body is dependent wholly upon the work which

has been done upon it, so that both work and energy may be measured by the same unit. The unit usually employed is the work done, or energy imparted, in raising one pound to a vertical height of one foot; it is called a foot-pound. With this unit we may measure any species of work, and thereby compare work of any kind with that of any other kind. For instance, let us compare the work done by a man in sawing through a stick of wood, whose saw must move 100 ft. against an average resistance of 20 lbs., with that done by a bullet in penetrating a plank to a depth of two inches ($\frac{1}{6}$ ft.) against an average resistance of 500 lbs. Moving a saw 100 ft. against a resistance of 20 lbs. is equivalent to raising 20 lbs. 100 ft., or doing 2,000 ft.-lbs. of work. A bullet moving $\frac{1}{6}$ of a foot against 500 lbs. resistance does the same amount of work as is required to raise 500 lbs. $\frac{1}{6}$ of a foot high; that is, about 83 $\frac{1}{3}$ ft.-lbs. of work; hence the sawyer does about 24 times as much work as is done by the bullet. The work done, the energy exerted by a moving body, is equal to the weight of the body moved, multiplied by the number of feet it is raised. With a given velocity a body will rise to a definite elevation, which is determined by dividing the square of the velocity by twice the force of gravity; formula: $\frac{V^2}{2g}$, the force of gravity being about 32 $\frac{1}{6}$. Hence, the energy of a moving body, the work it may do, can be estimated, if we know its weight and its velocity, by the following formula: $\frac{W \times V^2}{2g}$. Illustration: The energy of a cannon ball weighing 40 lbs., and moving with the velocity of 800 ft. per second, would be about 398,134 foot-pounds. The kinetic energy of two bodies having the same velocity will vary as the weight of the bodies; that is, if one body weighs 50 lbs. and the other 100 lbs., the energy in the one case will be twice as great as in the other. The kinetic energy of two bodies having the same weight varies as the square of the velocity; that is, doubling the velocity multiplies the energy by 4, or tripling the velocity multiplies the energy by 9. A railroad train, having a velocity of 20 miles an hour, will, if the steam is shut off, run four times as far as it would if its velocity were only 10 miles an

hour. Thus, light substances, as the air, exhibit great energy when their velocity is great. As a body is raised higher and higher the work accumulates in the form of potential energy. The accumulated work, or the potential energy, does not always equal the work performed. Some of the work done is used in overcoming friction, and is wasted. The work done by the sawyer and the bullet imparted no energy to the bodies upon which they did work; it was entirely consumed in overcoming resistance, disappearing as energy. Of the vast amount of work done in propelling steam cars or vessels none accumulates, all is wasted, and cannot be recovered or made available for doing work. The available energy that a body possesses is the work done upon the body, less the lost or wasted work. We may calculate in foot-pounds the work performed on a body, and from this deduct the number of foot-pounds wasted, and the remainder is the number of foot-pounds of energy that is imparted to the body.

In estimating the total amount of work done, the time consumed is not considered. The work done by a hod-carrier in carrying 1,000 bricks to the top of a building is the same whether he does it in one day or a week. But in estimating the power of any agent to do work, or the rate at which it is capable of doing work, time is an important element. The unit in which power or rate of doing work is estimated, is called a horse power. A horse power represents the power to perform 33,000 foot-pounds of work in a minute.

Energy, like matter, is indestructible. It may be transmitted, it may be changed into other forms, but not destroyed. The quantity of energy cannot be increased or diminished. Whenever a body in motion meets an obstacle energy is transmitted to it as in the case of the bat and the ball.

Let a ball be shot vertically upwards. On starting, its energy is kinetic, and it rises more and more slowly until it stops, and then falls to the ground. At the moment it stops at the top of its path its energy is potential. During its flight upwards kinetic energy has been changing into potential energy, and again, dur-

ing its fall, potential energy is changed into kinetic energy. There is no loss, but simply a change in the character of the energy. The same thing is true in a swinging pendulum. The mechanical energy of the hammer is not lost when the hammer stops. It has been changed into molecular energy or heat. Whenever energy disappears it has been changed into another form.

One of the most interesting discoveries of modern science is that all forms of energy are so related to one another that energy of any kind may be changed into energy of any other kind. That a definite quantity of mechanical work when transformed without waste will yield a definite quantity of heat; and that this heat, if there were no waste, could perform the original mechanical work. That when one form of energy disappears an exact equivalent of another form takes its place, so that the sum total of energy is unchanged. This principle is known as the law of conservation of energy.

CHAPTER VII—*Continued.*

MACHINES.

A MACHINE is any contrivance which has for its object the transferring or transforming of energy. In an electric-light plant the energy of the steam is communicated to the moving parts of the engine, to be transferred by belts to the armatures of the dynamo, where it is transformed into electric energy. In mechanics it is customary to restrict the term "machine" to such devices as merely transfer energy. This is clearly the case with those known as simple machines. They are the lever, the wheel and axle, the pulley, inclined plane, wedge and screw; all other machines, however complicated, are but combinations of two or more of these simple machines.

No force is gained by the use of machines; indeed, much of the force applied to the machine is wasted in overcoming friction and other resistances, so that force is lost by the use of machines. But machines enable us to apply force advantageously; enables us to employ the force of wind, water, steam or the strength of animals. By the use of machines a small force moving rapidly may move a great body slowly, or a great force moving slowly may put a small body in rapid motion. The force applied to do work is called power, P .; the resistance to be overcome is called weight, W . Work consists of overcoming resistance, and equals the product of the weight by the vertical height to which it has been raised. Two forces, acting in opposite directions upon the same body, will be in equilibrium when they do equal amounts of work.

With this principle as a test, we may study with interest the simple machines mentioned, considering the parts as without weight and moving without friction.

The lever is an inflexible bar, turning freely on a point called

the fulcrum. Levers are divided into three classes, on the relative positions of the fulcrum and the points of *application* of the power and weight. If the fulcrum is between the points of application it is a lever of the first class, as in Fig. 3. The ordinary

steelyard and beam balances are illustrations of levers of this class. If the weight is between the power and the

fulcrum, the lever is of the second class, as in Fig. 4. The ordinary crowbar, when used for prying, is a lever of the first class; when used for lifting, it is a lever of the second class. Two persons carrying a weight hung from a pole are using a lever of the second class, and a wheelbarrow is an illustration of a lever of this class. If the power is between the weight and fulcrum the lever is of

the third class, as in Fig. 5. The common fire tongs, sugar tongs and sheep shears are pairs of levers of this class. When we lift a weight with the hand the forearm is a lever of the third class; the fulcrum is at the elbow and the power is applied through the tendons which are inserted between the fulcrum and

weight. Levers may be combined in various ways. Fig. 6 shows a combination of a lever of the first class

and one of the second class.

A lever consists of two arms—a long arm or power arm, which is the distance from the fulcrum to the power, and a short arm or weight arm which is the distance between the fulcrum and the weight. Thus in Fig. 3, PF is the long arm and WF the short arm, which is shorter than the power arm, while in Fig. 5, the power arm, PF , is shorter than the weight arm WF . It may be shown by geometry

that the distances PF and WF in Fig. 3, have the same relations to each other as the perpendicular distances through which the power and weight, respectively, move, so that work will equal the product of the power by its arm, and the product of the weight by its arm, and the forces will be in equilibrium when

$P \times PF = W \times WF'$, in which case $P : W :: WF : PF$. That is the power and weight will be in equilibrium when they are to each other inversely as the lengths of their respective arms. The greater the difference in the length of the arms, the more effective is the lever in transferring power. If the arms of the lever are equal, the power and weight will be equal, and in case of motion the space moved by each will be equal. If the weight arm is shortened by moving the fulcrum toward the right a given power will overcome a greater resistance and do more work. If the power arm is shortened by moving the fulcrum toward the power, the power becomes less effective for overcoming resistance, but more effective for producing motion, as in lifting a weight with the hand the power acts through two or three inches, while the weight moves through two or three feet.

In the case of the compound lever the power and weight will be in equilibrium when the product of the power by the long arms equals the product of the weight by the short arms, as in Fig. 6. $P \times PF' \times P'F = W \times WF \times W'F'$.

The wheel and axle consists of a wheel and cylinder fitted together so as to turn on the same axis. The power is applied to the circumference of the wheel, and the weight, usually by means of a rope is applied to the circumference of the cylinder or axle. The power acts through the circumference of the wheel while the weight acts through the circumference of the axle. And they will be in equilibrium when $P \times \text{cir. of the wheel} = W \times \text{cir. of the axle}$. An end view of the wheel and axle shown in Fig. 7, shows the wheel and axle to be a lever of the first class and the equation may be $P \times PF$ the radius of the wheel $= W \times WF$, the radius of the axle. If power is applied to the axle there is gain in velocity, as in the case of a circular saw. The common windlass for drawing water from a well or raising weights is a familiar illustration of this machine. The capstan used in moving build-

FIG. 7.

ings, and on shipboard for raising the anchor or drawing the ship to the dock, is a vertical wheel and axle.

Sometimes the wheel and axle appears in a modified form as when they are on separate axes and connected by belts, cogs or friction, in which case equilibrium is obtained by using the ratio of the circumferences or the radii as above. In the case of a compound wheel and axle there will be equilibrium when the power multiplied by the product of the radii of the wheels equals the weight multiplied by the product of the radii of the axles.

A pulley is a grooved wheel, turning freely on an axis, over which runs a rope, to which the power and the weight are attached. The frame of the pulley is the block and the pulley may be fixed or movable. It is a lever of the first class having equal arms. No force, or motion is gained by the use of a single pulley, yet it is one of the most useful of the simple machines. By its aid the sails of ships are adjusted, objects may be moved to places otherwise inaccessible, and by the use of a horse or man working on the ground, objects can be raised to the highest elevations.

In the case of a single pulley or group of pulleys with a single rope, power multiplied into the vertical distance it moves equals the weight into the vertical distance it moves. If the weight is supported by one branch of the rope, power and weight are equal. If the weight is supported by two branches of the rope, as the weight rises both branches shorten and the power moves twice as far as the weight, in which case power would equal weight divided by two, so in a general way power equals weight divided by the number of ropes supporting it.

In the case of movable pulleys with separate supporting ropes the equation is: power equals weight, divided by the power of two, whose index is the number of pulleys.

Any sloping surface may be used as a simple machine called an incline plane (See Fig. 8.) AB represents the incline plane; BC the height of the plane; AC the

base of the plane. In case a weight is carried up this plane, it rises only through the distance BC, while the power moves through the distance AB, so that power multiplied by AB equals weight multiplied by BC. That is, power is to weight as the height of the plane is to the length of the plane. Casks, etc., are frequently loaded into wagons by an inclined plane. It was by means of the inclined plane that ancients raised the great blocks of stone which we find in the ruins of the pyramids, temples, and other buildings. Common stairs are examples of an inclined plane.

A wedge consists of two inclined planes joined by their base. It is mostly used for cleaving timber. It is inserted in a crack, and then driven home by blows from a hammer; but as we cannot measure the energy of these blows, we cannot determine the equilibrium of force in the case of a wedge.

A screw is a cylinder of wood or metal around which runs a spiral ridge called a thread. This cylinder passes through a block in which there is a corresponding groove to fit the ridge or thread of the cylinder. When the cylinder makes one revolution it rises in the nut to a distance equal to the distance between two consecutive sections of the thread. The arm or bar through the head of a screw increases the length of the power arm. The equation of a screw is: power multiplied by the circumference of the circle through which it moves, equals weight multiplied by the distance between two contiguous threads of the screw. The screw is used for raising buildings and for exerting pressure, as in the pressing of hay or cotton; and when the thread is very fine, it may be used to measure short distances, as in the case of the micrometer screw.

The toggle joint, used commonly in adjusting the tops of carriages, is a very useful form of the lever, especially in exerting pressure through a short distance.

In every class of machinery there is loss of power through friction, rigidity of ropes, resistance of air, etc., so that power must be furnished not only to do the work but to run the machine. Illustrations of the simple machines are common, and it

is interesting to notice how widespread their application is. Every motion of the body, every tool, and nearly every article we use, involves the action of some form of a simple machine.

Water wheels are simple machines, something like the wheel and axle, designed for the utilization of the force of gravity through running water. One of the most common forms is the undershot wheel, which is driven by the current flowing under the wheel against the floats. In the case of the breast wheel, the water falls on the wheel near its center and more power is exerted. In the case of the overshot wheel the water falls upon the top of the wheel, and more force is exerted than in either of the other cases. The undershot wheel, with plane floats, transmits about 30% of the power of the water. With curved floats it transmits from 50% to 60%. The breast wheel transmits from 40% to 50%, and the overshot wheel transmits from 70% to 80%.

The turbine wheel is the most valuable and economical of the water wheels. While the other wheels are horizontal the axis of the turbine wheel is vertical. In the center of the wheel is a stationary disk of cast-iron, circular in form and horizontal in position. On the upper surface of this disk are fastened curved guides. The wheel proper revolves outside of this disk. It consists of two cast-iron plates, one above the other, the space between them being divided into numerous channels by curved partitions. The partitions in the wheel, and the guides on the disk, curving in opposite directions. To the bottom of this wheel is fastened a cast-iron plate which extends under the central disk, and to the center of this plate is attached a vertical shaft which comes up through the disk. The revolving part, therefore, consists of an outside wheel, an iron plate underneath, and the vertical shaft. This wheel is placed at the bottom of a column of water. The weight of water upon the disk forces the water between the curved guides on the disk against the curved partitions of the wheel. The energy of these streams turns the wheel and the shaft, and by means of cogs and belts this motion is transferred to machinery. The turbine wheel transmits 80 per cent. or more of the computed energy of the falling water.

While experimenting in the line of conservation of energy, Mr. Joule of England discovered that a quantity of heat necessary to raise one pound of water one degree Far. would raise 772 lbs. one foot high, or would do 772 foot-pounds of work, which is called the mechanical equivalent of heat. A steam boiler and engine constitutes a machine whose purpose is to transform heat into mechanical motion or work. The essential parts are the furnace, the boiler, the steam pipe, the steam chest and slide valves, the cylinder, the piston, the exhaust pipe, piston rod, crank and shaft. The fire in the furnace expands the water in the boiler into steam. The steam pipe conveys this to the steam chest from which it passes through the slide valves into the cylinder, where expanding now against one, then against the other end of the piston, gives a forward and backward movement, which is conveyed by the piston rod to the crank, where the backward and forward movement is changed into a rotary movement. The steam after expansion in the cylinder passes out through the exhaust pipe. The shaft carries a heavy balance wheel which serves as a reservoir of energy, which is needed to make the rotation of the shaft and all machinery connected with it uniform, so that the sudden changes connected with the driving power or resistance are avoided by means of the inertia of this wheel. Motion may be communicated from the shaft to any machinery desirable. While this machine is for the purpose of transforming heat into mechanical work, yet with all modern improvements not more than 20 per cent. of the heat units can be utilized as work.

CHAPTER VIII.

LIGHT: ITS SOURCES — INTENSITY — REFLECTION AND REFRACTION.

IF we place the hand in the sunlight it soon becomes warm. It also becomes illuminated so that it can be seen, and the skin of the hand at length becomes tanned. Some force has been transmitted to us causing the sensations of heat and of light, and causing also chemical action. What we receive from the sun, whether it affects the sense of touch, or the sense of sight, or whether it promotes chemical action, must be energy.

These forms of energy are transmitted to us from the sun, through waves of an exceedingly rare and tenuous medium, called ether. This method of transmitting energy is called radiation. All the ether waves from the sun, whatever their intensity, cause an increase of heat in terrestrial objects, but only those of a particular intensity give us light. Probably all the ether waves promote chemical action, but particular waves are more active. Bodies hot enough to emit light waves are said to be incandescent. The sun, the fixed stars, and other bodies which are sources of light, are incandescent. Most artificial sources of light depend for their light waves on the incandescence of carbon. There are some substances which, receiving light waves, absorb their energy without becoming hot, and in turn emit light waves in the dark for several hours after exposure to the light. Such bodies are said to be phosphorescent. Some forms of vegetable and animal life emit phosphorescent light, as certain fungi among plants, and the glowworm and firefly among animals.

Light waves move in straight lines, as may be seen by arranging screens before a source of light, or by examining a ray of light through the dusty air of a room. A single line of light,

or the path of a single point in the light wave, is called a ray of light. The smallest portion of light which can be separated for experiment is called a beam of light; a collection of rays which diverge from a point or converge to a point is called a pencil of light.

When light waves fall upon the surface of bodies some of them are thrown back or reflected, and some of them are absorbed by the bodies, so that they disappear as light waves, while in the case of some bodies many of the light waves are allowed to pass through them without much loss or change, the bodies being called transparent, translucent, or opaque, as they allow different quantities of light to pass. Transparent bodies allow so much light to pass that objects can be seen through them distinctly, as in the case of air, glass, water, etc. Translucent bodies allow light to pass through them, but in such a scattered condition that objects cannot be seen distinctly, as ground glass, oiled paper, etc. Those objects are opaque which apparently absorb or cut off the light waves so that nothing can be seen through them. Transparent and opaque are relative terms, as no body is wholly transparent or wholly opaque.

The Velocity of Light.—For all distances upon the surface of the earth the passage of light seems to be instantaneous, but in observing the eclipse of one of the moons of Jupiter it was found to occur earlier than the time indicated by calculation. On investigation it was found that when the earth is in that part of its orbit nearest to Jupiter, the eclipse begins 16 minutes 36 seconds sooner than it appears to begin when the earth is in the opposite part of its orbit. From this it was concluded that light must take 16 minutes 36 seconds to go across the earth's orbit. This distance being known and divided by the number of seconds, the velocity of light is found. The result is about 186,000 miles a second. Other investigations have led to the same conclusions.

The intensity of light varies as the intensity of light in the source. Again, the intensity of light varies inversely as the square of the distance of the bodies emitting light, which is the same law

that applies to the intensity of heat and gravity, and in fact to all forms of radiant energy. This law may be illustrated by the following experiment: Take a piece of stiff cardboard, or tin, about four inches square, and place it at a distance of four feet from a wall or screen. Now, if a candle be placed in front of this card, a shadow will be cast upon the wall which will be larger or smaller as the candle is moved nearer or farther from the card. If the candle is one foot in front of the card the shadow on the wall will be about sixteen inches square, that is the light which is intercepted by the card if allowed to pass on, would be spread out over a surface sixteen times as large upon the wall, but if the same amount of light is spread over sixteen times as much surface in one case as in the other it can be only one-sixteenth as in-

FIG. 7'.

tense. At four times the distance from the luminous body in this case the intensity of light is one-sixteenth as great; at threetimes the distance the light would in the same way be found to be one-ninth as intense. In other words, the intensity of light varies inversely as the square of the distance from the luminous body. These experiments may be varied in numerous ways with the result of establishing the truth of this law.

It is often desirable to compare the illuminating power of different flames. The art of doing this is called photometry. The simplest method employed is to place the two flames to be compared at such distances from a screen that the intensity of light each throws upon it shall be equal. Suppose, for example, we want to know how many times more light one candle will give than another candle of inferior quality. Let a slender rod be placed just in front of a screen, and then move the flames to

such a distance that the two shadows of the rod falling side by side upon the screen shall appear to be of equal darkness, then measure the distance from the flames to the screen, and the amounts of light they give will be as squares of their distance; that is, the one twice as far away gives four times as much light.

The angle formed in the eye by the rays of light coming from the extremities of an object is called the visual angle, and its size varies with the distance of the object. (See Fig. 7'.) The angle ACB is greater than the angle AEB , and the object seen from C appears larger and nearer than when seen from E . The distance and size of objects are so associated in our minds that we judge of the distance of objects knowing their size, and knowing their distance we judge of their size.

The different kinds of vibrations, as sound waves, heat waves, light waves, etc., may be reflected, but the laws of reflection which are the same in each case, may be more easily illustrated in connection with the study of light. More or less light is reflected from bodies; in fact, we see bodies by reflected light, but some of the metals with smooth surfaces throw back nearly all the light

FIG. 8'.

waves and are the best reflectors. In the case of ordinary reflectors or mirrors, the reflecting surface is mercury. In fine telescopic reflectors silver is considered the best material for a reflecting surface. Reflecting surfaces may be plane, concave, or convex. When a beam of light falls on a mirror so as to make a right angle with the surface of the mirror, it is thrown back over the incident path; but when the beam falls upon the surface so as to form an oblique angle with it, the beam is reflected in some other direction. Suppose a beam of light falls upon a mirror MM at the point A from the direction IA ; it will be reflected in the direction AR . (See Fig. 8'.) Now, if we measure the angles made with the line AP perpendicular to the mirror at A , we find that the

angle IAP equals the angle PAR, that is the angle of reflection PAR equals the angle of incidence IAP. IA is called the incident beam, AR the reflected beam, and A the point of incidence.

Rays of light may be parallel, or converging or diverging. They cannot have any other relation. As the angle of reflection equals the angle of incidence in the case of plane mirrors, they do not change the relations of rays of light falling upon them. The reflected rays are parallel, converging or diverging after as before reflection. In the case of *concave* mirrors the effect on the rays of light is different and more interesting. Let MM in Fig.

FIG 9

9 represent a concave mirror, C the center of curvature, G the vertex of the mirror, and CG, its principal axis. The lines CA, CB, and CG are radii, and perpendicular to the mirror. Light waves emanating from the point C would be reflected to their source at C, but rays of light from E, as EA and EB, fall upon the mirror at the points A and B, and as the angle of reflection is equal to the angle of incidence, they would be reflected to H; while if H were a source of light the rays HA and HB would be reflected to E. The diverging rays in each case are by reflection made to converge to a point called a focus. As the light waves which emanate from either of these points are brought

by reflection to a focus at the other, they are called conjugate foci. Parallel rays, as IA and KB falling on the mirror at A and B are reflected to F , a point midway between C and G , which is called the principal focus; while rays diverging from the principal focus would be reflected as parallel rays, and the converging rays LA and PB are reflected to S . This shows that the general effect of the concave mirror is to converge the rays of light they reflect, and they converge rays of heat as well, so that a piece of paper or a chip of wood at the principal focus, may be burned in the collected rays of the sun.

The reflector of a locomotive headlight is a parabolic mirror. The light is placed at the principal focus, so that the reflected rays are parallel.

The general effect of *convex* mirrors is to separate rays of light.

The image of an object made by a plane mirror appears to be behind the mirror as far as the object is in front of it. It appears to be of the same size as the object and is erect—that is, the plane mirror gives a perfect image of the object.

In the case of the concave mirror, if the object is beyond the center of curvature the image will be between the center of curvature and the principal focus, and will be inverted and smaller than the object. If the object is between the center of curvature and the principal focus, the image will be beyond the center of curvature, inverted and larger than the object. The image of an object between the principal focus and the mirror will be back of the mirror, erect and larger than the object.

The images formed by the convex mirror are always erect, behind the mirror and smaller than the object, and are generally curiously distorted.

Many valuable and interesting experiments may be made with cheap plane and curved mirrors, which will serve to verify these laws. A bright silver spoon may serve both as a concave and a convex mirror; so of metal cups, bells and other articles of common use.

Light moves with different velocity, through different trans-

parent substances. This is shown by the bending or breaking of a ray of light as it passes from one medium into another of different density, if the ray is oblique to the surface separating the two media. Thrust a pencil into the water so that it is perpendicular to the surface of the water and there is no apparent change in the shape of the pencil, but if it be made oblique to the surface of the water it appears to be bent or broken at the surface, and the immersed portion seems elevated. Again, place a coin on the bottom of an opaque dish as at B (Fig. 10), then standing so that the coin is just hid from sight by the side of the dish, have water poured slowly into the dish and the coin will rise into view

FIG 10

as the dish fills with water. The difficulty of putting a stick on a given object in a body of water is a familiar illustration of the same principle. Now, if we remember that objects are seen by light reflected from them, we know that a ray of light from the coin or

pencil point, is bent at the surface of the water at C toward A, instead of going on to E, so that the ray appears to come from D, and the coin seems to have been lifted from B to D, the pencil appearing to be shorter and the water shallower than it is in reality. If one looks at a pencil so that one part is seen through glass oblique to the surface, and the other part through air, the pencil appears broken at the surface of the glass, on account of refraction of light.

The laws of refraction are that a ray of light, in passing from a rarer into a denser medium, is bent toward the perpendicular at the point of incidence, while in passing from a denser into a rarer medium it is bent from the perpendicular at the point of incidence. (See Fig. 10.) The angle ACF is the angle of

incidence, BCG is the angle of refraction, and DCB is the angle of deviation. The ray AC passing into the water at C is bent toward the perpendicular FG, instead of going to D, while the ray BC passing into the air at C, is bent from the perpendicular FG, toward A, not going on to E.

The cause of refraction.—In the case of ether waves, the particles vibrate transversely to the direction in which the waves move. Now, as the waves pass obliquely from one medium into another that is more dense, the end that first enters the denser medium seems to move more slowly, while the end that is still in the rare medium moving as before gets a little in advance, so that there is a bending of the ray at the surface separating the two media; much as a column of soldiers changes direction by filing right or left. The reverse is true as the light passes into a rarer medium. (See Fig. 11.)

FIG 11

From A as a center (see Fig. 10) describe the circumference of a circle and draw the lines *ab* and *df*. The line *ab* is the sine of the angle of incidence ACF, and the line *df* is the sine of the angle of refraction BCG. Now if we divide the line *ab* by the line *df* the quotient will be what is called the index of refraction, which is constant with the same substance but varies with different substances, lead chromate having the highest index of refraction, 2.97; the diamond next, 2.5, and flint glass next, 1.61.

CHAPTER IX.

OPTICAL INSTRUMENTS—RAINBOW AND COLOR.

LENSES are transparent bodies, usually glass, one or both of whose surfaces are curved. The principal forms are the *double convex* lens A, bounded by two convex surfaces; the *plano convex* lens B, bounded by a plane surface and a convex surface; the *concavo convex* lens C, in which one surface is convex and the other concave, the concavity being less than the convexity;

FIG. 12.

the *double concave* lens D, which has two concave surfaces; the *plano concave* lens E, with one plane surface and the other concave, and the *concavo convex* lens F, in which there is one concave and one convex

surface, the convexity being less than the concavity. The convex lenses diminish in width towards the edge, while the concave lenses increase in width towards the edge. (See Fig. 12.)

The effect of convex lenses on rays of light may be shown by tracing them through a lens according to the law of refraction. Suppose MN, Fig. 13, represents a double convex lens, C and C' representing the centers of curvature, and the line C C' the principal axis of the lens. Now, if a ray of light from C fall upon the lens at A it will be bent toward the perpendicular C'A at the point A towards the point B, on emerging from the lens the ray will be bent from the perpendicular CB at the point B towards C'; and the ray of light from C' in the same way would be refracted to the point C, so that C and C' are called the conjugate-

foci of the lens, as light diverging from one point is converged to the other.

Suppose that a ray of light from H parallel with the principal axis, falls upon the lens at the point A, it will be bent toward the perpendicular $C'A$ to the point of G. At G it will be bent from the perpendicular CG to F, which is called the principal focus, while rays diverging from the principal focus become parallel on the other side of the lens. Thus the general effect of the double convex lens is to collect the rays of light. Diverging rays are made to diverge less, parallel rays are made to converge, and

FIG 13

the converging rays will be made more convergent. Experiments with the other convex lenses show the same effect. The point S in the center of the lens on the principal axis is called the optical center of the lens. Any line, as LSO , through the optical center is called the secondary axis.

The effect of the concave lenses on rays of light may be shown as follows: (See Fig. 14.) Let MN represent a double concave lens, C and C' being the centers of curvature. Suppose the ray of light S should fall upon the lens at A it will be bent toward the perpendicular CB to D , on emerging from the lens it will be bent from the perpendicular $C'D$ to F , showing that the effect of

the double concave lens is to render rays parallel to the principal axis divergent.

Experiments with diverging and converging rays show that the general effect of the double concave lens is to disperse rays of

FIG 14

light. Experiments with the other concave lenses show the same effect.

The double convex lens, or any of the convex lenses, not only collect rays of light, but rays of heat as well, and are sometimes called burning glasses. These lenses are also used as magnifying glasses, or simple microscopes. The relations of images to objects in different cases are shown in the following figures (see Fig. 15), in which the object is between the focus and the lens.

Let MN represent the lens whose focus is at C, and let the object AB be placed between this point and the lens;

FIG. 15.

object AB be placed between this point and the lens; if we trace the rays of light from the object through the lens, they are diverging after refraction and cannot meet;

but if the eye receives these rays at E, they will have the same effect as if they came from A' and B'; hence the image will be formed at A'B', which will be on the same side of the lens as the object, erect and larger, than the object. In case the object

be placed beyond the principal focus, and less than twice the distance of the principal focus, the image will be inverted and larger than the object. (See Fig. 16.) Again, if it is twice the distance of the principal focus the image will be inverted, but of the same size. (See Fig. 17.) If the object be placed more than twice the distance of the principal focus the image will be inverted and smaller.

FIG 16

For the image in the case of the double concave lenses (see Fig. 18.) MN represents a double concave lens; suppose the object at AB , the rays of light are made to diverge in passing through the lens, and if received by the eye at E , they appear to come from $a b$, and the image is on the same side of the lens as the object, erect and smaller.

FIG 17

The compound microscope consists of two double convex lenses, the smaller called the object glass and the larger the eye-piece.

If the object is placed just beyond the focus of the object glass, an image will be formed on the other side which is inverted and larger than the object; the eye-piece is so placed that the image formed by the object glass falls just within its focus, so that it is again enlarged by the eye-piece, as in Fig. 15.

The refracting telescope consists of two double convex lenses, the larger called the object glass, the smaller the eye-piece.

FIG. 18.

The object is so far beyond the principal focus of the object glass that the image is inverted and smaller, and the eye-piece is adjusted so that the image formed by the object glass falls just within its principal focus, and is magnified by the eye-piece. In a microscope an object is magnified both by the object glass and

the eye-piece; but in the case of the telescope the object is magnified only by the eye-piece. . The object glass of the telescope serving as a light gatherer, an object glass of 20, 30 or 35 inches collecting vastly more light than can the unaided eye.

The Galilean telescope consists of a double convex object glass and a double concave eye-piece; the object being more than twice the focal distance of the lens, the image would be inverted and smaller than the object; but between the object glass and its focus the concave lens is inserted which separates or disperses the converging rays, and the image is seen erect and enlarged. The ordinary opera glass consists of two Galilean telescopes.

The terrestrial telescope used in surveying frequently consists of four double convex lenses; the inverted image of the ordinary telescope being confusing, two more lenses are added so as to give an erect image of the object.

In the reflecting telescope light is gathered by a large concave mirror, and the image formed is enlarged by a double convex lens.

The magic lantern is an instrument by which the image of a small object greatly magnified may be thrown upon a screen. It consists of a dark box in which there is a strong light; behind this light there is a concave mirror, and in front of it an opening from which projects a tube. At the entrance of the tube is placed a double convex lens, or two plano convex lenses; inside of this tube slides a smaller tube in which is fixed another double convex lens. The picture or object is placed between the lenses.

The first lens receiving light from the lamp, and by reflection from the mirror, concentrates it upon the transparent object or picture, strongly illuminating it. Light from the object goes on through the second lens to a distant screen and there forms a large and perfect image.

The camera consists of a dark box divided by a partition or screen of ground glass. The box has openings in two opposite sides, from one of which projects a tube in which slides a smaller tube carrying a double convex lens. If the lens is properly

adjusted a distinct image of objects in front of it may be seen upon the screen by looking through the opening in the opposite side of the box. When the image is properly focused the photographer replaces the screen by a sensitized plate, and the chemical powers of the sun's rays impress a true picture of the object on this plate. (See Fig. 19.)

The human eye is a camera which differs from the common form of that instrument only in its wonderful perfection.

A *prism* is a triangular transparent body that so refracts the white light of the sun as to separate it into a band of colored light called the *solar spectrum*. The solar spectrum is made up of seven colors—red, yellow, orange, blue, indigo, and violet, and depends upon the fact that the waves of ether which give rise

to the different colors are bent at different angles by refraction through the prism. This is explained by the fact that the vibrations which give rise to red light are longer and less rapid than those which give rise to the yellow light, and are less refrangible; that is, are bent less than those which give rise to yellow light, and so on through the spectrum—the waves which give rise to violet light being shorter, more rapid and more refrangible than those which give rise to any other color. Experiments show that there are waves outside those which give rise to the red light, which are less refrangible than the red waves, and which we may recognize as heat waves; and there are other waves, which are more rapid, shorter and more refrangible than the violet rays, which we may recognize by their chemical effects.

To the naked eye the colors of the spectrum seem continuous, but when examined through a telescope the spectrum is found to

be crossed by great numbers of fine black lines, which for a long time could not be explained.

Each of the elements which make up our earth gives its own peculiar spectrum; as sodium gives two yellow lines, potassium two red lines and one purple line, nitrogen many lines of different colors, hydrogen two lines, etc. The colors are as variable as those of the solar spectrum, and vary in number through an immense range. For instance: Iron shows as many as 450 lines, while sodium shows only two. On comparing the spectrum of iron with the solar spectrum, the bright lines of iron were found to correspond with certain black lines in the solar spectrum, and similar results were obtained by experimenting with other substances. This coincidence called for explanation. Experimenting with sodium vapor it was found that light passing through sodium vapor gave a spectrum that was perfect, excepting that the place of the yellow light was occupied by a dark band. Similar results were obtained from experimenting with the vapor of other substances. These facts led to the conclusion that vapors absorb the kind of light which they emit, letting the other kinds pass through. And these facts led to the further conclusion that the sun consists of a molten mass surrounded by an atmosphere of metallic vapors, which absorb the light from the molten metals within, thus giving rise to the dark lines in the solar spectrum.

An examination of the light of the fixed stars shows that they are bodies like our sun, while the nebulae seem to be composed entirely of gaseous matter. As the spectrum of the most important terrestrial substances is known, the composition of bodies may be determined by the spectroscope, and several new substances have been discovered by its use. It has been used to detect adulteration of liquids and diseased conditions of the blood. By it iron, sodium, calcium, nickel, copper, zinc, cobalt, manganese, aluminum, and other metals are shown to exist in the sun. Hydrogen has been shown to exist in hundreds of different stars. In the star Aldebaran, hydrogen, iron, sodium, mercury, and five other elements common on the earth are shown to exist. Some stars are so far from the earth

that light traveling with the inconceivable velocity of 186,000 miles per second would be fifty years or more in traversing the profound space, yet with the spectroscope we can analyze that light and make it tell what substance sent it out.

The rainbow is a beautiful and gigantic solar spectrum, which has been formed by the refracting power of thousands of rain-drop prisms. The bow is seen when the sun is back of the observer, and sometimes a second bow may be seen outside of the primary one. The primary bow is formed by light that enters the upper part of the drop, is refracted, reflected and refracted

again to the observer. The second bow is formed by the light which enters the lower part of the drop, is refracted, reflected twice, then refracted to the observer. (See Fig. 20.) R indicates red ray, V violet ray and S'' the sun.

The white light of the sun falls upon all bodies alike. This light is decomposed in different ways by different bodies, some of it being absorbed and some reflected. One body is red because it reflects the red rays, absorbing the others; another is blue because it reflects only the blue rays, absorbing the others. The foliage of plants receives the sun's white light, decomposes it, reflecting only the green rays. The petals of the rose decompose the sunlight, reflecting to us the colors peculiar to itself. A body

which reflects all the colors of the light it receives is white; when it reflects none it is black. The clouds both refract and reflect the sun-light, and all their varied colors are due to the decomposition of light by the water vapor in the clouds of the morning or evening sky.

The color of objects depends upon light. All objects are black in the dark. When we paint our houses we apply to them a substance that has the property of reflecting the colors we desire and absorbing the others. Thus bodies have no color of their own. If a white body in a dark room be successively illuminated by the colors of the spectrum, it appears red, yellow, orange, green, etc., according to the light which illuminates it.

Red, green, and violet are called fundamental colors, since, with these, all possible colors may be formed by mixture.

Two colors or tints which together give white are called complementary colors. The following pairs of colors give white: Red and bluish-green; orange and blue; yellow and indigo; violet and yellowish-green.

Spectrum colors differ from pigment colors. Pigment yellow and pigment blue produce green, not white.

CHAPTER X.

FRICTIONAL ELECTRICITY AND MAGNETISM.

IF a dry glass tube, as a lamp chimney, is rubbed vigorously with a piece of dry flannel for a moment or so, it will attract small pieces of paper or pith, which, after remaining a short time in contact, are repelled. After being rubbed, if the glass tube is held near the cheek, a gentle breeze will seem to blow against the cheek, and perhaps a pricking sensation may be felt and crackling sounds be heard. Like phenomena sometimes occur when stroking a cat or while combing the hair with a hard-rubber comb. Sealing wax when rubbed in the same way exhibits the same property. Bodies having this property are said to be electrified.

When a glass tube is rubbed with a piece of flannel, only the part rubbed will be electrified, and the same is true of sealing wax. In these bodies electricity does not pass from one part to another; that is, they do not conduct electricity, but when metals become electrified by friction or otherwise in any of their parts the electricity immediately spreads out over the entire surface, that is, metals do conduct electricity. Bodies which resist the spread or passage of electricity through them are called poor conductors, or non-conductors; while others which resist the passage of electricity but slightly are called good conductors. The difference between these two classes of bodies is in the quantity of electricity they convey, as no body is absolutely a non-conductor. Nearly all the metals are good conductors of electricity, and so are graphite, water, charcoal, animal and vegetable bodies and other substances, while lime, India rubber, silk, diamond, wax, resin, air and other bodies are poor conductors. A good conductor retains electricity only so

long as it is surrounded by poor conductors, as glass or air, which are sometimes called insulators.

It is often desirable to detect the presence of electricity, which is done by the use of the electroscope. This, in the simplest form, consists of a ball of pith from a cornstalk or elder, hung by a silken thread from a glass support. Now, if a glass rod which has been electrified by friction is brought near the ball of pith it will attract the ball, but on coming into contact with the rod the ball receiving electricity from the rod is instantly repelled. Now, if an electrified stick of sealing wax and an electrified rod of glass are alternately brought near the pith ball the glass rod will repel and the wax attract the ball, which seems to show that the glass and wax have different kinds of electricity, and that the same kinds of electricity repel each other while unlike kinds attract each other. The electricity produced on the glass is called vitreous or positive electricity; that developed in the wax is called resinous or negative. They are developed together, positive in the glass and negative in the rubber, the negative in the wax and positive in the rubber. The supposition is that each body is endowed with neutral electricity, and by friction this is decomposed, one body retaining the positive and the other the negative. Another curious phenomenon which complicates matters somewhat occurs when glass is rubbed with cat-skin, in which case negative electricity is developed in the glass instead of positive, as when rubbed with the flannel.

In all electrical experiments the air and the apparatus should be dry, many delicate experiments fail by loss of electricity through the conduction of moisture in the air.

Frictional electricity seems to rest only on the surface of bodies. An insulated conductor charged with either kind of electricity decomposes the neutral electricity of bodies near it, attracting the opposite and repelling the like kinds. The action thus excited is called induction.

Machines are made for developing electricity by friction, and with them are condensers of some kind for the accumulation of the electricity developed; sometimes the condenser is part of the

machine and sometimes separate. A common form of condenser is the Leyden jar, which is a wide-mouthed jar covered inside and out with tin foil for about two-thirds its height. Through the wooden stopper passes a brass rod, terminating at the upper extremity in a ball and at the other in a chain, which rests on the bottom of the jar. The condenser in this case consists of two good conductors separated by glass, a poor conductor, or insulator. The jar is charged by connecting the inner coating with the electrical machine, the other with the earth, the electricity inside the jar holding or developing the opposite kind on the outside of the jar by induction. The jar may be discharged by connecting the two coatings of tin foil by holding the jar in one hand and touching the ball with the other, which may be done with safety if the jar is a small one, or by connecting them by a wire attached to a glass handle.

It has been found that smooth bodies without angles or points retain electricity best. It is usually impossible to charge the condenser of an electrical machine if it has points or angles, as electricity passes away so quickly through them, but in such cases it passes away very quietly, while in the case of a smooth body the electricity is retained until the accumulation is so great that disastrous results are liable to follow its discharge.

The electricity of the atmosphere is of the same nature as the frictional electricity. The air is usually positively electrified, while the earth is negatively electrified. It is stronger in summer than in winter, and during the day than in the night. During cloudy weather, and on the approach of thunder storms the electrical condition of the air changes frequently and rapidly. Clouds separated by dry air become Leyden jars or condensers, and the electricity bursting across through the non-conducting air causes lightning and thunder and often rain; again the clouds and the earth separated by dry air form a condenser, and while electricity is streaming toward the clouds from every angle and point, from every tree and shrub, in some places the accumulation becomes so great that it bursts through

the air and lightning and thunder follow, and sometimes withered trees, burned buildings, and loss of life is the result.

As some protection from accidents from this cause lightning rods have been devised. They consist of metal, usually of iron, although copper is a better material. The lightning rod should be of ample size, and attached securely and closely to the building and to all metallic pipes about the building. It should reach downward to ground that is permanently moist, and it would be better if it terminated in a broad plate of metal. It should extend upward for some distance above the building and terminate in bright, sharp points. When first invented it was thought necessary to separate the lightning rod from the building, but it was soon discovered that it was better to connect the whole building with the rod, which discharges electricity so rapidly that no accumulation occurs to cause dangerous results. The effects of lightning, so well known to all, show that electricity can do mechanical work, as in the tearing of trees, shattering of walls, etc.

To Doctor Franklin belongs the immortal honor of proving the identity of electricity and lightning. A kite was the simple instrument which he employed. Having made a kite by stretching a silk handkerchief over two sticks in the form of a cross, he went out into a field accompanied only by his son; raised his kite; fastened a key to the lower end of its hempen string; insulated it by fastening it to a post by means of a silk cord, and anxiously awaited the approaching storm. A dense cloud, apparently charged with lightning, soon passed over the spot where he stood, without causing his apparatus to give any sign of electricity. He was about to give up in despair, when he caught sight of some loose fibers of the hempen cord bristling up as if repelled. He immediately presented his knuckle to the key, and received an electric spark. The string of his kite soon became wet with the falling rain; it was then a better conductor, and he was able to obtain an abundance of sparks from the key. By this experiment he furnished a decisive proof of the identity of lightning and electricity.

Magnetism.—A magnet is a body which has the property of attracting iron, and when suspended, so as to turn freely, of assuming a north and south direction. The end toward the north is called the north pole of the magnet, while the other end is called the south pole. An ore of iron, called magnetite or lodestone, is found in many localities. Lodestone was known to the ancients, being found in Asia Minor, in Sweden, in the region of Lake Superior, and in many other localities. The name lodestone or leadstone seems to have been derived from the Saxon *lædan*, to lead. When a steel bar or needle is rubbed by a natural magnet, it acquires magnetic qualities and becomes an artificial magnet. Artificial magnets are more powerful and convenient than lodestone magnets, and are the only ones in ordinary use.

Magnets may be straight, when they are bar magnets; or they may be in the shape of a letter U, when they are called horseshoe magnets. A bar of soft iron, called an armature, laid across the poles of a magnet enables it to retain its magnetism for a longer time. In the case of bar magnets they are laid in pairs, an armature connecting the north pole of one with the south pole of the other.

If a magnet is rolled in a mass of fine iron filings, it will be seen that the attractive force is stronger at the ends, gradually diminishing to zero at the center. If a bar magnet, as an ordinary knitting needle, is broken at the zero point, each end instantly becomes a complete magnet, with strong poles and zero center as before, and the same will be true however short the pieces become. Either pole of the magnet attracts iron, but if we experiment with two magnets, one of which is suspended, we find that the north pole of one attracts the south pole of the other, but repels the north pole, and *vice versa*; that is, poles of the same name repel each other, while poles of different names attract each other. The iron or steel attracted by a magnet becomes itself a magnet, has a north and south pole, is polarized, and in turn may polarize other pieces of iron or steel, as is shown by the experiment of rolling the magnet in iron filings. If a piece of writing paper is laid over a strong magnet, and then fine iron

filings be sprinkled over the paper, on tapping the paper gently the filings will arrange themselves in beautiful curves about the poles of the magnet, showing that a magnet makes magnets without contact, and all these iron filings, as secondary magnets, are arranged pole to pole in regular order according to the laws mentioned above. The most important use of the magnet is in the construction of the compass. A slender bar magnet balanced on a pivot, is called a magnetic needle. The compass consists of a circular box, usually of brass, with a glass cover, in which a magnetic needle is balanced over a card on which the different directions are marked. The mariner's compass is so mounted that whatever the motion of the ship the compass is always horizontal. With it the mariner, aided by observations of the sun and stars, finds his way across the trackless sea.

In general, the needle varies more or less from the true north. The line of no variation passes near Cape Lookout, Cleveland, Ohio, thence across Hudson's Bay to the pole, entering Europe just east of the White Sea, thence across the Caspian Sea, and through Western Australia to the south pole, thence northward through eastern South America. West of this line the needle varies west, east of it the needle varies east. This line itself varies east and west. In 1580, the variation of the needle, at Paris was $11^{\circ} 30'$ east, showing that the line of no variation was west of Paris. In 1663 this line was at Paris, while in 1825 the variation was $22^{\circ} 22'$ west, showing that the line of no variation was far to the east. Besides this slow variation there are annual and daily variations, and variations due to volcanic eruptions and earthquakes, and variations attended upon marked displays of the Aurora borealis, and disturbances in the sun as shown by sun spots. These latter variations are said to be due to magnetic storms or disturbances.

The magnetic needle does not remain in a horizontal position, but north of the equator the north end dips, while south of the equator the south end dips, so that in practice one end must be weighted to keep the needle horizontal. Here again we have no rational explanation of the phenomena.

CHAPTER XI.

DYNAMICAL ELECTRICITY.

ABOUT the year 1786, Luigi Galvani, a professor of anatomy, discovered that in the case of a recently killed frog, if one end of a metal conductor, composed of zinc or copper, was placed in contact with the nerves of the lumbar region and the other with muscles of the thigh or leg, a prompt contraction of the muscles ensued. He assumed that the electricity was inherent in the animal substance; but Professor Volta from his experiments, attributed to the metals the active part of the phenomena of contraction. The investigations of these men and their successors have led up to the dynamical electricity of to-day.

A little experiment will help us to understand how this form of electricity is developed. Get a strip of sheet copper and two pieces of zinc, each about five inches long and one and one-half inches wide; and have a piece of No. 16 copper wire about ten inches long soldered to one end of each. Fill a tumbler about two-thirds full of water and add to it two tablespoonfuls of strong sulphuric acid. Amalgamate one piece of zinc as follows: Dip it into the acidulated water, and then pour a little mercury over the surface, rubbing off any excess with a cloth. Put a piece of copper and a piece of zinc that is not amalgamated into the liquid without allowing them to touch each other, and vigorous action takes place between the acid and the zinc, but none between it and the copper. Now substitute amalgamated zinc for the other and no action appears on either plate. Now, if the wires of the two plates are brought in contact, gas is given off from the copper but not from the zinc plate; and, if we separate the wires carefully, we may see a little spark of light, and the action in the fluid ceases. There is no action between the liquid and the amalgamated zinc, unless it is connected with the copper. The wire

conductors seem to be necessary to the action which takes place. Do they acquire any new properties? Place a magnetic needle near the tumbler and hold the connecting wires over it, and the needle will be deflected from its north and south direction, which indicates the presence of electricity in the wire.

This action is explained as follows: the zinc takes the place of the hydrogen of the acid, forming zinc sulphate which remains dissolved in the liquid, and the hydrogen is forced along from molecule to molecule through the acid until it reaches the copper plate where it escapes in bubbles. This action is so rapid as to appear continuous, and it is believed to be the cause of the electricity or electrical current in the wire, as the result of the conversion of chemical energy into potential energy. If this action continues the acid becomes weaker, and the zinc is dissolved so that it must be renewed from time to time.

In order that water may flow from one place to another there must be a difference of level; so in the case of electricity, there must be a difference in electrical conditions before there can be a flow of electricity. When electricity at any place is greatly in excess of that in the earth it is described as *high potential*, when slightly in excess as *low potential*; when there is more electricity in one body than in another again the terms high and low potential are used. Electricity moves from the place of high potential to the place of low potential. Differences of potentials and *electromotive force* are commonly used in the same sense. The zinc is positive, that is, has a higher potential than the copper, and the electricity passes from the zinc through the liquid to the copper in the attempt to restore the equilibrium of the potentials. But as the chemical action is practically continuous the motion toward the copper is continuous, and we have what is called an *electrical current*. The current passes through the liquid between the metal plates and through the wire connecting them, and to this whole path or course of the current the term *circuit* is applied. The wires are called the conductors, the end of the wire from the copper plate is called the positive pole and the other the negative pole. Separating the poles is called opening the circuit, bringing

them together is called closing the circuit. Opening the circuit and filling the gap with an instrument of any kind is called introducing the instrument into the circuit.

The tumbler of acid with the two metals is called a *voltaic cell*, the metals are called elements. There are several different kinds of cells, but all are constructed on the same general principle. A number of cells working together form a battery. By enlarging the plates of the cells batteries of low resistance are made, but they furnish great quantities of electricity. By increasing the number of cells, batteries of high resistance and great intensity may be made. No conductor, whether liquid or solid, is perfect; each resists the passage of electricity more or less. The resistance in a circuit is principally in the cells, when it is called internal, or in the conductors, when it is called external.

The greatest difference between current electricity and frictional electricity is this: Current electricity is remarkable for its great quantity but feeble intensity, while frictional electricity is equally remarkable for its great intensity and small quantity.

If a bar of soft iron be inclosed in coils of wire, and the ends of the wire be attached to the poles of a battery, the current passing through the wire makes the bar of iron a magnet. Break the current and the magnetism is gone. The rapidity with which an iron bar may receive and part with magnetism as the current is made or broken is very great; it may occur as many as 8,000 or 10,000 times per minute. Such magnets are called *electro magnets*, and may be made much stronger than permanent magnets. The induction of magnetism by current electricity is the principle on which depends the working of the electric telegraph. The wire connecting the battery and the coil about the soft iron may be very long, even miles in length; so the battery may be in one city or town and the coil in another, and still the magnet is made and an armature may be attracted every time the circuit is closed. For a long time two wires were thought necessary, but it was discovered that if one pole of the battery was connected with the coil by a wire, and both the battery and coil connected with

the earth, that the earth would complete the circuit. As the resistance of the earth is practically nothing, less powerful batteries were needed, as they had only to overcome the resistance of one wire instead of two. The distance may be so great that the battery at one end cannot entirely overcome the resistance, in which case relay batteries are introduced. In addition to the battery, coil and line wire, an instrument called a key for opening and closing the circuit is necessary, and a mechanical device for the purpose of registering the action of the armature, which may be by blows on a sounder or by marks on paper moved by clock work. If the circuit is closed for an instant a dot is made on the paper, or a short sound on the sounder; if for a longer time, a line is made on the paper or a longer sound, and the differences between the blows on a sounder, made by the dot or line closure is easily distinguished by the ear, so that all first-class operators work by sound. The telegraphic alphabet, consisting of dots and dashes, is called the Morse alphabet, and the telegraph is usually known as the Morse telegraph. But there is reason to believe that while Morse introduced them to the world, they were really invented by another man of whom the world has seldom heard. Electric bells and electric clocks are based on the same principle as the telegraph.

The magnetic needle whose deflection indicates electricity in the connecting wires of the voltaic cell, is in fact a galvanoscope. It may be made so that the needle hangs over a graduated circle under which a coil of wire is placed, and so arranged that the instrument may be introduced into a circuit.

Make two coils of wire, one containing a few feet of stout copper wire, called the primary coil; and another containing a much greater length of fine copper wire, called the secondary coil, and make them so that the primary coil may be placed inside the secondary, or removed at pleasure; connect the primary coil with the battery and the secondary with the galvanometer. Now, lower the primary coil into the secondary coil and the galvanometer shows the presence of a current in the secondary coil, but the needle of the galvanometer soon settles to zero, showing that

the current was temporary. Draw out the primary coil and again the current is shown, but in the opposite direction, and again it appears to be temporary. Again place the primary coil inside the secondary, then break and close the circuit and in each case we have a current in the secondary coil as before. When introducing the primary coil, and when closing the primary circuit, an inverse induction current is formed in the secondary coil, while on withdrawing the primary coil or breaking the primary circuit a direct current is formed in the secondary coil.

Further, it has been discovered that the same results are reached by using a magnet with the secondary coil, as are reached by using a primary coil. That is, if a magnet be lowered into the secondary coil, an inverse current is indicated in the coil, and if the magnet is removed, a direct current is indicated. Now, if a bar of soft iron be placed in the secondary coil, and the pole of a permanent magnet be brought near it, the soft iron becomes a magnet by induction and a current is manifested in the secondary coil. Now, remove the permanent magnet and the soft iron ceases to be a magnet, and a current is again indicated, but in the opposite direction.

Again, a permanent magnet is placed within the secondary coil and a bar of soft iron is moved toward it; the magnet causes the soft iron to become a magnet by induction, and this seems to increase or change the magnetism of the permanent magnet, and a current is indicated in the secondary coil, and a current in the opposite direction is shown on the removal of the soft iron.

The same effect may be obtained if an electro-magnet be placed within the secondary coil and a strong magnet rotate rapidly in front of it, so that its pole acts inductively upon the branches of electro-magnet in succession.

Similar results may be obtained by passing coiled wire around the poles of a permanent horseshoe magnet, and revolving the plate of soft iron in front of the poles of the magnet. The soft iron becoming magnetized acts on the permanent magnet, and alternate currents are induced in the coils of the wire.

On the principles just mentioned many different kinds of ma-

chines or dynamos have been constructed by which electricity may be transformed into work.

The dynamo electric machine, or the dynamo, consists of an iron core wound with long coils of wire constituting the armature, which revolves between the poles or within the field of a powerful electro-magnet, called a field magnet. The armature is rotated by steam, and the currents induced are gathered up for transmission by brushes of copper wire. These machines vary greatly in detail, but all contain the above essentials. The energy generated in the dynamo is transmitted through wires to a similar machine called a motor, which transforms the electrical energy into mechanical work.

The energy developed in the dynamo may be transmitted to electric lamps where it is transformed into light. If the terminals of the wires from a dynamo are connected with pencils of carbon and these brought near each other, their tips are intensely heated, some of the carbon being volatilized. This vapor, a conductor of high resistance, attains a very high temperature, emitting intense light. The light of the incandescent lamps is produced by introducing some refractory substance of lower conducting power into the circuit, which soon becomes heated to incandescence. The substance commonly used is carbon, inclosed in a glass bulb from which the air has been exhausted.

The value of the dynamo machines and the conducting wires is not in gain of power, but in the distribution of power. The heat energy which drives a great engine may through the dynamo and conducting wires be distributed to hundreds of motors in different parts of a city, to hundreds of arc lamps or thousands of incandescents.

The power of falling water, as at Niagara Falls, may be transformed through turbine wheels and dynamos into electric energy, which may be transferred through long distances, even as far as Buffalo, and then through motors be transformed to light or mechanical work. In this way water power becomes as available as steam power, and much cheaper.

The dynamo is also used in charging storage batteries. A

storage battery consists of two lead plates, which have been coated with the red oxide of lead, and these with a layer of paper or cloth between them suspended in dilute sulphuric acid. When these plates are connected with the terminals of a dynamo, a portion of the water is decomposed, the lead oxide of the positive pole is peroxidized, and that of the negative pole reduced to metallic lead of a spongy form. The electrical energy has been transformed into chemical energy. The plates will remain in this condition for several days if the circuit is left open, and may be transported for long distances and used as ordinary voltaic cells are used. They are used for moving cars, boats, wagons, etc.

The principles just given enable us to explain the action of the Bell Telephone. It consists of a permanent bar magnet with a coil of wire about one of its poles; a thin disk of sheet iron, called a diaphragm, very near but not touching the pole of the magnet; two wires, one leading from the coil to the second instrument, the other to the earth. At the other end of the line is a second instrument of the same kind. The speaker puts his lips to the mouth of the instrument and speaks, while the listener at the other end hears what is said. The air waves of the voices vibrate the diaphragm of soft iron; these motions to and from the pole of the magnet strengthen or weaken the magnetism, and this sends electric pulses through the wire to the distant station; the electric pulses from the transmitting telephone act through the coil of the receiving telephone at the other end of the line, and alternately strengthen and weaken its magnetism, and as the strength of the magnet varies the thin disk springs back and forth. These vibrations of the disk produce air waves, which enter the ear of the listener. Vibrations in the disk of the receiving instrument are the same as those of the disk in the transmitting instrument, and the air waves formed by the disk in the receiving instrument are the same as those which caused the vibrations of the disk in the transmitting instrument; and the two sets of air waves will affect the ear in exactly the same way, so that the voice at the transmitting instrument is reproduced in the receiving instrument; hence by the telephone sound waves

are converted into electric pulses in the transmitter, and these electric pulses reaching the receiver are converted back again into sound waves.

The *Telantograph* is an electrical instrument by which writing or drawing may be reproduced at a distant station. "A common lead pencil is used to write the message; near its point are fastened at right angles to each other, two silk cords, which, connecting with the instrument, follow the motion of the pencil and control the receiving pencil at the other end."

"At the receiving station two aluminium arms hold the capillary glass tube which serves as a pen. This pen is guided by the electrical impulse from the sender, and moves simultaneously and in like direction and extent with every motion of the distant pencil, so that the ink tracing which results must be a *fac-simile* of whatever the sender writes or draws." It conveys a written message, as the telephone conveys a spoken message.

A piece of No. 30 copper wire about 9.7 feet long has a resistance of one *ohm*, and is used as a unit in measuring the resistance of wires to the passage of electricity. The difference in potentials is measured in *volts*, and the unit of current strength is the *ampere*, but these units are not as definite as the *ohm*. Many other interesting subjects might be discussed under the head of physics, but the subjects considered seem to be sufficient for the development of the general principles of this branch of science and for the illustration of their more important applications.

CHAPTER XII.

CHEMISTRY—HISTORICAL AND GENERAL.

CHEMISTRY is a branch of natural science which has always been of great interest to mankind. There is ample evidence to show that even before historic times men were able to extract several of the useful metals from their ores, knew something of the processes of tanning, dyeing, soap making and glass making; could mix mortar and paints, and do many other things which indicate considerable knowledge of practical chemistry.

But these ancient people do not seem to have had any knowledge of the laws of chemical changes or any definite idea of the chemical elements. In the time of Aristotle, 350 B.C., the four elements were *fire*, hot and dry, *air*, hot and wet, *earth*, cold and dry, and *water*, cold and wet. The qualities mentioned are physical, not chemical. The elements, according to the Hindoos, were earth, air, fire, water and ether. Among the Chinese they were earth, fire, water, metal and wood; but in no case do the ancients seem to have recognized chemical qualities.

The first mention of chemistry is found in a dictionary of the 11th century, where it is defined as the preparation of silver and gold. In the 16th century Paracelsus says the true use of chemistry is not to make gold but to prepare medicines. In the works of Glauber (1604–1668) he speaks of various compounds of iron and copper, and of sulphuric, nitric, and hydrochloric acids, but gives no idea of their composition. He also states that salt and mercury are the principles of all metals, and that salt is the origin of all things, and that water and earth have produced all the minerals and metals.

Georg E. Stahl (1660–1734), whose researches gave rise to a marked advance in chemistry, enumerated four elements, water, acid, earth, and phlogiston. Phlogiston was supposed to be a constituent of all combustible bodies, and it was believed that

when bodies burned the phlogiston made its escape, and the residue was regarded as the substance with which the phlogiston had been combined. The British chemist, Black, about 1750, began to use the balance as an aid in chemical investigation.

About 1774 Dr. Joseph Priestly discovered and isolated oxygen, but called it dephlogistigated air. Scheele, a Swedish chemist, discovered oxygen the next year, and the French chemist, Lavoisier, claimed to have discovered the same gas independently of the others. He at least understood the nature of the gas better than the others, and in 1781 gave it its present name, oxygen, "acid-former," as he had recognized that it was an essential ingredient in several important acids. Lavoisier pointed out the fallacies of the phlogiston theory, and gave the received explanation of combustion. He also introduced system into chemistry and chemical research, and by many is called the father of modern chemistry.

The discovery of oxygen has been called the capital discovery of the last century, rivaling in importance the great discovery of Newton in the previous one. It formed one of the great eras in human progress. It resulted in gradually putting away old and fanciful theories, the outgrowth of limited knowledge, and laid the foundation of modern chemical science. It opened a way to a knowledge of the composition of the air and of water, of plants and animals. It may be said to have changed the manners, customs and business habits of the world. More than anything else it has explained the phenomena and opened up the resources of the material universe.

The introduction of instruments for weighing has been of immense value in chemical science, even rivaling the discovery of oxygen. One of the greatest discoveries of modern times is the truth that nature works with the same exactness on the small scale as on the large. It is the glory of Newton to have proved that the movements of all celestial and terrestrial bodies are regulated by mathematical law. "It has been established by chemists that the minutest particles of matter, in their actions and reactions, obey law, and that every chemical compound has

a mathematical constitution as fixed as that of the solar system itself. The stones and soil beneath our feet, and the ponderous mountains, are not mere confused masses of matter; they are pervaded throughout their innermost constitution by the harmony of numbers. The fuel we burn wastes away before us, dissolves in air, and passes beyond the reach of sight; but the invisible changes among the unseen particles are definite, exact, and harmonious. And so it is with all chemical mutations." It was found that, however often matter might change its form, nothing was either gained or lost—that its quantity always remained the same; and it was likewise discovered that the constituents of chemical compounds are always combined in the same definite proportions.

Chemistry deals with those phenomena of matter and energy which involves some change in the composition of bodies. The combination of two or more simple substances into one substance possessing properties different from those of either of the components is a chemical process. If we mix carefully powdered sulphur and copper filings, they remain sulphur and copper and may be separated; but if they are heated strongly the sulphur combines with the copper forming a compound which shows none of the peculiar properties either of copper or sulphur. This illustrates something of the difference between a physical mixture and a chemical combination. The liquid, water, may be separated into the gases oxygen and hydrogen. A piece of wood is composed mainly of the gases, oxygen and hydrogen, and the solid, carbon. When wood is burned, oxygen of the wood and of the air unites with the hydrogen forming steam, which may be condensed into water. Other portions of oxygen unite with some of the carbon forming carbonic acid gas; some of the carbon may be left as charcoal; some, very finely divided, may be carried away with the steam, making a black smoke from which the carbon may be collected as soot; and in the ash are several mineral ingredients which existed in small quantities in the wood. The various reactions which take place in all kinds of combustion, whether slow or rapid, are chemical changes.

Another difference between a physical mixture and a chemical combination is that the former may consist of any possible proportion of the ingredients, while in the case of chemical combinations the proportions are definite. Take the case of sulphur and iron; they may be mixed in any proportion, but they combine in the proportion of 56 parts of iron to 32 parts of sulphur. If there is either too much sulphur or too much iron, the surplus does not enter into the combination. In the case of oxygen and sulphur the proportion of the chemical combination is 32 of oxygen and 32 of sulphur. Experiments with many substances have led chemists to the conclusion that chemical combinations always occur between definite weights of substances. In some cases the weight of a substance may vary in different combinations, but in every such case some number can be found which shall express the combining weight, or the weight will be some simple multiple of that number.

Some of the ancients considered matter as made up of atoms, but the idea was never more than a speculation. And when it had been proved that chemical combinations were in definite proportions, the old idea of atoms assumed a different position. Dr. Dalton, who, early in this century, discovered and announced the law of definite and multiple proportions, saw that the conception that matter is made up of indivisible particles or atoms might have some connection with this law. As a result of his studies he conceived that the law might be explained by assuming that all matter consists of indivisible, unchangeable particles, or atoms; that atoms of the same kind have the same weight, while those of different kinds have different weights, and that the combining weights of chemistry represent these atomic weights. The supposition is that atoms of iron and atoms of sulphur unite to form molecules of the compound substance, sulphide of iron, so of the oxygen and sulphur, and other chemical combinations. Atoms are considered the units of simple substances or elements, and molecules, made up of atoms, are the units of compound substances. The atomic theory, and the law of definite and multiple proportions in chemical combinations

may not be at once apprehended, but they underlie the whole work of chemistry and will become clearer and more satisfactory with every step of chemical investigation.

Chemists have discovered and isolated some seventy or more elements which make up the earth as we know it. The composition by weight, of the crust of the earth is as follows: Oxygen 45 per cent., silicon 25 per cent., aluminium 9 per cent., iron 8 per cent., calcium 5 per cent., magnesium 2 per cent., sodium 2 per cent., potassium 2 per cent. If we add to these elements hydrogen, nitrogen, carbon, chlorine, iodine, phosphorus and sulphur we not only have those that make up the solid crust of the earth, but the constituents of the air, water, plants and animals as well, fifteen elements which those must study who pursue chemistry as a branch of general education, since a knowledge of their properties is essential to the explanation of those chemical changes which are common about us everywhere. Several other elements are interesting and will receive brief consideration. It is the study of the laws in accordance with which the elements combine with one another, and of the properties of the elements and of the compounds formed by them, which constitutes the science of chemistry.

The elements are divided into metallic elements, as iron, copper, aluminium, sodium, mercury, etc., and non-metallic elements, as oxygen, hydrogen, nitrogen, silicon, etc. The metals generally are better reflectors of light and heat, better conductors of heat and electricity, and as a rule have a higher specific gravity than the non-metals. All these elements are designated by symbols, which usually consist of the initial letter of the English or Latin name of the element, as O for oxygen, C for carbon, Si for silicon, Cl for chlorine, Fe for iron, from its Latin name *ferrum*; Na for sodium, from its Latin name *natrium*; K for potassium, from its Latin name *kalium*; Ca for lime, from *calcium*, its Latin name. The symbols for other elements will be given as they are described. The various sub-groups into which the elements seem to be naturally divided can be more intelligently considered as the elements are studied more in detail.

CHAPTER XIII.

OXYGEN, HYDROGEN AND WATER.

OXYGEN is a colorless, odorless, tasteless gas that constitutes nearly one-half the weight of the solid crust of the earth, eight-ninths of the water, one-fifth of the air, and enters largely into the composition of all vegetable and animal bodies. Its symbol is O, and its combining weight 16. While it is so abundant, so important in every way, it was not known, or isolated so that its properties could be studied until the year 1774. Its discovery marks an era not only in the growth of chemical science, but in the progress of human affairs.

Oxygen may be prepared by heating crystals of potassium chlorate in a test tube over a spirit flame; it soon melts into a clear liquid which presently begins to boil from the escaping bubbles of gas. That the gas is oxygen may be shown by thrusting into the tube a stick whose end is a glowing coal, when it will burst into flame, burning with great vigor. Any substance that burns in air burns much more rapidly in oxygen. Take a piece of wire and wind about one end of it a piece of twine and soak the twine in melted sulphur, then ignite the sulphur and thrust the wire into a jar of oxygen, the burning sulphur ignites the iron, which burns brilliantly as long as the oxygen lasts.

Another very common method of preparing oxygen in a small way, is from the red oxide of mercury, which yields, when heated, the liquid mercury and the gas oxygen. If the oxide be weighed carefully, and after the decomposition the mercury and the oxygen are weighed, their weight will be found to be equal to the original weight of the oxide, which is thus shown to have contained only oxygen and mercury in chemical combination. The heat applied overcame the force of chemical attraction and the

compound was decomposed into its original elements. The red oxide of mercury is represented in chemistry by the symbol HgO , which signifies that it is a compound whose molecule contains one atom of mercury and one atom of oxygen, and the proportion of the components by weight is 200 parts of mercury and 16 parts of oxygen.

The chemical formula of potassium chlorate from which oxygen is usually prepared for laboratory purposes is KClO_3 , which indicates a compound body whose molecule is composed of one atom of potassium, one atom of chlorine and three atoms of oxygen; by weight there are 39 parts of potassium, 35.5 parts of chlorine and 48 (16×3) parts of oxygen. Potassium chlorate however made, wherever found always contains these substances, and in the proportions named. The decomposition may be represented by an equation as KClO_3 , after heating strongly equals KCl , potassium chloride, $+ \text{O}_3$, the atoms of oxygen. The KCl a solid, remains in the tube or retort, and the oxygen is collected in jars over water.

The heat, strong enough to separate all the oxygen from the original compound, was not sufficient to separate the chlorine from the potassium. This shows that the attraction of the potassium for the chlorine is stronger than the attraction of the two, as combined, for the oxygen, which illustrates the general fact that the elements differ widely in their attractions for each other, which is a prominent feature in all chemical reactions.

In preparing oxygen in quantity a glass or metal flask of appropriate size is used, and the gas is collected in jars over water, or in regular gas receivers. The jars are immersed in water, then inverted and placed on a perforated shelf so adjusted that the mouth of the jar will be just below the surface of the water. The delivery tube conducts the gas under the mouth of the jar, which, rising through the water crowds it out, occupying its place in the jar. When wanted for experiment, a piece of glass or board may be slipped under the mouth of the jar, which may then be inverted. As the gas is heavier than air it can be retained in the jar for some time, even though it be covered loosely.

The most marked characteristic of oxygen is its prompt and vigorous support of combustion. But combustion, whether slow or rapid, is a chemical process, and when we remember the wide dispersion of oxygen, being found in chemical combination everywhere, we judge that it must be an extremely active chemical agent, and yet at ordinary temperatures its action is by no means vigorous. But if substances are heated to a greater or less degree before being brought into contact with oxygen, it unites promptly with most of the elements, making an endless variety of compounds.

Sulphur burns in the air; it burns with greater vigor in oxygen than in air. Sulphur has but a slight odor, oxygen has none; and yet, after burning sulphur, whether in air or oxygen, a pungent, suffocating odor is present, the odorless sulphur and oxygen have disappeared and something with a pungent odor remains. If a piece of charcoal, nearly pure carbon, be ignited and thrust into a jar of oxygen it burns fiercely for a few moments, then gradually ceases. Some of the charcoal has disappeared, the oxygen is gone and in their place is a gas in which the charcoal will not burn and which quickly extinguishes a lighted candle thrust into it.

In the first case, the oxygen combined with the sulphur forming a gas whose molecule contains one atom of sulphur and two atoms of oxygen, its chemical symbol is SO_2 and it is called sulphur dioxide. The chemical equation is $\text{S} + \text{O}_2 = \text{SO}_2$. In the other case, oxygen united with carbon forming a compound whose molecule contains one atom of carbon and two atoms of oxygen called carbon dioxide. The equation is $\text{C} + \text{O}_2 = \text{CO}_2$. If we had used phosphorus, only a slight elevation of temperature would have been necessary to start the chemical action. More was needed in the case of sulphur, more still in the case of carbon; but when started in each case it continued vigorously till the oxygen was all gone.

As soon as one atom of sulphur or carbon combined with two atoms of oxygen their activity ceased, their attractive powers had been satisfied. As these atoms rushed together

under the action of chemical attraction, the collision gave rise to the heat and light which attended the action. The heat and light of chemical action being due in reality to atomic percussion as the hammer and iron become warm from the blows necessary to shape the iron. As the sulphur and carbon burn in the air, forming the sulphur dioxide in one case and carbon dioxide in the other, we have reason to suppose that oxygen exists abundantly in the air.

Combustion means any chemical action attended by the evolution of heat, but is usually restricted to the union of oxygen with other substances which results in the evolution of heat and light. Substances which unite with oxygen are said to be combustible, those that do not are incombustible. Most of the elements are combustible, but the compounds resulting from combustion, as the sulphur and carbon dioxides, are incombustible. Chemical action, or combustion, always produces the same amount of heat whether the action be rapid or slow. When it is slow the heat escapes by conduction or otherwise almost as rapidly as it is formed, so that there is at no time any great intensity of heat and no light, while if the combustion is rapid the heat becomes intense and is accompanied with light as well.

The amount of heat generated by chemical action may be measured. This is done by causing the action to take place in such a manner that the heat resulting may, without waste, be applied to raising the temperature of water. The quantity of heat is shown by the number of grams of water it will raise one degree in temperature. From careful experiments in this direction, it has been shown that the chemical combination not only contains definite unvarying proportions of simples, but that in its formation a definite unvarying amount of heat was generated. Chemical combination and the evolution of heat represent work done. When the carbon united with the oxygen forming carbon dioxide, a certain amount of heat was given off, a definite amount of work was done, and the same amount of work will be necessary to separate the oxygen from the carbon as was developed in bringing them together. The law

of conservation of energy holds in chemical as well as in physical phenomena.

Combustible substances are endowed with potential energy; they can do work. The carbon of the coal, uniting with oxygen generates heat which converts the water into steam, whose expansive force acting through machinery does manifold kinds of work. The carbon dioxide formed by the respiration of animals by many kinds of slow combustions has no potential energy, but plants under the influence of sunlight can separate the carbon from the oxygen and the carbon stored up in wood, coal, oil, or gas, has acquired *potential energy, can do work*. Potential energy, derived from the sun, stored up in coal, oil and gas, millions of years ago, is now doing a great part of the work of the world. This is an interesting illustration of one of the wonderful economies of nature.

The compounds of oxygen with other elements are called oxides. Thus the union of oxygen and mercury forms mercuric oxide, composed of one part of mercury to one part of oxygen. In some compounds, called dioxides, there are two atoms of oxygen, as the carbon dioxide, and sometimes there are trioxides, as in the case of sulphur. In the case of copper there are two oxides, whose formula are Cu_2O , the oxide of copper, or cupric oxide, and CuO , suboxide of copper, or cuprous oxide.

HYDROGEN is a colorless invisible gas having neither odor nor taste, and is the lightest substance known. Its symbol is H and its combining weight 1. Its weight is considered as the unit of the system of combining weights. It has been found free in volcanic gases, but usually exists in combinations with other substances, making up one-ninth of the weight of water, and forming a constituent part of all vegetable and animal bodies. Hydrogen is in many respects the most interesting of all the elements. It unites with oxygen to form water, and by the decomposition of water we may obtain both of these gases.

Water may be decomposed by the voltaic current, oxygen being given off at the positive pole and hydrogen at the negative.

Some of the metals decompose water. Throw a small piece of the metal potassium on water; it takes fire, burning with a fine violet flame floating about as a melted globule on the surface of the water. The potassium unites with the oxygen in the water, and the heat generated is intense enough to ignite the hydrogen which has been set free, and is also sufficient to vaporize some of the potassium which gives the violet color to the flame.

The metal sodium behaves much like potassium, only that the heat is not quite sufficient to ignite the hydrogen. These experiments are interesting, but for preparing hydrogen in quantity, a simple process consists in passing steam over red-hot iron. The iron combines with oxygen of the water, forming the black oxide of iron (Fe_3O_4) the hydrogen passes on and is collected in jars over water. The equation is as follows: $4\text{H}_2\text{O}$, steam + $\text{Fe}_3 = \text{Fe}_3\text{O}_4$, oxide of iron + H_8 . While the decomposition of water by potassium and sodium at ordinary temperatures is prompt and spontaneous, iron must be heated to a red heat before it can separate oxygen from hydrogen.

The most convenient method of preparing hydrogen for use is by treating a metal, as zinc, with a strong acid. Put two or three pieces of granulated zinc into a test tube and pour upon them some dilute sulphuric acid. A brisk action takes place immediately, gas being given off in abundance. After the action has continued for a few moments, bring a lighted match to the mouth of the tube and the gas takes fire with a slight explosion, burning with a pale flame. In preparing the gas in a larger way, use a wide-mouthed bottle with a cork having two holes; through one of these pass a glass funnel whose stem is long enough to reach nearly to the bottom of the bottle; through the other hole pass the delivery tube. Use zinc and acid as before, being sure that the funnel tube extends below the surface of the acid in the bottle. After the chemical action has continued long enough so that all of the air has been driven out of the bottle, the gas may be collected over water as in the case of oxygen. Acid may be added through the funnel if the action

becomes too weak. Care should be taken to see that the bottle is closely corked so that the gas shall be free from air, as hydrogen with a little air makes an explosive mixture of great vigor.

The chemical equation in the preparation of hydrogen by this method is as follows: Zn , Zinc + H_2SO_4 , sulphuric acid = ZnSO_4 , zinc sulphate + 2H , that is one atom of zinc has taken the place of two atoms of hydrogen, forming zinc sulphate and free hydrogen. Hydrogen may be kept in an inverted jar for some time, but quickly escapes from one that is upright. It can be poured up but not down. Hydrogen or some of its compounds is used for filling balloons. It is combustible, but must be heated up to the kindling temperature when it unites vigorously with oxygen. The temperature of the hydrogen flame is higher than that of any other flame known. The oxyhydrogen flame, while giving very intense heat gives but little light. But if a cylinder of lime be put in the focus of this flame, it is soon heated to incandescence and gives out a light second only to that developed by electricity.

Oxygen and hydrogen combined form water, whose molecule is composed of one atom of oxygen and two of hydrogen; formula H_2O . Two volumes of hydrogen combined with one volume of oxygen forming two volumes of water vapor or steam.

Water can be produced from a mixture of oxygen and hydrogen. If we introduce into a stout test tube a mixture of two volumes of hydrogen and one of oxygen, on touching a lighted match to the mixed gas it explodes, the hydrogen burning rapidly, so that a flash of flame fills the tube. After the explosion water will be found deposited as dew on the sides of the tube. In this experiment there is no attempt to measure the water formed, but careful experiments show that all the oxygen unites with all of the hydrogen, forming the corresponding amount of water vapor or steam.

In the decomposition of water by the voltaic current the volume of the hydrogen is double that of the oxygen, and that experiment seems to show that water contains only oxygen and

hydrogen in its composition. Pure water has been decomposed by the action of several different metals and by the electric spark. It has been analyzed and found to contain only the gases oxygen and hydrogen.

Pure water at ordinary temperature is a clear transparent liquid, tasteless, odorless and neutral in its reactions. It is essential to the life of plants and animals, forming the chief ingredient of all the liquids they contain. It is the standard for obtaining the specific gravity of solids and liquids. It is the standard for the measurement of specific heat. It is an abundant ingredient of many rocks. Its presence or absence determines whether a region shall be a barren waste or a teeming garden. As a chemical compound, the combining tendencies of water extend over a wider range than those of any other compound. Its combinations with other substances are usually called hydrates. Water combines with the elements bromine and chlorine, forming an exception to the general rule that combinations do not take place between elementary and compound bodies. Water dissolves more substances than any other liquid known, so that in nature pure water is seldom or never seen. But it may be easily purified by filtration and distillation.

The purest water in nature is rain water, which falls after it has rained for some time. During the first part of the storm the rain washes dust and impurities out of the air, so that later the water is nearly pure. Large quantities of natural waters contain carbonate of lime in solution, and are called hard waters, forming deposits on the inside of boilers and kettles. Others contain iron, salt, soda and other minerals, some of which are of medicinal value. The solvent power of water is of great value in chemical operations, as well as in the operations of nature. In some cases substances which do not act upon one another when dry act promptly when in solution, the particles come into more intimate contact and chemical action seems to be facilitated. In solutions the particles of the dissolving liquid seems to have some attraction for the particles of the dissolved substances so that they are uniformly distributed through the solution, but this attracting power may

be saturated, and any amount added beyond this limit gradually settles to the bottom of the solution.

Oxygen and hydrogen, whether free or combined as water, are the most important and interesting substances within the domain of chemistry. They are alike in most of their physical qualities, but differ widely in their chemical properties. Oxygen combines with many substances with which hydrogen does not combine, while hydrogen combines with some substances which do not readily combine with oxygen, but under favorable conditions they combine with each other. In fact, in this case and in many others, unlike elements combine more freely than those which have many properties in common.

CHAPTER XIV.

NITROGEN, THE AIR, AMMONIA AND NITRIC ACID.

THE air, an invisible, tasteless, odorless gas surrounds us everywhere. In motion it is wind, from which we may recognize not only the existence of the air but something of its power as well. It has weight, as shown by the action of the common pump and mercurial barometer.

The air contains oxygen as shown by the fact that the same products arise from burning sulphur, carbon and other substances in the air, that arise from burning those substances in oxygen. But combustion in the air is not as prompt and vigorous as it is in oxygen, so that the oxygen of the air seems to be in a sense diluted. On a broad piece of cork, or bit of board, fasten a porcelain crucible or a piece of earthenware; place it on the surface of water; put on the porcelain a piece of phosphorus about the size of a pea and set fire to it, then invert a jar over the burning phosphorus, at first the heat of combustion may drive out a few bubbles of air, but soon the water will rise in the jar, taking the place of oxygen used in the combustion. The white clouds which fill the jar at first is oxide of phosphorus, which the water at length absorbs, and a transparent, tasteless, odorless gas remains, but does not fill the jar. If we measure the jar carefully it will be found that water occupies about one-fifth of its capacity, the gas occupying the balance.

This gas is called *Nitrogen*, its symbol is N, and its combining weight 14. If an experiment is carefully performed it will show that the air is composed of about 21 per cent. of oxygen to 79 per cent. of nitrogen. Close the jar and invert it, then lower into it a lighted candle and it is extinguished. Confine in it a mouse or a bird and it dies; the gas will not support combustion, it will not support life. Nitrogen is prepared in quantity by passing

air over red-hot copper, the oxygen combines with the copper forming copper oxide, leaving the nitrogen free. Oxygen enters into many combinations, and compounds of oxygen are generally stable, while nitrogen enters into comparatively few combinations and they are generally unstable, breaking up under the least provocation.

Besides occurring in the air nitrogen is an essential ingredient of animal and vegetable substances, and is an important ingredient in many other interesting compounds. Besides the oxygen and nitrogen the air always contains more or less water vapor, carbon dioxide or carbonic acid, ammonia and small quantities of other gases, and the lower portions are often loaded with various kinds of dust. The air seems to be simply a mechanical mixture of these various gases and not a chemical compound. If the oxygen and nitrogen were in chemical combination we would expect the proportions by weight to be as 14 of nitrogen to 16 of oxygen, or in some multiple of those numbers, but the proportion is as 23.10 of oxygen to 76.90 of nitrogen, and when these gases are mixed in this proportion, under no circumstances is there any generation of heat, light or electricity, as occurs in chemical combinations. As far as known the gases of the air exist everywhere in uniform proportions. The carbon dioxide and ammonia are small but important ingredients of the air, as it is from the air that plants get the greater part of the carbon dioxide and ammonia necessary to their existence.

Ammonia is a colorless gas, formula NH_3 , composed of one atom of nitrogen and three atoms of hydrogen. Formerly it was made from the horns of harts, hence the name spirits of hartshorn. The chief source of ammonia and ammonium compounds is now the ammoniacal liquors of gas works derived as a by-product in the distillation of coal. It is greedily absorbed by water, and a solution of the gas in water is the ammonia of the shops. This solution has a strong alkaline reaction, turning red litmus to blue, neutralizing strong acids, forming salts of ammonium.

In certain compounds a group of nitrogen and hydrogen

atoms, represented by NH_4 , behave very much like some metals, as potassium and sodium, and the name of ammonium has been applied, but no such substance has ever been isolated. Ammonia gas at a temperature of -40°F . becomes a liquid and at -103° it becomes a white crystalline solid. It can be reduced to a solid by a pressure of about 10 atmospheres. When the pressure is removed it expands into a gas by the action of heat derived from surrounding objects. On this principle machines for making ice are constructed.

Ammonia and hydrochloric acid, whether as gases or in solution, unite to form ammonium chloride, a white solid. If bottles containing the gases in solution be uncorked and brought near each other, a cloud of the ammonium chloride will be formed by the volatile gases. The chemical equation is $2\text{NH}_3 + \text{HCl} = 2\text{NH}_4\text{Cl}$. This compound, called sal ammoniac, is found in volcanic regions in considerable quantities.

Pure nitrogen may be prepared from the air, but the compounds of nitrogen have never been prepared successfully from the nitrogen of the air. It is difficult to cause nitrogen to combine directly with either hydrogen or oxygen, but through the action of myriads of minute organisms in some soils, atmospheric nitrogen and decaying nitrogenous matters are transformed into nitrates of lime or potassium.

One of the most important compounds of nitrogen is nitric acid, whose molecule is composed of one atom of hydrogen with one atom of nitrogen and three atoms of oxygen. Its symbol is HNO_3 . It is prepared by the action of sulphuric acid on potassium nitrate or sodium nitrate. The action is as follows: $\text{KNO}_3 + \text{H}_2\text{SO}_4 = \text{HNO}_3 + \text{KHSO}_4$. Nitric acid is a colorless, corrosive liquid whose applications in the arts and manufacturing industries are very extensive.

Dilute nitric acid by adding an equal bulk of water, then add ammonia water in small quantities from time to time, as long as the mixture shows an acid reaction. If this mixture be evaporated slowly, a solid substance with many transparent crystals, called ammonium nitrate, will be formed. This experiment is a

good illustration of what is meant by chemical combinations. Two liquids of strongly marked qualities, one an acid, one an alkali, united forming a solid as unlike its constituents as could well be imagined. Neither acid nor alkaline, neither sour nor bitter, and with but slight odor. The chemical equation is $\text{NH}_3 + \text{HNO}_3 = \text{NH}_4\text{NO}_3$.

If the ammonium nitrate obtained above be heated moderately, it melts and a colorless gas is given off which supports combustion almost as vigorously as oxygen. The equation is, $\text{NH}_4\text{NO}_3 = 2\text{H}_2\text{O} + \text{N}_2\text{O}$. This gas, the sub-oxide of nitrogen or nitrous oxide, is the laughing gas used by dentists as an anæsthetic.

The several compounds of oxygen and nitrogen that occur are of little value beyond illustrating the law of multiple proportions. They are the nitrous oxide, N_2O ; nitric oxide, NO ; nitrous anhydride, N_2O_3 ; nitrogen peroxide, NO_2 ; and nitric anhydride, N_2O_5 . An anhydride is an oxide which combined with water, forms an acid, as nitrous anhydride $\text{N}_2\text{O}_3 + \text{H}_2\text{O} = 2\text{HNO}_2$, nitrous acid; and nitric anhydride $\text{N}_2\text{O}_5 + \text{H}_2\text{O} = 2\text{HNO}_3$ nitric acid.

Acids are composed of hydrogen and some other non-metallic element, and in most cases they contain oxygen, as hydrochloric acid, composed of hydrogen and chlorine, formula HCl , nitric acid, composed of hydrogen, nitrogen and three atoms of oxygen, formula HNO_3 , and sulphuric acid composed of hydrogen, sulphur and oxygen, formula H_2SO_4 . Acids usually have a sour taste, turn vegetable blue colors to red and are often poisonous.

The combination of a metal with hydrogen and oxygen, non-metals, forms a compound called a *base*, as sodium hydroxide composed of sodium, hydrogen and oxygen, formula NaHO , called caustic soda, as potassium hydroxide, composed of potassium, hydrogen and oxygen, formula KHO , called caustic potash, and as calcium hydroxide, formula CaO_2H_2 , called caustic lime. The bases are sometimes bitter corrosive poisons, turning red colors to blue, but generally they are mild compounds.

The customary method of testing a substance for acid or basic reaction is by the use of paper colored by the dye litmus.

Acids change litmus blue to red, while a basic solution changes the red to blue again.

When a base and an acid are mixed in solution they neutralize or change the properties of each other, forming water and a compound called a *salt*. If we mingle hydrochloric acid and sodium hydroxide the salt, sodium chloride will be formed, together with one molecule of water, according to the following equation, $\text{HCl} + \text{NaHO} = \text{NaCl}$, common salt, $+ \text{H}_2\text{O}$. The hydrogen of the acid exchanges places with the metal of the base, as shown in the equation. The following equation shows the same exchange. Sulphuric acid, $\text{H}_2\text{SO}_4 + 2\text{NaHO}$, sodium hydroxide, $= \text{Na}_2\text{SO}_4$, sodium sulphate, $+ 2\text{H}_2\text{O}$.

The names of the stronger acids end in *ic*, as nitric, sulphuric and hydrochloric. If an acid containing the same elements has a less proportion of oxygen the name ends in *ous*, as nitrous acid, sulphurous acid. In the case of acids of which chlorine is a distinguishing element we have a hypo or subchlorous acid and a perchloric acid; the former contains less oxygen than the *ous* acid, the latter more than the *ic* acid.

The bases are metallic hydroxides, and the metal of the compound is the distinguishing part of the name, as sodium hydroxide, potassium hydroxide and calcium hydroxide. Such compounds are sometimes called hydrates, as they may have been formed by the metal replacing one atom of hydrogen in water, as $\text{H}_2\text{O} + \text{K} = \text{KOH} + \text{H}$, one atom of free hydrogen.

Salts are named from the acids forming them, as nitrates, sulphates, chlorates, etc., and they are further distinguished by the name of the metal of the base, as potassium nitrate, sodium sulphate, etc. The salts formed by nitrous acid are called nitrites and those by sulphurous acid are called sulphites, etc. If the name of the acid ends in *ic*, the name of the salt ends in *ate*, if the name of the acid ends in *ous*, the name of the salt ends in *ite*. The reciprocal action of chemical agents, as in the case of an acid and a base, or the action of some form of energy causing chemical changes, is called a *reaction*, and a substance capable of producing with another substance a chemical reaction is called a *reagent*.

CHAPTER XV.

CHLORINE, BROMINE AND IODINE.

CHLORINE is a greenish yellow gas, never found free in nature, but existing in great quantities as an ingredient of common salt. It also occurs in combination with potassium, magnesium and silver. Its formula is Cl and combining weight 35.5. If common salt be mixed with sulphuric acid and heated, a transparent intensely acid gas will be given off, which must be collected over mercury, as water absorbs it greedily. The sodium of the common salt and hydrogen of the sulphuric acid change places and the acid is formed, which, dissolved in water, is the hydrochloric acid of commerce. The equation is common salt, $2\text{NaCl} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4$, sodium sulphate, $+2\text{HCl}$, hydrochloric acid.

This acid is one of the most useful agents in the chemical laboratory, and is extensively used in manufacturing industries. As an acid it forms the class of salts called chlorides, as sodium chloride, or common salt. A mixture of hydrochloric and nitric acids, called aqua regia, is the only solvent for gold, the acids decompose each other, and the chlorine, when set free, attacks the gold.

If hydrochloric acid be well mixed with the binoxide of manganese, and the mixture heated gradually, chlorine gas will be set free. As it is heavier than air it may be collected in an open jar by carrying a delivery tube to the bottom of the jar, its color enabling one to see when it has filled the jar. The equation is, $\text{MnO}_2 + 4\text{HCl} = \text{MnCl}_2 + 2\text{H}_2\text{O} + 2\text{Cl}$. Chlorine is usually prepared by heating a mixture of common salt, oxide of manganese and sulphuric acid.

Chlorine combines readily with many elements and decomposes many compounds from its strong affinity for hydrogen. If a piece of paper, soaked in oil of turpentine that has been slightly warmed, be dropped into a jar of chlorine there will be

a flash of flame, followed by a dense black smoke; the turpentine is composed mainly of hydrogen and carbon, the chlorine uniting with the hydrogen leaves the carbon free, which helps to form the dense black smoke.

Chlorine is a powerful bleaching agent. Pieces of calico or other colored fabrics placed in chlorine gas, if dry, will remain unchanged for some time, but when moistened the color will in most cases disappear promptly. Some of the hydrogen is taken from the coloring matter and oxygen set free, which doubtless assists in decomposing the compounds which constitute the color, but the action must not be allowed to continue long or the fabric itself will be destroyed by the chlorine.

For bleaching purposes chlorine is usually prepared from calcium chloride, which readily gives off chlorine when acted on by dilute sulphuric acid. An interesting experiment illustrating the difference in specific gravity between chlorine and air may be shown with the chloride of lime. On the bottom of a glass jar or wide-mouthed bottle place a much smaller bottle containing some bleaching-powder, add a little sulphuric acid, diluted by an equal bulk of water and partly cover the larger bottle with a piece of glass or pasteboard. Chlorine gas will be set free, will gradually fill the smaller bottle, and falling over the sides to the bottom of the larger one will gradually crowd out the air till it fills the bottle. With a small bottle as a dipper the gas may be dipped out and poured into other jars. Care should be taken not to breathe the gas.

Hydrogen is an important ingredient in many unpleasant, unhealthful odors, and the strong affinity of chlorine for hydrogen makes it a valuable disinfecting agent in such cases. It removes the hydrogen, breaking up the compounds, and the oxygen set free oxidizes or burns other parts into harmless compounds.

Chlorine combines with hydrogen even more promptly than oxygen does. If hydrogen and oxygen be mixed in the proper proportion for water, they will not combine except by the aid of heat, as the electric spark. While if hydrogen and chlorine be mixed in the same way the combination takes place with explosive vio-

lence under the influence of direct sunlight, taking place slowly and quietly in moderately strong, diffused light. The action of sunlight in this and other cases of chemical action, as in photography, is not well understood. It does not seem to be the heat, as even a higher degree of heat without light has no such effect. Compounds of oxygen with elements are called oxides, the compounds of chlorine with elements are called chlorides.

Chlorine combines energetically with bromine, iodine, sulphur, phosphorus and arsenic, and with most of the metals also, making it the rival of oxygen in the extent of its combinations. Chlorine forms several interesting compounds with hydrogen and oxygen. They are, hypochlorous acid, HClO ; chlorous acid, HClO_2 ; chloric acid, HClO_3 ; perchloric acid, HClO_4 .

The chloric and hypochlorous acid are the most important, but the whole series is interesting as illustrating the law of multiple proportions. Chloric acid may be prepared by treating potassium chlorate with sulphuric acid. The reactions are as follows: $2\text{KClO}_3 + \text{H}_2\text{SO}_4 = \text{K}_2\text{SO}_4 + 2\text{HClO}_3$. The potassium taking the place of the hydrogen in the sulphuric acid forms potassium sulphate, and the hydrogen with the chlorine and oxygen forms the chloric acid. The chloric and hypochlorous acids form salts as the calcium hypochlorite, usually called chloride of lime, or bleaching powder, and the potassium chlorate. These compounds of hydrogen, chlorine and oxygen are not very stable. The affinity with oxygen is not strong.

In considering the composition of hydrochloric acid it is found that one volume of hydrogen unites with one volume of chlorine to form two volumes of hydrochloric-acid gas. In the composition of water, two volumes of hydrogen combine with one volume of oxygen forming two volumes of water-vapor. In the case of ammonia, three volumes of hydrogen combined with one of nitrogen to form two volumes of ammonia, and in marsh gas we have four volumes of hydrogen combined with one of carbon into two volumes of marsh gas.

These facts were discovered and have been abundantly verified by experiment; but how are they explained? Dr. Dalton formu-

lated the atomic theory. Avogadro, after a careful study of gases, formulated this theory, that equal volumes of all gases, whether simple or compound, under the same conditions of temperature and pressure, contain the same number of molecules. Elements differ in their chemical combinations, as HCl , hydrochloric acid, H_2O water, NH_3 ammonia, CH_4 marsh gas. The atom of chlorine can hold one atom of hydrogen, the atom of oxygen holds two, the atom of nitrogen three and the atom of carbon four. On examination it is found that a similar difference occurs among other elements. An element, whose atom can hold only one other atom is called univalent, as hydrogen and chlorine. An element whose atom can hold two others in union is called a bivalent, as oxygen and mercury. An element whose atom can hold three atoms in combination is called trivalent, as nitrogen and antimony, and one that can hold four is called quadrivalent, as carbon and tin. In the formation of salts elements of the same valence replace each other, as in the formation of potassium nitrate, the univalent potassium replaces the hydrogen in HNO_3 and the compound becomes KNO_3 . In the case of potassium sulphate two atoms of the univalent metal replace the two atoms of hydrogen and H_2SO_4 becomes K_2SO_4 . In zinc sulphate one atom of zinc, a bivalent metal, replaces the two atoms of hydrogen and H_2SO_4 becomes ZnSO_4 sulphate of zinc. From the foregoing data we may form a theory for the peculiarities of combination by volume.

If we suppose our unit volume to contain 1,000 molecules then, according to the law of Avogadro, one volume of hydrogen containing 1,000 molecules unites with one volume of chlorine containing 1,000 molecules forming two volumes of hydrochloric acid gas containing 2,000 molecules. But each molecule of the hydrochloric acid contains two atoms, and in the two volumes there must be 4,000 atoms. From this we judge that the molecules of hydrogen and chlorine are each made up of two atoms. In the case of water we have two volumes of hydrogen containing 2,000 molecules or 4,000 atoms, combining with one volume of oxygen containing 1,000 molecules or two thousand atoms, forming

two volumes of water vapor, containing 2,000 molecules or 6,000 atoms. The two-atom molecules of hydrogen and oxygen were rearranged into three-atom molecules of water vapor, diminishing the bulk by one-third. With ammonia the case is similar, one volume of nitrogen containing 1,000 molecules or 2,000 atoms, unites with three volumes of hydrogen containing 3,000 molecules or 6,000 atoms, forming two volumes of ammonia, containing 2,000 molecules with 8,000 atoms. The two-atom molecules were broken up and rearranged into four-atom molecules and the volume diminished by one-half. Thus the atomic theory, Avogadro's principle, the theory of valence and the phenomena of combination by volume, all seem to harmonize with the facts of definite and multiple proportions in chemical combinations, and to sustain and mutually verify each other. The law of definite proportions has been demonstrated, the others are still theories.

It has been found that elements at the instant they are set free from compounds are much more active and can effect changes which they cannot effect under other circumstances. Hydrogen gas passed into nitric acid causes no change, but hydrogen liberated in direct contact with nitric acid reduces the acid and forms the lower oxides of nitrogen. Examples of similar action are of frequent occurrence. An element at the instant of its liberation is said to be in the nascent state or atomic state when it seems to be more active than after the atoms have combined into molecules.

BROMINE (Br) is a dark brown liquid heavier than water having an irritating disagreeable odor, hence the name, meaning a stench. It is the only non-metal which is a liquid at ordinary temperatures. It occurs in seawater and other natural brines, as magnesium bromide, which is the main source of the bromine of commerce. It is generally obtained from bittern, the residue which remains after sodium chloride has been crystallized out from the natural brines. Bromine forms compounds with hydrogen and oxygen, which are analogous to those of chlorine, and in physical and chemical properties is somewhat similar to that

element. Some compounds of bromine are used as bleaching and disinfecting agents. Some are used in photography, and bromide of potassium is used extensively in medicine.

IODINE (I) is also found in seawater. Certain varieties of seaweed separate the sodium iodide from the seawater and concentrate it in their tissues. The seaweed is collected, dried and burned. The ashes and other residue are leached with water, which dissolves out the sodium iodide, and this solution yields the iodine of commerce. Iodine is a grayish black crystalline solid of metallic luster. It melts at 225° F. and boils at 356° , forming a beautiful violet-colored vapor, which is the heaviest known, being 872 times heavier than air. Drop a piece of iodine as large as a grain of wheat into a test-tube and apply heat; observe the vapor, notice the coating it forms on the tube; apply heat to different parts of the tube and study the effects. Examine the coating for crystals.

Iodine is soluble in alcohol or ether and is sparingly soluble in water. Iodine colors starch paste a deep blue; this reaction constitutes the most delicate test of its presence. Take a thin solution of starch paste and add to it a few drops of an aqueous solution of iodine and notice the color. Dip a piece of white paper in the paste and suspend it while moist in a bottle or jar on the bottom of which has been placed a small piece of iodine. In a few moments the paper begins to show a blue color, indicating that iodine is volatile at ordinary temperatures. Iodine stains the skin yellow but is not as corrosive as either chlorine or bromine. A solution of iodine in alcohol is familiarly known as tincture of iodine and much used as a liniment. Iodide of mercury is sometimes used in painting as a pure scarlet; the iodide of lead has a bright golden color; the iodide of silver is yellow and the iodide of potassium is white. The iodide of potassium is extensively used in photography and in medicine.

Iodine combines with hydrogen forming hydriodic acid, a colorless gas, with a suffocating odor. One part of hydrogen, weight one, combines with one part of a highly colored iodine vapor, weight 127, and the one part discharges the color and

changes the properties of the 127 parts forming a colorless gas, formula HI.

Iodine forms an acid with hydrogen and oxygen called iodic acid, formula HIO , analogous to chloric and bromic acid.

Chlorine, bromine and iodine constitute a well-defined natural group of elements. They each unite with hydrogen in the same proportions, forming acids of similar properties and each forming similar salts. Each of these elements forms a powerful acid containing three atoms of oxygen. With nitrogen they each form explosive compounds. At ordinary temperatures chlorine is a gas, bromine a liquid and iodine a solid. Chlorine is yellow, bromine reddish-brown and iodine violet. In general chlorine is more energetic and its compounds more stable, while iodine is least energetic except in its combinations with oxygen.

FLUORINE is an element, known only in its compounds, of which the most common is the mineral fluor spar. It occurs in vegetable and animal substances and in several other minerals. Fluorine forms an acid with hydrogen analogous to hydrochloric acid, which is very corrosive, attacking glass vigorously, so that it must be collected in lead, rubber, or platinum vessels. It is used for etching glass. The glass is covered with a thin coat of wax, and lines or figures are drawn with a pointed instrument so as to cut through the wax. The glass is then exposed to the action of the acid, and soon the figures drawn are corroded into the glass. Fluorine seems to have affinities with the chlorine group of elements, but so little is known of it that no extensive comparison can be made.

CHAPTER XVI.

CARBON, SILICON AND BORON

CARBON (C) is an essential constituent of all animal and vegetable bodies. It is found in the air, in many kinds of rocks and soils, and in many natural waters, but is especially the element of organic bodies. Every living body from the microscopic animalcule up to the giant whale, from the tiniest vegetable to the lofty red-wood contains carbon. It occurs in its purest form in the crystalline transparent diamond, the hardest substance known. Another form of nearly pure carbon is graphite, and another still is common charcoal. Diamonds are found in South America, South Africa, in the East Indies and in Australia, and to some extent in other localities. They are usually found in alluvial deposits as water-worn pebbles whose crystalline form and transparency have been obscured by abrasions. It is the most beautiful and highly prized of all the gems. It is a powerful refractor of light, and is sometimes employed in making the lenses of microscopes. Small, dark stones are much used for cutting glass, drilling gems and in making the cutting edges of core drills. If heated to a very high temperature in oxygen gas it burns up, the sole product of the combustion being carbon dioxide.

Graphite, another form of carbon, occurs in great quantities among the older rocks of Canada and other localities, and is often associated with iron ores. It sometimes occurs in six-sided plate-like crystals, while the diamond usually has the form of an octahedron. Graphite has a grayish black color with a metallic luster; has an oily feel, and is often used in place of oil to prevent friction in machinery. Graphite resists a very high degree of heat, and is used in manufacturing crucibles for melting steel and other refractory substances. When subjected to a high degree of heat in oxygen it burns, evolving intense heat and light, but the

sole product, as in the case of the diamond, is carbon dioxide. Graphite is insoluble and unaffected by moisture or air, and forms a valuable coating for protecting iron from the effect of the weather. Its chief use is, perhaps, the manufacture of pencils. For this purpose it is reduced to a powder and subjected to great pressure. It is then sawed into little bars which are cased with wood. A mass of graphite seems soft and friable, but the particles are extremely hard, and soon wear out the steel saws used in cutting it into shape.

We know nothing about the formation of diamonds, but geologists consider graphite to be the residue of some of the forms of life occupying the earth when the materials of the older rocks were being deposited.

Another form of nearly pure carbon is charcoal. It is formed when any organic substance, as wood, sugar, flesh, bone or blood is burned in a limited supply of air. It is a black, brittle, tasteless, solid. It is not easily affected by the action of air or water at ordinary temperatures; charred cloths, grains, fruits, and other remains of the Lake Dwellers of Switzerland, are as perfect to-day as when entombed in the mud and waters of the lakes thousands of years ago. The charcoal of commerce is formed from wood by burning it in a limited supply of air. Wood is made up mainly of carbon, oxygen and hydrogen, and when burned in the open air the oxygen combines with the hydrogen forming water, and with the carbon forming carbon dioxide until only a few ashes are left; but if the supply of oxygen is limited the hydrogen and part of the carbon are driven off, but the main part of the carbon remains as charcoal. Charcoal is used as a fuel, burning, when dry, without flame, yielding a high degree of heat. Burned in oxygen the sole product is carbon dioxide, as in the case of diamond and graphite.

Charcoal is very porous, and possesses in a remarkable degree the power of absorbing gases, some specimens absorbing 90 times their bulk of ammonia, 35 times their bulk of carbon dioxide. It is said that freshly burned charcoal will absorb moisture from the air so as to increase at least 10 per cent. in weight.

The absorbing properties of charcoal make it a good deodorizer and a powerful disinfectant, and it is much used in making water filters. Charcoal from bones is much used in sugar refineries to decolorize sirups. It destroys bad odors, and discharges colors, not only by absorbing gases, but the absorbed oxygen acting chemically on the noxious gases and other substances changes them to harmless compounds.

Soot is another form of nearly pure carbon. It is carbon which has been released by heat from its combinations, without being burned, it helps to form the smoke of combustion. It may be condensed from the smoke as a fine black powder. It is used for making printers' ink, black paint, etc. In the distillation of coal for the manufacture of illuminating gas, there is deposited on the inside of the retort a grayish coating called gas carbon. It is quite as nearly pure carbon as any of the other forms, but whether it is a variety of graphite, or a fourth form is not settled. Gas carbon is a good conductor of electricity, and is used for electric-lamp carbons and other purposes. Coke and anthracite coal are nearly pure carbon. The different kinds of soft coal and peat all have carbon as the basis of their composition but associated with various impurities.

All these forms of carbon seem to be the result of the slow decomposition of organic matter, mainly vegetation, usually under water, so that the supply of oxygen was limited. This mass of decomposing matter covered with sand or clay, subjected to pressure and heat, gradually changed into various kinds of coal and graphite. It seems hardly possible that the black, brittle, porous charcoal, and the soft compact graphite are chemically identical with the beautiful diamond. They are specimens of the same element appearing in different or allotropic forms, and notwithstanding their marked differences, they have well-marked properties in common. The explanation of these different forms of carbon is one of the unsolved problems of chemistry.

Carbon combines freely with oxygen in all forms of combustion and combines also with hydrogen, nitrogen and other elements. When any of the forms of carbon is burned in oxygen

the product is *carbon dioxide*, formula CO_2 , one atom of carbon uniting with two of oxygen. It is ordinarily prepared by treating calcium carbonate, limestone, with hydrochloric or some other strong acid. It may be collected over water, or as it is much heavier than air it can be collected in an open jar. The chemical equation is $\text{CaCO}_3 + 2\text{HCl} = \text{CaCl}_2 + \text{H}_2\text{O} + \text{CO}_2$. Calcium, a bivalent element, replaces two atoms of hydrogen forming calcium chloride, the two atoms of hydrogen taking one atom of oxygen form water setting free (CO_2) carbon dioxide, which at ordinary temperatures is a colorless, tasteless, odorless gas. If a lighted stick or candle be put into a jar of this gas, it is extinguished as promptly as if thrust into water; if a bird or mouse be confined in it, life is quickly destroyed.

Carbon dioxide will not support combustion, will not support animal life, and for the same reason that water does not, they each contain plenty of oxygen, but it is so firmly bound to the other members of the compound that it cannot be utilized for the processes of life or combustion. Water and the dioxide of carbon are cinders, the affinities of the oxygen, hydrogen and carbon have been satisfied, their energy has been expended, they are like rocks at the foot of a hill, work must be done on them before they are in a condition to do any more work; and that work must be equal to the work they did as they clashed together into molecules of water and carbon dioxide.

This gas sometimes accumulates in wells, abandoned mines and caves. As a test of its presence a lighted candle is lowered into places where its presence is suspected; if the light is not extinguished or dimmed, the air does not contain a dangerous amount of the dioxide. Carbon dioxide is a product of respiration. Immerse a jar in water and invert it so as to keep the mouth under water; then through a tube fill the jar with air from the lungs, displacing the water; cover the mouth of the jar with the hand or piece of board and place it upright on the table and test the contents with a lighted candle for carbon dioxide. If the air is held in the lungs for a little time before being breathed into the jar the effect will be more marked. This experiment will show

that air that has been breathed once is not safe for breathing a second time. But lesser quantities of the dioxide are harmful, and a more delicate test of its presence is often desirable. Put a small piece of quick lime into a tumbler or jar of water, after a few minutes stir it well, and when the sediment settles pour off the clear water for use. Fill a test-tube about two-thirds full of lime water and force air from the lungs through the water by means of a tube, and quickly the water becomes cloudy and milky. This makes a delicate test for the dioxide. The lime of the water combines with dioxide forming calcium carbonate which is insoluble in water. If lime water is exposed to the air in an open dish, the dioxide of the air uniting with the lime soon forms a thin coating of calcium carbonate on the surface of the water.

The dioxide of carbon accumulates so rapidly as the product of combustion and respiration that the air of a room occupied by a number of people soon becomes loaded with this gas unless special arrangements have been made for free ventilation. Tests of the air of almost any school or assembly room, especially when fires or lights are in use, will show dangerous quantities of a gas which cannot support life, and which by limiting the supply of oxygen becomes detrimental to health.

Under a pressure of 36 atmospheres (about 450 lbs.) carbon dioxide becomes a liquid; when the pressure is removed it begins to evaporate rapidly, the evaporating portion absorbing so much heat from the other that it freezes into a snow-like solid.

Carbon dioxide is absorbed freely by water and other liquids, the sparkling appearance of wines and mineral waters, the foam of beer and "soda water" are due to the presence of this gas. It is also used in the manufacture of fire extinguishers. An English coal mine that had been smouldering for years was extinguished completely by the use of carbon dioxide. This gas combined with water forms *carbonic acid*, formula H_2CO_3 , and it is probable that in the tests with lime water we find the carbonic acid not the dioxide.

When coal is burned without a free supply of air, a gas is

formed called *carbon monoxide*. It is colorless, tasteless, odorless, but exceedingly poisonous when inhaled. We often hear of deaths caused by coal gas, and the gas from a pan of smouldering charcoal is often the cause of suicidal death, especially in France. In an open coal fire, before all the coal is fully ignited, the pale blue flames flickering over the mass are burning monoxide of carbon. It is probably the cause of death in the cases mentioned.

All forms of artificial light, except the electric light, are flames due to the combustion of some gas. In the case of illuminating gas, the source of the light is made and stored as gas, in the case of oil, the wick is ignited and as the oil comes up by capillary attraction it is expanded into gas and burns as a flame, and so with the candle. At first a flame seems a simple thing and illumination seems as simple as the flame, but when one attempts to explain the phenomena, the simplicity vanishes. We have already learned that the hydrogen flame, while intensely hot yields but little light. If we pulverize a little charcoal and dust it into a flame of hydrogen it gives out an intense light; or if the hydrogen flame be turned upon a piece of lime or other refractory substance it is soon heated to incandescence giving out intense light, which leads us to suspect that an illuminating flame must contain some solid incandescent substance which is the cause of the illumination.

If we examine a flame, as of a candle, we find it conical in shape, pale blue below, dark in the center and yellow at the sides and at the apex. Put a piece of porcelain or any solid substance into the flame and the coat of soot deposited indicates the presence of solids in the flame. Pass a piece of paper into the flame just above the wick, hold it there a moment, then remove it, and if skillfully done there will be a ring of burnt paper with a little portion uncharred within it, which indicates that the outside of the flame is hotter than the inside dark portion. The substances used for illuminating flames, as gas, oils and fats are composed largely of compounds of hydrogen and carbon. About the wick of a lamp or candle or the opening of the gas jet the unburned gas makes the cool dark center of the flame. The oxygen uniting more readily with the hydrogen than with the carbon forms

the hydrogen flame just outside the dark center and the liberated carbon passing through the hydrogen flame is heated to incandescence, and just outside this hydrogen flame it combines with the oxygen forming the dioxide of carbon.

If air is admitted to the center of the flame, as in an Argand burner, the dark center is lessened and the light increased. In the case of the Bunsen burner air is allowed to mingle with the gas so that the combustion is practically complete, yielding a hot flame but very little light; for use in chemistry it is better as it gives greater heat and leaves no deposit of soot. The flame of alcohol yields but little light and deposits no soot. Within certain limits the amount of light depends upon the temperature of the flame. The temperature may be so low as to hardly heat the carbon to incandescence when the light must begin to fail. If by any means the temperature of the flame falls below a certain limit it is extinguished.

A piece of fine wire gauze held across the flame of a lamp or candle cools the combustible gases below the ignition point so that they rise through the gauze in the form of smoke, the gauze may become red hot and still not allow the flame to pass, so rapidly does the wire conduct the heat away, and yet the gases may be ignited above the gauze. On this principle the miner's safety lamp is constructed. Light carbureted hydrogen or marsh gas, abundant in some coal mines, forms with air an explosive mixture of great power, but the mixture must be raised to the igniting temperature before explosion takes place. As the gas is odorless often the first intimation of danger was the fatal explosion of fire damp, lighted from the miner's open lamp. Sir Humphrey Davy studied the problem, and at last made a lamp in which the flame was surrounded by a wire gauze which so confined it that the explosive gases outside could not be ignited. As the gauze restricted the light it soon became the custom to explore the mine for dangerous gas with a safety lamp and if none was found the men went to work with open lamps. A flame seems a little thing, but the full discussion of a candle flame would make quite a complete treatise on chemistry.

Cyanogen, formula C_2N_2 , is a colorless poisonous gas composed of carbon and nitrogen, which is best known in combination with the metals potassium and iron, in connection with which it will be more fully discussed.

No other two elements are capable of occurring in so many different combinations as carbon and hydrogen. Compounds of these elements are known as hydrocarbons, and include most of the inflammable gases and a great many essential oils, naphthas and other interesting substances. It is supposed that all these compounds were originally derived from the vegetable kingdom, and they may be considered under the head of organic chemistry. Three members of this group of compounds may be mentioned here for the purpose of affording a little insight into the mutual relations of these important elements. When intensely heated, as by the electric spark, carbon combines with hydrogen forming a colorless gas called *acetylene*, formula C_2H_2 . This gas is found among the products of incomplete combustion, having a peculiar odor something like that of geranium. It burns with a smoky flame in the air, bursting spontaneously into flame when brought into contact with chlorine. *Olefiant* gas, formula C_2H_4 , is also a product of the action of heat on coal, and is one of the illuminating gases. This gas derives its name from its property of uniting with chlorine and bromine, forming oily liquids.

If the mud and decaying vegetable matter at the bottom of stagnant pools is stirred up, bubbles of gas rise more or less abundantly to the surface. This gas has received the name of *methane*, or marsh gas. It is abundant in coal mines, as the fire damp of the miners; it is a constituent of petroleum oil and is the initial member of an interesting series of hydrocarbons. It is a colorless, odorless, inflammable gas, burning with a luminous flame. When petroleum is brought up to the air several gases are given off. The simplest of these is methane, formula CH_4 , the next Ethane, C_2H_6 , the next Propane, C_3H_8 , the next Butane, C_4H_{10} , the next Pentane, C_5H_{12} , and so on, each member differing from the preceding one by CH_2 , altogether forming what is called an homologous series. Such series are distinguishing

marks of the hydrocarbons. The ordinary illuminating gas consists of free hydrogen, marsh gas, olefiant gas, carbonic oxide, acetylene and other substances.

SILICON (Si), next to oxygen, is the most abundant element in nature. It has never been formed in an uncombined state, occurring most abundantly as silicon dioxide or silica, formula, SiO_2 . The dioxide uniting with water forms silicic acid, H_2SiO_3 . This acid forms silicates of sodium, potassium, aluminium, calcium and other metals. These silicates are very abundant, silica and the silicates make up the greater part of the crust of the earth. The granite rocks, volcanic rocks, sand rocks, clay or slate rocks—everything except limestone and coal is composed largely of the compounds of this element. Silica is not only abundant and useful but is beautiful as well. The purest natural variety is the transparent, colorless quartz crystal or rock crystal, occurring in six-sided prisms terminated by six-sided pyramids. They may be distinguished from most other crystals not only by their form, but by their hardness, scratching glass almost as readily as the diamond. With a little tinge of purple, the rock crystal becomes the beautiful amethyst; when brown or smoky, Scotch pebbles. Losing its transparency and crystalline form, we have the translucent chalcedony, the brilliant carnelian, the banded agate, the catseye, the onyx and the opal. Each of these forms beautiful and enduring. Flint is a dark colored variety of silica which is proverbial for its hardness. The percussion of flint and steel for many years served our forefathers as a source of light and heat in place of the lucifer match.

While silica is insoluble, some of its compounds are soluble, and plants contain considerable quantities in their composition, and animals as well. Many natural waters contain silica in solution, as in the Geysers of Iceland, and petrified wood indicates that silica is soluble to some extent in water, but probably only in hot water and under considerable pressure.

Hydrofluoric acid is the only substance that can decompose silica at ordinary temperatures. Silicic acid does not appear to be a very strong acid, seeming to be of about the same strength

as carbonic acid, and yet the silicates generally are quite stable compounds. Glass is manufactured from the silicates of sodium, potassium, calcium, etc., with other ingredients.

Silicon has been obtained as a brownish powder and in the form of crystalline scales with metallic luster resembling graphite. Carbon and silicon are similar in some respects, as both form dioxides and weak acids, and the same hydrides and chlorides, but differ in that most of the compounds of carbon are derived from the hydrocarbons, while the compounds of silicon are derived from silicic acid.

Boron (B) is an element which has not been found in vegetable or animal bodies; is never found free; is not abundant; is not essential to life, and yet in many ways it is an interesting element, similar in some respects to carbon and silicon. It forms with oxygen boric trioxide, B_2O_3 , which uniting with water forms boracic, or boric acid, H_3BO_3 .

This acid is found issuing from the earth as vapor, accompanied with steam in certain volcanic regions, as Northern Italy. This steam is passed into water, which absorbs the acid yielding boracic acid crystals on evaporation. Boracic acid is feeble like silicic and carbonic acids. It fuses at high temperatures, when it dissolves many of the metallic oxides forming glassy borates which are of characteristic and often beautiful colors. On this property depends the chief value of boron in the arts and in chemistry. It forms a good test for detecting the presence of metals, and is valuable in the manufacture of colored glass and porcelains. It is used in hard soldering and in brass manufacture. The most important borate is the sodium borate called borax, which is the form under which boron is best known.

Boron has been isolated as an olive-green powder; also in copper-colored scales similar to graphite; also in transparent octahedral crystals, rivaling diamonds in brilliancy and hardness. Carbon, silicon and boron seem to form a natural group; each has a crystalline, amorphous and graphite-like form. Neither can be made a vapor, and each is practically insoluble.

CHAPTER XVII.

SULPHUR, PHOSPHORUS AND ARSENIC.

SULPHUR is an element that has been known from the earliest times, as it is found in great quantities in volcanic regions, especially in those of Southern Europe. It occurs as hydrogen sulphide in mineral waters. It forms compounds with several metals, as the bisulphide of iron, sulphide of iron and copper, sulphide of lead, zinc, antimony and mercury. It also is a constituent of numerous sulphates, as the sulphates of lime, baryta, strontia, magnesia and soda. It is also found in small quantities in animals and some plants.

Sulphur is a yellow brittle solid. It melts at 239° F. to a thin straw-colored liquid; when heated to a higher temperature it becomes darker in color, and at 350° F. becomes a dark viscid body. At this point the temperature remains stationary for some time, although heat is applied continuously, showing that heat is doing other work besides raising temperature. As it begins to rise in temperature again it becomes liquid at about 500° F., and at 836° F. it boils, forming a brownish-yellow vapor, which burns in oxygen or in the air with a bluish flame. When a liquid at about 500° , if poured into water, it becomes a dark plastic mass much like india rubber, but this form is not permanent—it soon changes back to the yellow brittle form.

The plastic sulphur not only differs from brittle sulphur in physical properties but it differs in chemical properties as well, for brittle sulphur dissolves readily in bisulphide of carbon while the plastic form is entirely insoluble; and further, they differ in their electrical relations, the plastic form is electro-positive while the other is electro-negative.

The diamond crystallizes in the form of an octahedron and

so does sulphur. Nearly all the compounds of sulphur as well as most other substances of the mineral world have definite crystalline forms, and so constant and definite is this form that it is one of the marks for the identification of minerals. The natural crystallization of sulphur is the octahedra, and it takes this form when crystallizing from solutions, but when crystallizing from the melted state it takes the form of oblique prisms. The difference between these two crystalline forms of sulphur extends to their specific gravities and the temperatures of their melting points. Ordinary rolled sulphur contains many prismatic crystals when first made which gradually change to octahedra. This change in structure of the solid gives rise to a state of tension which accounts for the extreme brittleness of sulphur.

Sulphur is one of the most interesting of the non-metallic elements, and it may serve as the basis of many interesting and instructive experiments. A large part of the sulphur of commerce comes from Sicily. As the melting point and boiling point of sulphur are low it is comparatively easy to separate it from impurities by the aid of heat. Large quantities of sulphur are also obtained by decomposing iron pyrites or bisulphide of iron. Sulphur is used in the manufacture of gunpowder and matches.

Sulphur unites with oxygen, forming many interesting compounds. When sulphur is burned in the air, *sulphur dioxide*, formula SO_2 , is formed with the evolution of light and heat. It occurs among the products of volcanic action, is a transparent colorless gas, having a pungent suffocating odor, such as arises from a burning match. It may be prepared for examination by treating copper with sulphuric acid. It is readily absorbed by water but may be collected by displacement, as in the case of chlorine or carbon dioxide, as it is heavier than air. It may be condensed to a liquid by cold or pressure, and is a solid at -105°F . Sulphur dioxide SO_2 + water, H_2O forms sulphurous acid, H_2SO_3 . When neutralized by a base this acid forms a class of salts called sulphites, as the sulphite of soda.

Sulphur dioxide is extensively used as a bleaching agent. Al-

though less powerful than chlorine it is preferred in some cases, because it is less liable to injure the fabric. The articles to be bleached are moistened and hung in a chamber in which sulphur dioxide is produced by burning sulphur. The coloring matters seem to form colorless compounds with the acid and in some cases the colors may be restored by neutralizing the acid. Sulphur dioxide, like carbon dioxide, will not support combustion and is used to stop combustion. This acid is an antiseptic promptly arresting fermentation. It is used as a disinfectant and as an insecticide. The dioxide becomes an acid so readily by taking water from the air that it is often difficult to decide whether a given result is due to the dioxide or the acid.

While sulphurous acid is useful in many other ways its principal use is in the manufacture of *sulphuric acid*, formula H_2SO_4 . It is a powerful acid which has very many practical uses. It is said that more than 100,000 tons of it are used each year in England alone. The steps involved in the manufacture of sulphuric acid are the formation of the sulphur dioxide, and sulphurous acid H_2SO_3 , which combined with one atom oxygen forms sulphuric acid. The last step is the most difficult and most interesting. The sulphurous acid cannot readily get the necessary oxygen from the air, but nitric oxide, formula NO , takes oxygen from the air forming nitrogen peroxide NO_2 . The peroxide gives off one atom of oxygen to the sulphurous acid and sulphuric acid is formed, the nitric oxide simply carrying oxygen from the air to the sulphurous acid. Sulphurous acid is supplied from burning sulphur or decomposing iron pyrites. Nitric acid, from which the nitric oxide is formed, is supplied by the decomposition of niter by sulphuric acid. A mixture of sulphurous and nitric acids, air and steam are conveyed into a leaden chamber containing a layer of water. The nitric acid by the action of the sulphurous acid is reduced to nitric oxide, which takes oxygen from the air and gives it up to the sulphurous acid, converting it into sulphuric acid. This is absorbed by the water forming a weak acid which is concentrated by evaporation, at first in leaden pans and then in glass retorts or platinum stills.

This acid is a heavy corrosive liquid, colorless when pure, but usually brownish from charred organic matter. It blackens wood and cloth and almost every form of organic matter is utterly destroyed by this powerful acid, even when much diluted. If a few lumps of sugar be dissolved in a little water and mixed with sulphuric acid, a violent action takes place and a black mass of semi-solid substance results. Some varieties of shoeblackening are made by the action of sulphuric acid on molasses or treacle. Sulphuric acid has a strong affinity for water; if exposed to the air in an open dish it soon absorbs water from the air so as to greatly increase its bulk. It is frequently used in the laboratory for drying substances without heat.

A high degree of heat is developed by the action of sulphuric acid on water, when the two are mixed, which leads one to suspect chemical action. The diluted acid has a smaller bulk than that occupied by the acid and water before mixing. The corrosive action of this acid seems largely due to its power of absorbing water from the objects with which it comes in contact.

Sulphuric acid acts on all the metals except gold and platinum, and has a more powerful attraction for bases than any other acid, displacing all other acids from their salts. Some bases form two salts with sulphuric acid, as $\text{H}_2\text{SO}_4 + \text{KOH} = \text{KHSO}_4 + \text{H}_2\text{O}$, acid potassium sulphate, and $\text{H}_2\text{SO}_4 + 2\text{KOH} = \text{K}_2\text{SO}_4 + 2\text{H}_2\text{O}$ neutral potassium sulphate, while in the case of nitric acid only one salt seems possible, as $\text{HNO}_3 + \text{KOH} = \text{KNO}_3 + \text{H}_2\text{O}$. An acid as sulphuric, which has the power to form two salts with one metal, is called dibasic, while others that can form but one are called monobasic.

Sulphuric acid is one of the most important substances used in manufacturing. It is used in making sodium carbonate, citric, tartaric, acetic and nitric acids, sodium and magnesium sulphates, and various paints. It is used in calico printing, in dyeing, in gold and silver refining, in purifying oil and tallow. It is used in medicine and is invaluable about the chemical laboratory.

Hyposulphite of soda is a salt used extensively in photog-

raphy. There are other hyposulphites, but no hyposulphurous acids have ever been isolated.

When sulphur vapor is passed over red-hot charcoal the sulphur combines with carbon, forming carbon sulphide, formula CS_2 . It is a volatile liquid of high refractive powers. It has never been frozen and is used in making thermometers. It dissolves crystalline sulphur, phosphorus, India rubber, fatty matters, and is one of the most injurious impurities of illuminating gas.

When hydrogen passes over heated sulphur the two elements combine forming hydrogen sulphide, a colorless gas of disgusting odor, whose formula is H_2S . It occurs in some natural waters, and is formed in the decomposition of some organic substances, as the albumen of eggs. It is soluble in water, and is usually prepared by treating sulphide of iron with diluted sulphuric acid. The chemical equation is $\text{FeS} + \text{H}_2\text{SO}_4 = \text{FeO} + \text{H}_2\text{S}$. This gas acts promptly on nearly all the metals forming sulphides. Nearly every sulphide has a characteristic color, so that this gas is an important reagent in chemical analysis. This gas becomes a liquid under a pressure of 255 pounds, and a solid at -122°F .

PHOSPHORUS combined with calcium exists in the older rocks and the soils formed from them. Its compounds are abundant in plants, especially in the seeds of the cereals which furnish such a large portion of the food-supply of men and domestic animals. Its compounds are abundant in all parts of the animal body, especially in the bones, three-fifths of whose weight consists of calcium phosphates. Formerly bones were the chief source of phosphorus, but extensive deposits of phosphatic rocks have been discovered in Florida and other localities, from which phosphorus and its compounds may be obtained. These deposits are among the later rocks, and probably derive their phosphorus from decomposing animal matters, so that our supply of phosphorus comes from the older rocks through the medium of plants and animals.

In the preparation of phosphorus the animal matter is dissolved out of the bones by hot water at a high pressure, and

used in the manufacture of glue. The mineral matter of the bone is then subjected to distillation, from which results ammonia and bone charcoal. The charcoal is used by the sugar refineries until its decolorizing power has been exhausted, when it is strongly heated, burning away the carbon, leaving the bone-ash, consisting largely of calcium phosphate. This bone-ash is heated with diluted sulphuric acid, which forms with the lime a nearly insoluble calcium sulphate, leaving *phosphoric oxide*, P_2O_5 , in solution. This solution strained and evaporated to the consistency of sirup is mixed with charcoal and strongly heated, when the oxygen unites with the carbon, and the phosphorus rising as vapor is condensed in water.

Phosphorus is a soft, yellowish, semi-transparent, waxy solid, which exposed to the sunlight soon becomes darkened. It is extremely inflammable, taking fire in the air by the heat arising from the slightest friction. It is kept under water to protect it from oxygen, and it should be kept and handled under water, as the heat of the hand will cause it to burn. It not only burns in oxygen and the air, but burns in chlorine, bromine, or iodine. When exposed to the air it undergoes slow oxidation, giving off a white vapor of a garlic odor. In the dark phosphorus gives out light; hence its name, meaning bearer of light.

If phosphorus is heated without access of air a second variety called red phosphorus is formed. Ordinary phosphorus is soluble in the bisulphide of carbon, is poisonous and easily inflammable. The red phosphorus is insoluble, not poisonous, not easily inflammable. The allotropic forms of phosphorus are as well marked as those of sulphur and carbon, and are as yet unexplained.

The principal use of phosphorus is the manufacture of matches. Matches were invented early in the present century, but the phosphorus friction match was first produced on a commercial scale about 1832. A match consists of a splint of wood, one end of which has been dipped in melted sulphur or wax, or paraffine, and this substance covered with the "match composition," which is generally composed of chlorate of potash, phosphorus, red lead and glue. The match depends for its action

on the easy ignition of phosphorus by friction, when mixed with oxidizing agents, like chlorate of potash, the glue only serving to bind the other parts together and attach them to the wood. The phosphorus ignited by friction sets fire to the sulphur or paraffine, which in turn ignites the wood. Several different "match compounds" are made. When chlorate of potash is used there is a slight explosion when the match is lighted. When potassium nitrate is used a silent match is made. This form is most common in Germany, while the other is more common in this country and in England.

A single match is a little thing, but the manufacture of matches for the use of mankind is one of the great industries of the world. More than 2,000 tons of phosphorus are used annually with corresponding amounts of the other ingredients, and thousands of acres of forests are necessary to supply the splints used every year. It is estimated that forty thousand millions of matches are used annually in the United States alone. Matches made with red phosphorus, called safety matches, are sometimes manufactured, but for some reason they are not in general use. A match is made in France, using red phosphorus, which is ignited by breaking the match and rubbing the ends together. In Mexico matches, as generally made, are little wax tapers, tipped at both ends with the "match compound."

Phosphorus forms several compounds with oxygen and hydrogen. When phosphorus burns in air or oxygen, the dense white fumes formed are phosphoric oxide. This oxide combines with water forming two acids as $P_2O_5 + H_2O = H_3PO_4$ *metaphosphoric acid* and $P_2O_5 + 3H_2O = 2H_3PO_4$ *orthophosphoric acid* commonly called phosphoric acid. It is the most important of the compounds of phosphorus. It is tribasic, forming three salts with the same metal, but the most common and important salt is calcium phosphate, the chief mineral constituent of the bones, and the form in which phosphorus usually occurs in nature.

Phosphorus (P) is an indispensable ingredient in the food of animals and plants. No other mineral substances can bear com-

parison with it as a measure of the capability of a country to support life. Hence substances containing phosphate of lime are of great value as fertilizers. The phosphate being practically insoluble, is not easily distributed through the soil. But by treating the phosphate with sulphuric acid it is transformed into a soluble lime salt called superphosphate, which is easily distributed to the soil by water. It is said that in England alone more than 500,000 tons of phosphate materials are used annually in the manufacture of artificial manures. Phosphorus forms a compound with hydrogen called *phosphine*, formula PH_3 . It is somewhat analogous to ammonia. It has no economic value, and is characterized as having the most villainous odor known.

ARSENIC (As) is often classed with the metals because of its metallic luster, but it forms no base with oxygen, and in many respects is similar to phosphorus. It is sometimes found pure in nature and sometimes as an oxide, but more commonly in combination with various metals, as the arsenides of nickel, cobalt and iron. The principal source of arsenic and its compounds is arsenical pyrites, formula, FeAsS . Arsenic is also obtained as a by-product in working ores of tin, nickel and cobalt.

When arsenic is heated in the air it burns with a bluish flame, giving off fumes which have the odor of garlic, and are very poisonous. These fumes condense into a white solid called arsenic trioxide, formula As_2O_3 . It is the arsenic of the shops. It is used in glass-making, in the manufacture of coloring matters; with water it forms a weak acid which forms salts, called arsenites. An arsenical soap made of arsenite of potash, soap and camphor is sometimes used by naturalists to preserve the skins of birds and animals. Arsenite of copper, called Scheele's green, is much used in coloring wall papers, feathers, muslin, etc.

In quantities less than poisonous doses arsenic trioxide has peculiar effects on the animal body; it seems to favor the deposition of fat; grooms use it to improve the appearance of their horses, and in some parts of Europe men and women take it for the same purpose. A solution of arsenite of potash is much used in medicine as Fowler's solutions. Arsenic pentoxide, formula

As_2O_5 , combined with water, forms arsenic acid, which forms arseniates. Arsenic acid by its action upon aniline forms the beautiful dye called magenta. It is also much used in calico printing. There are three sulphides of arsenic. Realgar, or red orpiment, formula As_2S_2 , is a beautiful mineral crystallizing in orange red prisms. It is an important ingredient in compositions used for fire-works and signal lights. Yellow orpiment, As_2S_3 , is found native as yellow prismatic crystals. A fine yellow paint is made from this substance. The other sulphide is not of special interest.

Arsine is a compound of arsenic and hydrogen, formula, AsH_3 , analogous to ammonia and phosphine. It is a colorless, poisonous gas, having an unpleasant odor. Arrange an apparatus as in preparing hydrogen, adding a little arsenic. Arrange a delivery tube so that the gas formed may be burned. When the gas is burning freely bring into the flame a piece of porcelain, and a dark spot is formed by the condensed arsenic called a mirror of arsenic. When carefully performed this is a very delicate test for the presence of arsenic, and is extensively used in examining the contents of the stomach of persons in cases of suspected poisoning. It is known as Marsh's test. Arsenic and its compounds are notable for their poisonous properties, and for their bright and beautiful colors.

CHAPTER XVIII.

POTASSIUM, SODIUM AND LITHIUM.

WE have discussed briefly the non-metal or acid-forming elements that seem of most importance, considering some of their compounds, and we have developed and illustrated some of the principles of chemical action. This work has, however, been somewhat fragmentary and incomplete, because at every step it was necessary to refer to and employ the aid of metallic or base-forming elements, and of salts, that great class of compounds resulting from the combinations of both acid and base-forming elements. In the study of the more important metals, we must at every step invoke the aid of the non-metallic elements in explaining the varied actions and other chemical phenomena that occur. The work will consist, then, in taking new steps in reviewing and completing many steps already taken, and in the practical application of chemical ideas and principles to the ordinary affairs of life.

Potassium and sodium are typical representatives of the alkaline metals, and from the number of times they have been mentioned while studying the non-metals we may form some idea of their importance in all lines of chemical phenomena.

POTASSIUM (K), best known in its hydroxide called potash, is a silver-white metal, lighter than water and so soft that it can be cut and molded like wax. When thrown upon water it unites rapidly with the oxygen, generating heat enough to ignite the hydrogen set free and to vaporize some of the metal, which, burning with the hydrogen, gives the flame the beautiful violet color characteristic of potassium. The oxide formed is dissolved in the water, giving it a soapy feel which is a common property of alkaline solutions.

Potassium compounds are components of many of the older

rocks, and these, broken down and pulverized, yield up a portion of their potassium to growing vegetation. When vegetable structures are burned, the potassium forms a portion of the ash in the form of a *carbonate*, formula K_2CO_3 . When the wood ashes are leached with water the potassium carbonate is dissolved out and the solution evaporated yields an impure salt, called potash, which is much used in the manufacture of soft soap and of glass. It is also a valuable fertilizer. The hydroxide or caustic potash is obtained from the solution of potassium carbonate by treating it with slaked lime. The chemical equation is $K_2CO_3 + CaO \cdot H_2O = CaCO_3 + 2KOH$, calcium hydroxide, calcium carbonate + 2KOH, the *potassium hydroxide*. This compound is a brittle, white solid, having a strong affinity for water, so that it rapidly deliquesces in the air. It is the most powerful alkali in use, and its activity as a chemical agent makes it of great value to the chemist. It is used in medicine as a caustic. It replaces the hydrogen of acids forming salts, as the carbonates, nitrates and sulphates. It decomposes animal and vegetable substances, whether living or dead. Potassium bicarbonate, formula $HKCO_3$, is a salt much used in medicine for making effervescent solutions by adding citric or tartaric acids.

Another very common and important salt of this metal is *potassium nitrate* niter, or saltpeter, formula KNO_3 . It is a natural product of some parts of India and is produced in an artificial way, by heaping up organic matter with lime, ashes and soil, keeping the mass well moistened with urine for two or three years. In the mass nitrates are slowly formed and may be leached out with water and purified for use. The potassium nitrate may also be prepared from the sodium nitrate by treating it with potassium chloride, according to the following equation: $NaNO_3 + KCl = KNO_3 + NaCl$, sodium nitrate, potassium chloride, potassium nitrate, sodium chloride, all in solution together. In evaporating this solution the sodium chloride, being less soluble in boiling water, crystallizes out, leaving the niter still in solution. When the solution is allowed to cool the niter crystallizes out, as it is less soluble in cold water, leaving some chlorides

still in solution. In refining the niter it is dissolved in boiling water, filtered, then allowed to cool and crystallize while kept in constant motion, so that the salt may be deposited in smaller crystals than if allowed to crystallize from a quiet liquid. The crystals are thoroughly washed, then dried for use.

These operations illustrate some curious and interesting properties of the substances spoken of, and how these properties have been studied out and made use of in preparing the substances for use, and in most cases they were discovered and utilized by non-scientific men, under pressure of business competition long before they were even partially explained by a scientific man.

Potassium nitrate is a crystalline salt that readily dissolves in water, having a cooling saline taste, and strong antiseptic powers, so that it is often used in preserving meats. Potassium forms an interesting compound with chlorine, called potassium chloride, formula KCl , which occurs in great masses in the salt mines in Saxony, and is an important source of potassium and its compounds. It resembles rock salt in appearance. Another important salt of potassium is potassium chlorate, formula $KClO_3$. It is prepared by passing chlorine gas through a solution of potassium carbonate. As this salt gives up its oxygen freely to other bodies, it is called an oxidizing agent.

Pulverize carefully a small piece of potassium chlorate and mix with it an equal bulk of sugar; put the mixture on a brick in the open air, then let a drop of sulphuric acid fall on it and a vivid combustion will follow. Care should be taken both in pulverizing and mixing not to use percussion or heavy pressure, and small quantities should be used at least until one is familiar with the explosive powers of this salt. Cream of tartar, much used in cooking, is potassium tartrate, mainly obtained from fermenting grape juice.

Potassium as a metal is of no economic value, but some of its compounds are among the most important known. The use of the carbonate as an alkali in making soap, the use of the chlorate as an oxidizing agent in the manufacture of matches, and the use of the nitrate as an oxidizing agent in the manufac-

ture of gunpowder, puts potassium in the front rank of useful metals.

Gunpowder is an intimate mixture of potassium nitrate, sulphur and powdered charcoal. The nitrate furnishes oxygen in great abundance, charcoal, carbon in available form, and the sulphur ignites at a low temperature, altogether tending to rapid and intense combustion. The nitrate for the manufacture of gunpowder should be free from the chlorides of potassium and sodium, should be free from coloring matter and should show neither acid nor alkaline reaction. The charcoal for gunpowder is best made of some light wood, as alder or willow, as charcoal from these woods is lighter and more easily combustible. The wood is burned in a retort at a temperature of about $1,000^{\circ}$ F. which yields a charcoal of the most desirable density. The charcoal is allowed to cool slowly, and is then exposed to the air for several days, so that it may absorb moisture; for if ground before it is liable to spontaneous combustion. It is then ground and sifted to free it from dust. Distilled sulphur is used, as it is soluble and free from sulphurous and sulphuric vapors. The proportions of these ingredients varies among manufacturers. English government powder contains 75 per cent. of saltpeter, 15 per cent. charcoal and 10 per cent. sulphur. These substances are first thoroughly mixed, and the mixture, in charges of about 50 pounds each, is subjected to the action of the incorporating mill, which is something like the dry pan used in preparing clay for brick making, consisting of heavy iron rollers with scrapers and plows so as to keep the mass well mixed while it is being pressed by the rollers. This process continues about three hours for slow-burning cannon powder, and about five hours for rifle powder. The mass is sprinkled with water during the time, so that at the close of the process the grayish mass of mill cake contains from 2 to 3 per cent. of water. The mill cake is broken up and packed in layers about half an inch thick between copper plates and subjected to great pressure under the hydraulic press. This not only makes the powder compact, but it seems to have less capacity for absorbing moisture. But this mass will not

burn rapidly enough. It must be broken up into grains, which are separated by sieves, so that the grains of the same size go together. These grains are polished by friction among themselves in revolving barrels, sifted from dust, dried and sifted again, when the powder is ready for packing. For cannon powder the grains are sometimes a half inch in diameter, and sometimes they are made in molds, so that the form is definite.

Good powder should be composed of hard angular grains which do not soil the fingers, and when fired on a sheet of paper should burn without sparks and without scorching the paper or soiling it to any great degree. The products of the combustion of powder are chiefly potassium carbonates and sulphates, with carbon dioxide, carbonic oxide, hydrogen and marsh gas. The solid powder changing into these gases, which are expanded by the great heat of the combustion, accounts for the mechanical effects of the explosion.

It is estimated that the temperature resulting from the explosion of powder as ordinarily used is over 5,000° F., at which temperature some of the gases might be separated into their elements, which would increase the expansive force. It has been estimated that the explosion of a cubic inch of good gunpowder would exert a pressure of about fifteen tons to the square inch if it could all be burned on the instant. It is at present impossible to fully explain the phenomena of the combustion of powder, as the products and conditions at the time of explosion must be different from what they are afterward when the products may be collected and studied. Gunpowder is of very great value. Some have considered its influence on civilization as next in importance to the discovery of the printing press and application of steam to machinery. Besides its use in war it is of immense value in all mining and quarrying industries and in many engineering operations, although other explosives are supplanting it in some directions. Gunpowder is superior to most other explosives in the uniformity of its action, in that its manufacture and transportation are less dangerous, in that it is not liable to change when stored, and for use in gunnery its slower action

exerts less strain on the gun. The early history of powder is obscure. Our first knowledge of its use as a military agent dates from the seventh century, while its first use as a propelling agent was in Spain in the 12th century. It was known and used in England early in the 14th century.

Potassium and its compounds have been derived from the rocks through the medium of plants, but *sodium* and its compounds are derived from seawater, which derived them from the older rocks by solution. While land plants gather up potassium compounds along with some sodium compounds from the soils, water takes up sodium compounds, with some potassium compounds, and carries them down to the sea. These sodium compounds are taken up to some extent by seaweeds, and we can obtain sodium compounds from sea plants as we obtain potassium compounds from land plants; but it is more profitable to take them directly from the seawater, or from beds of rock salt which are supposed to have been deposited from seawater.

Rock salt is sometimes mined as other rock is mined; sometimes water is let into the mine, then pumped out after it has dissolved its load of salt. Again in connection with these salt beds natural brines are abundant, which flow out as springs or may be pumped out for use. In some places seawater is pumped into shallow ponds or lakes and allowed to evaporate in the sun until it becomes strong enough to pay for artificial evaporation. In Russia, sometimes a portion of the pure water is allowed to freeze out of the brine. Seawater, rock salt, and natural brines, besides the sodium chloride, contain also magnesium and potassium chlorides, and sulphates of magnesia and lime. But as the water is evaporated, most of the sodium chloride crystallizes out, leaving the other substances in solution with iodine, bromine, etc. From the sodium chloride, chlorine, hydrochloric acid and the metal sodium with its various compounds are derived. Sodium chloride, common salt, formula NaCl , is too well known to need any description. Its usefulness in preserving meat, and as an article of food for man and beast make it almost essential to

the existence of animal life. It is also used in glazing pottery ware.

Previous to the war of the French Revolution most of the carbonate of soda came from Spain. As the supply became scanty and the prices high, Napoleon offered a premium for the discovery of a process by which the carbonate could be made in France. The chemist LeBlanc discovered the process now in use for the manufacture of sodium carbonate from sodium chloride, a case in which science took the lead in an economic process. By this process sodium chloride is mixed with an equal weight of sulphuric acid and strongly heated, which results in the formation of the sodium sulphate, called salt cake and hydrochloric acid, as follows: $2\text{NaCl} + \text{H}_2\text{SO}_4 = \text{Na}_2\text{SO}_4 + 2\text{HCl}$. Arrangements are usually made so that the acid passing off as a gas is absorbed by water. The sodium sulphate is then mixed with about an equal weight of limestone and about half its weight of fine coal, and strongly heated, when the carbon takes up the oxygen of the sulphate which reduces it to sodium sulphide, Na_2S , and this acted upon by the carbonic acid liberated from the limestone, forms sodium carbonate Na_2CO_3 and sulphide of calcium CaS , according to the following equations: $\text{Na}_2\text{SO}_4 + 4\text{C} = \text{Na}_2\text{S} + 4\text{CO}$, and $\text{Na}_2\text{S} + \text{CaCO}_3 \text{ limestone} = \text{Na}_2\text{CO}_3 + \text{CaS}$. The sodium carbonate is dissolved from the mass and crystallized from the evaporating solution. Sodium bicarbonate HNaCO_3 is the saleratus or soda used in bread making, etc.

The metal SODIUM (Na) is prepared from the carbonate by heating it with coal when the carbon takes the carbon dioxide from the sodium forming carbonic oxide, and the sodium passing over as vapor is condensed under oil or naphtha. Equation, $\text{Na}_2\text{CO}_3 + 2\text{C} = 2\text{Na} + 3\text{CO}$. This metal is similar to potassium, but does not decompose water as vigorously, and burns with a yellow flame. It is used for the extraction of the metals aluminum, magnesium, gold and silver from their ores.

Sodium hydroxide, formula NaOH , is prepared by treating sodium carbonate with calcium hydroxide, equation $\text{Na}_2\text{CO}_3 + \text{CaO} + \text{H}_2\text{O} = \text{CaCO}_3 + 2\text{NaOH}$. It is a white solid somewhat similar to

caustic potash in appearance and quality. It is usually obtained as a by-product in the manufacture of sodium carbonate. It is used in the manufacture of hard soap. Sodium sulphate, Na_2SO_4 , is a salt called Glauber's salt. It is produced as a by-product in the manufacture of hydrochloric acid.

Nitrate of soda, or Chili saltpeter, is imported from Peru. It is used as a fertilizer and in the manufacture of potassium nitrate. Fifteen parts of clean sand fused with eight parts of carbonate of soda form a *silicate of soda*, which is soluble in hot water, forming a strongly alkaline solution called *soluble glass*. It is sometimes used to lessen the inflammability of wood, and sometimes as a matrix in forming some kinds of artificial stone.

Ammonia, NH_3 , and the hypothetical metal ammonium, NH_4 , have been mentioned; but several salts of ammonium are interesting, and may be considered here as they are somewhat similar to corresponding compounds of sodium and potassium. Ammonium chloride is sometimes found in nature, but is usually prepared from the ammoniacal liquors of gas works. These liquors are treated with hydrochloric acid, the solution evaporated and the residue heated, when the ammonium chloride vaporizes without melting, and is condensed on cold surfaces in a crystalline form. It has a sharp salty taste, and is freely soluble in water, lowering the temperature considerably, so that it is frequently used in making freezing mixtures. From it ammonia and carbonate of ammonia are prepared, and it is used in dyeing, in soldering copper and brass, and in galvanizing iron.

Ammonium sulphide $(\text{NH}_4)_2\text{S}$, is prepared by passing hydrogen sulphide through aqua ammonia, $2\text{NH}_3 + \text{H}_2\text{S} = (\text{NH}_4)_2\text{S}$. This compound is a colorless liquid of unpleasant odor, which soon becomes yellowish from partial decomposition. It is a very useful agent in the laboratory.

Bicarbonate of ammonia $\text{H}(\text{NH}_4)\text{CO}_3$, called "smelling salts," is frequently used in medicine, and it is also used by bakers and confectioners. Ammonium sulphate, $(\text{NH}_4)_2\text{SO}_4$, is used in the manufacture of artificial manures and ammonium alum.

LITHIUM, the lightest metal known, occurs in small quantities in some kinds of mica and other minerals ; is found in the waters of many springs; in tobacco, milk, blood, seawater, etc. It is somewhat similar to potassium and sodium in its properties. It gives a bright carmine color to flame. Lithia water is much used in medicine. Potassium, sodium and lithium are alike in the powerful alkalinity of their oxides and in the solubility of their salts, and in that they give bright colors to flames, sodium yellow, potassium violet or lilac, and lithium red.

CHAPTER XIX.

CALCIUM, BARIUM, STRONTIUM, MAGNESIUM AND ZINC.

CALCIUM (Ca) is a very abundant element, as calcium carbonate it forms the limestones, the marbles and the chalk of the earth. Calc spar, the marbles and many limestones are crystalline forms of this mineral. It occurs in bones, corals and the shells of mollusks are nearly pure calcium carbonate.

Calcium oxide called lime or quick lime is formed by heating the carbonate which drives off the carbon dioxide, leaving the oxide as a white infusible solid, formula CaO . The oxide, combines vigorously with water, forming the calcium hydroxide CaO_2H_2 . In this process a high degree of heat is evolved, often enough to ignite wood, the oxide swelling up and crumbling to a white powder, called slacked lime, which is somewhat soluble in water forming what is called lime water. If exposed to the air the oxide taking water from the air slowly changes to the hydroxide. The hydroxide is the most important of the bases, and is used in almost every art or manufacture which involves chemical changes. It is used in making mortar, glass and soap.

Calcium sulphate ($\text{CaSO}_4 + \text{H}_2\text{O}$) occurs in nature as the transparent selenite and the opaque gypsum, which is often beautifully colored, sometimes it is pure white when it is called alabaster. When heated to a temperature of 350° to 400° F. the water of the gypsum is driven off and it becomes, what is called, plaster of Paris. When this powder is mixed with water a combination takes place forming a solid nearly as compact and strong as the original gypsum. In the act of setting the plaster expands slightly which makes it especially valuable for taking casts of objects. It is much used in the reproduction of statues and other sculptural forms. The walls and ornamentation of the Columbian Fair buildings were made of light wood covered with

plaster of Paris, and at a little distance they have the appearance of stone. Stucco is plaster of Paris sometimes colored, and some cements are made by mixing alum with the plaster. Its property of quickly assuming a solid condition makes it an interesting and very valuable substance. It is interesting to note that plaster of Paris cannot be used a second time, indicating that it is not the same as the gypsum.

Calcium chloride (CaCl_2) is a crystalline substance which has a strong affinity for water and is much used as a drying agent in chemical work. The bleaching powder, called chloride of lime, is an impure hypochlorite of lime which depends for its action on the chlorine it contains.

MORTAR is a compound of one part of freshly slacked lime and two or three parts of clean sand mixed with water enough to form a stiff paste. When this mixture is exposed to the air the water evaporates, carbon dioxide from the air combines with the calcium oxide forming the calcium carbonate. In this way the mortar becomes very hard so that however massive the structure the mortar can bear its share of the load.

COMMON GLASS is a silicate of calcium and sodium made by melting together sand (silica) and the carbonates of sodium and calcium. Bohemian glass, used in the manufacture of chemical apparatus is a silicate of calcium and potassium. It is not as easily fusible as common glass. Plate glass contains some potassium silicate in addition to the silicate of calcium and sodium. Flint glass is a silicate of potassium and lead. It has a high refractive power, is easily fusible and easily cut. It is much used for optical instruments, and ornamental glassware. Glass of various colors is produced by melting with it certain metallic oxides, as the oxide of iron gives a green color, the suboxide of copper a red color, the oxide of cobalt a blue, etc.

BARIUM (Ba), a yellowish malleable metal, is of little value but some of its compounds are interesting. Barium sulphate, called heavy spar, occurs abundantly as an associate of lead ores in the mineral regions of Missouri. It is a white, heavy mineral sometimes used to adulterate white lead paint, and for

glazing cards, etc. Barium chloride, BaCl_2 , is much used in laboratory work as a test for the presence of sulphuric acid. Barium compounds give a yellowish green flame.

STRONTIUM is less abundant than barium and is of little interest. It occurs in nature chiefly as the mineral celestine which is the strontium nitrate. This salt gives a bright red color to flames, and is often used in the preparation of fire works.

MAGNESIUM (Mg) is a silver white metal. It burns at a low temperature with a brilliant white light, which may be used to illuminate objects for photographing. It is widely distributed in nature as an ingredient of dolomite or magnesian limestone, soapstone, asbestos, horeblend and talc. Most of these minerals have a soapy feel. Magnesium sulphate $\text{MgSO}_4 + 7\text{H}_2\text{O}$ is the epsom salts of the shops, and the oxide is the common magnesia. When dolomite is burned it becomes what is called water lime, which makes a mortar that will harden under water.

ZINC (Zn) is a bluish white metal of a crystalline structure, light, easily fusible, but not easily corroded by atmospheric influences. The strength of iron and durability of zinc are combined in the so-called galvanized iron, which is made by dipping well cleaned iron in melted zinc, much as tin plate is made. Zinc is an ingredient of brass and German silver.

Zinc oxide is used in painting as zinc white, and zinc sulphate ($\text{ZnSO}_4 + 7\text{H}_2\text{O}$) is used in calico printing and to some extent in medicine as white vitriol. Zinc is easily attacked by acids, and the chemical action of acids on zinc is the most common source of the galvanic current. Zinc precipitates lead, copper and silver from solutions. A very interesting experiment is to place a strip of zinc in a solution of acetate of lead. The lead quickly begins to collect on the zinc forming what is called the lead tree. Zinc occurs in nature most abundantly as the carbonate and as the sulphide, which is the black jack of the lead miner.

CHAPTER XX.

COPPER, MERCURY, SILVER AND ALUMINIUM.

COPPER (Cu) is a reddish, malleable, ductile metal found abundantly in nature as native copper, and as an ore combined with sulphur and iron. Copper is used for coins in all parts of the world, and is an ingredient of most of the gold and silver coins, giving them additional hardness. Brass is an alloy of copper, tin and zinc; bell metal and gun metal are alloys of copper and tin, and aluminium bronze consists of 90 parts copper and 10 parts of aluminium. Hard solder contains equal parts of copper and zinc. Copper is extensively used as a protection for wooden ships; copper wire of different sizes is the substance generally used in transmitting electricity for power and lighting purposes. As copper is found pure, or nearly so, in nature, it was one of the earliest metals worked by man. The early inhabitants of America made cutting tools and ornaments of copper.

In Europe and the east brass or bronze was extensively used for many purposes before the discovery of methods for working iron. While iron has supplanted copper in many places, it still remains one of the most useful and valuable of the metals. Copper sulphate ($\text{CuSO}_4 + 5\text{H}_2\text{O}$), blue vitriol, is largely used by the dyer and calico printer, and in the manufacture of pigments. It is also used in electrotyping, in galvanic batteries, and in medicine. When heated the crystals lose their water of crystallization, crumbling down to a whitish powder, which again becomes blue when allowed to combine with water.

Copper is precipitated from the solutions of its salts by the metals zinc and iron and by the galvanic current. If a strip of zinc is placed in a solution of copper sulphate it will soon become covered with a layer of copper, the zinc displacing the copper in the sulphate as follows: $\text{Zn} + \text{CuSO}_4 = \text{ZnSO}_4$ in solution + Cu as a

coating on the zinc. A knife blade placed in the solution is quickly covered with copper. Objects are plated with copper by placing them in a solution of copper sulphate and connecting them with a galvanic current, when the sulphate is decomposed and the copper deposited on the article. There are oxides, sulphides, chlorides, carbonates and arsenites of copper, but perhaps the most interesting are the blue and green malachites, carbonates of copper which are highly prized for their beauty.

The metals generally are solids, but *mercury* is a liquid at ordinary temperatures, having none of the properties usually ascribed to metals except its brilliant luster and high specific gravity. The pure mercury is sometimes found in nature, but it more commonly occurs as a sulphide in the mineral cinnabar.

MERCURY (Hg) is obtained from cinnabar by the heat, which burns out the sulphur, vaporizing the mercury, which is condensed in brick chambers or flues. It forms alloys, called amalgams, with most of the other metals, especially with gold and silver. This property makes mercury a valuable agent in separating gold and silver from their ores.

Mercury is used in making thermometers and barometers, but its chief use is in silvering mirrors. The silvering of a mirror consists of an amalgam of tin. A sheet of tin foil is laid on a table and rubbed over with mercury, and then another thin layer of mercury is poured over it. The glass is then carefully slid over the foil so as to push off some of the superfluous mercury, together with impurities; then heavy weights are laid on the glass to squeeze out any excess of mercury, and in a short time the amalgam adheres firmly to the glass.

The mercurous chloride is the calomel used in medicine, and the mercuric chloride is the active poison, corrosive sublimate. An oxide of mercury is an ingredient of red precipitate ointment, and the pigment vermilion is the sulphide. The vapor of mercury, and nearly all its compounds, are poisonous, and all those who work with mercury in any of its forms suffer from its effects.

SILVER (Ag) is a white, malleable, ductile metal which is not easily tarnished or corroded. Pure silver is often found in na-

ture, but it occurs most abundantly as the silver sulphide, combined with lead sulphide and other substances. It also occurs as the chloride and bromide. The process of obtaining silver from its ores is somewhat complicated and costly. In a general way it is accomplished by heat aided by chlorine from common salt, and by the dissolving power of mercury or lead, or both.

Silver is used for coin, for plate and for ornaments. Pure silver is so soft that it is usually hardened by the addition of from 7 per cent. to 10 per cent. of copper, so that coins and silverware are in fact alloys of silver and copper. It is extensively used in plating ware made of cheaper metals or alloys. The chloride of silver, formula, AgCl , is one of the richest ores of silver, and is the form into which silver is usually converted in extracting it from ores. The chloride, bromide and oxide of silver are insoluble in water and change color on exposure to the light. There are many other compounds of silver of which silver nitrate, AgNO_3 , called lunar caustic, is the most important. It is used in surgery, and as it blackens on exposure to light is made the basis of indellible inks. Silver may be precipitated from solutions by zinc, copper, mercury and other metals.

The chemical changes which silver salts undergo on exposure to light is the basis of the art of photography. To get a photograph on glass pour over the glass a mixture of collodion and potassium iodide, which forms a thin film over the glass, which is then placed in a bath of silver nitrate, here a layer of silver iodide is formed in the film. The plate is then exposed in the camera to the action of light from some object to be photographed. When removed from the camera no image is perceptible, but on treating the film with a "developer" as a solution of gallic acid in alcohol and acetic acid, the illuminated portions appear black while the shaded portions retain the yellowish color of the iodide. When the details come out clearly, the developer is washed off and the film treated with a solution of sodium hyposulphite, which dissolves out the iodide that has not been affected by the light, then the hyposulphite is washed away and the plate dried and varnished to protect the film.

After oxygen and silicon the most abundant element is the metal ALUMINIUM (Al). It is a tin-white, malleable, ductile, sonorous metal. It is lighter than most other metals and yet it is very strong, approaching iron in this respect. It is never found pure in nature, but is an abundant ingredient in many minerals. The double silicate of aluminium and potassium AlKSi_3O_8 a constituent of feldspar, is abundant in trap rock, basalt, mica, and porphyry. Aluminium silicate is the chief ingredient of clay, shale and slate. Aluminium oxide, Al_2O_3 , called alumina is nearly pure in the ruby, sapphire and emery. This metal is an ingredient of several double sulphates called alums, as $\text{AlK}(\text{SO}_4)_2 + 12\text{H}_2\text{O}$ potassium alum, $\text{AlNa}(\text{SO}_4)_2 + 12\text{H}_2\text{O}$ sodium alum, $\text{AlNH}_4(\text{SO}_4)_2 + 12\text{H}_2\text{O}$ ammonium alum.

Aluminium hydrate (AlO_3H_3) combines readily with many organic coloring matters, forming insoluble compounds. To a solution of common alum add a solution of cochineal, and to the mixture add a little ammonia when a colored precipitate of aluminium hydrate and cochineal will be formed, which is called *carmin lake*. Similar precipitates may be formed with other organic coloring matters. Fiber of cotton that has been soaked in a solution of alum will retain colors which the cotton alone cannot hold. Soak a piece of cotton cloth in alum water and let it dry a day or two, then treat it and a piece of ordinary cotton with a solution of logwood and observe the difference in the amount and permanence of the color taken by the two pieces. Substances having this property are called *mordants*.

Clay, aluminium silicate, is the material of which all grades of porcelain and pottery ware and all kinds of brick, tile and terra cotta are made. Clay mixed with water may be moulded in any required shape and after drying may be burned so as to become firm and durable, but pure clay shrinks so much in burning that articles made of it lose their shape and often crack, so that in making bricks, pottery, etc., more or less sand is added to the clay making a mixture which shrinks less and holds its form better than pure clay.

Bricks are made of a great variety of material and vary in

quality from the heavy compact vitrified brick that will absorb not more than two or three per cent. of water to the light porous, fragile brick that will absorb half of its weight of water. Bricks are made by hand as they were in Egypt four thousand years ago, and they are made by different kinds of machinery.

Pottery ware that is designed to hold water must be glazed, which is done by dipping the ware in a mixture of fine sand and water and heating it intensely, in a kiln into which a quantity of wet salt has been thrown. The water, sand and sodium of the salt from a sodium silicate glass, which fuses on the surface of the ware, making it impervious to water.

In the manufacture of porcelain great care is used in the selection and preparation of the material, definite proportions are used and all the manipulations approach mathematical exactness. One very fine ware is made as follows: The purest materials are selected in the following proportions: Kaolin, $\text{Al}_4(\text{SiO}_4)_3 + 4\text{H}_2\text{O}$, 62 parts, chalk, CaCO_3 , 4 parts, sand SiO_2 , 17 parts and feldspar AlKSi_3O_8 , 17 parts. These materials are ground up with water and allowed to settle. The water is drained away and the mass well kneaded, then stored away in a damp place for some months, during which time any organic matter is oxidized and the texture of the mass seems to be improved. It is then moulded, dried in the air, and strongly heated in a kiln with a wood fire. After burning, the ware must be glazed, care being used to get a glaze that will expand and contract with the ware so that it will not crack or craze. The glaze employed at Sevres is a mixture of finely ground feldspar and quartz. When the ware is dipped in this mixture some of it is absorbed, a thin coating remaining on the surface. It is now baked the second time when the glaze fuses, forming a glass varnish, which covers the surface penetrating the ware to some extent. If the ware is to have a uniform color, some mineral pigment is mixed with the glaze. If designs are to be painted, glasses colored with metallic oxides ground up with the oil of turpentine are used. After painting, the ware is again burned so that the paint is fused upon the glaze.

CHAPTER XXI.

IRON, NICKEL, COBALT, GOLD AND PLATINUM.

IRON (Fe) is the most useful, the most widely diffused, and next to aluminium, the most abundant of the metals. Meteoric iron is nearly pure, but native iron is seldom found. Minerals in great numbers contain iron; in fact there are few substances, liquid or solid, that do not contain more or less of this element. The most important ores of iron are the oxides and carbonates, as the magnetic oxide, hematite, or sesquioxide, which constitute the great bodies of ore found in the old rocks of New York, Canada, Michigan and Missouri. Clay-ironstone, abundant in the coal measures, is the carbonate of iron, FeCO_3 , mixed with clay. It is the chief ore of England.

Iron is reduced from its ores by the action of heat and fluxes in a blast furnace. The steps in the process are to expel the water, sulphur, carbonic acid, etc., by heat reducing the ores to oxides. Next reducing the oxides to the metallic state by heating them with carbon, and third, the separation of the earthy impurities by fusion with limestone or clay into a glass or slag, and lastly the carbonizing and melting of the iron. The blast furnace is charged at the top with coal, ore and flux in alternate layers. The air for the support of the combustion is forced in by a powerful blast. The melted iron sinks to the bottom and is drawn off into molds, forming the pig iron of commerce. The lighter slag is also drawn off from time to time. The resulting gases are collected and used in raising the temperature of the air of the blast. This iron contains from two to five per cent. of carbon, is hard, crystalline and easily fusible, being generally contaminated with silicon, sulphur and phosphorus.

This pig iron is subjected to heat in the puddling furnace, which oxidizes most of the impurities, finally reducing it to a

pasty mass, when it is carried to a squeezer which drives out the slag, welding the iron into a compact body called wrought iron. Wrought iron may be obtained from some of the purer ores by heating them with charcoal in an open forge. It is such ores that are worked by the natives of Africa and Southern Asia.

The pig iron or cast iron is capable of bearing great pressure, and is useful in the manufacture of articles which are not subjected to heavy tension. Wrought iron is tough, and when heated slightly may be drawn into wire or rolled into bars or plates, and is extensively used, especially where toughness is a quality desired. Steel, in composition, is intermediate between cast iron and wrought iron. They are each compounds of iron and carbon, the wrought iron containing very little carbon, one or two parts in a thousand only, while steel contains from three to ten parts and cast iron from fifteen to twenty-five parts. In neither case does there seem to be a definite chemical combination.

Steel is made by heating wrought iron bars with charcoal to a temperature of about $2,000^{\circ}$ for several days, during which time carbon penetrates the iron and the fibrous structure changes to a fine granular form. This process is called cementation. These bars broken up, heated and hammered become more uniform in texture, more tenacious and ductile, forming what is often called shear steel. Steel from the cementation furnace is melted in crucibles and molded, forming cast steel, which is more dense, uniform and hard than the shear steel.

Cast iron is converted into steel by melting it in a large vessel called a converter, and then oxidizing the mass by currents of air forced through it. When the oxidation is nearly complete cast iron enough is added to furnish carbon for converting the whole mass to steel, when it is cast into ingots. This is called the Bessemer process. Steel becomes very hard and brittle when heated and suddenly cooled, but when allowed to cool slowly it can be given almost any degree of hardness, with some degree of elasticity. Pure iron is almost unknown, and of no value in the arts. With all the care exercised in working iron and steel it is almost impossible to secure uniform product.

Ferrous sulphate ($\text{FeSO}_4 + 7\text{H}_2\text{O}$) is commonly known as green vitriol or copperas. It is manufactured from iron pyrites, so common in the coal measures. It is used in the manufacture of ink and black dyes. There are ferrous and ferric oxides and chlorides, sulphates, nitrates and silicates, and many other interesting compounds of iron, but they are of little value in the arts and need not be discussed.

Iron oxides, hydrates and other compounds yield a large variety of colors, and these compounds are so abundant everywhere that iron has been called the pigment of nature.

There are ferrous and ferric cyanides of iron. Common Prussian blue seems to be a mixture of these cyanides, formula ($\text{Fe}_7\text{C}_{18}\text{N}_{18}$). It is largely used in dyeing and calico printing. Potassium ferrocyanide is a mordant of great value.

NICKEL (Ni) is a metal sometimes found in meteoric iron, and is found associated with cobalt arsenic and sulphur. It is chiefly valuable from its property of imparting a white color to alloys of copper and zinc, as German silver and the five-cent coins. The salts of nickel form green solutions.

COBALT (Co) is a metal somewhat similar to iron, but is not abundant enough to be of great value, but some of its compounds are important on account of their brilliant and permanent colors. The salts of the oxides have a fine red color in the hydrated state, while they are blue in the anhydrous. Cobalt blue is the more common color. Chloride of cobalt is used as a sympathetic ink. It has a slight pink color when cold and turns blue when heated.

MANGANESE (Mn) is a hard, grayish-white metal resembling iron in some of its physical and chemical qualities, and is often associated with iron in nature. The principal ore of Manganese is the dioxide, MnO_2 . The compounds of Manganese give up their oxygen readily; the use of the dioxide in preparing oxygen has been noted. One of the most interesting and valuable compounds of Manganese is potassium per manganate, KMnO_4 ; it is soluble in water, forming a dark purple solution. It gives up its oxygen easily, losing its color, and is much used in purifying

water, as well as in disinfecting or deodorizing decaying animal and vegetable substances.

CHROMIUM (Cr) is found in nature chiefly as chrome iron ore, $\text{Fe}_2\text{Cr}_2\text{O}_4$. When this ore is heated with potassium carbonate and potassium nitrate, potassium chromate is formed. And this salt treated with nitric acid yields potassium dichromate, $\text{K}_2\text{Cr}_2\text{O}_7$, the most important form of chromium. It occurs as beautiful red tabular crystals, which dissolve in about ten parts of water. It is sometimes used in electrical batteries, and is a good oxidizing agent. Lead chromate is the chrome yellow used in painting and calico printing.

BISMUTH (Bi) is a grayish brittle metal of crystalline form. It is used in some alloys as type metal, giving them the property of expanding slightly in the mold so that they are forced into the finest lines. Two parts of bismuth, one of lead and one of tin forms an alloy which melts below the temperature of boiling water. The nitrate of bismuth is used in medicine.

LEAD (Pb) is a soft grayish metal which is useful in many ways. Its most common form in nature is the sulphide which occurs in connection with sulphides of copper, iron, zinc and silver, with quartz, barium sulphate, calcium fluoide and sometimes with bismuth and antimony. Sulphide of lead or galena crystallizes in cubes, having a bright metallic luster. Lead is obtained from galena by heating it with iron, when the latter combines with the sulphur and the lead is set free. Or the sulphide is roasted in the air until some of it is converted into lead oxide and the lead sulphate, then heated without the access of air when the lead and sulphur are set free as represented in the following equations: $\text{PbS} + 2\text{PbO} = 3\text{Pb} + \text{SO}_2$ and $\text{PbS} + \text{PbSO}_4 = 2\text{Pb} + 2\text{SO}_4$.

Lead is malleable, and in the form of sheets is used to line tanks, cover roofs, make pipes, etc. Lead oxide, PbO is *litharge* which heated in the air becomes red lead, Pb_3O_4 . The red lead is used in storage batteries, where it takes up oxygen becoming lead peroxide PbO_2 . The red oxide is used as a paint, and in the manufacture of glass and matches and as a glaze for pottery.

One part of litharge, and ten parts of brick dust with enough linseed oil to form a paste makes a cement often used by builders in repairing broken stone. Acetate of lead, or sugar of lead, is formed by dissolving litharge in vinegar. Lead carbonate, PbCO_3 is the well-known and much-used white lead.

Lead resists the action of most acids, but when exposed to the air the surface is soon covered by the lead oxide, which with a little moisture becomes lead hydrate, which, combined with carbon dioxide of the air, becomes lead carbonate. The salts of lead are in general poisonous, and lead in all forms should be used with care. Nearly all natural waters act on lead, forming dangerous compounds. Lead is a constituent of several alloys, as type metal, and solder; bird shot are an alloy of arsenic and lead, and some bullets are an alloy of lead and antimony, the alloys being harder than lead.

TIN (Sn) is a soft, malleable white metal, having something of the appearance of silver. The principal ore of tin is the stannic oxide, SnO_2 , from which the metal is obtained by heating it with coal. Tin does not tarnish in the air at ordinary temperatures, and is largely used as a coating for other metals, as copper and iron. It is also an ingredient of several alloys, as bronze, solder, pewter and type metal. The stannic oxide, when melted with caustic soda, forms the sodium stannate, Na_2SnO_3 . This substance is largely used as a mordant by calico printers. Stannous and stannic chlorides are also used in calico printing. Stannic sulphide, SnS_2 , is known as mosaic gold, or bronze powder.

GOLD (Au) is a beautiful yellow metal, surpassing all others in malleability and ductility. It may be beaten into sheets so thin that 282,000 of them would make a pile only one inch high. Gold is less affected by exposure to the air than any other metal, and is used as a coating of other metals for their protection and to increase their beauty. Gold is usually found free in the veins of rocks, or in the sands resulting from the disintegration of the rocks. It is sometimes so associated with iron, sulphur and copper that it is very difficult of reduction. There are oxides and chlorides of gold, but they are of little importance. Gold is so

soft that for coin and most other purposes it is alloyed with at least 10 per cent. of copper.

PLATINUM (Pt) is a grayish-white metal, which is very malleable and ductile. It resists the action of most non-metallic substances, and is valuable to the chemist in many ways. It is used for crucibles, forceps, tubes, stills, etc. It forms alloys readily, so that it should not be used with easily fusible metals. It is much used in connection with voltaic electricity. None of the platinum compounds are of much value. It usually occurs as an alloy with palladium, iridium and other metals.

CHAPTER XXII.

ILLUMINATING GAS, ANILINE DYES AND RESINS.

ILLUMINATING gas is one of the products of the destructive distillation of coal. The coal is heated in earthenware retorts without access of air till all the volatile matters are driven off, leaving only gas carbon and coke in the retort. The volatile products passing through water and coolers loses ammoniacal liquids and tarry matters by condensation, then through beds of lime or the ferric hydrate, which removes the sulphur and carbon dioxide, and thence to the gasometer. The gas in the meter consists of marsh gas, hydrogen and carbon monoxide, with some vapor of benzole, olefiant gas and other hydrocarbons.

The ammoniacal liquids are the main source of ammonia and the ammonium salts. The coal tar contains, or is made up of many substances which are volatilized at different temperatures. The first to pass over is water with salts of ammonia in solution, then a brown, oily liquid, lighter than water, containing benzole toluole, etc., then a yellow oil heavier than water, containing naphthaline, aniline, carbolic acid, etc., and a black residue called pitch remains, which is employed in making Brunswick black and asphalt for paving. The benzole from the light oil is a colorless liquid with the odor of coal gas. The fact of its dissolving caoutchouc and gutta percha, and that it removes grease from cloth and other objects, makes it a valuable substance.

The chief purpose to which benzole is devoted is the preparation of *aniline*, which may be converted into the brilliant dyes now so extensively used. Benzole treated with nitric acid forms a dark red liquid from which water precipitates a yellow oily liquid called nitrobenzole. Benzole, $C_6H_6 + HNO_3 = C_6H_5(NO_2)$, nitrobenzole. When nitrobenzole is treated with sulphuric acid

and zinc the hydrogen set free from the acid replaces the oxygen of the nitrobenzole as follows: $C_6H_5(NO_2) + 6H = C_6H_5NH_2$ or C_6H_7N aniline, $+2H_2O$. Aniline is colorless when pure, becoming brown if exposed to the air. Aniline mixed with a little toluidine derived from toluole, and treated with chloride of lime, yields a beautiful violet dye. What share the toluidine has in the production of the color is not known, and the chemical changes are not understood, but it is known to be an oxidation. Red, blue, green, black, yellow, etc., in varying shades may be obtained from these substances by the action of various chemical agents.

Carbolic acid ($C_6H_6O_2$) makes up the greater part of commercial kreasote, which is extensively used as an antiseptic to prevent the decay of wood. Carbolic acid is much used as a disinfectant. The value of aniline dyes and other products from coal tar manufactured in Europe amounts to about \$30,000,000 annually. The recovery of the materials for aniline dyes, carbolic acid and other substances from the waste products of gas manufacture is a striking example of the utility of purely scientific work.

While aniline dyes have superseded many of those formerly used, yet a few are worthy of mention. Madder, furnishing beautiful red and purples, is derived from the root of a plant much grown in Europe. The essential ingredient of madder is alizarin, which has been prepared artificially from coal-tar products, so that the madder industry is fast passing away. Brazil wood and logwood, quercitron from oak bark, fustic and indigo are important dyes. Indigo is prepared from various species of plants by allowing them to ferment in water, and when a blue scum appears on the surface of the water a little lime is added, when the indigo is precipitated. Cochineal, a dye prepared from an insect, gives a beautiful red.

The art of coloring fabrics of various kinds has been practiced by man everywhere from the earliest times. The process varies with different colors and different fibers. To obtain the finest shades of mauve, magenta, purple and many other colors on

silk or wool fiber the whole process consists in placing the material in a solution of the desired color; it absorbs the color becoming dyed. The color enters into such intimate combination with the fiber that it cannot be washed out. There is probably no chemical action between the fiber and the coloring matter, although the union is very close and some have considered it a chemical union.

In the case of the same kind of fibers, with cochineal, logwood or madder, there would be no permanent color. In such cases another class of bodies called mordants is necessary. They in some way help to make the coloring matters adhere to the fiber. The substances commonly used as mordants are the salts of aluminum, iron, tin, chromium, copper and a few other metals. Woolen goods, after boiling in salts of tin, will take on a brilliant scarlet in a solution of cochineal. The process of dyeing calico with logwood is first to pass the calico through a hot solution of sulphate of iron, then through lime water, which decomposes the iron salts, setting free the iron oxide, which remains in the fiber; the excess of lime is then washed away, preparing the calico for the logwood. The calico, now of a buff color from the oxide, when placed in the hot solution of logwood, speedily acquires a dark hue, and in about half an hour has become dyed a dense black color. The above will give some idea of the methods employed in one of the most important industries we have, and that at every step from the preparation of the dye or mordant it is mainly a chemical process. And a very large proportion of all the chemical elements are in some way used in this industry.

Some interesting products arise from the destructive distillation of wood. Wood and coal are both of vegetable origin, but coal, having suffered partial decomposition, has lost much of its original oxygen, so that the products of wood and coal differ somewhat. The gases derived from wood are marsh gas, and the carbon oxides. Among the liquids are toluole, kreasote, acetic acid and wood spirit. Paraffin, a beautiful, semi-transparent, waxy substance, is the most important solid. It is used

extensively as a lubricating oil. It burns with luminous flame, and is used in the manufacture of candles.

Petroleum oil is a mixture of hydrocarbons of the marsh gas and olefant gas series, which makes it valuable for lubricating and lighting purposes. Bitumen, or *asphaltum*, is a hydrocarbon something like turpentine, which seems to be derived from petroleum oil. It is soluble in turpentine, and is used as a waterproof varnish and in making roadways, walks, etc.

When incisions are made in the bark and wood of the different varieties of pine, spruce and allied trees, a viscous substance flows out called pitch, gum, turpentine or balsam. It consists of resin mixed with the essential oil of the plant. When this substance is distilled with water the oil passes over and the resin remains, which is called *rosin*. Turpentine obtained from the pine yields from 75 to 90 per cent. of rosin ($C_{20}H_{30}O_2$), and from 10 to 25 per cent. of essential oil commonly called spirits of turpentine, $C_{10}H_{16}$.

Rosin burns with a smoky flame, and is used in the preparation of lampblack and varnish. The resins generally are insoluble in water, but dissolve in alcohol, naphtha and the oil of turpentine. The solutions thus obtained are called varnishes. When exposed to the air in a thin layer the solvent evaporates, leaving a layer of resin over the substance which is impervious to air and water. Gum copal, shellac, amber and the balsams are resins similar to common rosin.

The oils of bergamot, cloves, lemons, tolu, valerian and others are similar to the oil of turpentine, having about the same composition.

Camphor, obtained from the camphor laurel of Japan, is similar to the resins, having the formula $C_{10}H_{16}O$. It is a crystalline substance, melting at 175° F., burning with smoky flame, and passing into vapor at ordinary temperatures. It is almost insoluble in water, but is dissolved by alcohol and ether. The alcoholic solution is known as spirits of camphor.

Asafœtida, aloes, gamboge, myrrh and others are gum-resins which exude from plants in a milky state, gradually solidifying

on exposure to the air. They consist of a mixture of gum, resin and essential oil. They are partially soluble in alcohol, and are used in medicine.

Caoutchouc is prepared from the milky juice of several varieties of tropical plants. It is insoluble in water, but soluble in turpentine and naphtha. It is elastic, and when warmed becomes soft and pliable. It is not acted on by alkalies or dilute acids. In time it oxidizes into a resin, losing its strength and waterproof qualities. It is extensively used in the manufacture of waterproof goods, water tubes, springs, elastic fabrics, gas holders, etc. In many cases it is used in the manufacture of waterproof cloth or felt, which is prepared by dissolving the caoutchouc and spreading it over the cloth or felt, which is then passed between rollers, which causes firm union, waterproofing the cloth and strengthening the caoutchouc.

Caoutchouc placed in fused sulphur will absorb large quantities of that element, and if heated to about 300° F. it becomes vulcanized, and if heated to a higher degree it at length becomes vulcanite, which is used in the manufacture of combs, etc. Vulcanized caoutchouc is not soluble in turpentine or naphtha, and is not sticky when warmed.

Gutta percha is similar to caoutchouc in many respects, but is only slightly elastic at ordinary temperatures. It is insoluble in water and a poor conductor of electricity, so that it is much used for water pipes and as an insulator for electric wires, etc. Gutta percha is a hydrocarbon, $C_{20}H_{32}$, often mixed with resins. Caoutchouc, C_5H_8 , has the same composition with the same proportion of elements, but of different-sized molecules. Such bodies are said to be isomeric (equal parts). There are many instances of isomerism among organic compounds.

Gums, as gum arabic, gum tragacanth appear like resins, but unlike them are soluble in water, and contain oxygen, gum arabic having the formula $C_{12}H_{22}O_{11}$, and tragacanth $C_{12}H_{20}O_{10}$, differing by only one molecule of water.

Wood, free from sap, consists of cellulose ($C_6H_{10}O_5$), lignine and some mineral substances. The cellulose composes the wood cells,

and is the most abundant constituent; the lignine is the material lining the cells, and is more abundant in the harder varieties of woods. Woods differ widely in their physical properties, but are quite similar in their chemical composition. Beech, birch, oak, aspen and willow each contain about the same amount of carbon. Aspen 49.26 per cent., birch 50.29 per cent., and the others between these amounts varying less than 1 per cent. Of oxygen willow contains 39.38 per cent., beech 42.36 per cent., the others between, varying less than 4 per cent. The hydrogen, sulphur, nitrogen and ash are also nearly the same in each. Cellulose is nearly pure in cotton, linen and the best kinds of paper. If dry white paper, pure cellulose, be drawn through a cooled mixture of two parts of strong sulphuric acid and one part of water, and then thoroughly washed, it is changed into a semi-transparent substance called *vegetable parchment*; when dried it is found that there has been no alteration in weight or composition, but it is at least five times as strong as before, and is waterproof. This change is supposed to be due to change in the molecule. Cellulose treated with a mixture of nitric and sulphuric acids is converted into nitrocellulose or *gun cotton*. Gun cotton dissolved in a mixture of alcohol and ether is the *collodion* much used by photographers.

CHAPTER XXIII.

STARCH, SUGAR, ALCOHOL AND OILS.

STARCH, $C_6H_{10}O_5$, is a product prepared by growing plants, as food, for the nourishment of succeeding plants of their kind. The starch of commerce is prepared from potatoes, rice and wheat. Starch has the appearance of a white powder, but when examined under the microscope it is found to consist of grains which vary somewhat in size and appearance in different plants. The grains of potato starch are about $\frac{1}{300}$ of an inch in diameter, those of wheat about $\frac{1}{1000}$, and of rice about $\frac{1}{3000}$ of an inch.

Starch is insoluble in cold water but if heated with water to a temperature of about 140° F. the grains swell up, burst and yield the well-known paste used for stiffening linen and other fabrics. A dry heat of 140° will also cause the grains to burst, as in a roasted potato. A few drops of iodine added to a solution of starch gives a deep blue color, which disappears as the solution is heated, reappearing as it cools.

When starch is heated to a temperature of about 400° F. it is converted into a substance, called *dextrine*, which is soluble in water. Dextrine has all the properties of gum, and is used by calico printers for thickening their colors. It is also used as a mucilage, and for immovable surgical dressings. Dextrine ($C_6H_{10}O_5$), is isomeric with starch.

When starch is boiled with water containing a few per cent. of sulphuric acid it is first converted into dextrine, and then into *glucose* or grape sugar ($C_6H_{12}O_6$). These changes are usually explained by supposing that in dextrine the starch molecule has been changed in form, and in glucose has taken up one molecule of water. Cellulose may be changed to grape sugar by the same process.

SUGAR ($C_{12}H_{22}O_{11}$), occurs in the juices of several plants, as in sugar-cane, sugar-maple, and sugar-beet. In this country most

of the sugar is made from the juice of the sugar-cane, while in Europe the juice of the sugar-beet is generally used. In the manufacture of cane-sugar the canes are crushed between grooved iron rollers and the juice mixed with the milk of lime is boiled in open pans. The lime neutralizes the acids and hardens some of the impurities; the albuminous matters, hardened by heat, entangle these impurities and rise as a thick scum. The scum is removed and the clear liquid remaining is evaporated to such a consistency that on cooling it separates into two parts, one crystalline, called brown sugar, the other uncrystalline, called molasses. These products are purified, refined and converted into the various grades of sugar and sirup of commerce.

Sugar melts to a colorless liquid which on cooling forms an amber colored mass called barley sugar. When heated to about 400° F. sugar is changed to a dark brown substance called *caramel*, which is soluble in water, being used for coloring sauces, gravies, wines, brandies, etc.

The white of an egg is a typical form of an interesting and important substance called *albumen*, which is found in all animals and vegetables. It is composed of carbon, hydrogen, oxygen, nitrogen and sulphur, but the chemical formula is not fully known. It seems to be about $C_{108}H_{169}N_{27}O_{34}S$. It is found in the blood and milk and in lean meat; it is associated with starch in plants, as the *gluten* of wheat, and the *legumin* of beans. The elements which compose albuminous compounds are not firmly bound together; they break up and decompose very readily, and in many cases promote change and decomposition in other substances.

In addition to the starch, seeds and grains contain some form of albumen. When placed in warm moist air the albumen takes up oxygen forming carbon dioxide, and a substance, containing carbon hydrogen, nitrogen and oxygen, called *diastase*. Diastase has the power to set up changes by which the insoluble starch is converted into the soluble glucose, which can be used by the growing plant as food. If the seed is kept dry or cool it will remain dormant for thousands of years, but expose it to air,

warmth and moisture and at once the seed becomes a theater of activity. Substances similar to diastase occur in the saliva and other digestive fluids.

In the manufacture of ale and beer the barley is caused to germinate for a short time and then it is dried at a high temperature which stops the germination, forming what is called *malt*. The malt is ground and heated with water for some hours, during which time the diastase formed, has converted the starch into glucose and the liquid is called the *wort*. Yeast is then added to the wort, which by the process of fermentation changes some of the glucose to *alcohol*.

YEAST is a fungoid plant, made up of minute cells, which contain cellulose albuminoid matter and mineral salts. These cells multiply rapidly in solutions of sugar containing albuminoid and mineral substances, changing cane-sugar to grape-sugar, and grape-sugar into alcohol and carbon dioxide. This decomposition is called alcoholic fermentation. The changes may be represented by the following equation: cane-sugar ($C_{12}H_{22}O_{11} + H_2O = C_{12}H_{24}O_{12}$ or $2(C_6H_{12}O_6)$ grape-sugar, and grape-sugar, $C_6H_{12}O_6 = 2(C_2H_6O) \text{ alcohol, } + 2CO_2$.

ALCOHOL is the important ingredient in all fermented and distilled liquors, and is obtained from fermented liquors by distillation. Alcohol dissolves resins, oils and other vegetable substances, and is much used in preparing medicines and varnishes. It is used as a fuel and as a preservative fluid, preventing from decay animal or vegetable substances immersed in it. Wood spirit, or methyl alcohol, is often used in place of ordinary alcohol.

When a mixture of strong sulphuric acid and alcohol is heated in a retort there distills over with water a highly volatile inflammable liquid called ether. When ether is inhaled for a few moments it produces insensibility, and is extensively used in surgical operations.

When a fermented liquor is exposed to the air it gradually becomes sour; the alcohol taking up oxygen is converted into acetic acid as follows: $C_2H_6O + O_2 = C_2H_4O_2$, acetic acid $+ H_2O$. The chief source of this acid is the destructive distillation of

wood. Vinegar is a dilute acetic acid which is prepared in various ways. It is made from alcohol treated with yeast. It is made from wine or cider by adding a ferment called the mother of vinegar, and is prepared from dilute solutions of sugar. Acetate of lead, or sugar of lead, is used in medicine, and aluminum acetate is used in dyeing.

The process of fermentation is intimately related to bread-making. Flour is composed of starch, an albuminoid substance called gluten, with some mineral substances. The flour is mixed up into a dough with water, yeast and salt, and allowed to stand for some hours at a temperature of between 70° and 75° F., during which time some of the starch has been broken up by fermentation into alcohol and carbon dioxide, which causes the dough to swell up and become porous. The bread is then baked at a temperature of about 500° F. The dioxide expanded somewhat by the heat increases the lightness of the bread, finally escaping with the alcohol and some of the water. The internal portions of the bread do not rise above the temperature of boiling water, but the outside becomes much hotter and is hardened into a crust, and some of the sugar is converted into a caramel-like substance which gives the crust a sweetish taste. Sometimes the fermentation is caused by leaven, being dough in which fermentation has already commenced, and sometimes the gas for making the bread light is formed from soda bicarbonate and hydrochloric acid.

The various fats and oils, whether of vegetable or animal origin, are mixtures of three well-defined bodies, stearin and palmatin solids and olein, a liquid. Tallow is mainly stearin, olive oil mainly olein, lard a mixture of olein and palmatin. They are composed of carbon, hydrogen and oxygen of a complicated formula, but are in effect salts of *glyceryl*. When stearin is boiled with milk of lime, calcium stearate and *glycerin* are formed, and when olein is boiled with litharge (PbO) lead oleate and glycerin are formed. Glycerin ($\text{C}_3\text{H}_8\text{O}_3$) is a sweet, colorless, sirupy liquid which dissolves in water or alcohol, but not in ether. It is used in medicine and as a preservative fluid.

When glycerin is poured slowly into a mixture of sulphuric and nitric acids a yellowish oil, called *nitroglycerin*, is formed. It is insoluble in water, but very explosive. For use it is mixed with some inert matter, as finely divided silica, when it is known as dynamite.

One of the oldest industries involving chemical principles is soap-making from natural fats and oils. Hard soap is made as follows: A solution of carbonate of soda is boiled with lime, forming an insoluble calcium carbonate and a soluble sodium hydrate, called soda lye. Tallow is then boiled with a weak lye, and as the process continues, stronger lyes are added until all of the tallow has disappeared. In order to separate the soap from the solution, a quantity of salt is thrown into the liquid, when the soap rises to the surface, and is transferred to molds. As tallow contains both stearin and olein the soap formed consists of a mixture of sodium stearate and oleate, while glycerin remains in solution. When a lye of potassium hydrate is used, soft soap is formed. A great variety of soaps are made, but in every case the essentials of the process are the same. Soaps contain from 30 to 80 per cent. of water, which evaporates slowly, so that in general soap that has been well dried is more economical than that which is freshly made.

Tallow is extensively used in the manufacture of stearine candles. For this purpose the tallow is first converted into lime soap, which is decomposed by sulphuric acid, causing the fatty matters to separate from the other parts of the solution. They are then strongly compressed to squeeze out the olein, leaving the solid elements for manufacture into candles.

Palm oil, cocoanut oil, olive oil, castor oil are common and useful oils. Linseed oil has a tendency to become solid when exposed to the air, and is called a drying oil. This tendency is increased by heating the oil with litharge or the binoxide of manganese, when it is called boiled linseed oil. This oil is extensively used by painters everywhere.

Several interesting acids of vegetable origin are used extensively in the arts. Of these, perhaps the most interesting is

oxalic acid occurring in sorrel, rhubarb and other plants. It is prepared by mixing sawdust into a paste with a strong solution of the potassium and sodium hydrates, and heating the mixture on iron plates. The wood fiber is converted into oxalic acid, which combines with the potassium and sodium forming oxalates, from which the pure acid is obtained. Oxalic acid is very poisonous; the best antidote is chalk or magnesia. It is much used in calico printing, in cleansing articles of brass and copper, in removing stains of iron rust or ink and as a solvent of Prussian blue in the manufacture of blue ink.

Wine during fermentation deposits on the inside of the cask a crust called *argol*. It is a hydrogen potassium tartrate, and when purified it is called *cream of tartar*. From argol, or cream of tartar, tartaric acid ($C_4H_6O_6$) is prepared by the aid of lime and sulphuric acid. It occurs in many fruits besides the grape and is extensively used in dyeing and calico printing. It is also used in medicine, as Rochelle salts and tartar emetic.

The acid of lemons, oranges and some other acidulous fruits, called citric acid, is used in the preparation of acidulated drinks. It is also used in medicine and in dyeing operations.

In the bark of the oak, pine, hemlock and other trees, in the roots of many plants, in tea, coffee, and many other vegetables is found an astringent substance called *tannin* or *tannic acid*. Tannic acid may be extracted from its various sources by water, and is chiefly valuable from the fact that it forms a black precipitate with the salts of the peroxide of iron, and that it forms a tough insoluble compound with gelatine, a form of albumen, and with gelatinous membranes. The first characteristic makes it useful in the manufacture of inks, and the second in the preparation of all kinds of leather.

In the process of tanning the skins are first soaked for three or four weeks in strong lime water which removes the fat and loosens the hair. They are then washed and treated with very dilute sulphuric acid which removes any remaining lime and opens the pores of the skin fitting it better for the action of the tanning solution. They are then soaked in tannic acid solution

for five or six weeks, then packed with alternate layers of coarsely ground oak or hemlock bark and covered with water for six or eight months, changing them occasionally so that all shall be treated by a uniform strength of the tannic acid. By this time the hide or skin has increased in weight from 30 to 40 per cent., has acquired a uniform brown color and is chemically leather, ready for various mechanical operations which give it the desired texture and finish. Special processes are used in preparing kidskins, buckskins, etc. Tannic acid is used in medicine.

Morphine obtained from opium, quinine derived from Peruvian bark, both used extensively in medicine, are vegetable alkaloids. Strychnine from *nux vomica*, and nicotine from tobacco, two of the most active poisons, are alkaloids, as are theine and caffeine, the active elements of tea and coffee.

A list of the more important elements, with the symbol and combining or atomic weight of each.

NON-METALLIC ELEMENTS.

Name.	Symbol.	Weight.	Name.	Symbol.	Weight.
Oxygen	O	15.96	Carbon	C	12.00
Hydrogen.....	H	1.00	Silicon	Si	28.00
Nitrogen	N	14.00	Boron	B	11.00
Chlorine.....	Cl	35.36	Sulphur	S	31.98
Bromine.....	Br	79.75	Phosphorus.....	P	30.96
Iodine	I	126.53	Arsenic	As	74.90
Fluorine.....	F	19.10			

METALLIC ELEMENTS.

Potassium (Kalium)....K	39.04	Mercury (Hydrargyrum) Hg	199.80
Sodium (Natrium).....Na	23.00	Iron (Ferrum).....Fe	55.90
LithiumLi	7.01	Nickel.....Ni	58.60
CalciumCa	39.90	CobaltCo	58.60
BariumBa	136.80	Manganese.....Mn	54.80
Strontium.....Sr	87.20	Chromium.....Cr	52.40
Aluminium.....Al	27.30	Bismuth.....Bi	207.50
Magnesium.....Mg	23.94	Lead (Plumbum).....Pb	206.40
ZincZn	64.90	Tin (Stannum).....Sn	117.80
Silver (Argentum)....Ag	107.66	Gold (Aurum).....Au	196.20
Copper (Cuprum).....Cu	63.30	Platinum.....Pt	196.70

CHAPTER XXIV.

BOTANY—GENERAL AND STRUCTURAL.

THE science of Botany includes everything relating to the vegetable kingdom. It considers the external forms of plants, their anatomical structure, however minute, their classification, geographic distribution, and economic value. It treats of the varied relations of plants among themselves, and of their relations to minerals on the one side, and to animals on the other. It attempts to examine plants in their earliest form, as single cells, and to follow them through all their stages of development until they reach maturity; in short, endeavors to learn the life history of plants.

Many plants are minute in size, and much of the structure of all plants is microscopic, so that there is considerable botanical work which can be done only in well equipped laboratories, with microscopes, re-agents, and mechanical appliances beyond the reach of most individuals; but wide and interesting fields, the greater part of botany, lie easily within the range of the unaided vision. A good pocket magnifying glass will, however, be found useful in the study of plants, animals or minerals.

Plants are composed of carbon, hydrogen, oxygen, nitrogen, sulphur, iron and potassium as essential elements, necessary to their life and growth, and sometimes they contain phosphorus, calcium, sodium, silicon, magnesium or chlorine, as elements of secondary importance in the vegetable structure. While the plant is made up of the elements mentioned, it cannot feed on them as elements, they must be united into compounds as water, carbon dioxide, ammonium nitrate, calcium phosphate, etc., before the plant can utilize them for food. Oxygen seems to be the only exception to this rule, being an elemental plant food.

The living portion of the plant, that which moves, appropri-

ates food and grows, is a transparent, semi-fluid, albuminous substance, called protoplasm. It is the protoplasm that takes up these mineral compounds and transforms them into the structures and compounds of the vegetable kingdom. It is impossible to distinguish the protoplasm of plants from that of animals. We cannot say that they are the same for the precise nature of living matter cannot be determined, but we know that the "physical basis of life" has in all cases some common characteristics of structure and behavior, diverse as are the ways in which its activity may be manifested.

Corn, beans, wheat or other grains growing by themselves or in pots with other plants, are interesting objects for observation and comparison, whether in the home or schoolroom. If the tip of the root of a grain of corn or the bean be divided lengthwise with a sharp knife, then moistened with a solution of iodine, it will assume a yellowish or brownish color indicating the presence of protoplasm. If the tip of the root is dipped in a solution of sugar and then moistened with a dilute sulphuric acid, a reddish color will show the presence of protoplasm.

Sometimes in the lower order of plants, as in slime-moulds, the protoplasm is without form, but in general it occurs in somewhat definite forms of minute size called cells, which are enclosed by a wall of cellulose, secreted by the protoplasm. The protoplasm contains carbon, oxygen, hydrogen, nitrogen, sulphur, and possibly iron; and in addition the cellulose contains potassium and possibly lime, so that the cell contains the essential elements of the plant. The cell is the unit of all vegetable structures from the simplest to the most complex. In some cases it performs all the functions of a plant; it takes food, grows, reproduces its kind, and dies.

Free cells are in general somewhat spherical in form, but when grouped in masses they are more or less angular from pressure upon each other, so that they may be cubical, tabular or many-sided. It frequently happens that cells grow more in some directions than in others, and thus elongated cells are formed which are sometimes cylindrical and sometimes angular. The walls of

cells are often thickened in various ways, forming wood cells, spiral or banded cells, etc.

New cells are formed by the division of old cells, each division soon growing to the size and form of the original, as in the growth of some of the lower forms of plant life, and in the tips of growing roots. And new cells are also formed by the union of the contents of two cells, as in the reproduction processes of some of the lower plants.

Besides the protoplasm within the cell wall there is often a delicate green coloring matter called chlorophyll, which may be dissolved out with alcohol. The chlorophyll gives the green color to the leaves, stems and other parts of growing plants. Another product of plant cells is starch, as in the potato, wheat, corn and other grains. In addition to other substances many cells contain solutions of various forms of sugar, as cane sugar, grape sugar, beet-root sugar, etc.; and the cells of some plants secrete oils, as olive, castor, linseed and palm oil, the oils of turpentine, lemon and thyme. Others secrete such substances as camphor, essence of cinnamon, wintergreen, etc., and as the essential oils of onions, mustard, asafoetida, etc. Others again secrete gums, as gum tragacanth, gum arabic, and many others. Several important acids are the product of vegetable cells, as tartaric, citric and tannic acids. In addition to those mentioned, opium, quinine, and other valuable medical substances, and many valuable dyes are the products of cell action.

The embryos of all plants begin as single cells, and some of the lower plants during their whole existence consist only of single cells. In some cases cells at first distinct become united more or less closely into a common mass, each cell to a great extent remaining a distinct individual. Sometimes the partitions between contiguous cells are dissolved away, and the two cells are merged into one. In this way long tubes or vessels are formed. But in the great majority of plants the cells are combined into *tissues*. They may be joined end to end, forming threads, filaments or hairs, or they may be joined end-wise and sidewise, forming cell surfaces, or they may be joined

in three directions forming masses of greater or less size and solidity.

At the tips of young stems and roots there are groups of active cells which, multiplying by division and growing rapidly, form what is called the vegetative cone of the root or stem. This mass of cells is sometimes called the *primary meristem*, the secondary meristem being a layer of cells between the bark and wood of plants called the *cambium layer*. From the meristem tissue all the other tissues of the higher plants are developed.

The next most important tissue is called *parenchyma*. It is composed of cells whose walls are thin, nearly colorless and transparent, and which vary greatly in form. This tissue makes up the whole substance of many plants of the lower order, and the essential portions of the green or assimilative, growing and reproductive parts of the higher plants. Another tissue, perhaps developed from parenchyma by thickening the walls of the cells along their angles, is called *collenchyma*, or thick angled tissue. It is found beneath the epidermis of many plants, for the purpose, doubtless, of giving support and strength to it. Another, in which the cell walls are somewhat uniformly thickened, is called *sclerenchyma*. It occurs in the mosses, ferns and higher plants.

The most abundant and important tissue after parenchyma is the *fibrous tissue*. It is composed of long thick-walled cells, which constitute the tough, flexible part of the bark, called bast, and the hard woody parts of the stems of plants and the framework of leaves. In some plants, as the milkweeds, there are numerous vessels, containing a milky or colored fluid, which form what is called the *lactiferous* or milk tissue. Another group of vessels having numerous openings in their thin walls constitute what is called the *sieve tissue*, which is abundant in the grape vine, in ferns and other plants. Besides those mentioned, there are in the higher orders of plants elongated cells whose thickened walls are perforated at places where similar vessels touch each other. They are called spiral, pitted or banded vessels, etc., and together make up the *tracheary tissue*. While young these cells

contain protoplasm, but as they become older it disappears and the tissue only contains air.

These various tissues are grouped into three systems: the epidermal, the fibro-vascular, and the fundamental. Neither of these systems occur in the lowest plants. The epidermal system is the most simple, and appears earlier in the life of the individual, and earlier in passing from lower to higher forms than the other systems. The first indications of this system is in smaller, darker colored surface cells in some of the lower fungi and their allies, while in some of the mosses a distinct epidermis occurs, becoming well developed in the ferns and flowering plants. The epidermis proper consists of modified parenchyma, the cells changing form, thickening and hardening their walls and finally losing their protoplasm.

From these epidermal cells hairs are produced, especially on young roots, which vary somewhat in form and are active agents in absorbing nutritive matters for the plant. And in the epidermis there are numerous *stomata* or breathing pores, which open directly into intercellular spaces below. They are more numerous on the under surface of leaves; on the lower surface of a black walnut leaf there are nearly 300,000 stomata in one square inch of surface, with none on the upper side; while in the case of a leaf of corn or maize, there are about 60,000 to the square inch on the upper surface and about 100,000 on the lower surface. In the case of the iris leaf and oat leaf there are more on the upper surface.

In most of the higher orders of plants the fibrous, sieve and tracheary tissues, with some parenchyma, form bundles of compact tissue running through the plant from roots to leaves. They are called the *fibro-vascular* or *vascular* bundles. The young radish is crisp and brittle—the vascular bundles are not noticeable; but later, as they are more fully developed, the radish becomes stringy and woody. They constitute the framework of leaves and may be separated from the more delicate tissues by maceration, and they are easily found as threads in the pith of the cornstalk. The components of the bundles vary in their pro-

portions in different plants; but in every case they serve to strengthen the plant structure and as a means for conducting liquids from roots to leaves.

The fundamental system includes all the tissues not found in the other systems, being made up mainly of parenchyma, thick angled tissue, milk tissue, etc.

An examination of a green stem of Indian corn will give one a good idea of the vascular bundles and the parenchyma surrounding them. An examination of the leaf stalk of the squash shows whitish bands extending from end to end just beneath the epidermis. They are masses of thick angled tissue, which may be torn out, when the stalk becomes weak and flexible. The large pores seen in cross sections of oak, ash and other woods are pitted vessels.

Plants are made up of the various tissues and systems mentioned. The lower plants consist mainly of parenchyma, while all three systems unite to form the bodies of the higher plants. Such plants are made up of *stem*, *leaves* and *roots*.

The typical stem is illustrated in the trunk of a tree or the body of an upright plant, bearing branches and leaves and supported by roots; but it also appears in many other forms: First, as *runners*, which are slender and weak, creeping along the ground and bearing stunted leaves or bracts, as in the case of strawberries. Second, *rootstocks*, scale-bearing underground stems, as in the case of ferns. Third, *tubers*, scale-bearing, thickened and subterranean, as the potato. Fourth, the *cormb*, a thick, solid body with thin leaves, subterranean, as the Indian turnip. Fifth, *bulbs*, small bodies covered by the thickened bases of leaves, as the onion. Sixth, *tendrils*, slender branches usually destitute of leaves. Seventh, *thorns*, short, thick, pointed branches without leaves.

The leaves are broad, flat expansions of chlorophyll-bearing tissue, supported by a framework of fibrous tissue. They may be reduced to *bracts*, or *scales*, which have but little chlorophyll, or, modified in form and color, they make up the different parts of the flower, as the *sepals*, *petals*, *stamens*, *pistils*, and sometimes

they become *tendrils*, *spines*, and in some cases cups. Besides these there are numerous outgrowths of the epidermal system, known as *bristles*, *prickles*, *scales*, *glands*, *root hairs*, etc., which are called *trichomes*.

The roots which fix the plants in the ground, or on some support, and absorb nutriment for the plant, show little variation in form. The roots of parasites are usually short and thick, and sometimes provided with sucker-like organs. And the aerial roots of orchids, and similar plants, often have a thickened epidermis containing more or less chlorophyll.

All parts of a growing plant are abundantly supplied with water; it makes up about 75 per cent. of the weight of plants. Water is constantly being taken up by the roots, and as constantly being evaporated from the leaves. It has in solution, materials from the soil and soluble products of plant action. The tissues are constantly taking materials from this liquid for their growth, and the various secretions, as oils, gums, acids, etc., are formed from materials taken from the same source. The cause of the movement of water or sap in plants is not fully understood.

In the chlorophyll parts of plants during the daylight water and carbon dioxide are broken up into materials for starch, cellulose and other hydrocarbons, and oxygen is set free. This process is called *assimilation*. These materials are then changed to sugar, cellulose, protoplasm, etc., by a process called *metastasis*, or *metabolism*. This process is not understood, but it seems to go on more rapidly at night, and to be attended with the evolution of carbon dioxide, while assimilation is attended by the evolution of oxygen.

In many plants starch or other material is stored up for the future use of the plant in modified stems, as potatoes, onions, etc.; in seeds, as in the various grains, and in buds. In most cases this material is used as a supply of food for the growth of young branches or the young plant. Some plants are *parasites*, taking materials already assimilated from other plants. Again, they are partially parasitic, where some food is assimilated in the

plant. Many plants are *saprophytes* or partly so, deriving their food wholly or partly from decaying matters.

The processes of assimilation and metabolism can only be carried on within certain degrees of temperature; the limits vary with different plants. In many plants these changes progress at temperatures very little above freezing point, and in some plants they are carried on freely at a temperature of from 110° to 120° F. Many of the subjects mentioned in this chapter will be more fully discussed and illustrated in subsequent chapters.

CHAPTER XXV.

BACTERIA, ALGÆ, FUNGI, AND LICHENS.

AMONG living things two processes must be maintained; first, the nutritive, on which the life and vigor of the individual plant or animal depends; second, the reproductive, on which the life of the race, the perpetuation of the species, depends. The differences in structure among plants, and the modifications of structure by which the plant adapts itself to its surroundings, are important items to consider in the study of plants. The structure of plants and the processes of nutrition and reproduction comprise nearly all the work of botany.

There are a great many kinds of plants, and it would be an endless task to try and study each one; but many plants are similar to other plants in structure, in methods of reproduction, etc., so that a careful study of one plant gives a good idea of many similar plants. Plants are divided into species, genera, families, orders, divisions, etc. On the basis of structure we have *cellular* plants, made up wholly of parenchyma, and *vascular* plants in which the vascular bundles are prominent features of the structure. These groups are separated into *divisions* mainly on the basis of differences in the reproductive processes.

The division including the lowest plants is called PROTOPHYTA, first plants. These are the lowest and simplest plants, usually of minute size; the cells are poorly developed, and often there is no cell wall. In many cases the plants consist of only one cell, and when there is an aggregation of cells, the union is usually so slight that each cell is practically an individual.

If we add a few drops of yeast to a solution of sugar and keep it in a warm place, the mixture will soon become turbid and then frothy, will lose its sweetness and acquire a spirituous odor, and at length a scum of yeast will collect on the surface of the liquid.

If some of this scum be spread out on a piece of glass and examined with a pocket magnifier, fine grains may be seen scattered through the mass. These grains, called *torulæ*, are the active part of the yeast. They are living bodies, as shown by the rapidity with which they grow and multiply. Each torula is a cell which gives rise to minute buds, which grow rapidly and finally become detached from the parent cell, though generally not till they have themselves developed other buds. When yeast is dried and burned it gives rise to an odor similar to that which arises from burning meat. Dried yeast forms a fine powder which diffuses itself rapidly through the air, so that a solution of sugar open to the air, if kept warm, will soon begin to ferment from yeast particles received from the air.

Infuse or steep some hay in warm water for an hour or so, then filter it and set the filtrate in a warm place, and from time to time notice the changes which take place in it. At first the solution is clear, after 24 or 36 hours it becomes turbid, as did the yeast solution, and at length a scum forms on the surface and the solution acquires a putrid odor. These changes are due to the growth and multiplication of *Bacteria*. All forms of putrefaction are due to fermentation set up by bacteria of different kinds. A living thing dies, other things still living attack the dead body and speedily convert it into gases and liquids which may be used for food by the same or other forms of life.

Bacteria may be developed in almost any vegetable infusion. They are minute; they cannot be studied in detail without powerful instruments, but it is interesting to note the work of these minute but numerous beings, which in some sense are the substratum of life. When dry the bacteria forms a dust of minute grains which is diffused through the air everywhere, furnishing the material for fermentation wherever the air can go freely. They have size and form, for they may be filtered out of the air.

Take three test tubes and fill each about one-third full of freshly made hay infusion; cause the solutions in two of the tubes to boil for a few minutes, then while it is boiling cork one of the tubes with a mass of cotton wool and let it boil for a min-

ute or so after closing; put the three tubes in a warm place and note the results. Bacteria are developed promptly in the un-boiled solution, and also appear in the boiled solution of the unclosed tube, but not as promptly as in the first, while none appear in the other if the experiment was well performed. Experiments show that every form of bacteria may be filtered out of the air by a mass of cotton wool and in other ways; that they may be filtered out of water by such material as porous pottery-ware, and that if a body of air remains at rest for a few days these germs of bacterial life will settle out of it so that it is as pure as if filtered.

It is by excluding the germs of bacteria that vegetable and animal substances are preserved from decay by the process of canning. The discovery of bacteria and the recognition of their importance in the economy of nature has been of great value to man. It has promoted a more rational treatment of disease, and has greatly extended the domain of surgery.

Another interesting one-celled plant, sometimes called a green slime, is found as a green coating on the north side of old fences or trees, especially after a few days of wet weather. Pieces of wood or bark bearing this plant may be kept dry for a long time, becoming fresh when moistened. Notice the color, and with the pocket lens notice that it appears as if dusted over the surface. Scrape off some of the slime and put it in a little alcohol, and after an hour or so notice the color of the alcohol. The green color of the plant and the color it imparts to the alcohol is due to the delicate coloring matter called chlorophyll, which, in general, is formed only in the sunshine. Potato stems growing in the sunlight are bright green, but are nearly white when growing in the dark. This slime is called *Protococcus*. It multiplies rapidly, not by the process of budding, as did the torula, but by division, one cell dividing into two and these dividing again, etc.

A dark blue-green scum is very common on stagnant water about watering troughs, along street gutters and other places. It can be kept for observation in water in an open dish. If a small portion of this scum be allowed to remain for a few hours

in a saucer with a little water it will spread out in good shape for study. Then notice the form and color of the hairlike filaments and possibly careful observation will allow one to see the slow vibratory movements which give this plant the name of *Oscillaria*. The filaments are composed of cells attached end to end in colonies, but each is an individual as fully as the cells of protococcus.

These minute plants all live in water or in damp shady places, yet all retain their vitality for a long time when dried so as to form an impalpable dust. While these plants are minute in size and simple in structure they constitute an important branch of the vegetable kingdom.

On the surface of stagnant water and in quiet water along the edges of streams, in the early spring, little patches of a frothy substance appears, sometimes called frog spittle, later the surface is covered with a bright green scum, and during June and July great patches of a dirty brownish scum is present with the green. When lifted from the water it has a slippery feel, and strings out like wet hair. The plant is some species of *Spirogyra* or *Zygnema*. It may be grown for observation in an open dish of water, with some soil at the bottom, in which some water loving plant is growing.

The long hairlike filaments are colonies of cells attached end to end as in oscillaria. The cells in spirogyra are marked by spiral bands of chlorophyll, while in zygnema there is a central starlike nucleus, with the chlorophyll in bands or plates. They multiply by division as do protococcus and oscillaria, but in addition there is another form of reproduction. At the close of their growth in the spring, the cells push out little processes from their sides, which meet similar processes from other cells of parallel filaments. They flatten upon each other, the walls fuse and are absorbed, leaving a connecting channel between the two cells, through which the protoplasm of both cells become one mass. This mass secretes a wall of cellulose forming a *zygospore* or germ, which has much thicker walls than the ordinary cell, and from which a colony of cells or plants may be developed.

These bodies sink to the bottom of the water, when released by the decay of the old cells, resting there till the next season. With the warmth of spring, the zygospore becomes active, little bubbles of gas are formed, which float it to the surface of the water, the central portion lengthens, partitions are developed forming cells, which multiplying by division extend into a hairlike filament. Some idea of the cell markings and of the fruiting stage can be gained by examination with the naked eye or with the simple magnifier, but these plants are interesting if we can do no more than observe the different stages of growth, the changes in color, the rapid increase in bulk, their complete disappearance at the end of the growing season and other phenomena visible to the naked eye.

Another interesting plant colony common in ponds and sluggish streams is the *Water net*. It is a tubular net composed of elongated cells which, when full grown, are sometimes one-third of an inch in length. The protoplasm of some of these cells breaks up into a great number of daughter-cells which arrange themselves into a miniature net inside the mother-cell which is set free by the absorption of the enclosing walls. In other cells thousands of little ciliated swarm spores are formed, which, after swimming about for a time, thicken their walls and sink to the bottom of the water, where they remain for a time in a resting stage, as in the case of *spirogyra*.

The Fungi or Moulds are closely akin to the plants just considered. A common one forms a greenish coating upon bread, leather and other substances left in damp places. When examined the green color seems to be due to a fine powder which is apparently the same as the *torulæ*. Each of these grains or spores gives rise to a long tubular filament called a *hypha*, and a number of these *hyphæ*, make up the body of the fungus, which is called the *mycelium*, *hyphæ* projecting downward and upward like roots and shoots from the *mycelium*. Some of the *hyphæ* projecting upward develop spores at their summit.

Moulds are easily grown for observation. A little moistened horse dung placed in a dish and covered with a glass will furnish

a vigorous growth of Mould. When these are full grown, some of the spores may be sown on a piece of moistened bread, which, under a glass will soon develop a fine crop of Mould. The moulds do not contain chlorophyll and are saprophytes, living upon decaying vegetable or animal matter, or they are parasitic.

With the moulds, *spirogyra* and water net are associated *desmids* which are found abundantly in shallow fresh water, and *diatoms* which occur in both salt and fresh water, often forming a thin yellowish layer at the bottom of the water. These forms of life are beautiful and interesting objects of study, but their minute size makes their observation difficult. This group of plants is called *ZYGOPHYTA*, from the fact of their forming a *zygo-spore* or yoke spore. The plants of this group differ considerably among themselves but are similar in their modes of reproduction, but not alike, as in some cases the spores have organs of locomotion while in others they do not have them. Yet in this respect this class is clearly superior to the *protophyta*.

The next division of plants is called *OÖPHYTA*, egg-spore-plants. The distinguishing characteristic of the plants of this group is that they develop special cells which contain one or more rounded masses of protoplasm which are fertilized by the contents of another special cell of smaller size, which results in the production of an *oöspore* from which a new plant may be developed.

In streams and ponds tufts of dark green plants may be seen floating in the water from stones or sticks or other objects to which they are attached. These masses of vegetable matter are probably the simple or branching filaments of some species of *Edogonium*. These plants multiply by the sexual process of reproduction as above, and by an asexual process as well.

The *Vaucheria* is another member of this division of plants. It forms dense felt-like masses in water, or on damp ground or rocks. They do not have the slippery feel of *spirogyra* but change to a dingy color at the fruiting stage and the filaments are coarse enough so that many things can be learned about

them from observation with the naked eye. In studying the *vaucheria* during the fruiting stage, it will be found interesting to observe them carefully several times during the day, especially late at night, and early in the morning.

Other members of this group are the seaweeds, *Fucus* and *Sargassum*. They grow from just below low-tide to just above high-tide, and often attain great size. They are washed ashore in great quantities during storms, and are much used for manure, and from their ashes Iodine and Bromine may be obtained.

The CARPOPHYTA or spore-fruit-plants are distinguished by the formation of a *sporocarp* as the result of the fertilization of the female element. The sporocarp usually consists of a fertile part which produces *spores*, and a sterile part, so formed as to inclose the fertile portion. The spores are not the direct but a secondary result of the fertilization. The plant body usually has a more perfect development than in the previous divisions.

To this division belong the large and interesting class of seaweeds called *Florideæ*, which are noted for their delicate forms and rich coloring. They are mostly of a red color, due to a pigment soluble in cold fresh water. The color varies through every shade of red from bright rose to purple. Irish moss used for making *blanc mange* is one of the best known.

To this division also belong a great group of parasitic plants or fungi, and while they are too minute for detailed study, yet their presence in patches on plants and something of their effects, their color, their changes when fruiting, etc., are interesting subjects of study. A species occurs on the leaves of the apple and cherry, another on the leaves of the willow; another on the leaves of the grape, doing much injury, is called *Oidium Tuckeri*. One occurs on the leaves of the maple and a very common species is found on the leaves of the lilac. They occur on the leaves of the oak, elder, mandrake, pea, and many other plants.

In the study of these fungi or mildews, or any other plant, it is interesting to watch several plants of the same species through the whole growing season, noting all changes, so as to get some idea of the life history of the plant. By watching several plants,

mere accidental changes may be eliminated, so that at the end of the season a clear and complete history can be given of the particular species studied.

Lichens, a large and well-known group of plants, belong in this division. These plants are common everywhere and have been carefully studied, yet there has been much difference of opinion about their true nature. The idea seems to prevail that they are fungi which live in association with algæ, which may be proto-phytes or zygophytes, plants of a higher order as parasites on those of lower orders. A lichen of Asia Minor is used for food, and the so-called Reindeer moss is a lichen. They grow on the bark of living trees, on rocks and decaying wood, and on the ground; they vary greatly in form and color, and are interesting subjects for study. The ergot of rye, the rust of wheat, and the smut of wheat, oats and barley and their allies, belong to this division of plants.

The most valuable and best known group of this division are the *mushrooms*. They are saprophytes, and the largest of the Fungi, growing with great rapidity and decaying rapidly after maturity is reached. Many species are poisonous, but many are edible, and in France they are extensively cultivated for food; in one cave there are over six miles of mushroom beds.

The only chlorophyll-bearing plants in this division are the *Characeæ*. They are submerged water plants, slim and delicate in structure, sometimes attaining the height of two or three feet. They grow in close patches at the bottom of fresh-water lakes, ditches and streams; in deep or shallow, stagnant or running water. They are easily grown in an open dish, and associated with *spirogyra*, or some other of the scums, make an attractive and entertaining addition to a group of house plants.

The divisions already considered constitute the *Thallophytes* of some authors, who generally divided them as follows: *Algæ*, aquatic chlorophyll-bearing plants; *Fungi*, terrestrial, saprophytic, or parasitic plants destitute of chlorophyll; and *Lichens*, terrestrial plants containing green gonidia. But the classification already given, based mainly on the character of the

reproductive apparatus, has the sanction of the latest and best authorities.

These plants show no indication of true roots, stems or leaves. They are made up mainly of parenchyma cells—showing no wood cells, tubes or other characteristics of stems. Yet while they are low in form and structure, and are of comparatively small economic value, they are numerous, far exceeding the number of the higher plants. We cannot learn many things about them by examination with the naked eye; but what we can learn is of great interest, leading us into comparatively untrodden fields of nature.

Among these cellular plants the nutritive processes go on in all parts of the organism, there being little or no division of labor, each cell acting as an individual. In the study of these plants we have found three classes: the chlorophyll plants that absorbed their nourishment, as carbon dioxide, water, etc., from the mineral kingdom—these in the sunlight were changed into such compounds as the plant could build into tissue; others, called *parasites*, absorbed compounds already prepared for use from the juices of chlorophyll plants, and from them built up their tissues; others called *saprophytes* absorbed compounds from decaying vegetable substances, from which their tissues could be nourished.

The members of this group of plants affect man in various ways; directly, in causing such diseases as intermittent, typhoid, yellow, scarlet and typhus fevers, cholera, smallpox, croup, consumption, erysipelas, and many other diseases; and indirectly, in causing diseases of domestic animals, as splenic fever, fowl cholera, swine fever, rabies, glanders and others. And they are the cause of the various kinds of fermentation, some of which are valuable and some harmful. Some fungi are valuable for food, but many of them are injurious. They cause skin diseases, as ringworm. They infest almost every useful plant, lessening the quantity of the food product, injuring its quality, as in the case of the rust of wheat, the potato fungus and those which infest the grape.

They attack many kinds of insects, as flies, wasps, beetles, spiders, butterflies, etc., in some cases causing their death. Fish are subject to attack from fungi. As saprophytes fungi are doubtless in many cases beneficial; but they promote the decay of timber, whether in the house, ship, bridge, furniture, or the piece thrown aside as useless. Without going into further detail it seems clear that Bacteria, Fungi and Algæ are important members of the vegetable kingdom, that they are present everywhere, and that their general effect is to disintegrate and destroy the more highly organized groups of plants and animals.

CHAPTER XXVI.

BRYOPHYTA, MOSS PLANTS AND PTERIDOPHYTA, FERN PLANTS.

THE BRYOPHYTA are in some sense a transition group between the cellular plants below and the well developed vascular plants above. A plant called *Marchantia polymorpha* is a good representative of a portion of this group. It is found in damp shady places, growing on the rocks or on moist ground. It consists of flat leaf-like stems, producing fine silky hairs from the lower surface which serve to attach it to its resting place, and they probably absorb nourishment as well, acting as true roots. The dark green upper surface is covered with minute diamond-shaped markings.

The reproductive organs occur on separate plants as disk-crowned stems about an inch high. The *antheridia* or male elements have a scalloped disk, while the *archegonia* or female elements have the disk cut into finger-like rays. After fertilization a sexual spore, called an *oöspore*, is formed in the archegonium, from which a *sporogonium* is developed. In the sporogonium *asexual* spores are formed from which new plants grow. On the upper surface of the plant little cups or *cupules* occur which contain bright green scale-like bodies called *gemmae*. The *gemmae* grow into new plants.

In studying this plant notice carefully the points already mentioned, note the difference in color between the upper and lower sides of the plant, note the mode of branching, the indented apex, the median line or midrib. Note also the pores on the upper surface. Remove some of the *gemmae* and placing them on a white surface, study their form. Examine carefully the archegonial and antheridial branches, and compare them with

each other. Write out an account of everything observed, with a description of the locality in which the plant was found.

In the plants heretofore studied there was little differentiation of parts, but in the *marchantia* the upper surface seems to have been specialized for the purpose of assimilation and reproduction, and the under side for the absorption of nourishing liquids. And there is some thickening of cell walls, and some indications of the development of a vascular system. *Marchantia* grows well in greenhouses and may be grown for observation on moist earth anywhere about the house.

The true Mosses are common wherever moisture is abundant, in swamps, on the ground, on trees, rocks and decaying vegetation. The stem, roots or root hairs and leaves in form and function are similar to those of the higher plants. The spore formed by the sexual organs produces a branching body called the *protonema*, from which the moss plant proper grows, producing at length the archegonia and antheridia. Mosses may be grown for observation on moist decaying wood or earth under a glass.

In studying mosses, notice the following: the stem, its height, shape and color, make a cross section of it and note different tissues as shown by different colors. Note the shape, color and arrangement of the leaves; study the flowering heads, the male with its rosette of green leaves, and the female with the leaves folded into a bud; compare them in other respects; note the fruit which is a cylindrical pod or *capsule*, and the hood fitting over the pod, remove the hood and note appearance and contents of the pod. Make full notes of what you observe and describe the locality in which the moss was found.

In the groups previously studied the sexually formed spore produced a plant like the parent, but in this group it grows into a fruit or sporogonium, which forms asexual spores that produce plants like the original. This process is known as an alternation of generations.

In the economy of nature Mosses, with Lichens and other plants of the lower orders, are precursors of higher plants; they appear first on rocks and sterile places; sand and dust collecting

around them with the decaying leaves and stems at length form soil suitable for higher plants. Some species of *Sphagnum* growing in swamps enter largely into the formation of peat bogs, and perhaps helped to form some varieties of coal. This moss is extensively used in packing trees and plants for shipment, and some species are used for stuffing mattresses. Some species of mosses and lichens are almost the only flora of the polar and high mountain regions.

Pteridophytes or *Ferns*, produce no highly colored flowers, yield no rich perfume, yet no group of plants attracts more notice, are more sought for cultivation, or more enjoyed than the ferns, whose sole charm consists in their delicate, graceful, feathery foliage. Ferns are abundant in all parts of the world, but exist in greatest variety in the hot moist regions of the tropics. There are said to be some 3,000 species ranging in size from less than an inch to the gigantic tree ferns of Australia, some of which reach an elevation of 75 feet, with leaves or fronds which exceed in size those of any other plants. While in general they seem to enjoy rich soil and warm, moist, shady localities, they do grow on exposed hillsides, on rocky cliffs, and sometimes on trees as air plants. They are not only abundant now, but they have been a marked feature in the flora of the earth from very early times. Their remains are found in the rocks of the Devonian age, while the coal of the succeeding age is made up mainly of the stems and leaves of ferns and allied plants.

Ferns consist of a stem, rootstock or *rhizoma* which is usually horizontal and subterranean, but in some cases it creeps along the surface; and sometimes it is erect, as in the case of tree ferns. From the rhizoma arises the leaf which consists of a stalk or *stipe* and the blade or *frond*. The stipe may be green or black; may be smooth and polished or covered with scales or hairs; the frond may have an even, uniform outline, like the leaf of an apple tree, or it may be divided and subdivided into many distinct parts, as in the case of the maiden hair fern, so common everywhere.

The continuation of the stipe through a simple frond is called

the *midvein*, in a divided frond it is called the *rachis*. When a frond is cut into lobes extending halfway or more toward the midvein, it is *pinnatifid*; when the divisions extend to the midvein the frond is *simply pinnate*, and the divisions are called *pinnæ*. When the pinnæ are lobed the frond is *bipinnatifid* and the lobes are called *segments*. When these divisions extend to the midvein of the pinnæ the frond is *bipinnate* and the divisions are called *pinnules*, and the midvein of the pinnæ becomes a *secondary rachis*. The delicacy and extent to which this division is carried is the chief beauty of many ferns.

Besides the leaves, the stem gives rise to roots, so that the ferns and their allies are the first plants to show distinct stems, roots and leaves; and in them the three tissue systems first make their appearance. If the stipe of almost any fern be crushed or broken, the vascular bundles, as yellowish bands, are easily found and with a little care may be traced into the stem or rhizoma, and also into the divisions and subdivisions of the frond. The epidermal and fundamental tissues can easily be made out at the same time.

The reproductive process in the ferns is interesting and somewhat peculiar. On the under surface of the frond bodies called *sporangia* are developed, in which spores are formed. The spores, when mature, develop into a flat roundish body, deeply notched on one side, so that it is sometimes heart-shaped, which is called the *prothallium*. The prothallium develops the sexual organs, *archegonia* and *antheridia*. After fertilization an ovum is developed in each archegonium which produces a young fern. The prothalia in most cases are small, and they escaped the eye and investigation of the botanist until about 1848, when they were discovered and the mystery of the reproduction of ferns was cleared up.

Some variety of the maiden-hair fern may be found in almost any locality. It may be recognized by its black polished stem, which divides into two equal recurved branches, from these arise secondary branches which support oblong leaflets. On the under side of the leaflets, along their margins are the crescent-shaped

masses of sporangia called *sori*. The plant should be gathered for study some time in August, and the fresh specimen may be studied, or the stem and roots may be preserved in alcohol, and the stipe and frond dried in a plant press or book, and the study made at some other time.

With the complete plant in hand, notice the dark brown stem, from which the slender branching roots arise, then the leaf with its polished stipe and green leaflets, and lastly the hairs on the roots, the scales on the rhizome, and the *sori* on the leaflets, which together are called *trichomes*. Each of these parts is worthy of study. Notice the shape, size and surface of the rhizome, its growing apex and dying base. Those places on the rhizome from which leaves grow are called *nodes* and the intervals between the nodes are the *internodes*. Examine the buds at and near the growing end of the rhizome; some show rudimentary leaves with coiled stalks, and one or more are simply continuations of the stem. Notice the arrangement of the buds and leaves on the rhizome.

Crush a portion of the rhizome and then pick out the whitish bands of vascular tissue, trace this tissue into buds, leaves and branches of the stem. Make cross sections of the rhizome at the nodes and between them and note the outer ring of brown tissue, and the somewhat horseshoe-shaped whitish mass, the vascular bundle; examine several sections so as to get a clear idea of the position of this tissue in the internodes, at the nodes and other places. Split a portion of the rhizome with a sharp knife and examine the sections carefully. Notice the shape of the roots, their mode of branching, the root hairs, the growing tip, make a cross section and look for the vascular bundle.

Note the color, form and mode of branching of the stipe or rachis of the leaf, trace the vascular tissue into branches and smaller divisions of the rachis. Make cross sections at different places along the rachis, and compare with sections of the rhizome. Study the shape of the leaflets and compare the one at the apex with others on the secondary branches. Note the surface, texture, color and framework or veins of the leaflet.

On the under side of some leaflets note the crescent-shaped sori, find out if there is any law as to which leaflets carry sori. After soaking in water open a sorus, and note what forms the cover, called the *indusium*. The yellowish spheroidal bodies in the sorus are the *sporangia*, notice that they are attached to the veins of the leaflet. Study a sporangium noting its shape, stalk, and the ridge, called the *annulus*, extending part way round it. Burst a sporangium and note the minute bodies called *spores*. The sporangium is opened by the straightening of the annulus; place some sporangia that have been soaked in water on a piece of glass, watch them through a lens, noting the process of opening. Make a diagram of the mode of branching, and write out a description of what has been observed. A larger fern might be more interesting and easier to examine in some respects. The same general plan can be followed in examining any fern.

Such a study gives one some idea of the gross anatomy of the fern and is full enough for purposes of classification. For classification the maiden-hair fern *Adiantum pedatum* is described as follows by Prof. L. M. Underwood: Root, many delicate fibers somewhat matted. *Rhizome*, scaly somewhat creeping. *Stipe*, slender, polished, black, forked at base of frond forming two recurved rachises. *Frond*, roundish in outline, formed of several pinnæ, which branch from the recurved rachises; *pinnules* unequal sided, oblong or deltoid; upper margins irregularly lobed, surfaces smooth. *Veins*, free, several times forked. *Sori*, borne at the end of the veins on the under side of the reflexed margins of the lobes, which form somewhat kidney-shaped membranous indusia. *Sporangia*, globose with a nearly complete vertical ring. *Spores*, too minute for examination with an ordinary lens.

The germination of fern spores may best be studied by sowing them on closely pressed muck, or even on a piece of glass, and keeping them warm and moist. In this way the prothallium may be obtained for study.

The method of veining varies somewhat and often serves as an aid in classification. In many cases the veins are free, that is arising from either side of the midvein they do not unite with

any other vein. In other cases the branches of adjacent veins unite forming a net work near the margin of the leaflet. The sporangia in the true ferns are collected in clusters on the back of the frond or are variously arranged in lines along the veins or around the margins. The sporangia may be naked or covered by an indusium. In the case of the ostrich fern, the sensitive and cinnamon ferns there are sterile fronds, and fertile fronds, the latter bearing large globose sporangia, appearing very little like fronds; only a careful study of their life history would make one sure of their origin.

Besides the ferns, the pteridophyta include the *Equisetaceæ*, called horsetails or scouring rushes, and the *Lycopodiaceæ* called lycopodium or club-moss. No member of the pteridophyta is of great economic value, yet as the source of our coal supply they have an honorable historical record.

CHAPTER XXVII.

THE ANTHOPHYTA, LEAVES, REPRODUCTIVE ORGANS AND FRUIT.

THE *anthophyta*, or flowering plants, make up the greater part of the vegetable kingdom. They include the common herbs, shrubs and trees, the plants that are cultivated for pleasure and profit, the plants that furnish materials for the food, clothing and shelter of man.

Among these plants, the stem, roots and leaves are usually well developed and the three tissue systems are clearly defined. And there is a strict division of labor in all physiological functions, indicating a more complex and highly developed organism than among the plants already studied.

Leaves are organs of assimilation, and in a modified form constitute the organs of reproduction for this group of plants, so that they seem the most important parts of the plant. A leaf consists of a vascular framework covered by a mass of parenchyma, whose cells are well supplied with chlorophyll, and the whole covered with a delicate epidermis. The parts of a leaf are the stalk or *petiole*, and the *blade* or expanded portion, and at the base of the petiole there are sometimes leaf-like bodies called *stipules*. The petiole continued through the leaf is the *midrib*, and its branches and subdivisions are called *ribs*, *veins* and *veinlets*. The framework of the leaf is a branch from the vascular system of the stem.

On the basis of the arrangement of the veins, leaves are divided into two classes, namely *netted-veined*, as the leaves of the apple and oak, the veins forming a conspicuous net work, and the *parallel-veined*, as the leaves of corn and grass, in which there are few branches, and no net work is formed.

Leaves vary greatly in form, some of the more common forms

are: *linear*, when the leaf is several times longer than wide and of the same width throughout; *lanceolate*, when several times longer than wide and tapering upwards and downwards from the lower third of the leaf; *oblong*, when two or three times as long as broad with rounded base and apex; *elliptical* and *oval*, much the same as oblong but tapering more toward the ends of the leaf; *ovate*, when the outline is like the lengthwise section of a hen's egg, the broader end downward; *orbicular*, when nearly circular in outline. When the leaf tapers toward the base it may be *oblanceolate*, *spatulate*, *obovate*, or *wedge-shaped*.

If we consider the base of the leaf it may be *cordate*, or heart-shaped, *reniform* or kidney-shaped, *auriculate* or eared, *sagittate* or arrow-shaped, and *hastate* or halberd-shaped. The leaf of the water-lily and mandrake are peltate or shield-shaped.

When the apex of the leaf is considered it may be *acuminate* or pointed, *acute* or *obtuse*; *truncate*, when the end appears as if cut off square; *retuse*, when the rounded summit is slightly indented; *emarginate*, when the summit is decidedly notched; *obcordate*, when the apex is heart-shaped; *cuspidate*, when tipped with a sharp rigid point; *aristate*, when the apex is like a bristle.

Leaves also vary in outline. When the margin is an even line without teeth or notches the leaf is *entire*. It is *serrate* or saw-toothed when the margin is cut into sharp teeth pointing toward the apex of the leaf. *Dentate*, when the teeth are wider and point outward; *crenate*, when the teeth are rounded; *repand* or wavy; *sinnate*, like repand with deeper waves; *incisid*, when the margin is cut into sharp, deep and irregular teeth.

When the incisions do not extend more than halfway to the midrib, dividing the leaf into a definite number of somewhat rounded parts, it is said to be *lobed*, and the divisions are called *lobes*, and their number is expressed by the phrase *three-lobed*, *five-lobed*, etc. If the divisions extend more than halfway to the midrib, the leaf is said to be *cleft*, and it may be *three-cleft* or *five-cleft*, etc. If the incisions go nearly to the midrib or base of the

blade, the leaf is *parted*. If the divisions extend to the midrib, or petiole, the leaf is said to be *divided*.

In studying leaves it will be noticed that the lobes, divisions, etc., correspond to the veining of the leaf, the veins and divisions in some cases radiating from the base of the leaf blade, when they are said to be *palmately* veined, lobed, parted, etc., as in the maple leaf; in other cases the branching, lobes and divisions are related to the midrib rather than to the base of the leaf, when it is said to be *pinnately* veined, lobed, parted, etc., as in the leaves of the oak.

When a leaf consists of two or more parts, each part with a distinct petiole, joined to the midrib or common petiole, it is a compound leaf. It is often difficult to determine whether a leaf is compound or simply divided. Leaves may be *palmately* compound, as in the case of the horsechestnut, or *pinnately* compound, as in the case of the locust and pea.

A pinnately compound leaf may terminate with a *single leaflet*, a pair of *leaflets*, or a tendril. The leaflets of compound leaves may be divided and subdivided, and the leaf be bipinnate or tripinnately compound, or *twice palmate*, etc.

Sometimes the stem grows through the base of the leaf, when the leaf is called *perfoliate*. Sometimes two opposite leaves seem to have grown together at the base, forming one roundish leaf with the stem through the center. Such leaves are said to be *connate-perfoliate*.

Many leaves are nearly horizontal with an upper and lower side. Many others are nearly vertical, having inner and outer surfaces, as the leaves of the iris. An examination of the leaves of the iris shows the older straddling over the younger, as a man straddles a horse, hence the leaves are called *equitant* leaves. Equitant leaves, and many others, have no distinction of petiole and blade, as the leaves of the pine, spruce and juniper. The stipules are sometimes large and conspicuous, as in the case of the pea and clover. Sometimes they form a sheath around the stem, as in some grasses, where they serve as petioles.

Leaves sometimes take the form of cups, as in the pitcher

plants; sometimes they are so formed as to serve as insect traps; sometimes they serve as storehouses for food and as foliage also, and sometimes they appear as spines, tendrils or scales. Foliage leaves are the most prominent parts of the plant, and are much used in describing and classifying plants; hence the necessity of studying carefully the forms of leaves, and of naming them accurately. Leaves differ in color. The under side differs from the upper side. Sometimes they are smooth, sometimes hairy or woolly, etc., all of which may be important details in the identification of a plant. To gather leaves, to study them in all their details, to describe them accurately, is an interesting and valuable educational exercise.

Leaves usually arise from definite places on the stem called *nodes* or joints. If two arise from the same joint, they are on opposite sides of the stem, the pair above stand at right angles with the first pair and the third pair above are directly over the first, so that there are four ranks or rows of leaves along the stem. Another arrangement is when the second leaf is opposite but on the joint above, the third being over the first, when there are only two rows of leaves along the stem. Another is when the second leaf is on the joint above, but only one-third the way around the stem, so that the fourth above stands over the first and there are three rows of leaves along the stem. Sometimes there are several leaves on one joint when they are called *whorled* leaves, and sometimes, as in the pine, they form a *cluster* or *fascicle* which appear to be the leaves of a whole branch, which is so short that the leaves seem to arise from one joint, but examination shows a spiral arrangement. Other arrangements occur, any of which can easily be made out from the careful study of young stems.

The buds from which branches grow are developed in the axils of leaves, so that the branching of a plant or tree follows the arrangement of the leaves and is always definite, although it is often difficult to discover the law on the older parts of the stem as many branches have been destroyed. This same arrangement extends to the location of flowers on the stalk, so that while on

a hasty glance, one might think the top of a plant, shrub or tree a mass of disorder, yet a careful investigation would show that everything was in a definite place according to a plan.

The flower consists of parts or organs designed for the production of seeds from which new plants may grow. The parts of a complete flower are the *calyx*, the *corolla*, the *stamens* and *pistil* or *pistils*. The flower is a short branch and the parts are composed of more or less modified leaves arranged according to the leaf plan of the plant.

The calyx is the lowest or outer whorl of leaves, they usually have about the same color as the foliage leaves, and are called *sepals*. Sometimes the sepals grow together forming a cup or tube, when the calyx is called *monosepalous*. When the sepals are distinct the calyx is *polysepalous*. The calyx may be regular when all the sepals are alike, or they may vary in form when it will be irregular.

The second whorl of leaves called *petals* make up the *corolla*. They are usually of some attractive color differing widely from that of the foliage leaf. The corolla may be *monopetalous* or *polypetalous*, and it may be regular or irregular, and in some cases it is wanting, when the flower is said to be *apetalous*, the sepals sometimes having the appearance of petals.

The next whorl of leaves have been changed into stamens. A stamen consists of a *filament* or stalk and the *anther*. The filament, usually slender, is sometimes broad and leaf-like. Sometimes the stamens are distinct, sometimes united into a tube, when they are said to be *monodelphous*. Sometimes they stand on the common receptacle of the flower, as an independent group of organs, when they are said to be *hypogynous*, under the pistil; they may be on the calyx around the pistils, when they are *perigynous*; they may be on the ovary, when they are *epigynous*; they are sometimes united with the pistil, when they are *gynandrous*; and again they may stand on the petals, when they are *epipetalous*. Sometimes the anthers are united, when they are *syngenesious*. The filaments may be of different length; if there are four stamens, two long and two short, they are *didynamous*.

When there are six, four long and two short, they are *tetradynamous*. The variety of positions in which stamens are found has led some authors to doubt whether they are changed leaves, considering them as possibly outgrowths from the epidermal system of the plant.

The anther consists of two lobes or cells in which pollen grains are formed, that contain the fertilizing element of the plant. When the anther is attached by its base to the apex of the filament, it is *innate*; when attached for its whole length to the side of the filament, it is *adnate*, and when fixed near the middle to the apex of the filament, it is *versatile*. When it faces inward, it is *introrse*; when outward, it is *extrorse*.

The upper or innermost whorl of the floral leaves form the pistil or pistils. A pistil consists of a *stigma*, *style* and *ovary*. The ovary is the enlarged hollow part of the pistil in which the *ovules* are formed, the part from which the ovules arise being called the *placenta*. Above the ovary the pistil narrows into the style which bears the stigma, which is a moist, glandular body of varying shape. There may be several pistils in one flower; or two or more may unite, forming a compound pistil. If we think of the ovary as formed from a leaf by bringing its edges together, the line of union is called the *inner suture*, and a line corresponding to the midrib of the leaf is called the *outer suture*. The inner or ventral suture is the *placenta*. When two or more ovaries unite to form a compound ovary, the union is usually along their ventral sutures so that the ovules are attached to a column in the center of the ovary; and sometimes the partitions dissolve away and a one-celled compound ovary results with the ovules on a stalk in the center.

In some compound ovaries the ovules are on the walls and not in the center. We may imagine in such cases that the three or four or more leaves forming the ovary united with each other by their edges, thus forming ventral sutures at the junction of two leaves instead of at the junction of the edges of the same leaf. In one case the placenta is *central*, in the other it is said to be *parietal*.

Ordinarily the calyx is below the ovary, but sometimes the calyx adheres to the ovary, so that the stamens and petals are around or above the ovary, when the ovary is said to be *inferior*, half *inferior*, or *superior*, as the case may be. Sometimes the leaf forming the pistil is not closed, the pistil being a scale-like leaf bearing the ovules on its upper or inner face near the base. This form of pistil is peculiar to the pine family which is named *gymnospermous*, or naked-seeded.

The ovule at first is a mass of parenchyma, a little later an integument grows over the mass called the *secundine* coat, and later another integument is formed called the *primine* coat. These coats do not completely cover the ovule, a small opening called the *micropyle* always remaining over its apex. Later an *embryo sac* forms near the apex of the ovule.

In fertilization, the pollen grains are conveyed to the stigma by the wind, by insects, or birds, or in some other way. The grain resting on the moist surface of the stigma, absorbs moisture and germinates, sending out a tube which penetrates the soft tissues of the stigma and style, to the cavity of the ovary where it enters the micropyle of an ovule, and through its tissues to the embryo sac, where fertilization takes place.

As a result of the fertilization there is formed a *proembryo*, from which is developed the *embryo*, which consists of one or two leaves or *cotyledons*, the *plumule* and the *root* or *radicle*. With the embryo in the embryo sac is formed the *endosperm* which serves to nourish the embryo. The walls of the ovule thicken and harden and the seed is formed.

Fruit usually consists of the seeds inclosed in a variously modified ovary. Sometimes the wall of the ovary thickens and becoming soft as it ripens, forms such a fruit as the currant, gooseberry, grape and tomato. This softened wall may be covered with a thick skin as in the orange and lemon, or a hard rind as in the melon and squash. While in the cherry and peach the inner part of the ovary forms a stony wall about the seed while the outer forms the delicious fruit. The blackberry consists of the softened end of the stem on which the flower stood, covered

with little stone fruits. In the case of the apple, pear and quince the thick fleshy part is not the wall of an ovary but a thickened calyx.

Sometimes the wall of the ovary becomes thin like a membrane, or hardens, or remains herbaceous, forming fruits, that in some cases open at maturity for the escape of the seed, while in other cases they remain closed, having the appearance of simple seeds, and are called *akenes*. The fleshy part of the strawberry is the softened end of the stem on which the flower stood and the real fruits are ripened ovaries, usually called seeds, scattered over its surface. The fruit of the sunflower, dandelion and many others are akenes. In the case of wheat, corn and other grains, the seed and ovary wall adhere so as to form one body, so that a grain of wheat is a true fruit, called a *caryopsis*.

Capsule or pod is the name for dry seed vessels that split open at maturity. The pea-pod is a good illustration. Fruits were designed to help in some way toward the reproduction of species; in many cases they serve as storehouses of food to aid in the growth of the young plant. And they are the most valuable sources of food for man and domestic animals.

CHAPTER XXVIII.

THE GYMNOSPERMÆ.

THE *Anthophyta* are divided into two classes, the *Gymnospermæ*, in which the ovules and seeds are not inclosed in an ovary, and the *Angiospermæ*, in which the ovules and often the seeds are inclosed in an ovary.

The *Angiospermæ* are divided into two subclasses, the *monocotyledons*, in which the embryo has one cotyledon, and the plants generally have parallel veined leaves, and the numerical plan of their flowers is three; and the *dicotyledons*, in which the embryo has two cotyledons, and the plants generally have netted veined leaves, and the numerical plan of the flowers is five. This subclass includes the greater part of plants and trees of the temperate zones.

The *gymnospermæ* all have woody stems, and generally narrow, needle-shaped, parallel veined leaves. The members of this class are mostly trees, including the redwood, pine, spruce, cedar, fir and cypress. The male and female organs are in different flowers, which are very simple, consisting of one or more stamens in the one case, and naked ovules in the other. After fertilization the embryo, consisting of root, stem and leaves, is soon formed. The various parts of the reproductive organs are homologous with those of the pteridophyta, the material from which the embryo sac and embryo are developed corresponding with the prothallium.

A careful study of the Scotch or the Austrian pine will give us clearer ideas of the whole class than to spend the same amount of time on several members of the group.

The Scotch pine is a species often planted for ornament. The leaves, from two to four inches long, occur in pairs, and are covered with a whitish powder which gives a peculiar color to the

tree. The cones are small, about two inches in length, the free ends of the scales being produced into protuberances, which are sometimes recurved. The Austrian pine has longer leaves of a dark green color, without powder. The cones are much larger, but without the recurved protuberances.

As plants vary considerably during the growing season, a complete study necessitates continuous observation during the interval between fertilization and maturity, with a study of every phase of growth; or specimens of the different stages of development may be collected and preserved in alcohol, so that the study can be made at any time of the year.

The male flowers of the Scotch pine form a catkin or spike-like cluster at the base of the young shoots, and should be gathered for study in May or June. The female flowers form inconspicuous clusters toward the end of the young branches. Specimens should be gathered as above, and later in the season also. Leaves and stems and young cones, found just below the new shoots, should be gathered in July or August, and the terminal buds and mature cones in late autumn. Fresh leaves and stems may be used at any time, but the resin which abounds in fresh material often makes it unpleasant to work with.

In studying the pine notice the central shaft or trunk of the tree, extending without division to the very summit. Note the whorls of branches at definite places on the stem, and also the angle they make with the main stem, and compare the pine with other kinds of trees in these respects. In young trees or branches of older trees note the difference in vigor between the terminal and lateral shoots. Make cross sections of the smaller stems and branches, then counting the rings of growth, notice if there is any relation between the age of the stem and the number of whorls of branches. Note the short branches bearing the pairs of green leaves, pull out the leaves and then from the scars study the numerical arrangement, also study the arrangement of the scales on a mature cone and compare the two. Notice the surface of the youngest shoots, then following the branch back to the main stem note any changes as to bark, scales, etc.

Notice the position, shape and size of the buds; split a terminal bud lengthwise and study carefully the relative position and the form of the different parts; carefully take off some of the scales with needles and note the character of their edges, and the differences between the apex and base; note the secondary or new buds, their form, position, etc. Compare the bud with a branch, and observe whether the bud is a branch or not. Make a cross section of a stem which is a half inch or so in diameter, and note the central pith, the woody portion with its rings of growth, and the bark outside the wood. Notice the fine lines radiating from the pith to the bark, called *medullary rays*, and note that many of them do not reach the pith. Notice also many scattered openings from which resin exudes, they are *resin ducts* occurring both in the wood and in the bark. Study the rings of growth noting the difference between the inner and outer portions.

The bark may be divided into three layers an inner, whitish, fibrous layer, the middle green layer and the outer brownish portion. Note the relative thickness of these layers and the resin ducts in the middle one. Split a portion of the stem and study the appearance and relation of the various parts in the longitudinal as well as in the cross section.

Notice the color, shape and texture of the leaves, note the apex, edges, base and surface. Make cross sections and longitudinal sections and notice the fibro-vascular bundles, resin ducts, the green tissue and the epidermis.

Take a cluster of male flowers and note that it is made up of a central axis on which are arranged the short-stalked bodies, called stamens. Each stamen consists of a flat scale, bearing on its inferior surface two enlargements, the *pollen sacs*. Find a pollen sac that has burst and note the location and character of the opening, burst a pollen sac and notice the yellowish grains of *pollen* that escape. The flowers on a very short stalk are crowded on an axis forming a cluster called a *spike*. Notice that the flowers each replace a branch on the young shoot.

Taking a spike of female flowers, notice the stalk or *peduncle* by which it is attached to the stem, and that the spike is com-

posed of thin scales or *bracts* and thicker ones called *carpellary scales*. Dissect out one of thicker scales and study its shape and texture and compare it with the thinner bract. Note the prominent ridge or *keel* on the upper surface and the two enlargements near the base, the *ovules*. Notice the position of the ovules and the opening at the free end called the *micropyle*. Note that the cluster seems to take the place of a branch.

Split a one year old cone and examine carefully all the parts in section, notice the ovules, the abortive ovules, the scales, and make a diagram showing the relation of the parts to each other. Dissect out an ovule and bisect it through the micropyle, and notice the nucleus, and a large cavity called the *embryo sac*, enclosing a soft substance called the *endosperm*.

In the mature cone notice the heavy carpellary scales, and the smaller bracts, and along the inner surface of the scales will be found a pair of thin wing-like scales, each bearing at its lower end a *seed* or an abortive ovule.

In the case of the seed, note its form, character of surface, micropyle, etc. Bisect the seed lengthwise, parallel with its flatter faces, and notice the firm outer coat, the *embryo* and the food for the embryo, the *endosperm*. Carefully pick out the embryo with needles and note the short stem, and the young leaves.

A study of the pine according to the foregoing scheme will give one a good idea of the gross features of the pine family. The careful study of one tree or plant is of great value even though it may be far from complete. The scheme suggested may be varied to suit individual ideas and opportunities. The idea has been to encourage careful, systematic study, and to this end full notes should be taken, and numerous drawings, diagrams and sketches made and specimens gathered and preserved for reference and study.

The wood of the pine is composed mainly of tracheides, while the bark is made of *sieve* tissue and bast fibers. The tree grows from the *cambium* layer or *meristem* tissue lying between the wood and the bark. The cells of this tissue undergo division by

the formation of partitions, and the new cells develop into tracheides or wood cells on the one side and into sieve tissue and bast fibers on the other. The new wood incloses the old, while the old bark is outside the new, serving as a protective coating for it.

In the class Gymnospermæ are included the *Cycads*, *Conifers* and the *Joint Firs*. The conifers are the only ones common in the United States, and the only ones of commercial value. The order *coniferæ* includes the juniper, cypress, white cedar, arbor vitæ, the giant redwood, the silver fir, the tamarack or American larch, the white pine, the sugar pine of California, the yellow pine of Georgia, and many others. There are some 300 species of pine, growing mostly in cool climates. In general, they are rapid growers, furnishing strong and durable timber and lumber.

CHAPTER XXIX.

MONOCOTYLEDONS.

THE class *Angiospermæ* includes the great mass of the flowering plants. They differ from the *gymnospermæ* in that they generally have the male and female organs in the same flower; they have the ovules in a closed ovary, and the flower differs more widely from the other parts of the plant.

The subclass *monocotyledons* has one cotyledon, parallel veined leaves, and parts of the flower in threes, and the structure of the stem differs from that of the dicotyledons. A cross section of a stalk of Indian corn, which belongs to this group of plants, shows it to be composed of parenchymatous tissue traversed by great numbers of fibro-vascular bundles. These bundles are more numerous toward the surface of the stem, so that it increases in density from the center outwards, the central portion often disappearing leaving a hollow stem, as in the grasses. These bundles are closed bundles; as they become permanent tissue no cambium or meristem tissue remains and no further development is possible, and such plants are usually short-lived.

The different stages of germination in these plants may be observed by planting several grains of corn, and then by examining a different grain every few hours the process may be followed closely. The first leaf of the young plant has its dorsal surface in contact with the endosperm or food supply, curving entirely around the remainder of the embryo. As it begins to grow the root pushes through the root sheath. The plumule, consisting of a minute stem and a few rudimentary leaves, pushes out through the curved cotyledon, which remains in contact with the food supply, absorbing nourishment for the growing parts. Make out these points from the study of the germinating grains, making notes and sketches.

The monocotyledons include about fifty natural orders of

plants. The most important of these is the order *graminæ*, or *grass family*. The members of this family are herbaceous, rarely woody plants, with round stems, mostly jointed and hollow, bearing alternate two-ranked leaves, each of which has a split sheath or stalk. The flowers are arranged in spikelets, which form a more or less compact cluster, which may be a spike or panicle. The calyx consists of leaves called *glumes*, and the parts of the corolla are called *palets*, which often bear bristles called *awns*. There are rarely more than three stamens, and the anthers are versatile. The ovary contains one ovule, which at maturity forms a *caryopsis*, or grain. This is a large and widely distributed group of plants, including the cultivated grains and grasses, which furnish the major supply of food for man and domestic animals.

The more important members of this order are wheat, rye, barley, the oat, rice, Indian corn, and the grasses, timothy, red-top, blue-grass, orchard grass, etc.; also the sugar cane, and many others. We may gain some idea of the characteristics of this interesting family by studying the cultivated grass known as the *oat*. Specimens should be collected when some of the flowers are expanded and others yet in the bud. They should not be pulled up, but dug up with care and the dirt shaken gently from the roots, which may be cleaned by washing. If possible secure specimens with the empty grain from which the plant grew still attached.

Notice first the parts of the plant, the roots, the stem with its numerous branches toward the top; the leaves, and possibly root hairs may be seen as well as outgrowths from the stem and some parts of the flower. Study carefully the different groups of roots, the points from which they arise, their arrangement, relative size, etc. The strongest root, from the grain, is called the *primary*; those from the nodes on the stem are *secondary* roots. Make a cross section of a primary root and of a secondary root and notice the parts shown and compare them. Strip off the bark from a root and note its character, and that of the fibrous tissue which remains—note the position of the root hairs.

Remove the leaves and study the stem, noting its shape and surface; make a section through a joint or node and note the partition separating the cavities of the internodes. Make a cross section and note the vascular bundles and the cortical or bark layer with its clusters of chlorophyll cells. Make longitudinal sections and find the parts shown in the cross sections.

In studying the leaves notice the split sheath with the thin membranous *ligule*, and compare the two as to texture, form and use. Notice the shape of the blade, the veins, their direction, and relations to each other; make a cross section and locate the vascular bundles; the green tissue between is the *mesophyll*, or parenchyma of the leaf.

The stem of the plant is the main *axis* of *inflorescence*; its branches are *secondary axes*, and some of these are branched, forming a flower cluster called a *panicle*. At the extremity of the smaller branches there is a cluster of two or three flowers called a *spikelet*. At the base of the spikelet notice two leaves which enclose the flowers, called the *glumes*; notice their position with respect to each other, also note their shape, surface and veins. The flattened axis on which the flowers stand is the *rachis* of the spikelet; note the relative size of the flower inclosed by the glumes and the tuft of hairs at the base of the lowest flower.

Take the lowest flower of the spikelet, and note the bract called the *lower palet* which almost incloses the flower; notice carefully the size, shape, surface, texture, number of nerves, etc., of the palet. It sometimes bears a bristle or awn; if so, note its position, length, texture, etc. Cut away the lower palet without injuring the flower, and note another bract called the *upper palet*. Study all its parts and compare it with the lower palet, also note two little scales at the base of the upper palet. Notice the number of stamens, the character of the filament and anthers, and the appearance of the pollen. Notice the top-shaped ovary, the thread-like styles, and the feather-like stigmas. Compare the lowest flower of the spikelet with the others.

In studying the ripe grain, strip off the chaff and note the whitish hairs, especially at the upper end; the longitudinal

groove, and the scar at the base. Make a cross section and note the white central portion and the darker shell or enclosing membrane. After soaking in water for some time, remove the skin and notice the embryo and try to make out the cotyledon, plumule, and stem; if this cannot be done, examine a grain that has just begun to germinate. The process of germination may be followed step by step in oats germinating on a piece of wet blotting paper. Any one of the grasses studied as indicated above will give one some idea of this order of plants, and will enable one to describe the plant examined accurately, so that it can be identified.

The value of the hay crop of the United States is not far from \$300,000,000, and the cultivated grass eaten by domestic animals is worth as much more; and when we add the value of the annual product of wheat, corn, oats, barley, rye, rice and sugar cane, the total amounts to at least \$1,500,000,000, as the annual value of the grass crop of the United States. Grass is king.

Another extensive order is the *Sedge Family*, made up of herbaceous, three-angled, solid-stemmed plants, growing in tufts, generally in wet places. The members of this family are of little economic value to man or beast. The papyrus, which the ancient Egyptians used for paper, was made from the pith of sedges. Ropes and mats are made from some species in India.

Order *Liliaceæ* or the *Lily Family* contains many interesting and valuable plants. The members of this family are herbaceous, rarely woody plants, with regular, and usually six parted flowers. The different parts of the flower are distinct and free from the chiefly three-celled ovary. Stamens six except in one case, anthers two-celled. Calyx and corolla colored alike except in trillium. The plants usually rise from a bulb or short root stalk.

The trillium is a very common flower in the woods during early spring and can easily be obtained for study. Secure several complete plants, and notice the thick horizontal underground stem or root stalk. It is covered with broad scales, and from it branch the roots, and it also sends up an aerial branch which bears a whorl of three green leaves and a terminal flower.

Note the arrangement of the unbranched roots, their wrinkled surface and the root hairs. Make transverse and longitudinal sections of the larger roots, and notice the cortical, parenchyma and fibro-vascular regions, and the thickness and peculiarities of each. In the fibro-vascular region several large tracheary vessels may be seen.

Notice the size and shape of the root stalk, the number of nodes and scars of former branches, and the number of roots from each node. Make the two sections and note the vascular bundles amid a mass of white material, which is probably reserved food. Crush a bit of the white matter in a little water and add a drop or two of iodine solution and note change in color indicating starch. Compare the ends of the root stalk, studying especially the growing end as a whole and in longitudinal section, and note the form, structure and veining of the scales or leaves of the root stalk.

Study the aerial stem with its whorl of leaves and flower, note its form, size and the absence of nodes. Make the two sections and note the three tissue systems, especially the two parts of the vascular area, the light colored or cortical portion toward the outside, and the darker woody portion toward the center of the stem. Notice the number, shape, arrangement and position of the foliage leaves, especially the outline of the apex and base of each. Note also the petiole and the *venation* or mode of veining of the leaves, which is not usual in this order. Make a drawing of a leaf.

The flower is composed of four whorls of organs, the lower, of three greenish sepals, the *calyx*, the next of three colored petals, the *corolla*, the next of six stamens, the *andræcium* and the innermost, of three partly united pistils, the *gynæcium*, and all these parts stand on the broadened end of the stem called the *receptacle*. Note that the parts of a whorl alternate with those of the whorl next to them. Notice the color, shape and venation of both sepals and petals. In studying the anthers, notice the pollen sacs, and the connection between them, which is a continuation of the filament. In the filament notice the vascular bundles, and the fundamental tissue. Note also the way the anther opens and the character of the pollen.

The tapering, divergent styles, stigmatic along the inner surface, unite below forming a compound ovary. Study the style, noting its form, size, etc., find also the vascular bundles. Make a cross section of the ovary and notice the form and position of the ovules, especially notice the *placenta* on which they stand and find out how it is formed. The fleshy pod incloses the seeds. Where the ripe seed breaks away from the stalk a scar called the *hilum* is formed. A cross section of a seed shows the thin brown coat or *testa*, and the food material making up the main body of the seed.

In these plants we have for the first time a complete flower. The calyx and corolla serving in the bud and blossom as organs of protection for the reproductive organs; the corolla in addition serves to attract the attention of insects and birds, whose visits are often beneficial to plants. Sometimes the calyx also becomes colored and attractive. And here first we find the typical closed ovary, the distinguishing characteristic of the Angiospermæ. In the oat the ovule and seed are adherent to the ovary, while in trillium they are distinct. The trillium represents the lily family very well except in the veining of the foliage leaves and the color of the sepals.

Among the useful plants of this order may be mentioned asparagus and the onion, used for food; the aloe, green hellebore, colchicum, sarsaparilla and others are used in medicine; and a large number of lilies are cultivated as ornamental plants.

The *Palm Family* belongs to the monocotyledons, and for economic value is second only to the grass family. The members of this family furnish enormous quantities of food materials, of material for house-building, and for an endless variety of household goods and utensils. But nearly all the useful members of the family are natives of the tropical regions.

The *Orchid Family* is an interesting member of this group of plants. They are terrestrial plants in some cases, but generally they are air plants, growing most abundantly and in greatest variety in the tropical regions. They all have irregular flowers, often having most grotesque forms, and sometimes simulating

the forms of insects and birds. They are noted for the beautiful color of their flowers and the varied forms of their foliage. They are especially interesting for the many curious devices for cross fertilization by insects and birds. They are very popular as ornamental plants, and are represented in the United States by the lady's slipper and a few other less showy flowers. The vanilla plant is an orchid, and other members of the family are useful, but in general they are of little economic value.

Another interesting member of this group is the *Banana Family*. The genus *Musa* of this family contains the plaintain and the banana of tropical regions. No other genus furnishes food for as many people as does the genus *musa*. It is estimated that about 25 tons of bananas can be grown upon an acre of ground, furnishing more food per acre than any other plant.

There are many other interesting plants in this subclass, but the ones mentioned are the most prominent, and will give a good and comprehensive idea of the whole. This monocotyledon group of plants is distinctively the *food group* of the vegetable kingdom.

CHAPTER XXX.

DICOTYLEDONS.

IN this group of plants the embryo has two cotyledons, the leaves are netted-veined, and the plants grow in diameter by the addition of new material each year between the bark and wood of the previous year, as among the gymnosperms. This subclass contains nearly 200 natural orders or families, but only a few of the more interesting and valuable can be noticed here.

The *Willow Family* consists of trees or shrubs, with bitter bark, light, soft wood, and dioecious flowers—that is, the male and female organs are in separate flowers on separate plants. Both kinds of flowers are in clusters called *catkins*, which are much like cones, only the scales are more leaf-like and the axis more slender. The staminate or sterile flower consists of stamens only, the pistillate or fertile flower of one pistil with a one-celled ovary. At maturity the ovary contains numerous seeds each of which is furnished with a tuft of cotton-like down at one end. This family includes the willows, osiers, aspens, poplars, and the cottonwood. Some of these trees are grown for ornament; from the aspen, pulp for coarse paper is made, and willow-ware is made from the young shoots of the osier.

The *Oak Family* consists mainly of trees, with some shrubs, bearing alternate leaves, which are sometimes entire and sometimes pinnately lobed or cleft. The flowers are *monocious* or *diclinous*, both on the same plant; the sterile in slender catkins, the fertile, solitary or clustered. Among the oaks proper, the sterile flowers have a four to seven lobed calyx, and from three to twelve stamens clustered in pendant catkins, while the fertile flower is one pistil in a bud-like involucre that becomes a scaly cup, called the cupule, which partly covers the brown ovoid nut or acorn.

Make a transverse and longitudinal section of an acorn, and notice the pericarp or shell, the thin, brown membrane investing the kernel, called the *testa*, and the whitish substance making up the bulk of the seed which constitutes the cotyledons, with their store of food for the young plant. Soak the seed of an acorn for several hours in water and it can easily be separated into two parts, but notice that they are united, study this bond of union, and make out the radicle and plumule of the embryo.

Make a transverse section of an oak stem and note the rings of growth, the medullary rays, the numerous very large openings which are pitted vessels, and the smaller ones, some pitted vessels and some tracheids, and wood fibers. Note that the rings of growth are not of uniform thickness, and an individual ring is not uniform throughout. Find out the reason. Make a longitudinal section through the heart and notice the numerous shiny plates, the silver grain, or medullary rays. Sometimes the oak has a strong taproot with few spreading ones. Occasionally the taproot is replaced by spreading multiple roots. Find out a reason for the difference.

Oak timber is usually heavy, tough, durable and beautiful. These qualities make it a valuable tree. It has a history; it is famous in poetry and prose alike; it is especially interesting to us as its history runs back through the early English and Anglo-Saxon periods, and backward to our Aryan forefathers. The tree has always been admired for its qualities, and it has often been invested with superstition and romance.

The oak grows best in the cooler regions; it is generally deciduous, but many evergreen varieties exist. It varies in size from a tiny shrub to the sturdy forest tree sometimes six to eight feet in diameter. It grows in a great variety of soils, and varies greatly in quality and appearance. There are some 250 species of oak which are found mainly north of the equator; about 100 species are found in the United States. The White Oak and its varieties furnish the best timber. The Live Oak of our southern states is especially valuable for shipbuilding. But nothing in North America quite equals the *Quercus robur*, the

British oak of England and Europe. The oak family not only includes the oaks, but the beeches, chestnuts and others. The nuts produced by members of this family are valuable food for domestic animals, and the tannic acid of oak bark makes it valuable in leather making, and some varieties furnish a beautiful yellow dye.

The *Walnut Family* includes the walnuts and the hickories. They have alternate pinnately compound leaves and monocious flowers, the sterile of numerous stamens in catkins, the fertile of a single pistil, and but few in a cluster. The calyx is adherent to the two-to-four-celled ovary which has only a single ovule. The outer part of the nut is the thickened calyx, the stone part the ovary walls, and the meat of the nut consists of the curiously crumpled cotyledons of the embryo. The wood of the walnut is highly prized for its beauty and durability. The bark and young branches are aromatic and strong scented, and from the bark a strong dye is made, and sometimes sugar is made from the sap.

The hickories have a white, tough wood much used as handles for tools, for parts of carriages, etc. Walnuts, butternuts, hickory nuts and pecan nuts are highly prized for eating.

The *Elm Family* is made up of trees and shrubs, with alternate two-ranked leaves which are usually rough entire and sharply serrate. The fruit is a one-celled, one-seeded *samara*, or winged fruit somewhat circular in form. Some of the elms are cultivated for ornament and some of them furnish a tough timber that is valuable when kept dry, or when kept continuously under water, otherwise it decays rapidly. The hackberry, the mulberry, and the osage orange are interesting and valuable trees that are closely allied to the elms.

The *Buckwheat Family* is represented in this country by a large group of herbs, having entire leaves with stipules in the form of scarious or membranous sheaths at the strongly marked joints of the stem. The flowers have a green or colored calyx, with the stamens on its base. The one-celled ovary ripens into an akene or nutlet, which is often triangular in form. Buck-

wheat is perhaps the most important member of the family, as its seeds furnish excellent material for food, and its honey producing flowers make it valuable to those who are raising bees. The rhubarb used in medicine and the well-known pie-plant are useful members of this family. Besides these there are knot-grass, smartweeds, sorrels, water pepper, and several kinds of Dock, belonging to this family, which are troublesome weeds.

The *Pink Family* includes some beautiful and interesting plants, but none that are of any great economic value. It is made up of herbs with opposite entire leaves, and regular flowers. The ovary is usually one-celled, with from two to five styles; it ripens into a many-seeded pod which opens at the top and contains a free central placenta. Stamens not more than ten, usually standing on the calyx. The petals with slender stalks or claws are also on the calyx. The calyx is composed of five sepals which are united below into a cup or tube on which the stamens and petals are inserted. Many varieties of pinks are cultivated for ornament and are much prized for their beautiful colors and sweet odor. The corn-cockle so injurious in the wheat fields is a member of the pink family, and so are the different varieties of the *catchfly*, which forms a sticky exudation on its stems and calyx by which small insects are caught. The *chickweeds*, which belong with the pinks, are mostly adapted to impoverished soils, sandy and gravelly wastes, etc. They are pioneers everywhere in nature's attempts to renew worn out soils and to clothe barren places with verdure.

The *Crowfoot Family* is made up mostly of herbs, growing more abundantly in the cooler climates and in moist localities. They have numerous stamens, usually more than one pistil, and distinct carpels. Sepals usually five, deciduous, often petal like; petals five, often wanting; plants usually with a watery acrid juice; leaves sometimes simple and entire, but often much divided; flowers sometimes regular, but often irregular. Many familiar plants belong to this family, as the clematis, hepatica, anemone, buttercup, the cowslip, columbine, larkspur, aconite,

peony, and others. Several of these are cultivated for ornament and some are used in medicine, as aconite, goldthread, etc., but no members of this family are of much economic value.

The *Magnolia Family* consists of trees and shrubs, with aromatic, bitter bark, alternate leaves mostly entire, and large, showy, solitary flowers, stamens and pistils numerous on a long receptacle, the pistils imbricated and cohering into a mass forming a cone-like fruit. The most important member of this family is the *tulip tree* or *white wood*, in some localities called poplar. It is a handsome tree with greenish-yellow flowers and dark green leaves. The leaves are broad, with two short side lobes and a truncate apex. The timber is white, soft and durable. The numerous species of magnolia are broad leaved evergreens noted for the beauty of their leaves and flowers, the latter yielding a rich perfume.

The *Water Lily Family* consists of numerous aquatic plants having large roundish leaves, which float on the water. The flower is large and showy, varying considerably among the different members of the family in color and arrangement of parts. The *water-shield*, growing in quiet water, has an oval, centrally peltate leaf, and a small purplish flower whose stem is coated with a clear jelly-like substance.

The *Nelumbium* has large root-stalks, large leaves, and large pale yellow flowers. The parts of the flower stand on a broad, top-shaped receptacle in which at maturity there are a dozen or more little pits, each containing an acorn-like seed. The seeds and the tuberous root-stalk are edible. The sepals and petals are numerous, passing gradually into each other so that one cannot tell where the calyx ends and the corolla begins. This plant is sometimes called the *lotus*.

The *white water lily* is a beautiful and highly prized flower with four sepals, but numerous petals, which pass gradually into the numerous stamens, and is given as an illustration of the fact that the stamens are changed leaves. The root-stalks are very large, and the fruit ripens under water. The *yellow pond lily* is a less showy flower than the others. It has six sepals and nu-

merous thick, yellow petals, the stigma forming a broad disk in the center of the flower. The Egyptian lotus and the *Victoria Regia* of the Amazon, with leaves three feet or more in diameter, belong to this interesting family.

The *Poppy Family* is made up of herbs which have a milky or colored juice. The calyx consists of two sepals which are deciduous; the petals and stamens are numerous, the ovary one-celled, ripening into a many-seeded pod. Several members of the family are cultivated for ornament. The juice of the *opium poppy*, furnishing the *opium* and *morphine* so much used in medicine, makes this one of the noted families of plants. The bloodroot, with its reniform, palmate-lobed leaf, its white petals, and its blood-red juice, is one of the most interesting flowers of early spring.

The *Cruciferae*, or *Mustard Family*, consist of a large group of herbs having a pungent watery juice and four-parted cruciform flowers. The cabbage, turnip, mustard, radish, water-cress and horseradish are members of this family which are used as food. Some are prized as ornamental plants, as candytuft and sweet alyssum, and others are troublesome weeds, as the shepherd's purse. These plants are widely distributed throughout the temperate regions, especially in southern Europe and southwestern Asia.

The flowers are much alike, having four sepals, four petals, with long claws and spreading blade; the stamens are tetradynamous, four long and two shorter. They have a two-celled ovary which forms a pod called a *siliqua*, or if short a *silicle*. These pods are two-celled by a false partition between the two parietal placentæ. It generally opens from the apex toward the base by the sides splitting off, leaving the partition with the placentæ and seeds. The flower cluster is a raceme, often a compound raceme. In this cluster each flower has a pedicel which is a branch of a common axis, the lowest blossoms being the oldest, so that often fruit may be found in the lower part of the cluster with buds at the top and all stages between. The flowers of the shepherd's purse are in a compound raceme, and the pod is a silicle. The root leaves are pinnatifid, and the stem leaves are

sagitate and partly clasping. The pod of the mustard is a silique.

Many of these plants, as the radish, are *biennials*, that is, they grow from the seed during one season, storing up in the roots some nourishment for the next season. During the second season they produce flowers, mature seed and die. Many plants live only one season, dying as soon as seed has been matured. Such plants are called *annuals*, while trees and many others live on from year to year and are called *perennials*.

The *Violaceæ* or *Violet Family*. The members of this family are well-known plants, highly prized for their beautiful flowers. The flower is irregular, with five sepals and five petals, which are more or less unequal, the lower one with a sack or spur at its base. The stamens are five, the broad, flat filaments, slightly cohering around the pistil. The somewhat showy flowers are seldom fertile. Another set of flowers, hidden under the leaves, produce most of the fruitful pods. These flowers are of a greenish color, and are more nearly regular than the more conspicuous ones above. The irregularity of the aerial flower is supposed to have some relation to insect agency in fertilization. Some of the violets send up flower stalks from underground stems, and some have aerial stems. This is a very interesting flower from its various irregularities, and a careful study of it according to the plan followed with the trillium would be a valuable and interesting work.

The members of the *Droseraceæ* or *Sundew Family* are interesting chiefly from the fact that they are carnivorous or insect eating plants. They are bog plants with regular flowers, on the plan of fives, having a tuft of glandular bristly leaves at the base of the stem, which in the bud are rolled up from the apex, after the manner of ferns. The common sundew has small roots with five or six root leaves spread out in a rosette around the base of the stalk. The upper surface of each leaf is covered with gland bearing filaments, each of which is crowned by a drop of a transparent viscid secretion. Insects are attracted to these leaves, and lighting on them are entangled by the secretion of the ten-

tacles or filaments, which by a curious waving movement transfer the insect to the center of the leaf where it is soon drowned in the liquid, and at length is digested and absorbed.

In the Venus fly-trap, the leaf with bristles on its edges and filaments on its surface shuts up like a book thus capturing insects, which are digested and absorbed. Neither of these plants are sensitive to wind or rain. The most vigorous leaves rarely digest more than twice, or at most three times. In these cases we have illustrations of movements in plants due to some kind of irritation that simulates very closely reflex action in animals.

The common *pitcher plant*, *sarracenia*, is carnivorous. The mouth of the trumpet-shaped leaves is protected by a lid, the inner surface of which is smeared with nectar, and in some cases a pathway, honey baited, lures the insect into the pitcher where they are soon drowned in the liquid secreted wholly or in part by the inner membrane of the leaf. This liquid does not digest the insect, but seems to accelerate decomposition, and if the plant gets any nourishment from the insect, it as a saprophyte, taking nourishment from decaying matter. There are several other pitcher plants which destroy insects, but their process is much the same as given above. The most extensive studies in this direction were made by Charles Darwin.

The *Linden Family* consists chiefly of tropical plants. It is represented in this latitude by the *lime tree* or *basswood*. It bears dull cream-colored flowers which are rich in honey. They are arranged in a cluster called a *cyme*, which is united to a long leaf-like bract; the fruit is a woody globular two-celled nut. The wood is soft, white, elastic, the inner bark rich in bast fibers. The dark green leaves are roundish, serrate and somewhat heart shaped at the base. It is a beautiful tree, much prized for its timber and as an ornament.

The *Mallow Family* consists of herbs, shrubs and trees that have alternate simple, palmately veined leaves, but are best known by their monadelphous stamens, which are united into a tube inclosing the pistil. The flowers are regular, sepals and petals five, and there is often an involucre of several green bracts,

resembling an outer calyx. In the mallow family the calyx is *valvate* and the corolla *convolute* in the bud. By *valvate* is meant that the edges of the parts meet without overlapping or infolding, while in the *convolute* arrangement one edge of each leaf covers one edge of the next, so that each leaf has one covered and one free edge. A cross section of a bud of a mallow blossom shows these arrangements nicely. Several members of this family are cultivated for ornament, as the hollyhock, abutilon, hibiscus and althea. But the family is best known from the *cotton plant*, which furnishes more material for cloth and other fabrics than all other plants. The cotton fiber consists of hairs which are developed on the surface of the seed; at first they are cylindrical, but on drying they become flattened and twisted, so that they are easily distinguished from other fibers. There are several varieties of cotton, the sea island cotton of our southern states being the finest in the world. The general superiority of American cotton is supposed to be largely due to climate. Cotton grows in all tropical countries, even as far north as Tennessee and Arkansas. Cotton was extensively grown and manufactured in India and Egypt centuries before the Christian era. The bast fibers of some of the plants of this family are valuable, and are much used in China, India and New Zealand. Besides the cotton fiber, the cotton seed yields an oil that from its cheapness is being extensively used for many purposes, adding much to the value of the cotton crop.

CHAPTER XXXI.

DICOTYLEDONS CONTINUED.

THE *Linaceæ* or *Flax Family* is composed of herbs, shrubs, and a few trees, but is represented in this country by the one genus of which the common flax is the only plant of economic value. The flowers are regular, opening for only one day, and the deciduous petals are especially delicate in texture and color. This plant rivals cotton in importance as a fiber producing plant. It grows best on the borders of the tropical regions, having a much wider range than cotton. The linen fiber consists of bast cells from the stem of the plant, and has been used from the earliest times. The oldest mummies of Egypt are wrapped in linen and its remains are found in the ruins of the Lake Dwellers of Switzerland and Italy.

The *Rue Family* includes the prickly ash, the hop-tree, the orange, lemon, citron and lime trees. The chief characteristic of the family is the transparent dots or glands in the leaves which contain a pungent aromatic oil. In some cases the juices are very bitter and in some cases acrid enough to blister the skin. The orange, lemon and citron are the most important members of the family.

The *Acerineæ* or *Maple Family* is made up of shrubs and trees that are prized for their beauty and for their timber, and the sap yields a sugar of a fine flavor. The flowers are sometimes perfect, sometimes dioecious; sometimes with petals, sometimes without. They appear in early spring, with or before the leaves, in drooping, umbel-like clusters. The fruit is a pair of samaras, or winged fruits, united at the base. The leaves are palmate-veined and palmately lobed or parted, and sometimes serrate. There are several varieties, as the sugar maple or hard maple, the soft

maple and the red maple. The hard and soft maples furnish excellent timber, much used in the manufacture of furniture.

The buckeye and the horse-chestnut, near relatives of the maples, have white, somewhat irregular flowers arranged in a conical cluster called a *panicle*, and large, palmately compound leaves.

The *Ampelidæ* or *Vine Family* consists mainly of woody shrubs or vines climbing by tendrils. The leaves are simple, rounded and heart shaped, sometimes lobed. In some cases the leaves and young shoots are covered with a cotton-like down. Flowers small and greenish forming a cluster called a *panicle*. The calyx is short, and connected by a thick disk with the ovary. On this disk the petals and stamens are inserted, five thick glands or lobes of the disk alternating with the stamens. The petals cohere slightly at the top and the corolla is thrown off without expanding.

The vine has been cultivated and used by man from the earliest times. It is indigenous to southern Asia and North America. There are many varieties. The best wine and raisin grapes grow in southern Europe.

The Virginia Creeper climbing by tendrils and rootlets belongs to this family. The flowers form a *cymose* cluster and the palmately compound leaf with five lance oblong cut tooth leaflets changing to crimson in autumn make it highly prized as an ornamental vine.

The *Euphorbiacæ* or *Spurge Family* is a vast group of more than 3,000 species, distributed through a wide range of climate, but growing most abundantly in tropical regions. They vary in size and habit from a tiny creeping plant to a giant tree. They usually have a milky, acrid, often poisonous juice, with flowers varying widely in structure, but the ovary and fruit are usually three-celled. Tapioca, castor and croton oil, caoutchouc and several valuable woods are furnished by members of this family. Many species, with thick succulent stems are cultivated for ornament.

The *Umbelliferæ* or *Parsley Family* is a large and widely dis-

tributed group of plants named from the fact that the small, five-parted flowers are grouped in clusters called *umbels*. The leaves are alternate, compound, and usually finely dissected. Many of these plants contain a poisonous juice, and in general the green parts are acrid and poisonous, while the seeds are aromatic and harmless. The parsnip, carrot, celery and parsley are food products of this family. Coriander, caraway, fennel, aniseed are aromatic and medical products, while gum asafoetida, poison hemlock, sweet cicely and others indicate the great variety of plants included in this interesting family.

The *Saxifrage Family* is made up of trees, shrubs and herbs, which are not marked by any distinguishing character. The leaves are opposite or alternate, pinnately or palmately veined. There are usually five petals, with from five to ten stamens. The calyx is generally monosepalous, and on it the petals and stamens are inserted. To this family belong the currant and the gooseberry, the syringia, hydrangea and the strawberry geranium, and other interesting and beautiful flowers.

The *Cactaceæ* or *Cactus Family* consists of succulent herbs, shrubs or trees, generally spiny and leafless. They grow mainly in dry regions, and the surface for evaporation has been reduced to the green rind of the stem, sometimes increased by a few branches or thick leaves. These plants are illustrations of the great changes in form which plants may undergo in adapting themselves to varied circumstances. The scanty evaporating surface and the protecting spines seem necessary to their existence. Many of these plants are cultivated as curiosities; some furnish edible fruits; the leaves of others furnish a valuable fiber. Some varieties instead of growing one year and maturing seed the second, grow for eight or ten years, and then send up a flower stalk from ten to twenty feet high, mature seed and die. In Mexico as the flower stalk of the pulque plant begins to grow, it is cut off and a bowl-shaped cavity made from which the juice, designed for the growth of the flower stem, is gathered for use by man. It is the Mexican pulque, and from it a distilled liquor, called mescal, is made.

The *Rosaceæ* or *Rose Family* is divided into several tribes, each of which contains interesting plants or shrubs. The Tribe *Pomæ* includes the apple, pear, crab apple, and quince, hawthornes, etc. They have simple leaves, two to five ovaries, which in the fruit are covered by the thick walls of the calyx tube.

The Tribe *Roseæ* includes the Roses, which exist in great variety. They have pinnately compound leaves with entire serrate leaflets. The calyx is five parted with a globose fleshy tube, which incloses the pistil. The corolla consists of five petals, which are greatly multiplied by cultivation, and the stamens are numerous.

The Tribe *Potentilleæ* includes the potentillas and the strawberries. They have palmate or pinnately compound leaves. Many of the potentillas are cultivated as ornaments, and the different varieties of strawberry furnish a delicious fruit, which is the enlarged and softened receptacle covered with the seeds or akenes which are the real fruit.

The Tribe *Rubeæ* includes the raspberries and the blackberries. The raspberries are clusters of little stone fruits, while the blackberry is a cluster of stone fruits with the receptacle on which they stand. They are usually shrubs with prickly stems and compound leaves.

The Tribe *Pruneæ* includes the almond, peach, apricot, plum, and cherry. They have simple, usually serrate leaves, and their stems and fruit yield a gum. The inner part of the ovary wall hardens into a stone inclosing the kernel or seed; the outer part forms the edible portion of the fruit. The wild cherry of the United States furnishes a timber much prized for its beauty and durability. No other family of dicotyledons furnishes as large quantities and as great a variety of fine fruit as does the rose family, and it easily leads all others in the beauty and fragrance of its flowers.

The *Leguminosæ* or *Pulse Family* is made up of herbs, shrubs, and trees, with alternate and usually compound leaves, and more or less irregular flowers. The stamens are ten, generally monadelphous, forming a tube inclosing the pistil; sometimes diadel-

phous, nine in one set and one in the other; and very rarely the stamens are distinct. This great family, containing some 6,000 species growing in all parts of the world, is divided into three subfamilies.

The *Papilionaceæ* includes the pea, bean and peanut; the lupine and the clovers; the locust, rosewood and many other fine trees; indigo, camwood and other dyes; the gums tragacanth and kino; the balsams of Peru and Tolu; and the plant that yields the medicinal product, liquorice, and species that yield good fiber, besides many species that are cultivated for ornament, as the laburnum and wistaria. The name is derived from the corolla, which is composed of five petals of such form and arrangement as to resemble a butterfly. The petals of this corolla have received special names. The upper and larger one, which is generally wrapped round the others in the bud, is called the *banner*; the two side petals are called the *wings*, and the two lower ones, the blades of which usually stick together inclosing the stamens and pistil, are called the *keel*.

The *Cæsalpinieæ* includes the honey locust, coffee tree, and judas tree of the United States, and many valuable timber trees from the tropical regions, as well as many dye-woods, and others that produce valuable gums and balsams. The members of this group have a somewhat irregular corolla, with usually ten distinct stamens, and often twice pinnately compound leaves.

The *Mimoseæ* have regular flowers, distinct stamens, and twice pinnate leaves. The most important product from this group is gum Arabic or acacia, and the different varieties of acacia furnish very fine lumber highly prized for furniture, veneers, and ornamental purposes generally. Some members of this group are especially interesting on account of the movements executed by their leaves, expanding in the light, closing in darkness, or upon the slightest touch or jar, opening again in a few moments. *Mimosa pudica*, is so prompt in its movements that it is called the sensitive plant; numerous others are more or less sensitive. As a whole the pulse family is interesting, important, and well worthy of study. The common bean plant is a good specimen

from which to study the characteristics of the dicotyledons; the same general plan may be followed as in the study of the trillium and oat. The bean plant can be grown easily at any time of the year, and its whole life history can be studied easily by starting a number of plants, and examining different individuals in the various stages of germination, growth and maturity.

The *Ericaceæ* or *Heath Family* is composed mainly of shrubby plants which have monopetalous regular or irregular flowers, and the calyx tube sometimes free and sometimes adherent to the ovary. This family includes the huckleberry, cranberry and blueberry; the wintergreen, trailing arbutus, laurel and other beautiful flowering shrubs.

The *Solanaceæ* or *Nightshade Family* includes the potato, tomato, and tobacco; red pepper, henbane, belladonna, bitter-sweet, and other important plants. These plants have regular monopetalous flowers, a two-celled many seeded ovary, and generally a colorless poisonous juice, with a strong unpleasant odor; many of them are cultivated for their beautiful flowers. While this family is important and interesting, it is peculiar, presenting many sharp contrasts. The potato and tobacco, natives of America, are now cultivated and used in all parts of the earth.

The *Figwort Family* is made up mostly of herbs and shrubs, with a more or less irregular monopetalous corolla and a two-celled ovary. There is often an interesting irregularity among the stamens, only a portion of them bearing anthers. In the pentstemons and others there are four anther-bearing stamens, the fifth represented by a barren filament or a scale. The family includes many plants that are cultivated for ornament, as the pentstemon, castilleia, veronica and others. *Digitalis*, used in medicine, and many coarse weeds are also members of this family. These plants are widely distributed from the tropics to the limits of vegetation towards the poles. A castilleia and a mustard were found at higher elevations on Mount Orizaba than any other flowering plants.

The *Labiataæ* or *Mint Family* consists of square-stemmed,

opposite-leaved aromatic plants, with an irregular corolla and didynamous stamens, and a deeply four-parted ovary. It includes lavender, hyssop, peppermint, sage, catnip and other interesting plants, but none of great economic value.

The *Oleaceæ* or *Olive Family* is composed of trees and shrubs, with simple or pinnate leaves, regular flowers, two stamens, and two-celled ovaries. It includes the olive, which yields fruit, oil and lumber, the different varieties of ash, which yield good timber, and some ornamental shrubs, as the lilac, jessamine and others.

The *Asclepiadaceæ* or *Milkweed Family*. The members of this family are woody or herbaceous plants with an abundant milky juice. The flowers are regular, calyx and corolla five parted; the two distinct ovaries have a common stigma; the five stamens monadelphous, the anthers closely surrounding the stigma and partly adhering to it. The pollen is in waxy masses which are distributed by insects. The structure of the flower is peculiar and difficult to describe, but exceedingly interesting to study, the structure no doubt having reference to cross fertilization by the aid of insects. The flowers are arranged in *umbels*; the fruit consists of a pair of pods containing many flat seeds, which are furnished with a tuft of soft, silky hairs, called a *coma*, at one end. The milky juice contains caoutchouc, and some plants are cultivated for ornament, but the plants are chiefly interesting for the peculiar structure of their flowers.

The *Gourd Family* is made up of tendril bearing herbs, with watery juice, alternate palmately ribbed and lobed leaves, and monopetalous flowers. It includes the gourd, pumpkin, squash, watermelon, muskmelon and the cucumber.

The *Compositæ* or *Sunflower Family*. This immense family including as many as 10,000 species has representatives in all parts of the world. Many of the species are of great beauty and are much admired as ornaments, but few are of any economic value. The small monopetalous flowers with their syngenesious anthers are gathered into compact heads or masses which often resemble single flowers. The tube of the calyx is coherent with

the ovary, its margin, consisting of rigid or downy bristles, teeth or scales is called the *pappus*. The end of the stalk on which the simple flowers stand is the receptacle. The greater part of the flower cluster is made up of tubular flowers, but often around the margin of the cluster there are flowers whose corollas have extended into a strap or leaf-like form called *rays*, which in many cases seem to be the petals of ordinary flowers. Some well-known members of this family are chickory, lettuce, dandelion, sunflower, golden-rod, chrysanthemum, thistle and burdock.

CHAPTER XXXII.

FORM, COLOR AND ODOR OF PLANTS.

PLANTS seem to differ widely in structure and in the processes of nutrition and reproduction, but a careful investigation shows that all plants are composed of essentially the same elements, so that the processes of nutrition must be about the same among all. And so with the process of reproduction, it is simply the formation of new cells, whether in the humble protococcus or in the stately oak. And the same is true in the matter of structure; every plant structure, however complicated, is made up of modified parenchyma cells. We have thus far studied typical members of different groups of plants, from which the plant world might seem to be composed of several distinct parts. When we try, however, to find the dividing lines between the groups, they continually evade us, one group seeming to merge into another by such insensible degrees that the idea of distinct parts soon fades away, and we are more impressed with the fact that the plant world is essentially a unit.

The plant world, then, is practically a unit in its structure, in its processes and in its relations. But why, in that case, the wide differences in form, color, odor and habit of plants? If we accept the theory of special creation, nothing came by chance, each peculiarity of form, each shade of color, each odor means something, nothing depends upon accident—the form, color and odor of each particular flower are, all things considered, the best possible, no others would do. Again, if we accept some form of the theory of evolution or development the same thing is true. Every peculiarity which distinguishes one group of plants from others is supposed to be beneficial to that group. Such peculiarities are not the result of caprice or chance, but of purpose.

The air with its changing temperatures, the water with its multiform impurities, the soil with its different qualities, the existence of other plants and animals, all constitute an endless variety of conditions under which plants exist; and which plants have been made to fit, either by their creation in special forms, or in a form adaptable to all the different conditions that might arise. And perhaps here lies the answer to our query—the form, color, fragrance and other peculiarities of plants are, or may be, determined by their surroundings.

The lowest groups of plants, those which are supposed to have appeared first on the earth, are water plants, or are active only when surrounded by an abundance of moisture. The air and water contain all the nutriment necessary to these, so that there is no call for special organs of nutrition, each cell performing all the functions of a plant, and as there is no division of labor the whole body is an organ of nutrition, and of reproduction as well. The ability to survive long periods of dessication, as in the case of *protococcus* and many others, implies some modification, some improvement over the organism of strictly aquatic plants.

As the rocks were broken down and pulverized into soil, plant life began to appear on the land. But water, one of the essentials of plant life, was not now present on all sides; the supply was in a sense limited, coming mainly from the soil below. It was not necessary for the upper surface to be fitted to absorb moisture, but it was necessary to so cover it as to prevent the evaporation of moisture, and hence the plant is differentiated into parts, consisting of a body from whose under surface roots are developed to take up moisture and other nourishment, and on the upper surface an epidermis is formed which protects the body from excessive evaporation.

Another interesting modification arose when plants, as *spirogyra*, in addition to reproduction by simple division became able to form resting spores, which enabled the species to survive extreme cold or drought, thus greatly extending the range of plant life. These examples illustrate the first steps in the differentia-

tion of organs, and in the division of labor, which exist so fully in the higher plants.

As the conditions became more favorable and plants increased in size, a fibro-vascular system became necessary to strengthen and support the plant, and to convey nutrient fluids to all its parts. As plants grew more numerous the supply of light and air became somewhat limited, the fibro-vascular system was strengthened and an erect form was acquired, thus greatly increasing their opportunity for these essentials of plant life.

The change in form and habit resulting from this struggle for light and air, is often very marked. Trees growing singly in the open field are shorter, thicker and have a relatively broader foliage system than trees of the same species growing in a crowded forest. The purslane, which is usually a prostrate creeping plant, when crowded by other plants will assume an erect position, rising to seek the light.

Coincident with this growth of the stem, the leaves were developed from the vascular system, parenchyma, and epidermis, and so arranged as to serve for digestive organs. As the work of digestion or assimilation can only be carried on in the light, we can easily understand that the struggle for light involves the life or death of the plant. This struggle may account for many interesting forms of plants; as vines climbing up the stems of sturdier plants, in whose shadow they could not live, to expand their leaves in the life-giving light above. In some cases climbing plants become air plants, able to derive nourishment from the air, or parasites, living on the juices of the host plant, in either case having no use for a stem connecting with the ground. In this way plants become permanent residents amid the branches of trees, so that a tree often appears to produce several kinds of foliage. Thus the common ivy, sometimes becomes an air plant, gathering nourishment from the air and from its support.

In some flowers the stamens and pistil or pistils are so arranged that self-fertilization is possible, but in general self-fertilization is difficult or impossible, so that most flowers are fertilized by pollen from other flowers. The pollen grains are carried

to the stigmatic surfaces by the wind, by insects, or in rare cases by birds.

The grasses, sedges, pines, oaks and others, having small uncolored flowers, produce great quantities of pollen. As this floats easily in the air it is widely distributed by the wind, so that while there may be instances of self-fertilization, cross-fertilization is the rule. Other plants have highly colored flowers producing nectar, which attracts such insects as bees, butterflies, etc. The insects, in their excursions from flower to flower, carry pollen from one blossom to the stigma of another. And this is by no means a matter of accident or chance; in many cases the flower and insect are so adapted to each other that only a particular insect can get nectar from a particular flower, and aid in its fertilization. One case of many may be mentioned; the *yucca* in southern climates, ripens its seeds regularly, but while it thrives well in the north it does not mature seed. In the south a little moth called the *yuccasella* gathers up masses of *yucca* pollen, and laying its eggs in them thrusts them down a stigmatic tube and thus fertilization is accomplished. The *yuccasella* cannot or does not live in the north and the *yucca* ripens no seed in that region.

It is said that cats saved the clover crop in a certain district in Australia. The cats caught the mice that destroyed the nests of a long-billed bumble bee, which was the principal agent in the fertilization of the clover blossoms. The orchids with their beautiful flowers of grotesque forms afford many interesting illustrations of mutual adaptation and dependence between flowers and insects.

The flowers are fertilized, the seeds have ripened and are ready for the soil; if they fall near the parent plant only one or two could find room for growth, so that it seems necessary for seeds to be scattered widely. This is accomplished in various ways; the seeds of the maple and elm are furnished with wings, those of the thistle, dandelion and milk-weed with plumes so that they may be dispersed by the wind. The seeds of many plants are furnished with hooks by which they may become attached to

animals and are distributed in their wanderings. The seeds of other plants are inclosed in edible fruits and are scattered by the animals using the fruit for food. In some cases the seed pod at maturity opens with a jerk throwing the seeds some distance.

Many plants, as the strawberry, multiply not by means of seeds alone, but send out runners which, rooting at the tips, develop into new plants. Again other plants send up new plants at intervals along an underground stem; such plants are more commonly found in sandy soils.

In general plants seem to spread out as much surface as possible for evaporation, but in the case of the cactaceæ and some of the spurges living in hot dry regions, this surface is much reduced, seemingly as a protection against excessive evaporation. Many plants living in cold climates are protected from cold by a thick growth of hairs, which frequently disappear when such plants are acclimatized to warm regions. Buds, the embryos of the next season's branches and flowers, are often furnished with coats of down or wool, and covered with thick varnished scales so that they are protected from moisture and sudden changes of temperature. Again, thorns, spines, prickles, stinging hairs, acid and bitter juices, etc., seem to serve plants as a defense against animals.

Some trees, as the red or soft maple, when cultivated will grow vigorously on the highland, but when left to their own resources other trees soon crowd them into the lowlands along the streams, resulting in more or less change of form. This is an illustration of the struggle going on between plants everywhere, by which many seeds have no chance to grow, and many plants which begin to grow are smothered out or stunted by stronger plants or are crowded into undesirable localities.

Some spreading plants creep out over rocks or barren places, dust collects along their stems, and mingling with the decaying leaves forms a soil in which other plants may grow, as illustrated by vegetation advancing over brick walks, and similar spaces. Often soil is formed in this way that is deep enough to support

forest trees. Sometimes lichens or algæ are the pioneers in such invasions, which are often very rapid in tropical regions. It is said that an island of lava, from the eruption of Krakatoa was covered from shore-line to summit with an abundant vegetation of ferns and allied plants within six years after the eruption.

The succession of plants on a tract of land that has been cleared and then allowed to go to waste is interesting. In one case a bit of pine forest had been cleared away and the land abandoned. It was soon covered with weeds and grasses, then quaking aspen and other woody plants began to smother out the herbs, and it seemed as if the aspen was the natural occupant of the soil. After a time, however, little pines began to grow; these grew larger and others started; the aspens began to decay, and in less than thirty years the pines were again in full possession of the ground.

The illustrations given may serve to suggest a possible explanation of many peculiarities of form and structure, of color, odor and other characteristic features, which exist among plants, and to indicate interesting and profitable lines of study and investigation, which may be pursued in almost any locality.

The collection and preservation of specimens is an important part of botanical work. A specimen, to be of value, should show roots, stem, leaves, buds, flowers, fruit, all with color and form as perfect as possible. And the label should show the locality and any peculiarity of position or surroundings that might in any way modify the character of the plant, and any peculiarity of the plant that cannot be preserved should be noted.

Most herbaceous plants may be preserved by drying them under pressure. The plant, with its leaves and other parts, should be carefully arranged in a fold of paper, and then subjected to pressure in a discarded book or some kind of a press, which may consist of two boards with a weight of stone. The plants should be aired frequently until they are thoroughly dry. A few trials will enable one to make good specimens of most herbaceous plants. In the case of some succulent plants much

care is necessary to prevent them from decay or from becoming mouldy.

Parts too thick or heavy for drying may be preserved in alcohol, or may be described in the label and not preserved. Lichens may be dried and kept in boxes without pressing. Mosses, liverworts and algæ, when it is desirable to preserve color, should be immersed in glycerine or Müller's solution.

When dry, the specimen may be transferred to a sheet of heavy paper and fastened by strips of gummed paper, and the label should be written on the paper or fastened to it in some way, so that it may not be lost or separated from the specimen. The size of the sheets commonly used for specimens is thirteen or fourteen inches long by ten to eleven inches wide.

CHAPTER XXXIII.

ZOÖLOGY—GENERAL AND STRUCTURAL.

THE science of zoölogy treats of everything relating to animals. It considers their external form, anatomical structure and physiological processes, their geographic distribution and economic value. It attempts to trace out the life-history of animals from the lowest to the highest forms; it considers also their relations to one another, to the members of the vegetable kingdom, and to other forms of environment.

The animal body is made up of about the same elements found in the plant, but the proportions are different; in animals the albuminous and calcium compounds predominate. From these compounds the different tissues of the body are formed, and the tissues variously modified and combined constitute the organs of the animal body, which may be divided into the organs of the mechanical system, the organs of digestion, circulation, respiration and excretion, the organs of reproduction and of the nervous system with those of the special senses. To trace the development of these different groups of organs and to follow out the processes carried on by them is an important part of the work of zoölogy.

The living portion of the animal, as of the plant—that which moves, assimilates food and grows—is protoplasm, and an individual portion of protoplasm, called a cell, is the unit of all animal structures. The cell consists of a small portion of protoplasm which is frequently surrounded by a structureless membrane. It usually contains a nucleus, which may contain a nucleolus. The nucleus may take different forms, but it always contains the nuclear fluid and the nuclear substance, each of which is of a protoplasmic nature.

Free, isolated cells exist in the blood, chyle and lymph. Those

occurring in the blood of the invertebrates, or lower animals, and some of those found in the blood of vertebrates, are colorless, irregular in form, having the capacity of movement. They can push out processes and draw them in again, by which means they change position. They originate in the lymphatic glands, and pass into the blood with the lymph. Others found abundantly in the blood of vertebrates have a regular form usually containing a reddish pigment, *hæmoglobin*, which gives color to the blood and is an important agent in the process of respiration. The ova and spermatozoa, active agents in the process of reproduction, are free cells differing widely in form and size.

The tissue covering the free surfaces of the body, whether external or internal, is called *epithelium*. The cells forming this tissue are cylindrical, ciliated, or flattened, making cylindrical, ciliated or pavement epithelium. The cells of the lower layers of this tissue have a semifluid consistency, and are active, continually multiplying by division and growing, while those of the upper layer are less active and more firm in substance, which, finally losing their vitality, are thrown off, to be replaced by others from the layers below.

On the outer surface of the body the upper cells of this tissue, as thick horny layers form claws, nails and hoofs, they form the leathery skin of insects, and with a little calcareous matter they constitute the hard shell or outer covering of the crawfish and lobster. Feathers, hairs, bristles, scales and the horns of some animals, are the outgrowths of the tissue covering the body.

The epithelium covering the internal surfaces of the body secretes a fluid which keeps the tissue moist, and facilitates the movements of objects over its surface. Sometimes tubular, flask-shaped or branching cavities called *glands* are formed in this tissue, which secrete special fluids, as the saliva, gastric juice, etc.

The *connective* tissue, made up of cells separated by various kinds of intercellular substance, is an important part of the body. In some cases the intercellular substance consists of white inelastic fibers, forming a tissue from which the ligaments and tendons

are made, and which invests the bones, muscles, nerves, etc. Sometimes these fibers form a network which serves as the basis of the skin and the fatty tissue.

Cartilage with spherical cells and a firm intercellular substance is another variety of connective tissue. Sometimes the intercellular substance contains a network of fibers, forming a fibro-cartilage, and there are numerous other intermediate forms.

When calcareous matters are deposited in the intercellular substance of cartilage, it becomes *osseous* tissue. This bony substance is traversed by numerous canals, through which nutrient fluids may pass to the cells. Sometimes the bones grow in thickness by the deposition of calcareous matter in the inner layers of their investing membranes.

The protoplasm of the cell has the power of contractility, but some aggregations of cells possess this in a high degree, giving rise to the *muscular* tissue, which is the chief agent in all the movements of the body. When acting, these cells change their form, becoming shorter and broader than when at rest, thus causing the muscle to contract. Two kinds of muscles are recognized, the smooth and the striated. The smooth muscles are made up of flat, spindle-shaped or band-shaped cells, and are somewhat sluggish in their action. They are more common among the invertebrata, but constitute the involuntary muscles of the vertebrata. The striated muscles are made up of elongated cells or fibers, across which there are minute lines giving them a striped appearance. These muscles are more prompt and energetic in their action than the smooth muscle, and are usually under the conscious control of the animal.

The *nervous* tissue is made up of cells and fibers, which differ not only in form, but in structure and chemical composition. The cells usually contain a nucleus and nucleolus with a fine granular substance, and have one or more branches, one of which is continued into a nerve fiber. The fibers consist of an axis cylinder or thread of grayish matter, covered by a sheath of whitish fatty matter, which in turn is covered by a sheath of connective tissue; such fibers are called medullated fibers. Sometimes the

axis cylinder is naked, having no sheath, and sometimes it has only the sheath of connective tissue.

A group of nerve cells with their branches forms a *ganglion*. The brain and the spinal cord are simply groups of ganglia. Nerves are made up of nerve fibers; one set serves to connect various sense organs located in the outer surface of the body with the brain and spinal cord, and another set connect the brain and spinal cord with the muscles.

The lowest organisms consist of a single cell; the body is the protoplasm and the cell membrane is the skin. The skin absorbs nutriment and removes waste, the protoplasm assimilates material and grows. But as the organism grows, the body increases in three directions, while the skin expands only in two directions, so that, finally, the area of the skin is relatively too small to furnish material for the growth of the body. Thus the size of a cell or a one-celled animal is limited. If the organism increases in size it does so by dividing into several cells which arrange themselves so as to give the largest extent of surface, eventually forming a cup-shaped organism with an outer and inner surface. In the outer layers organs of motion and sensation, of respiration and excretion are developed, carrying on the animal functions and some of the vegetative; while the inner layers or cavity receives and digests the food. Thus with an increase of size comes a greater complexity of organism, and the essential characteristics of the animal.

The more highly developed the organs, the more complete the division of labor, the better the work done by each organ and the higher and more perfect the life of the organism. The organs are not only correlated in size but in form, so that from one organ a good idea of the size and form of the organism may be made out.

The *digestive* apparatus, at first a mere cavity, then a tube which at length became separable into three parts, the fore part for the reception of food, the middle part for its digestion, and the hind part for the expulsion of the indigestible portions. Then a mouth with masticatory or sucking organs and salivary glands is developed at the fore end of the tube, and from the fore

part of it the stomach with its glands and accessory organs is formed. From the middle part, that portion of the intestine in which digestion is completed, by the action of fluids from the *pancreas*, *liver*, and *intestinal glands*, is derived, and from the hind part that portion of the intestine concerned in the collection and expulsion of undigested portions of food had its origin.

The liver and pancreas appear to be outgrowths of the alimentary canal which have become glands. The liver, distinguished for its relatively great size and weight in the higher animals, has been developed from a little patch of colored cells. The secretion of the liver sometimes aids in digestion and sometimes it does not.

Among the lower forms of animals no *circulatory* system is necessary, as the digestive cavity extends to all parts of the body; but in animals of a little higher grade the chyle or nutrient fluid circulates in the space between the wall of the digestive cavity and the body wall, doubtless due to the ordinary motions of the organism; later a particular portion of this tract acquires a muscular structure, which as a special organ maintains the circulation. Between this and the double heart of the mammalia, with its systems of arteries and veins, all gradations may be found.

The *respiratory* organs are appendages of the circulatory system, arising from arches of the greater arteries, gradually developing from simple tubes, the gills of fish and the tracheæ of insects, to the capacious lungs of the warm-blooded mammalia.

The respiratory organs are to some extent excretory organs, but the most important excretory organs are the *kidneys*. In the lowest animals they are represented by contractile vacuoles; in the worms they are known as water vascular vessels, and sometimes they are mere appendages of the lower intestine, while in the higher animals they are independent organs made up of a great number of narrow coiled tubes with an abundance of blood vessels. They separate from the blood broken down albuminous matters. The skin is also in some sense an excretory organ, while

the sweat glands and sebaceous glands serve to equalize temperature and keep the skin moist and supple.

The systems of organs already mentioned are all concerned in the process of nutrition or the vegetative functions. The organs of locomotion and sensation, however, belong to the phenomena of *animal* life. The organs of locomotion vary from the *cilia* of some protozoa, and the muscular walls of worms to the complicated *mechanical* apparatus of the vertebrata. The bones and other hard parts which assist in locomotion frequently serve as protecting organs for more delicate structures.

Among the higher animals the organs of sensation, in addition to the brain and nerves, consist of certain peculiar-shaped bodies of nervous tissue, which are called the end organs of certain nerves, as the *rods* and *cones* of the eye, the *auditory hairs*, *olfactory cells*, *taste bulbs*, and *tactile corpuscles*. Each of these has accessory organs which serve to protect them and at the same time aid them in gaining impressions of the outside world. These organs appear in various forms among the lower animals, and some of them are occasionally wanting.

Animals of the lower orders multiply by division and by budding, but some form of sexual reproduction is more common among animals. Sexual reproduction depends on the formation of two kinds of germinal cells, the combined action of which is necessary to the development of a new organism.

One of these cells contains the material from which the new individual grows and is called the *ovum* or *egg cell*; the other called the *sperm cell* contains the fertilizing material, which fuses with the contents of the ovum and in some unexplained way causes its development. The structure of the sexual organs varies widely among the lower animals.

The simplest and most primitive case is where the ovum and sperm cell are produced in the same individual; this is called the hermaphrodite arrangement, and while it occurs in almost every group of animals, the two cells are more commonly produced by different individuals. Sexual reproduction is in reality a special form of growth, as the egg cell sometimes undergoes

spontaneous development without fertilization. This frequently occurs among insects. Alternation of generations sometimes occurs among animals as with plants.

The ovum is a cell composed of protoplasm and containing a nucleus or germinal vesicle. In the ripe ovum a portion of the vesicle with some of the protoplasm is forced out of the egg cell forming the polar cells, the remaining portion as the female *pronucleus* fuses with the spermatozoon or male *pronucleus* and the resulting body is the nucleus of the fertilized ovum.

After fertilization the ovum divides into a great number of cells, the mass for a time retaining a spherical form; but at length, by invagination, one side is pushed or drawn in so that the mass has a flask shape, with an outer layer of cells, *ectoderm*, and an inner layer called *endoderm*, and between these layers a third is formed called *mesoderm*. The skin, the nervous system, and sense organs of the embryo are formed from the ectoderm. The muscular system, the connective tissues, the corpuscles of the lymph and blood, and the vessels carrying the fluids of the body, all arise from the mesoderm. The lining membrane of the digestive cavity and of the glands opening into it are derived from the endoderm; while the urinary and generative organs arise from all three of the layers. The formation of the ovum and its development is much the same among all classes of animals.

CHAPTER XXXIV.

PROTOZOA, CŒLENTERATA, ECHINODERMATA AND VERMES.

ANIMALS may be separated into nine groups or divisions, as follows, beginning with the lowest:

(1) PROTOZOA.—These are animals of minute size composed of a nearly structureless substance called sarcode, having no cellular organs, and usually asexual reproduction.

(2) CŒLENTERATA.—The cœlenterata are radiate animals, on the plan of two, four or six, having a central body cavity common to digestion and circulation.

(3) ECHINODERMATA.—The echinodermata are radiating animals generally on the plan of five, with a calcareous dermal skeleton or shell, often armed with spines, and having alimentary, circulatory and nervous systems.

(4) VERMES.—The vermes or worms are bilateral animals, without limbs, and with paired excretory canals, sometimes called the water vascular system.

(5) ARTHROPODA.—The arthropoda are bilateral animals with the body divided into segments, which carry jointed appendages or limbs, and they have a well-developed nervous system, as insects, spiders, crawfish, etc.

(6) MOLLUSCA.—The mollusca are bilateral animals with a soft unsegmented body inclosed in a single or bivalve shell, as the oyster and mussel.

(7) MOLLUSCOIDEA.—The molluscoidea are bilateral unsegmented animals with a ciliated circlet of tentacles. They usually have a hard shell case and one or two nervous ganglia.

(8) TUNICATA.—These are bilateral, unsegmented animals with barrel-shaped bodies, having a simple nervous ganglion with a heart and gills.

The divisions mentioned are sometimes grouped together as the invertebrata.

(9) VERTEBRATA.—The vertebrata are bilateral animals with an internal cartilaginous or bony skeleton, prominent in which is the vertebral column, which serves as a protection for the highly developed nervous system.

This scheme of classification is more or less incomplete and artificial. The knowledge of the animal kingdom is not sufficient to enable zoölogists to work out a natural system, if, indeed, such a system exists in fact.

The *Protozoa*, the first or lowest animals, like the protophyta, live in the water, and so much alike are these lowest plants and animals that in many cases it is difficult to determine whether a given organism is an animal or plant. One of the simplest forms of animal life is the *amœba*. This minute animal may be found on the submerged leaves of plants or in the mud at the bottom of stagnant water. It appears much like a piece of jelly, nearly colorless, often granular, and more fluid in its central portion. When active, they are constantly changing form, thrusting out rays or arms, called *pseudopodia*, from one part or another of the mass. In the larger pseudopodia the granular matter passes in a stream toward the extremity and back again, the circulation probably caused by the contractility of the protoplasmic mass. By means of the pseudopodia the animal creeps slowly along, but in no definite direction. The *amœba* has no mouth or stomach; it flows around its food, digests and absorbs such parts as it can use, then flows away from the undigested parts. Besides the granular matter they often contain a rounded body called a nucleus, and sometimes a contractile vesicle. The *amœba* multiplies by simple division as in the case of protococcus. The *amœba*, a little mass of protoplasm without organs of any kind lives, moves, absorbs oxygen, expels carbon dioxide, eats, grows and reproduces its kind—in short, appears to be a complete organism.

The *foraminiferæ* are much like the *amœba*, except that they secrete a calcareous shell. The earliest and oldest fossil known is supposed to be a member of this group. The shells of these

minute animals are the chief constituent of thick beds of limestone rocks, as the chalk cliffs of England and nummulitic limestone of France. They are exclusively marine animals, and good specimens of their shells may be obtained by shaking a sponge that has not been treated with acid.

The *radiolaria* are marine animals whose body contains a capsule in which are oil globules, albuminous bodies, and sometimes concretions, with vacuoles and granules. They secrete a silicious skeleton or shell. Their skeletons have given rise to extended rock formations.

If some vegetable or animal substance be soaked in water for a few days, the water will be found to contain a large number of different kinds of microscopic animals called *infusoria*. Among them may be vorticella, paramœcium, stentor and others. One group of the infusoria is especially interesting on account of their close relationship to some of the algæ. They consist of a colony of cells united by a gelatinous substance. In the inactive stage they possess a cellulose membrane, exhale oxygen and have an abundance of chlorophyll, and reproduce by simple division. During the active stage the cells give rise to daughter colonies. They are called *volvocinidæ*, and the most common is *volvox globater*. Some of the infusoria swim freely by means of their cilia; others, fixed in one locality, create currents in the water by the action of their cilia, thus bringing more food within their reach. The usual mode of reproduction is by self-division, sometimes by budding and sometimes by conjugation, the nucleus and nucleolus taking an important part in the process.

The *Cœlenterata*.—Among the cœlenterata we find organs and tissues composed of cells; they have external and internal epithelium, calcareous and silicious structures, with muscles, nerves and sense organs. To this division belong the sponges, which are composed of a contractile substance made up of amœba-like cells supported by a framework of horny fibers, or of calcareous or silicious spicules. The sponge is traversed by numerous canals, which open on the surface by larger or smaller openings. At numerous places in the sponge there are little cavities or pas-

sages which are occupied by ciliated cells, which, by the motion of their cilia, keep up a circulation of water through the sponge. Reproduction in the sponges takes place by division, by the formation of gemmules, and by the formation of ova and germ cells. The fertilized ova develop into embryos which are provided with cilia, by means of which they swim about until they find some suitable resting place. *Spongilla fluviatilis* is common in freshwater ponds; all other sponges are found in salt water. The sponges of commerce are the horny framework of the sponge, and come mainly from the Mediterranean sea. These sponge colonies vary greatly in form; one can often find a half dozen distinct forms in the display basket of one drug store.

The *coral polyps*, or actinozoa, belong to this division. They consist of a cylindrical or club-shaped tube fixed at one end, having a mouth surrounded by tentacles at the other. They have internal generative organs and usually a calcareous skeleton. The sexes are usually separate, although hermaphrodite individuals are sometimes seen. The embryos are frequently born alive as ciliated larvæ. They also multiply by budding. The body has an ectoderm and endoderm and a mesoderm, which in some cases becomes the seat of calcareous deposits. Corals are radiate animals on the plan of four, five or six. They exist in great variety in the shallow waters of the tropical ocean, building extensive reefs; there are corals having the form and appearance of a human brain; there are branching corals and fan corals, etc. They are not only abundant in the seas of the present time but their calcareous skeletons have been the most abundant rock-forming material since the earliest geologic time.

The *Medusæ* have a soft gelatinous semitransparent bell-shaped body, the margin of which is fringed with stinging tentacles. Near the margin are nerve rings and sense organs as auditory hairs, and in some there is an appearance of eye-spots. The medusæ are the jelly-fish or sea-nettles so abundant in many parts of the ocean. Many if not all the medusæ are simply the free swimming form of some of the fixed polyps. The polyp gives rise to a bud which becomes a free swimming medusæ, while the egg or genera-

tive bud of the medusæ produces a polyp. The radiating parts are on the plan of four.

The *Echinodermata* are popularly known as sea-urchins, star-fish, feather-stars, etc. They are radiate animals on the plan of five, and have a rough, often prickly skin, which has the power of secreting calcareous matter. They have a distinct digestive canal with mouth and vent, and a water vascular system, and a true circulatory system are sometimes present. The nervous system consists of nerves running down the five rays from a ring surrounding the gullet. Sexual reproduction is the rule. These animals are inhabitants of the sea; are generally capable of a slow creeping movement by means of suckorial tubes, feeding mainly on mollusca and seaweeds. Many of them possess great reproductive power, being able to replace lost parts with all their apparatus of tubes, nerves, etc.

The *Crinoids*, during the whole or a portion of their existence, are fixed by a jointed flexible stalk largely composed of calcareous matter. The radiating feather-like arms give the organism something of the appearance of a flower, hence the name, meaning lily-form. The crinoids have been very abundant since early geological times, their stems and crowns contributing largely toward building up great beds of limestone.

The *Star-fish* are characterized by their obviously star-shaped body, the stomach, reproductive organs and the nervous system all having the radiate arrangement. The color is yellow, orange or red, the upper surface leathery, roughened by calcareous plates, tubercles and spines. The mouth is below and the rays are furrowed underneath, having numerous holes through which pass the sucker-like tentacles or feet which serve as organs of locomotion and prehension. They are voracious, and the most destructive enemies of the oyster.

The *Brittle-stars* are similar to the star-fish, but the long arms are mere appendages of the body and do not contain any portion of the digestive canal.

The *Sea-urchin* varies in form from a sphere to a disk. The shell is composed of numerous calcareous plates, the whole cov-

ered with numerous tubercles, to which spines of varying lengths are jointed. The mouth on the underside is armed with a complicated apparatus of calcareous teeth. From the stomach proceeds a long convoluted intestine, attached to the interior of the shell by a delicate membrane or mesentery. The surface of the mesentery and the lining membrane of the shell are furnished with cilia, and by their motion the fluids of the body cavity are kept in circulation, and in this way respiration is effected, and, in some cases, they are provided with branched respiratory tubes. The reproduction is sexual, the fertilized ova forming ciliated free swimming embryos which pass through a complicated development.

The *Holothurians* or sea-cucumbers are worm-shaped animals with a leathery skin, endowed with longitudinal and transverse muscles, by which, when irritated, some species can break their bodies into several pieces. The mouth is surrounded by a circlet of feathery tentacles. Locomotion is accomplished by the alternate extension and contraction of their worm-like bodies. They sometimes attain considerable size, and are highly prized as food by the Chinese.

Vermes or *Worms*. The worms are bilateral animals with a much elongated, flat or cylindrical body without appendages. Just beneath the skin there is a strongly developed muscular system. The nervous system consists of a single ganglion, or a pair of ganglia situated toward the anterior of the body above the gullet, and sometimes of a nerve ring around the gullet. The nerves given off are distributed symmetrically, supplying the sense organs and forming two strong lateral nerves. The sense organs are eyes or eye spots, auditory apparatus and tactile corpuscles. The function of respiration is performed through the surface of the body. Sexual reproduction is common, but gemination and fission often occur.

The *Tubellaria* are worms that have a small flattened body covered with cilia. They occur in salt or fresh water, and lead an independent life.

The *Trematoda* are suckorial worms or flukes, and are all in-

ternal parasites. The mouth is in the middle of a small sucker, and frequently there are small hooks of chitin which may assist the worm in attaching itself to desirable objects, and sometimes there are several suckers. The best known is the liver-fluke, which infests the ducts of the liver in sheep. The fertilized ova produce ciliated embryos, which wander about till they die or find a host, usually a snail, in which they are transformed into sporocysts, which produce rediæ, that give rise to a generation of tailed cercaria. In this form they leave the snail and encyst on some foreign object, as a blade of grass; in this state they are swallowed by grazing sheep, and soon form mature flukes in their livers.

The *Cestoda* are the tape worms. They have flattened bodies without mouth or alimentary canal. They infest several different animals, but *Tænia solium*, which sometimes inhabits the intestines of man, is perhaps the most interesting one to study. It consists of a large number of flattened joints, each of which is a complete hermaphrodite organism. At one extremity the organism is fixed to the mucous membrane of the intestine by means of a crown of hooks and suckers. This part is called the head; the other parts are produced from the head by a process of budding. Each joint is well supplied with eggs. When mature the joint breaks off and is expelled from the body. The eggs are swallowed by the pig; the coat of the egg of the tape-worm is dissolved and the embryo is set free. It soon passes through the walls of the stomach to some of the internal organs of the pig, where it forms a cyst, giving rise to the disease known as measles. Meat containing these cysts is eaten, the worm is liberated from the cyst and fixes itself to the intestine and develops into an adult tape worm. The tape-worm of the cat is the mature cystic worm of the mouse. The tape worm is nourished by absorbing the nutrient fluids elaborated by its host.

The *Nematoda* are the round worms and thread worms which are parasites in the lower part of the human intestine, and they include about two hundred species that are not parasitic. The so-called *vinegar eel* is a familiar member of this group. The

trichina is a parasite belonging to the nematoda. There are other worms similar to the nematoda, but they need not be considered here.

The *Annelida* are worms whose bodies consist of definite segments. The segments are usually furnished with bristles or setæ which serve as organs of locomotion. The digestive system consists of a mouth, often with a proboscis which may be protruded, sometimes with horny jaws, a gullet, a stomach, intestine and vent. The vascular system is sometimes distinct, and sometimes in communication with the body cavity. When distinct the reddish blood in the vascular system and the fluid in the body cavity both contain amœboid cells. Branchia or gills are often present as respiratory organs, but frequently respiration is carried on through the general surface of the body. There are often organs which seem to serve as kidneys, and there are sometimes hepatic appendages. The nervous system consists of a cerebral ganglion above the gullet and a ventral ganglionic chain. The sense organs are paired eye spots, auditory vesicles, and tactile organs. Sexual reproduction is common, but gemmation and fission often occur. Frequently they develop with metamorphosis. Sometimes there is a distinct head with tentacles and branchia. They are terrestrial and aquatic animals, mostly marine, living generally on animal food; sometimes they are parasitic.

The *Tubicolæ* feed on vegetable matter and build tubes of sticks, sand, etc., as a protection for their soft bodies. They have external gills and red blood.

The *Oligochæta* include the ordinary earthworm or angle-worm. It has but few locomotive bristles, but has well developed digestive organs. Some of this group are, parasitic, but most of them lead an independent life.

The *Hirudinea* include the leeches inhabiting both salt and fresh water. The body is ringed but has no appendages. The common medicinal leech has a sucking-disk at each extremity, and the mouth is armed with jaws strong enough to cut through the human skin. When young it feeds on the blood of insects, then of frogs, and not till maturity is a diet of warm blood necessary.

The *Rotifera* are worms with a ciliated apparatus at the anterior end of the body which vibrates so rapidly as to produce the impression of a rotating wheel; hence the name of wheel-animalcules. Some are free-swimming and some are fixed. In the free forms the cilia are the organs of locomotion, and in all cases they create currents in the water by which particles of food, as small infusoria, algæ and diatoms are brought within their reach. In external appearance they are much like some infusoria, but they are evidently of a higher order. The rotifer can be dried, then brought to life by a little water, for many times in succession without apparent injury.

CHAPTER XXXV.

ARTHROPODA—CRUSTACEA, ARACHNIDA, AND MYRIAPODA.

THE *Division Arthropoda*, includes a multitude of animal forms which are distinguished from those already considered by the possession of special organs of locomotion, by which they may swim, creep, run, climb or fly. They are for the most part terrestrial or aerial animals. With the organs of locomotion a solid support was necessary for the attachment of the muscles, hence the outer layer of the skin is hardened into a firm exoskeleton.

The body among the arthropoda is divided into three parts, the *head*, *thorax* and *abdomen*, the appendages of each having different structure and function. Each of these parts seems made up of segments. The head is covered by a hard integument, incloses the brain and bears the sense organs and mouth parts. The appendages of this region are changed so as to form antennæ and jaws. The thorax is a fusion of seven segments having a hard integument. In some cases the head and thorax are fused together forming the *cephalothorax*. The thorax bears the appendages most important for purposes of locomotion. The abdomen, composed of distinct rings or segments, seldom has appendages, but when present they aid in locomotion, or in respiration, or may serve for carrying the eggs.

The skin is of two layers, a soft growing layer and an outer one that has been hardened by the deposition of calcareous matter in the chitin base, so as to form a firm external skeleton. The hairs, setæ, spines, bristles and other appendages of the skin, have their origin in the deeper layer. During the period of growth this shell is cast off and renewed from time to time when the animal is said to moult. The muscles are all of the cross-striped variety.

The nervous system consists of a brain, above the œsophagus, the ventral chain of ganglia and the œsophagal ring connecting the brain and the anterior ganglia of the ventral chain. The sense nerves arise from the brain, while the ventral ganglia send nerves to the muscles, organs of locomotion and skin. These animals usually have eyes, organs of hearing, organs of smell and tactile organs.

The digestive organs are well developed, with salivary glands, hepatic appendages and excretory organs usually present. The circulatory and respiratory organs exhibit the widest range of form. Circulation is sometimes effected by a pulsating organ, sometimes by the movements of the body, and again by regular movements of certain organs, as the intestines. Respiration is frequently effected by means of the surface of the body, sometimes by branched appendages of the limbs, and in other cases by means of internal tubes or tracheæ. The reproduction is usually sexual, but modified forms sometimes occur. The most of this group are oviparous, some are viviparous, and in most a somewhat complex embryonic development is followed by a complicated metamorphosis. The *Division Arthropoda* includes four classes, the *Crustacea*, as the crayfish and lobster, the *Arachnida*, as the spiders, *Myriapoda*, as the centipede, and the *Insecta*.

The *Crustacea* are for the most part aquatic, breathing by means of gills; some, however, breathe air and are terrestrial. They vary greatly in size and form, but a study of the common crayfish will give us a good idea of the whole class. Crayfish may be found hidden among sticks and stones of shallow water, and may be caught with a light dip net, which may be made of stout wire and mosquito netting. Preserve a number in alcohol for dissection and keep several in fresh water in a pan or glass jar for observation.

Notice how the crayfish walks, how and which way he jumps when frightened. Looking down upon the crayfish, notice the cephalothorax, with its smooth horny covering called the *carapace*, and the projection of the carapace forward between the eyes, the *rostrum*. Count the segments in the abdomen, and,

bending it backward and forward several times, notice how the segments are jointed together. With a pair of scissors or a knife separate one of the segments of the abdomen from the others, and notice the upper part or *tergite*, the lower part or *sternite*, the side piece or *pleurite*, and the two appendages or *swimmerets*. Compare the segment studied with other segments.

Observe the tail fin; the middle portion is the *telson*, the side lobes belong to the sixth joint of the abdomen. The abdomen of the female is relatively wider than that of the male, and the genital openings of the male are on the first joints of the last pair of thoracic appendages, while in the female they are on the first joints of the last thoracic appendage but two. The eggs are usually carried on the under side of the abdomen, glued to the swimmerets.

Placing the crayfish on its back, count the legs and other appendages of the cephalothorax and note if any of them appear to arise from segments. How many joints in each leg, how do the legs differ from each other, and how do the claws differ from the legs. Notice also the three pairs of peculiar appendages anterior to the claws or chelæ; they are called *foot jaws*; test them carefully so as to learn how they work. Compare the foot jaws with each other and with the legs and claws.

Now remove the legs, claws, and foot jaws from one side, using care not to tear other parts. Then turn back or break away the free edge of the carapace on that side, and the white feathery organs brought to view are the *gills*, of which there are eighteen pairs; six are attached to the second and third foot jaws, the chelæ, and the first, second, and third pairs of legs, the remaining are fixed to the sides of the body. Each consists of a central stem bearing a number of delicate filaments. Separate each pair of gills and find out to what it is attached and how it is attached. Study carefully the chamber containing the gills and note the parts which compose it. With a probe explore for openings from the branchial chamber. Projecting forward there is a well-marked canal; in this there is a flat oval plate, attached to

the second pair of jaws, and by its motion a circulation of water is kept up through the gill chamber.

When the foot jaws are removed two pairs of soft leaf-like appendages, called jaws or *maxillæ*, come into view, and anterior to these are the *mandibles*, short, hard, toothed organs which seem more like jaws than the softer *maxillæ*. Each mandible bears an appendage, which curves around its anterior border in a groove, and is known as the *mandibular palpus*. Fitting closely against the posterior margin of each mandible is a soft plate-like organ called the *metastoma*. Remove each of these organs, noting carefully its mode of attachment and its relations, experimenting with each so as to gain a clear idea of how the mouth parts are arranged, and what part each plays in the process of mastication.

Just in front of the mandibles are the long feelers or *antennæ*, the *antennulæ*, and lastly the *eye stalks*. Examine the antennæ; notice their mode of attachment, freedom of movement, etc. In the basal segment of the antennæ there is an opening leading to the green gland in the extreme front part of the body. It serves the purpose of a kidney. In the basal joints of the antennulæ are the auditory organs; notice the auditory hairs and the auditory sac. Examine the eye stalks and find the black tip or cornea, and try if you can tell whether it is simple or compound.

In the larger crayfish the digestive, circulatory, and nervous systems may be studied, but the dissections are best made under water. Wedge a thin board into the bottom of a shallow dish, or cover the bottom with wax, then placing the ventral surface downward, pin the body firmly through telson and claws. Then with a pair of scissors cut from the posterior margin of the carapace forward a little to one side of the median line to the cervical groove, then break away the whole side of the carapace. Push away the gills and cut them off at the point of attachment. Cut away the other side of the carapace. With the forceps clear away the lining membrane which discloses a small chamber containing a little whitish polygonal sac which is the heart. Notice

the tubes or blood vessels leading from the heart. In the heart there are two holes above, two below and one on each side, each hole guarded by a lip-like valve. From the gills the blood passes into the *pericardial* cavity; as the heart expands the blood flows through the holes into it; as it contracts, the valves close and the blood is forced into the different parts of the body, then to the gills again. Under the heart are the reproductive organs, the yellowish *ovaries*, and the oviducts leading to the genital openings already mentioned, while in the male there are the *testes* with long white coiled tubes leading to the genital opening in the last thoracic leg.

Cut away the roof of the head. The space within the head is quite fully occupied by the stomach. Pass a probe through the mouth into the stomach. Note carefully the gullet, stomach and intestine, and near the beginning of the intestine some reddish masses, the hepatic glands or liver. Observe the white muscles along each side the body cavity. Cut away the roof of the abdomen, and trace the muscles through it to the telson, the upper thinner layer straightens the abdomen while the thicker lower layer below the intestine bends it.

Over the gullet there is a large ganglion, extending outward and downward. Around the gullet are two masses of nervous matter connecting the ganglion above the gullet with the anterior of twelve pairs of ganglia that lie along the ventral surface underneath the intestine and deeper muscles. Trace out the ganglia and principal branches of this system. Try to have some crayfish for observation during their moulting season in the spring.

Those members of the crustacea living in the sea, as the lobsters, shrimps and crabs are the most numerous, and individuals among them sometimes attain great size. And these members of the class furnish large quantities of food material.

The *Barnacles* belong to this class, as did the *Trilobites*, animals that were so abundant during the early geologic ages. Besides the crayfish, there is a group of minute organisms called *Entomostraca* that inhabit fresh water. They are an abundant source of food for fish and other forms of aquatic life.

The *Arachnida* include the ticks, mites, scorpions and spiders, animals similar to the crustacea, but differing from them in some particulars. The arachnida are air-breathing animals, having only four pairs of legs, and usually no antennæ. Almost all the arachnida live on animals, a few only living on vegetable juices, and we may expect to find agility and intelligence as characteristics of this class.

One group of this class are parasites in the nasal cavities of dogs and wolves; the eggs find their way into the stomachs of rabbits, penetrate to the liver and form a cyst; after six months or so they again become active for a time, and again encyst, in which state they may reach the mouth of the original host.

Another group including the mites and ticks are called the *Acarina*. Their mouth apparatus is adapted for biting, or for piercing and sucking. There are no circulatory organs, and the nervous and respiratory organs are of the lowest order, suggesting the idea that the class is made up of degraded, depauperate forms, sunk to their present low estate through indolence and high living. Itch-mites, cheese-mites, ticks, water-mites and others belong to this group of repulsive animals.

The *Araneida*, or true spiders, are distinguished by having a much-swollen abdomen, four pairs of legs, an apparatus for spinning webs, with from six to eight eyes, and generally poison glands. In studying the spider make out the cephalothorax and abdomen, the mandibles, poison glands, maxillæ, and the jointed appendages of the maxillæ, the maxillary palpi. Examine the head for the eyes, usually from six to eight in number. Examine the posterior part of the abdomen for the spinnerets. Hold a live spider by one leg with a pair of forceps and watch him while spinning. The spinning glands secrete a viscid material which, forced out through fine holes, hardens in the air to delicate threads used by the spider for many purposes. Spiders differ widely in form, color, and mode of life, but in any event they are clean, active, intelligent and interesting.

The *Mygalidæ* are large spiders thickly covered with hair, who dig holes in the earth, or appropriate holes already made in

wood or elsewhere. These they line with a soft silk web, sometimes arranging a cover that opens and closes like a trap door, as the trap-door spider of Southern Europe and the bird spider of South America.

The *Saltigradæ* are springing spiders with eight eyes grouped in a square; they do not construct webs. They have stout anterior legs and a large arched cephalothorax.

The *Lycosidæ*, or wolf spiders, pursue their prey by running rather than by leaping. They build holes in the ground, often building little walls around the opening.

The *Laterigradæ* or crab-spiders have a rounded cephalothorax and a flattened abdomen, and the two anterior pairs of legs are longer than the others, so that they run sidewise or backward.

The *Tubitelæ* or tube spinners, have six or eight eyes in two transverse rows. The two middle pairs of legs are the shortest. They weave horizontal webs, with tubes in which they lie in wait for their food.

The *Inæquitelæ*, or web spinners, have eight eyes of unequal size, and long anterior legs. They construct irregular webs.

The *Orbitelæ*, or wheel-spinners. Among these spiders the head and thorax are separated by a groove and the abdomen is globular. The anterior legs are longest and the third pair shortest. They spin a geometrical web, often of faultless symmetry.

Spiders are especially interesting as objects of study. Many of them have fixed homes where they may be watched and studied during the season. Nearly every group of spiders mentioned has representatives in every part of the United States. If you wish to study burrowing spiders, they are everywhere in the fields along paths, about the yard, often between bricks in sidewalks. A little stream of water will usually force them to the surface. Study the spider; study his house, his family relations, his personal habits, his methods of catching food, etc.

Almost everybody thinks of the web-spinner as the typical spider, and doubtless more will be interested to study the web-weaving spiders. They are abundant everywhere, and at first may be found more easily than the burrowing spiders. But it makes

no difference about the kind ; locate a spider and commence observations on his habits and manners and customs at once, and the work will afford you as much pleasure as any you ever did.

The *Scorpions* have jointed bodies, with a hooked telson and poison gland ; they have a bilobed brain, and four pairs of lungs, evidently the most highly developed of the arachnida. They are more common in the warmer countries. The results of the bite of the largest spiders, and the sting of the scorpion have doubtless been much exaggerated, but enough is known to make it wise to avoid the bite or sting when possible.

The gossamer threads floating in great number in autumn are the work of young spiders. Mounting some little elevation, as a fence, in the warmer part of the day, they throw up the abdomen and allow the thread formed to float away on the ascending warm air until it becomes buoyant enough to carry the spider away in the air. Spiders are oviparous, often carrying their eggs on the abdomen until they are hatched. Spiders cast their skin or moult several times before they attain full size.

The *Myriopoda* are animals whose bodies are divided into many segments, but without division into thorax and abdomen. They have a distinct head, three pairs of jaws and numerous pairs of legs. The head is much like that of insects, while their form resembles that of worms. The black cylindrical many-legged worm that rolls up into a ball is a myriopod.

Some species of the centipede living in tropical countries attain a large size, and the secretion from their poison gland is dangerous even to man.

CHAPTER XXXVI.

INSECTA.

THE forms of life already studied have been for the most part water animals of such low organism and retiring habits that they have never forced themselves upon the notice of mankind.

But insects are air-breathing animals abounding everywhere, in the air and soil, in our homes and workshops; they are parasites inside the human body, and often find an abiding place on the outside; they bite and sting and irritate and annoy by night and by day, and so persistent and aggressive are they in their work that only occasionally can humanity turn aside from the irrepressible conflict to notice that insects are intelligent, that some are exceedingly beautiful, that some are useful, and that insects as a class fill an important niche in the scheme of nature.

Insects are very numerous, outnumbering by far all other forms of animal life; and while they differ widely in size, form and mode of life, they are usually easily distinguished from other kinds of life. Among the insecta there is a well-marked division of the body into head, thorax and abdomen.

The head appears to be composed of but one mass, but many think it really a consolidation of four segments. The appendages of the head are the eyes, the antennæ and the mouth parts. The simple eye or *ocellus* consists of a convex cornea resting on a crystalline lens, which in turn rests on a vitreous humor, forming quite a complete eye; the compound eye is but a collection of these simple eyes. Some think the ocelli are used in the perception of nearer objects. The *antennæ* are tubular bodies well supplied with nerves, seeming to be organs of touch, often appearing to be organs of hearing and smell. They differ widely in form and size.

The mouth parts consist of the *labrum* or upper lip; the *mandibles* or larger jaws; the *maxillæ* or lesser jaws, to which are attached little jointed bodies called *maxillary palpi*; and the *labium* or lower lip, to which are attached a pair of jointed bodies called *labial palpi*. These are the mouth parts of biting insects, but some have the *maxillæ* and *labium* more or less modified so as to fit them for licking or sucking up liquids. Sometimes the first *maxillæ* are changed into a sucking tube, as in butterflies and moths. Sometimes the *labium* forms a tube and the *maxillæ* forms cutting parts to open the way for the sucking tube, so that the mouth appears in a great variety of interesting forms.

The *thorax* consists of three segments, *prothorax*, *mesothorax* and *metathorax*. The appendages of the thorax are the legs and wings. All true insects have a pair of legs jointed to each segment of the thorax. Each leg consists of basal joint or *coxa*, the *femur*, the *tibia* and the foot or *tarsus*, which may be armed with a pair of claws. The legs vary widely in form and size, depending mainly on their use. The wings arise from the second and third parts of the thorax. They are considered by many as simply expansions of the integument spread out over a framework of horny tubes. The tubes are really double, consisting of a central air tube inclosed in a larger tube which is filled with blood, so that the wings serve the double purpose of organs of locomotion and respiration. In some cases the anterior wings are thickened and hardened by the deposition of horny matter so as to form a protecting case for the other pair of wings and for the abdomen.

The *abdomen* consists of nine or ten segments, each of which is made up of a dorsal and a ventral plate. The segments are joined together by soft connecting membranes, and the parts of the segments are united in the same manner, so that the abdomen is capable of considerable expansion. At the extremity of the abdomen there are terminal appendages, as stings, apparatus for depositing eggs, and other organs pertaining to the reproductive process.

The digestive organs after the mouth are the *æsophagus*, into which open the salivary glands; then a suctorial stomach in some cases, and in others a crop or a straight or coiled intestine; but whatever the name or form, one portion is adapted to digestion of food and another concerned in the ejection of feces. There is no liver, but certain glands in the walls of the stomach seem to perform the office of such an organ, and there are also indications of pancreatic glands and urinary glands.

The circulatory apparatus of insects is a simple dorsal vessel divided into eight chambers; as this vessel or heart expands blood flows into it, and as it contracts the blood is driven into all parts of the body without being conveyed by a distinct system of tubes. The blood is usually colorless, and always contains amœboid blood cells.

Respiration by tracheæ is one of the chief characteristics of an insect. The tracheæ are delicate tubes penetrating all portions of the insect body, which receive their supply of air through openings called *stigmata* situated in the membrane connecting the dorsal and ventral plates of the abdomen. The number of stigmata vary, but there are seldom more than nine or less than two pairs present. The tracheæ are kept open by a tough spiral fiber of chitin, so that their structure is quite like that of the tracheæ of higher animals. Many insects seem to be able to develop animal heat by increasing the vigor of respiratory movements. The nervous system of insects is highly developed, all variations between a common ganglionic mass in the thorax and a ventral chain of ganglia occur. In some cases the brain attains considerable size, which, according to one writer, "gives origin to the sense nerves, and seems to be the seat of the will and of the psychical activity." The ventral chain seems to correspond to the spinal cord, and there seem to be instances of a true sympathetic system. The muscular system lies just beneath the integument, and seems to be continuous with it. The muscles are numerous, especially about the head, some larvæ having as many as 4,000 distinct muscles. They are generally of the cross-striped variety, and give the insect great power and activity of movement. Some

insects are more powerful, all things considered, than any other form of life.

Insects are supplied with glands somewhat analogous to the cutaneous glands of higher animals, which secrete substances often of the most intense and penetrating odor, which seems to be used as a means of protection. Then there are glands that secrete wax, and those that secrete a sebaceous liquid that serves to lubricate the joints; and in some larvæ there are spinning glands which serve for the production of webs, pupa cases, etc. And many insects have poison glands in connection with stinging organs.

The sounds made by insects are produced by the friction of one part of the external skeleton on another, as the legs against wings, or wings against wings, etc., by the passage of air through the thoracic stigmata, by the rapid movement of the wings, and doubtless in other ways not understood. Insects emit odors and doubtless have a sense of smell, but observers are by no means agreed as to its nature or location. So it seems as if there must be a sense of hearing. Among the grasshoppers and crickets there seems to be an auditory apparatus in connection with the anterior legs, but in reality little is known about the sense organs among insects beyond what is known of the organs of sight. Among insects reproduction is sexual. In some cases the egg develops into a perfect insect without metamorphosis, but in most cases the embryo passes through a well-marked metamorphosis, often requiring considerable time before the perfect stage is reached.

After the egg is fertilized it gradually develops into a worm-like form called the *larva*, known commonly as caterpillar, grub or maggot. As soon as hatched the larva eats voraciously, growing rapidly, moulting from time to time, storing up fat from which to form the tissues of its future body. At length it stops eating, makes a cocoon and, slowly changing form, loses its worm-like body and develops the head, thorax and abdomen of the perfect insect. Sometimes this resting or pupa stage is very brief; sometimes it lasts for a considerable time.

As soon as the insect is complete, the sexes meet, and soon afterward the male, no longer useful, dies; the female lays her eggs in or near some food supply, then dies. For most insects this period occurs in the late summer or early autumn, so that the species is represented during the winter by eggs alone. Sometimes the winter is passed in the pupal stage, and in some cases in the larval stage. Insects may brood two, three or more times in one season, but in general, insects are annuals. Sometimes the larva live for many years, as in the case of the seventeen-year cicadia.

The insect-fauna of a locality comprise all the insect forms found in it. The limits of a fauna are usually determined by temperature or some natural barrier, as the ocean or a high range of mountains, etc. Insects may be distributed by the wind, by the agency of birds, or other animals, or of man. The life of an insect is short and active, and has but a single purpose, and yet many insects are subject to disease, for the most part diseases due to parasitic plants or animals. The honey bee, the silkworm, and the house fly are each subject to fungoid diseases.

There are so many different kinds of insects that the names of the principal groups with some distinguishing characteristics may be helpful. The lowest group of insects are the *Thysanura*, including wingless insects, with rudimentary mouth parts and setiform anal filaments which often serve as springing organs, so that they are sometimes known as spring-tails. They develop without metamorphosis, and seem to be the most ancient insects as well as the lowest.

The *Orthoptera*. The insects of this order including the grasshoppers, crickets, etc., have biting jaws, and pass through an incomplete metamorphosis. There is no resting stage; the newly hatched larva differs from the adult only in size, and the pupa is characterized by rudimentary wings. As a rule they are voracious eaters and make sounds of piercing shrillness.

Some of the largest insects are members of this group, and the grasshopper is one of the best subjects for investigation. Have several individuals in different stages of development confined

for observation, and have several large specimens preserved in alcohol for dissection. In studying the grasshopper note the general divisions of the body; examine carefully the antennæ and eyes, using the lens in looking for the ocelli. Dissect out and place by itself each one of the mouth parts. Notice the divisions of the thorax, and compare them in size and form and as to the appendages they bear. Note the position of the anterior wings when folded, open these wings so that the anterior margin shall be at right angles with the body, and then note the position of the inner wing while folded; spread it out, noting carefully how it was folded. Compare the framework of the two pairs of wings; also compare them as to size, shape, color, texture, position and use. Study the legs; note their number, arrangement and mode of attachment, and the parts of each. Notice the different ways in which the grasshopper travels, and how he makes sounds.

Note the number of segments in the abdomen and the two longitudinal grooves on its under surface. That part of the abdomen between the grooves is the *sternum*, the side is the *pleurum* and the upper part the *tergum*; and the corresponding parts of a segment are the *sternite*, *pleurite* and *tergite*. Note the *spiracles* or breathing pores on the sides of the abdomen. On the sides of the first segment find a pair of thin oval membranes called tympana, which some think are an auditory apparatus. The four short setæ, which may be discovered at the end of the abdomen of a female grasshopper, form an *ovipositor* by which she can make a hole in the earth as deep as the abdomen is long, at the bottom of which she deposits her eggs. Dissecting a large female grasshopper under water, as in the case of the crayfish, one may make out the air sacs and tubes, the egg masses and the alimentary canal.

The *Orthoptera* include *Forficulidæ* or earwigs, the *Blattidæ* or cockroaches, the *Phasmidæ* or walking sticks, the *Acridiidæ* or grasshoppers, the *Locustidæ* or locusts, the *Gryllidæ* or crickets, the *Termitidæ* or white ants, the *Ephemeridæ* or the May flies, the *Libellulidæ* or dragon flies, and others. They are all inter-

esting and many of them familiar insects, well worthy of study and investigation.

The *Neuroptera* includes insects that have biting mouth parts, membranous wings, and that pass through a complete metamorphosis. They have something the appearance of the dragon flies and May flies. One member of this order has long horns and long delicate wings, and is called the *Horned corydalus*.

The *Strepsiptera* includes a few insects of minute size and no special interest.

The *Rhynchota* are insects that have piercing mouth parts, and pass through an incomplete metamorphosis. The *Pediculidæ* and other animal parasites, the *Aphidæ* and other plant-lice, and the *Cicadidæ* belong to this order, and so do the *Hemiptera* or bugs, water bugs, etc. The bugs may be known by their anterior wings which are horny toward the base and membranous toward the tip. The *Coccus cacti* of Mexico yields a coloring matter called cochineal, which has considerable commercial value.

The *Diptera*. The members of this order are insects with piercing and sucking mouth parts, passing a complete metamorphosis. The posterior wings are reduced to mere knobs, so that they appear to have but one pair. This group includes insects that are parasites on animals, and sometimes on other insects. The common house fly, the bot fly, gad flies, gnats, fleas, mosquitoes and others are members of this order.

The *Lepidoptera* are insects having suctorial mouth parts, two pairs of wings similar in form, which are covered with delicate scales. This group includes the moths with feathery antennæ, that are active at night, and the butterflies with knobbed antennæ that are active during the day. Both moths and butterflies are noted for their beautiful colors and graceful forms. They pass through a complete metamorphosis, and the cocoons spun by some of the larvæ of this group are the source of the silk of commerce, making the silkworm chief among insects for the economic value of its work.

The *Coleoptera* are insects with masticating mouth parts, and hardened anterior wings, which are the chief characteristic of

this immense group of insects, numbering some 80,000 species. They are properly called *beetles*, not bugs, which is the name applied to the Hemiptera.

The *Hymenoptera*. This group includes the bees, wasps and ants. They have mouth parts adapted to biting and licking; the head is large with three ocelli and large compound eyes. There are two pairs of membranous wings fitted for prolonged flight. The body is compact, of about average size, the nervous system complicated and highly developed, so that in the matter of intelligence and capacity for work we would expect this group to stand easily at the head of the insect world. In the female the abdomen ends in an ovipositor, or more commonly with a sting and its associate poison glands. The leaf-wasps, wood-wasps, gall wasps, ichneumen flies and others have ovipositors and deposit their eggs in wood, leaves or other vegetable structures, some making quite deep excavations.

The *Formicidæ* or Ants, live together in communities, which contain winged males and females, but are composed mainly of wingless individuals called workers. The female has a sting and poison gland, and the workers, supposed to be aborted females, also have poison glands. The dwellings of ant communities consist of passages and cavities in rotten wood or in the earth. Customs vary in different communities, but the following is perhaps the history of an average colony: Some time during the summer the males and females reach the adult size; soon afterward they take the marriage flight. The males soon die, and the females attend to the matter of raising their brood or founding new colonies. In general there seems to be a tendency among the young females to form colonies by themselves or with a body of workers, but usually females enough are forcibly retained by the workers of the original colony to continue it as a strong community. The fertilized eggs are exposed to the morning sun, covered from its heat during midday and removed from the influence of damp and cold at night. The grub is treated in the same way, and besides is fed by the nurse or female with a liquid disgorged from the stomach. After passing into the pupa state they are still

under the constant care of the mother or nurse. It is supposed that different care or different feeding develops the male, female, soldier or worker from the same group of eggs, but this matter seems to lack confirmation. Wonderful stories are told of the intelligence of ants. It is claimed that they carry on war; that colonies are sometimes exterminated, sometimes enslaved, and that some ants keep domestic animals, and that they sometimes undertake migrations in great numbers.

The *Vespidæ* or Wasps. The life history of a wasp is about as follows: Males and females reach maturity in late summer, and copulate in the air; soon afterward the males die, but many of the females survive the winter. In the spring the wasp begins a nest, making it of gnawed wood which resembles paper. During the spring and summer she begets workers, which help to increase the size of her nest, and to rear the perfect insects later in the season.

The *Apidæ* or Bees. The nest of the bumble bee is founded by a single female which has survived the winter as in the case of the wasp. Some bees excavate cavities in wood for the deposition of their eggs. The common honey-bee is, next to the ants, the most interesting insect. Among them we have the community of the queen, males and workers, the queen living for four or five years—no other perfect insect having as long tenure of life. The wasp builds a cell of paper for its young, the bee builds one of wax. The cells are of hexagonal form, and of a larger and smaller size. In the smaller cells, provisions are stored, and in them the worker brood is placed, while the larger ones are used for the male brood and the reception of honey. On the edge of the comb a few large irregular queen cells are formed. In early spring the queen deposits eggs in the workers' cells, and later in the drone cells, and later still she deposits an egg in each of several queen cells. The larva in these cells receive richer food, and reach maturity in about sixteen days, while the male requires twenty-four days, and the worker twenty to reach maturity. Just before the oldest of the young queens reaches maturity, the queen mother leaves the hive or nest with a portion of the work-

ers as a first swarm. The young queen arrives at maturity, is fertilized in marriage flight, returns to the colony, kills the queen pupas in the remaining cells, and reigns undisputed; or, if prevented from this she leads out another colony before the maturity of a second queen. If the queen dies, the workers enlarge the cell of some young worker grub, and feed it with royal jelly, so that it develops into a queen, and the affairs of the colony go on as usual; but if there are no brood cells, a bee community soon goes to pieces on the loss of the queen. Division of labor is well marked among bees; the queen-mother and ruler, the fathers, gentlemen of leisure, and the workers; some collecting honey, some secreting wax and building cells, some nursing the brood, some attending to the ventilation of the hive, as their active respiration tends to raise the temperature and foul the air. Bees, silk-worms and the cochineal insects, are the only representatives of the great group of insects that are of much economic value.

The collection of specimens is an interesting and valuable exercise. A pint fruit jar two-thirds full of seventy-five per cent. alcohol will be a good receptacle for almost anything taken in the field except moths and butterflies. They may be killed with chloroform or cyanide. The cyanide bottle is perhaps the most convenient, and may be made by placing several pieces of cyanide over the bottom of a pint fruit jar, and just covering them with plaster of paris. Insects shut up in the jar are soon killed; after which they can be transferred to folds of paper and packed in boxes, or pinned in boxes. Great care is necessary in arranging the legs and wings so that when dry the specimen shall look natural, be neat, and well preserved.

CHAPTER XXXVII.

MOLLUSCA, MOLLUSCOIDEA AND TUNICATA.

THE *Mollusca* are soft-bodied animals without internal skeleton, and without segments or joints. The body is covered loosely with a soft contractile skin which usually secretes a calcareous shell as a protective covering. Most of the mollusca are aquatic animals or live in damp places, and many of them are permanently fixed to solid bodies, having no organs of locomotion. A mass of skin and muscular tissue called the *foot* is developed on the ventral surface of many of this group, by means of which slow movements may be accomplished.

The alimentary canal consists of the œsophagus, stomach and intestine, and the rectum. Attached to the digesting portion of the canal there is quite a complete liver, and kidneys are always present. There is a vascular system with a heart driving the blood through the body, but the system is not completely closed from the body cavity. Respiration is carried on through the general surface of the body, also by means of branchia or gills, and occasionally by means of lungs.

The nervous system consists of a pair of dorsal ganglia lying above the œsophagus, with pedal and visceral nerve cords; and sometimes it would be better described as consisting of a cerebral ganglion, a pedal ganglion and a ganglion supplying the walls of the body. The cerebral ganglia supply the sense organs, which usually consist of eyes, tactile and auditory organs. But no general description can do justice to this large and interesting group of animals; some notice must be taken of the more important subdivisions.

The *Lamellibranchiata* are mollusca without distinct head, that breathe by means of plate-like *branchia* or *gills*, and have bivalve shells. To this class belong the oyster, the salt water and the

fresh water mussel. The fresh-water mussel is abundant in the beds of most of the streams and ponds of the Mississippi valley, and can easily be taken during the low water of the summer. They may be kept for observation in a tub or bucket, in which there are two or three inches of mud and sand covered by six or eight inches of water. A few specimens should be preserved in alcohol for dissection. With a live shell in the hand, notice the two parts or *valves* of the shell: the edge along which the valves are joined is the *dorsal* margin, and the other is the *ventral* margin of the shell. The concentric lines parallel to the ventral margin are lines of growth, the raised portion which forms the center of these lines is the *beak* or *umbo* which is nearer the front or anterior end of the mussel. Holding the shell with the dorsal margin upward, and the anterior portion forward, notice the relation of parts, the anterior and posterior regions, the right and left valves, the ventral and dorsal margins, and the heavy *hinge ligament* binding the valves together.

Drop two or three live mussels into water that is nearly boiling hot. The hot water will kill the animal and loosen it from its shell. When cool enough to handle open the shell by turning back the left valve. Notice the white membrane, *mantle*, adhering to the inner surface of the shell; it can easily be removed with the fingers; then notice the glistening inner surface of the shell, and the rough line parallel with the margin of the valve called the *pallial line*, or impression, as it marks the line along which the mantle was attached to the shell. Notice that this line terminates in two oval rough-bottomed pits near the extremities of the hinge ligament. With the fingers or a thin piece of wood carefully separate the mussel from the other valve, noting the pits near the dorsal margin, and the bodies which occupied them. They are the anterior and posterior adductor muscles by which the mussel closes his shell. Note their relative length and thickness, and their structure. Notice that the shell does not remain closed, the elasticity of the hinge ligament opens it as soon as the muscles are cut or loosened. Notice that the mantle lobes are continuous across the dorsal portion of the mussel. The hatchet-shaped,

yellowish or whitish mass of flesh lying between the mantlelobes, and forming the ventral portion of the animal is the *foot*. On either side the foot find a pair of branchia or gills. Just in front of the gills on each side are a pair of triangular processes called the *labial palpi*, and between them just back of the anterior adductor muscle is the mouth. Toward the posterior of the animal notice that the mantle lobes coalesce so as to form two slit-like openings called the ventral or *inhalent siphon*, and the dorsal or *exhalent siphon*. By the action of cilia in the ventral siphon and gills, water is driven through the gill chamber, and food materials pass with the water over the palpi to the mouth. Commencing at the mouth with probe, blowpipe and scissors trace out the alimentary canal. This can be done more easily with an alcohol specimen.

Pry open the shell of a live mussel and insert a little block of wood to keep it from closing; then cut the adductor muscles, separate the mantle lobes from the shell, and on the dorsal border of the animal, near the region of the umbo, notice a thin space in the mantle covering a cavity filled with fluid. In this cavity, called the pericardium, a yellowish transparent sac, called the *heart*, may be seen pulsating in the pericardial fluid. This dissection can be made more satisfactorily with a live clam, but most of the work can be as well or better done with the alcohol specimen, or one that has been killed with boiling water.

Most mussel shells have hinge teeth with corresponding sockets on the dorsal margin of the valves, near the ligament, by which they are more firmly held together when the shell is shut. The anterior is conical, sometimes sharp, the posterior narrow and long. Notice a thin dark-colored membrane bordering the edge of the shell, seemingly an extension of the outer covering or *epidermis* of the shell. Burn some mussel shells in the open fire, and note what properties they lost and what they gained from burning. From the burned shells try to get some idea of how the shell was built up. Test portions of the burnt shell with acid and note results; also test a fresh shell with acid and note results. In observing the mussel note especially his methods of

locomotion, his position while lying in the mud, and the currents of water when the siphons are in action. Water snails and land snails having univalve shells are also interesting to keep for observation, as are also garden slugs or snails that have no shells, or only little scales on the dorsal surface.

The nervous system of this group consists of three pairs of ganglia, the cervical, pedal and visceral. The sense organs are but slightly developed. Usually the sexes are separate, but hermaphrodite individuals occur. They are generally oviparous, but the fertilized eggs are often retained in the pouches of the parent until the embryo is well advanced.

The *Ostridæ*, or oysters, belong to this class. They have a fixed left valve; the right valve closes upon the oyster held in position by a strong ligament. They have no siphons, and only a rudimentary foot. Oysters are either mainly hermaphrodite individuals or females. The fertilized ova, called *spat*, after escaping from the organs of the parent, swim freely for several days, then settle on some support as sticks, stones, old shells or other objects, and become fixed. The natural oyster beds of the Old World and many of those of the United States have been exhausted, and artificial beds have been made and cultivated and protected to such an extent that oyster culture has become an extensive and profitable industry.

The *Gasteropoda* have a distinct head, often with tentacles and stalked eyes, and simple mantle that secretes a plate-shaped or coiled shell. The muscular foot forms the ventral side of the body, hence the name signifying stomach foot. Eyes, olfactory, tactile and auditory organs are fairly well developed. Sometimes the mantle forms a long siphon. This family includes the univalve land snails and the fresh water and salt water univalve snails or mollusks, as well as some that do not secrete a shell.

The *Cephalopoda* have a circle of arms, bearing suckers round the mouth, and they have a funnel-shaped perforated foot. The water used for respiration, violently driven from the funnel, tends to force the animal backward. This method of locomotion is common among the animals of this class. The octopus, the

nautilus, cuttlefish and other interesting mollusks belong to this class. Some attain great size and strength, so that with their long arms, supplied with powerful suckers, they sometimes destroy men, and so fierce and destructive are they that one group has received the name of devil fish.

The *Molluscoidea*. The *bryozoa* and *brachiopoda*, now grouped as molluscoidea are interesting animals whose relations are not well made out, and which do not appear much alike, but a study of their developmental history seems to show them closely related. The bryozoa are small animals usually united together forming colonies so as to present the appearance of sprigs of moss. There is no vascular system, and the nervous system consists of a simple ganglion. The mouth, surrounded by a crown of tentacles, leads to a capacious stomach, the intestine terminating near the mouth. The brachiopoda are fixed animals of larger size, having a shell consisting of dorsal and ventral valves. A vascular system is present, and the nervous system is a ring about the œsophagus with two ganglia in it. The mouth is provided with two long, coiled arms, which serve as a respiratory apparatus, and aid in gathering food for the animal. The oldest fossils belong to this group.

The *Tunicata*. These are saccular or barrel-shaped animals, whose respiratory cavity has two wide openings, between which is placed the simple ganglion which constitutes the nervous system. Judging from the development of the different systems of organs the ascidians would appear to take low rank in the scale of being, but a study of their embryonic development seems to show that they have close relations to the lower vertebrates. They are nearly all marine animals of little or no economic value, and of no special value for study by beginners in zoölogy.

CHAPTER XXXVIII.

THE VERTEBRATA, PISCES, AND AMPHIBIA.

THE vertebrata are distinguished from other forms of animal life by the possession of an internal skeleton. The principal part of the skeleton is the vertebral column composed of several distinct bones called vertebræ. Each vertebra is made up of a body and several processes or projections. Some of these processes enable the vertebræ to articulate with one another so as to form an elongated, flexible, bony axis. Other processes jut out from each vertebra so as to form a narrow bony tube, or canal on the dorsal side of the axis, and at least the framework of a much larger cavity on the ventral. And perhaps we find here the chief difference between the two groups of animals: the invertebrates consist of one body cavity and its contents; the vertebrates have the same, and in addition a second cavity, the vertebral canal and its contents. While the *Vertebrata* are alike in many respects they differ widely among themselves, forming five quite well-marked classes: *Pisces* or *Fishes*, *Amphibians*, *Reptiles*, *Aves* or *Birds*, and *Mammalia*.

The class *Pisces* is made up of cold-blooded aquatic animals that breathe by means of gills. As usually constituted, this class includes several forms that are not regarded as true fishes. Of these the lowest in the scale are the *Leptocardii*. They have a membrano-cartilaginous skeleton, without a skull, the vertebral column represented by an elastic substance called the *notochord*, which in the higher vertebrates represents the column in the embryo. The colorless blood circulates in pulsating vessels without the aid of a heart; they have no nervous system or sense organs. The mouth without jaws leads into the pharyngeal sac, whose sides are pierced by numerous slits which serve for respiration.

The individuals of this group are small, and are found usually in the sands of shallow water along the seashore.

The *Marsipobranchia*, are vermiform animals with a cartilaginous skeleton, and persistent notochord. The mouth is suctional; the alimentary canal a simple tube. The blood is red, and the heart has two valves. The brain is distinct, with three sense nerves: the optic, auditory and olfactory. They have dorsal and caudal fins, but no scales. Respiration by means of five or six pairs of gill sacs. They are all parasites, including the marine hagfish, and the lampreys, living in both fresh and salt water. They attach themselves to dead or living fish, and also eat worms and other small aquatic animals.

The *Selachii* have a cartilaginous skeleton, pectoral and ventral fins, transverse mouth, and a capacious stomach. Respiration is accomplished by means of one or several gill openings. There is no air bladder, and the arterial bulb has three series of valves. The nervous system is well developed, but the optic nerves do not decussate. This group includes the different kinds of sharks, dog fishes, skates and rays. They are carnivorous, and generally marine.

The *Ganoidei* and *Teleostei* are regarded as *true fishes*. The *Ganoidei* have a bony or cartilaginous skeleton with enameled scales or osseous plates. The arterial bulb is muscular with numerous valves, and there is a partial decussation of the fibers of the optic nerve. The sturgeons, gar-pikes and mud-fish are the chief representatives of this group in the waters of the present time, but earlier in the history of the earth they were the dominant form of fish life.

The *Teleostei* are bony fish, and include the great bulk of the fishes of the present time; they are the typical fish, and perhaps we can best learn something of them by a somewhat detailed study of some common fish, as the yellow or ringed perch; or a bass or a croppie would serve as well.

Holding a fish in its natural position, notice that it is symmetrical, has an anterior and posterior region, a dorsal and ventral surface and a right and left side. A fish may be cylindrical, or flat-

tened from above downward, but they are usually "compressed," flattened from side to side; as in the case of the bass or perch.

The fins are membranous organs, probably folds of skin, supported by spines or rays. The principal one is the caudal or tail fin. Of these there are two kinds, the *homocercal*, when the backbone ends at the base of the fin and the fin is symmetrical, and the *heterocercal*, when the backbone extends into the upper lobe of the fin, making it unsymmetrical, as in the sturgeon and shark. The fin along the center of the back is the *dorsal*; it is sometimes single, sometimes double, and it may be supported by spines or soft rays. Then there are the *pectoral* or breast fins, the *ventral* fins and the *anal* fin. Count the spines in each of the fins, count the soft rays, measure along the base to find the length of the fin, and the length of the longest ray to get the height of the fin. Compare the fins as to length, height, number of rays and spines, and note their relative position. Close the mouth and measure from the tip of the *snout* to the posterior margin of the bone which covers the gill opening for the *length* of the head, and to the base of the caudal fin for the *length* of the fish, and measure from above downward at the widest place for the *depth* of the fish. Compare the length of the head with the length of the body, and the depth with the length and width, etc.

The bone that serves as an upper lip for the fish is the *premaxillary*; note its form, size, and movements; notice also the fine teeth on it, and their shape, size and arrangement. Back of the premaxillary on each side are the oblong *maxillary* bones, and above these in the median line are the *nasal*, *prefrontal* and *frontal* bones, and on the sides of the lower jaw are the *dentary* bones.

In the front part of the roof of the mouth find a group of teeth situated on a bone called the *vomer*. Extending backward on each side of the roof of the mouth find rows of teeth located on the *palatine* bones. Examine other parts of the mouth and the tongue for teeth; compare the different sets as to form, size and arrangement. In front of the eye is the *anteorbital* and below it are the *suborbital* bones.

The cavities in the sides of the fish which divide the head from

the body are the *gill openings*, and the bones covering them are the *gill covers*. The upper posterior part of the gill cover is the *opercle*; below it is the *subopercle*; between the opercle and the eye is the *preopercle*, which is sometimes serrate or toothed, and below it is the *interopercle*. Below the gill cover find the *branchiostegal membrane*, supported by curved bones called *branchiostegal rays*. The narrow body in the median line separating the right and left branchiostegal membranes is the *isthmus*.

Turn back or cut away the gill cover and examine the gills. Notice the central bony arch, and the fringe of red filaments that makeup each gill. On the front and inner border of each arch are teeth-like bodies, called *gill-rakers*. The slits between the gills are the gill *clefts*. A red spot on the inside of the gill cover is the *false gill*. Below the four gill arches is a fifth arch, called the *inferior pharyngeal bone*, and where the gill arches unite above is the *superior pharyngeal bone*, each of which bears teeth.

Study a scale; notice its radiate and concentric markings. A scale with an even posterior border is a *cycloid* scale, and one with a toothed border is a *ctenoid* scale. Compare scales from different parts of the fish. Notice a line called the *lateral line* along the side of the fish. Compare a scale from the lateral line with other scales and note the differences. Note that the arrangement of the scales is regular and symmetrical. Count the scales in the lateral line. Count the rows of scales above and below the lateral line on the side of the fish. Remove a scale carefully and notice a thin skin or epidermis covering it, and if we examine a dark spot we find that the coloring-matter is in the epidermis and not in the scale.

Open the fish by cutting from the anus forward in the median line to the isthmus; just back of the ventral fins, cut toward the spinal column on each side, so as to open the body cavity fully. Notice a silvery white membrane, the *peritoneum*, and in the front part, a little to the left, a brownish mass, the liver, and under it the *hepatic vein*.

Placing the fish on its right side; turn down the liver, uncovering the *stomach*. Pass a probe through the mouth and gullet

into the stomach; trace the intestine from the stomach to the anus, and notice the delicate membrane called the mesentery. Near the intestine find a reddish body, the *spleen*. Find the *air bladder*; it sometimes communicates with the alimentary canal. Does it in this case? Above the air bladder find two slender, dark red bodies, the *kidneys*, and in the posterior part of the body cavity find the *urinary bladder* and the reproductive organs; the yellow single or double *ovary* with the oviduct in the female, and the two white *testes* in the male.

In front of the liver, separated from it by the false diaphragm, is the pericardial cavity. Examine the heart; note the thin-walled *auricle* and the thicker walled *ventricle*. The auricle receives blood from the body through the *venous sinus* which passes to the ventricle, then through the arterial *bulb* to the gills, thence to the body; the blood is usually red.

The pectoral fins represent the anterior limbs of other vertebrates. They arise from the *pectoral arch*, which, in some cases, is a simple cartilaginous arch, in others composed of the clavicle, supraclavicle and post-temporal bones. The ventral fins represent posterior limbs.

Cut down to the ribs by the side of the dorsal fin and dissect away the flesh, studying the relation of the fin to the vertebral column. This, perhaps, can be done more easily in a fish that has been cooked, and in this way the flesh may be removed from the backbone so that it may be studied more satisfactorily. Study a vertebra. Notice the form of the body, the *dorsal spine* and *neural arch* and the *hæmal spine* and arch below, and note the neural canal with the spinal cord, and the hæmal canal with its contained blood vessels.

Open the cranial cavity and at least a portion of the spinal canal, and, beginning at the front, notice the *olfactory lobes* giving rise to the *olfactory nerves*, then the cerebral *hemispheres*, then the *optic lobes*, the widest part of the brain, then the *cerebellum*, and the *medulla oblongata*, merging gradually into the spinal cord.

Cut away the lower jaw, and, working from the mouth, dissect

out the muscles of the eye, and trace the *optic nerve* to the optic lobes. Notice the form of the eye, its flat *cornea* and spherical lens; its freedom of motion and the absence of eyelids.

Auditory organs are usually present, but it is said that fish cannot hear well, and the senses of taste and touch do not seem to be well developed. The olfactory sense is, perhaps, better developed than any other except the sense of sight.

Open and shut the mouth and note the motion of the different bones which make up that cavity. Cut away the gill cover on one side and note the motion of the gills corresponding to the motions of the jaws and tongue. Keep minnows or small fish in jars for observation, and notice their movements and habits.

Fish, in general, are carnivorous; they are voracious eaters and rapid growers. The flesh of most kinds is highly prized for food. The fishing industry is one of the great industries of the world.

Most fish are oviparous, producing vast quantities of spawn, but their natural enemies are so numerous, and the number destroyed by man so great, that many of the valuable fish began to diminish in numbers. This fact led several nations to establish departments looking toward the protection and culture of valuable food-fishes.

These departments have gathered an immense fund of information relating to the habits and life history of the more valuable food-fishes; to the habits and history of the various forms of life used by them as food; to the habits and history of those forms of life that prey upon food-fishes, and to the various forms of disease that attack valuable fish. This knowledge has led to the adoption of rational methods of protection and culture, so that waters formerly barren now yield an abundance of good fish, and other waters are furnishing a largely increased product. The more important food-fishes included in this group are the herring, cod, mackerel, shad, salmon, hake, haddock, halibut, white fish, trout, bass, pickerel, and many others.

The *Dipnoi*, are scaly animals breathing by means of gills and lungs; they have the form and appearance of fish, but their lungs

and the structure of the heart, make them appear as in some sense a transitional group between the true fishes and the amphibians. They are not found in this country, and are of no economic value, and are not numerous, although, during recent geological periods, they were prominent forms of life.

The *Amphibia* are cold-blooded, usually naked-skinned animals that are oviparous. The fertilized egg develops into a larva, somewhat fish-like in form, that breathes by means of gills. The larva eventually develops lungs and anterior and posterior limbs, sometimes retaining the gills during life but usually losing them. The lungs are not well organized and much of the respiration is carried on through the skin. The medium of respiration whether by gills, lungs or skin is supposed to be derived from the cutaneous surface.

The skeleton varies considerably, but the bones are usually more compact and calcareous than those of fish, and, with the development of the external limbs, the pectoral and pelvic arches are more fully developed and the amphibian is fitted for crawling, swimming, climbing and walking.

The nervous system seems, on the whole, to be more highly developed than among fishes, although the sense organs do not seem much superior to those of fish unless, perhaps, the senses of touch and taste may be exceptions. Some of the amphibians have a well-developed vocal apparatus in connection with the respiratory organs, which is a distinguishing mark of some importance.

The young, while breathing by means of gills, have the single auricle and ventricle and the same arrangement of arterial trunks as among fishes, but with the development of the lungs the auricle is divided into two chambers, one receiving blood from the body, the other from the lungs; but the ventricle remains single, containing mixed blood. The lymphatic system is well developed, in some cases the lymph receptacles are contractile, having the value of lymph hearts.

Some *amphibia* are terrestrial during the adult state, but usually live in damp localities since cutaneous respiration necessi-

tates a moist atmosphere. In larval life they live mainly on vegetable matters, in adult life on insects.

As a rule, their movements are sluggish, and the need of food is relatively small, so that they live for months without food. They also have the power of reproducing lost parts, as the limbs or tail.

The *Apoda* are worm-like amphibia, without limbs, that were for a long time thought to be snakes. They live in tropical climates and are of no special interest beyond the question of relationship.

The *Caudata* have four short limbs and a persistent tail, sometimes retaining external branchia through adult life.

This group includes the sirens, the mud puppies, which have external gills, and the land and water salamanders which have no gills.

The *Batrachia* are tailless amphibia with naked skin and well developed extremities. This group includes water frogs, land frogs, tree frogs, toad frogs and toads.

CHAPTER XXXIX.

REPTILIA AND AVES.

THE REPTILIA.

THE *Reptilia* are cold-blooded animals with a scaly or armored skin. In many cases there are no limbs, and when present they are usually weak, scarcely raising the body from the ground. In most cases the trunk, even when the limbs are present, is an important agent in locomotion, as the vertebral column is adapted to serpentine movements. The internal skeleton is always bony, and generally the ribs are numerous and well developed. Each half of the lower jaw is composed of several pieces joined by sutures, and the two halves are usually only loosely united. The lower jaw is jointed to the skull by means of the "quadrate bone," which enables the mouth to be opened much wider than would otherwise be possible. The jaws are usually supplied with prehensile teeth, and salivary glands are present. The stomach and intestines with pancreas and liver, are well developed. The heart has distinct auricles, but the ventricle is but imperfectly divided, so that mixed blood is distributed to the organs. Respiration is by means of lungs, which often reach considerable size, not being separated from the digestive organs by a diaphragm, as in the higher vertebrates. The nervous system is more highly developed than among the amphibians, the cerebral hemispheres being relatively large, but the senses are not specially acute. The reptilia in general are oviparous, the eggs having membranous shells. During the development a membrane called the *amnion* grows out from the blastoderm around the embryo so as to form a sac, which is filled with fluid. In addition the *allantois*, an extremely vascular organ, is formed, which serves as an embryonic respiratory organ. The appearance of the allantois corresponds with the disappearance of

branchial respiration, and every form of metamorphosis. Reptiles generally are tenacious of life; can to some extent replace lost parts; can live for long periods without food, and with but limited respiration.

The *Ophidia*, or snakes, have elongated cylindrical bodies, usually without limbs; sometimes limbs are represented by small spurs on the sides of the vent. They have an epidermal covering of scales, which are usually somewhat elongated, and may be smooth or provided with a longitudinal ridge. The head is covered with irregular-shaped plates, the abdomen with broad band-like plates, while the subcaudal plates are in pairs. The anal plate is sometimes entire and sometimes bifid. The number of rows of scales, the number of ventral plates and the character of the anal plates and body scales are important specific characteristics. The ribs, of which they have great numbers, are the chief locomotive organs of snakes. The free ends of the ribs are attached to the abdominal plates by muscular fibers, so that the ribs serve as legs and the plates as claws. The skin is shed and replaced at somewhat regular intervals; they have a forked protrusible tongue and no eyelids.

The *Colubriformia*, have both jaws armed with solid hooked teeth, with no poison fangs, and no spur-like appendages near the vent. This group includes the spreading vipers, watersnakes, garter snakes, blacksnakes, the racers, milk snakes, and other common snakes of our country. The harlequin, or bead snake, which is much like the members of this group in general appearance, has two grooved poison fangs in the upper jaw. It is jet black, with seventeen broad crimson rings, spotted with black, while the tail has yellow rings.

The *Crotalidæ* have the upper jaw provided with an erectile grooved poison fang on each of the relatively small upper jaws, and the short tail is often provided with a rattle. This group includes the rattlesnakes, massasaugas, copperheads and moccasins.

The *Lacertilia* or *Lizards*, are sometimes snake-like in form, but as a rule they have two pairs of limbs, and the body is usually

covered with scales; the pectoral and pelvic arches are present, and the bones of the head and jaws are more fully consolidated than in the snakes. This group includes the tree swifts, horned toads, glass snakes, which have hidden rudimentary limbs, lizards, skinks, etc. Lizards are more abundant in the warmer parts of the world, where they are common everywhere about walls, buildings, rocks, trees, etc.

The *Crocodylia* are not only larger than other reptiles, but they seem in every way more highly developed. The alligators of our Southern States are the only representatives of the class in this country.

Lizards and crocodilian reptiles existed in great numbers and variety and attained to an enormous size during middle geologic times, so that one period is called the Age of Reptiles.

The *Chelonia*, are a well-marked group of animals. They have a short stout body, with the dorsal and ventral surface covered with osseous shields, which in turn are covered by horny plates or a leathery skin. The neck and tail are flexible but the dorsal and sacral vertebræ help to form the carapace, uniting with ribs and overlying bony plates. The plastron or ventral plate seems to consist of membrane bones. There are no teeth, but the jaws are incased in horny sheaths which usually have sharp cutting edges. The eye is furnished with eyelids, and respiration is effected by means of air that is swallowed. This group includes the land tortoise, box turtles, terrapins, snapping turtles, soft-shelled turtles, etc.

The *Aves* or *Birds*. The birds are warm-blooded oviparous animals, clothed with feathers. They have four extremities, two adapted for walking or swimming and two fitted for service as organs of flight.

The bones of birds are more compact and lighter than those of reptiles. The cranial bones are fused together into a light, firm skull, which is articulated to the vertebral column by a single condyle. The face bones unite to form projecting beaks, the margins of which are covered with a horny substance that supplies the place of teeth. The vertebral column has a long, flexible,

cervical region, a short, slightly flexible, caudal region and a rigid dorsal lumbar and sacral region.

The ribs join the broad sternum forming a deep conical body cavity, whose walls are an excellent foundation for a strong shoulder joint. The clavicles unite so as to form an arch or fork, then the scapula and coracoid wedged in between the rigid vertebræ and the heavy sternum, making a socket for the broad faced humerus that gives the bird one of the best of shoulder joints. The wing is completed by the ulna and radius, and by the more or less modified parts of the wrist and hand.

The foundation for the articulation of the legs consists of an elongated pelvis made up of the lumbar and sacral vertebræ fused with the long iliac bones and the shorter ischial and pubic bones. The acetabular cavity is deep and the joint is firm. The short, heavy femur is concealed within the body, the knee joint usually being just at the surface of the body. The first free portion of the leg is composed of the tibia, the fibula being rudimentary; the second portion is a fusion of tarsal and metatarsal bones, which lead to the phalanges.

The muscular system is well developed and especially adapted to quick, vigorous movements. The skin is covered with feathers which correspond to the hair of the mammalia. A feather has a shaft and vane and the vane is made up of barbs and barbules. Feathers from different parts of the body vary considerably in appearance and use. Feathers are usually imbedded in the skin, but the larger stiffer feathers of the wing, called quills, are inserted in the bones of the wing.

The quills on the hand are the *primaries*, those on the forearm are *secondaries*, and when found on the arm they are *tertiaries*. The skin on the legs and toes is usually covered with horny scales or plates.

The nervous system and the sense organs are well developed. The alimentary canal consists of the mouth with the salivary glands, the œsophagus, crop, pro-stomach, stomach or gizzard, and the intestine with the pancreas and liver. The kidneys and the ovaries evacuate through the intestine. The heart and the

circulatory organs are double. The lungs are capacious, but instead of moving freely, as in the case of mammals, they are fixed to the dorsal aspect of the body cavity. They communicate freely with the cavities of the larger bones.

The matter of the adaptation of animals to their surroundings is perhaps more easily shown in the study of birds than in the study of any other group. The feet, the bill, the legs, the wings, the neck, the plumage, the whole appearance and habit of the bird depend on whether it is a wader, walker or swimmer; a scratcher, climber or a bird of prey. The idea is common everywhere, but in some way it seems more prominent among the birds.

Birds are oviparous, the eggs having a large amount of yolk, and requiring a high degree of heat for their development. In the fertilized egg, the process of development begins before it is laid; the blastoderm is formed, the primitive groove and medullary folds appear, then the cranial flexure, the digestive canal, the amnion and allantois membranes, and soon the young bird is ready to open the way to liberty from his stony cell.

Birds are intelligent; they have beautiful plumage and musical voices, and are interesting to man in many ways. No group of animals yet studied is as intimately related to man; none other more available for study than the birds. Study birds; note the migratory birds, the time they arrive and depart; note the ones that remain during the whole year, and those that only remain during the winter. Note also those birds that pass through your locality in their spring and autumn migrations, stopping only for a few days. Notice the birds that nest in your region; the kinds of nests they build; when they build them; how many eggs are laid, and what was the period of incubation. Make a careful study of the breeding and nesting habits of some particular pair of birds, making full notes. Study the legs, feet, wings, bill and other parts of birds and compare them. Study the bones and skeletons of birds, and compare with those of other animals. Notice that the claws of perching birds close automatically on the perch. Examine the arrangement of tendons in the legs.

Scald a bird and remove its feathers; notice if the feathers were uniformly distributed over the body; notice if they are distributed in the same way on different kinds of birds. After removing the feathers dissect the digestive, respiratory and circulatory organs, and dissect the brain and the sense organs. Study the development of the chick from day to day, breaking the egg into blood-warm water for observation. Study birds in every way.

The *Natatores* or *Swimming Birds*. These birds are clothed with a thick compact plumage and a heavy coat of down, and are supplied with a large oil gland. They are excellent swimmers and divers, and usually strong flyers. The beak varies from the strong cutting beak of the fish-eater to the soft yielding beak of birds who live on infusoria. They are usually gregarious on the seacoast or on large inland waters. Some species are valuable for food and other purposes. To this group belong the penguins with their fin-like wings, the auks, divers, swans, ducks, geese, pelicans, gulls, the albatross and stormy petrel.

The *Grallatores* or *Wading Birds*. These birds have a long beak, long neck and long legs, and are adapted for taking snails, larvæ, worms, frogs, fish and other materials for food from the mud of shallow waters. They are mostly migratory birds, some of them being highly prized for food. The plover, snipe, heron, stork, rail and water hen belong to this group.

The *Gallinaceæ*. These are terrestrial birds, having stout bodies and rounded wings not well adapted to flight. The legs are strong, of medium length and well fitted for running and scratching. To this group belong turkeys, domestic fowls, grouse, quail and partridge.

The *Columbinæ* or *Pigeons*. These birds are all of medium size, small heads and short legs, with soft beaks swollen about the nasal openings. They have long, pointed wings well fitted for sustained flight. They live on grains and seeds, and their plumage is often beautiful. To this group belong the pigeons and doves, and the lately extinct dodo was a member of the group.

The *Scansorial* or *Climbing Birds*. These birds in general have

a powerful beak, sometimes especially fitted for chiseling and hammering. They have strong climbing feet and a stiff plumage that often aids in climbing. They generally inhabit forests, living on insects, small birds, or on fruits and vegetable matters. The toucans, trogons, cuckoos, woodpeckers, parrots, cockatoos, etc., belong to this somewhat miscellaneous group.

The *Passeres* or *Passerine Birds*. The birds of this order are generally of a small size, well fitted for flight, dwelling mainly among the trees and bushes. They are sometimes divided into singing birds or *oscines* and shrieking birds or *clamatores*. They are usually divided on the character of the beak into *Levirostrres*, light beaks, as the hornbills, king-fishers and bee-eaters. *Tenuirostrres*, slender-billed birds, as the humming-birds, honey-suckers and tree creepers. *Fissirostrres* or birds with a deeply-cleft beak, and usually long-pointed wings, as the swallows, swifts, and goat-suckers. *Dentirostrres*, birds with the beak more or less notched at the point, as the crow, starling, shrike, flycatcher, titmouse, warblers and thrushes. And the *Conirostrres*, birds with conical beaks, that feed on seeds, etc., as the larks, sparrows, buntings and others.

The *Raptores* or *Birds of Prey*. These birds are of powerful build, having strong hooked beak and claws, and they are usually well adapted for vigorous long-sustained flight. Their sense organs in most cases are highly developed, thus fitting them well for their particular mode of life. They live mainly on warm-blooded animals, and the food is softened in the crop before digestion, the feathers and hair being rejected. To this group belong the owls, vultures, eagles, hawks, buzzards, kites, etc.

The *Cursores* include the ostrich, rhea, cassowary, emu, etc., large birds that are incapable of flight. The sternum has no keel, and the bones generally are massive and dense, more like those of the mammalia. The apteryx—sometimes called dwarf ostrich, clothed with long hair-like feathers—is also a member of this group. The recently extinct moa, and the *dinornis giganteus*, both enormous birds, were near relatives of the birds just mentioned.

CHAPTER XL.

THE MAMMALIA.

THE *Mammalia* are warm-blooded viviparous animals that suckle their young with milk from the mammary glands. The members of this class differ considerably among themselves in matters of detail, but in general the structure is the same, and the processes are carried on in the same way throughout the group.

A good general idea of the class may be gained by the careful study of some animal, as a rabbit, a cat, a puppy, or any other that is convenient. A good knife and a saw are all the instruments necessary, although a pair of forceps, and little hooks to hold parts in position or out of the way are a great convenience. First, go carefully over the external features of the animal, comparing it with others as far as possible. If not dead, kill it with chloroform and open the body cavity for its whole length, cutting away the breast bone and a portion of the ribs. Notice the diaphragm dividing the abdomen from the chest; note the form of the two cavities and the lining membrane of each. Study carefully the relative position of the organs in each cavity, turning them over so as to find them all; do not hurry; try to see every organ in its place, surrounded by its associated organs also in place. Through a tube, inflate the lungs, trying to imitate the breathing of the animal. Then study each organ and group of organs somewhat in detail, so as to get, if possible, some idea of how each organ performs its work. Study the heart carefully, tracing out the distribution of the larger blood vessels. Open the cranium; notice the protective coverings of the brain, its divisions and external appearance. Find the origin of the nerves of smell, sight, hearing and taste, and trace them to their respect-

ive external organs, and make a special study of those organs. Open the spinal canal and study the spinal cord; especially notice the origin of the spinal nerves. Study the bones, ligaments, muscles, tendons, joints, etc., in the legs, and in the spinal column. This study should be carried into detail as far as time and circumstances will allow. If it is inconvenient to get animals for dissection, material for an extended study may be obtained at the slaughter-house or butcher shop.

The Mammalia in general have a skeleton composed of compact bones filled with marrow, and the vertebral column is generally divided into five well-marked regions — the cervical, dorsal, lumbar, sacral and caudal. There are two pairs of limbs with the pectoral and pelvic arches well developed. The feet are especially interesting from the variety of forms under which the same group of bones appears. The digestive organs are well developed in all, but they vary widely with the nature of the food used by the animal. In nearly all cases the jaws are armed with bony teeth, differing in form, number and arrangement with the kind of food. The heart has four chambers and the circulation is double. The lungs are capacious and free to move in a special cavity, and the skin is usually covered with hair. The brain is relatively large and usually covered with convolutions, and the special senses are all highly developed. They easily lead the animal kingdom in matters of intelligence, and for this reason they are more useful and companionable to man.

There is considerable variation in the reproductive process, but the young are always born alive, and need the mother's care for considerable time afterward.

The *Monotremata*. This order includes the ornithorhyncus, or duck-bill, and the echidna, or porcupine ant-eater, both living in Australia. They have short legs armed with strong claws well adapted for burrowing. The urinary and reproductive organs open into the intestine, as with birds. The jaws are elongated into toothless beaks. The duck-bill is clothed with fur, has a smooth brain, a flattened body and swimming feet. The echidna is covered with spines, has a protrusible tongue and

folded brain; both have marsupial bones, but only the echidna has a pouch, and both live on insects.

The Marsupialia. This order includes the kangaroo, wombat, bandicoot and others of Australia, and the opossum of the United States. The females of this order are furnished with an abdominal pouch or marsupium, for the immature young after birth. The marsupials form no placenta, so that the young are born early in their embryonic life and transferred to the pouch, where they attach themselves to the nipples of the mammary gland and remain there during the remainder of their helpless existence. Some of this order are carnivorous, some herbivorous and others are omnivorous; some are specially adapted for jumping, others for climbing, and others have a naked prehensile tail; so that they are quite varied in form and habits.

The Edentata. The members of this order are all sluggish, stupid animals, with a small smooth brain; the teeth are frequently absent, and when present are usually incomplete or immature. To this group belong the ant-eaters, armadillos and sloths. The ant-eaters have an elongated narrow snout, protrusible tongue and weak jaws; the legs are short and adapted for digging. They live mainly on ants and termites. The armadillos are covered with bony plates, having legs and claws fitted for digging. They can rapidly bury themselves in the ground when pursued, and most of them can roll themselves into a ball that is well protected by bony plates from the attacks of enemies. The sloths are strictly arboreal, hanging by their curved claws from the underside of branches. The sloth, armadillo and one ant-eater live in South America, while the scaly ant-eater is found in Asia and Africa. The remains of many gigantic edentates are found in the later rocks of South America.

The Cetacea. The members of this order are aquatic mammalia, with fin-like anterior and no posterior extremities. The body is fish-like in form, only that the caudal fin is horizontal, not vertical as in the fishes. The surface is usually devoid of hair, but a thick subcutaneous layer of fat serves to protect from cold,

and perhaps lessens specific gravity. This group includes the *Dolphins*, *Whales* and *Sirenia*.

The dolphin is carnivorous, having both jaws armed with conical teeth. They live on fish, and frequent the mouths of large rivers. The narwhals have two upper teeth, which in the female are small, but in the male the one on the left side usually becomes a spiral tusk, which sometimes attains a length of twenty feet. The sperm whale has an enormous head, nearly one-third the length of the body. The head is swollen by the accumulation of fat—spermaceti. They inhabit the colder regions, and live mainly on cephalopoda. The whalebone whales have large heads and wide mouths without teeth. From the palate and upper jaw rows of whalebone plates project downward, forming a kind of sieve which strains the small medusæ and other forms of life from the water as it flows out. The sirenia have a distinct neck and no canine teeth, they feed on fuci and seaweed along the coast. They are known as sea cows, or manatees, on the coasts of America, and as dugongs on the coasts of the Indian ocean. Stellar's sea cow of the north Pacific has become extinct within the last 200 years.

The *Perissodactyla* are large herbivorous animals having one or three hoofs, and in all, the teeth are well developed. The teeth are divided into incisors, canines, premolars and molars. In this group the premolars and molars form a continuous series of broad grinding teeth all much alike. The dorsal-lumbar vertebræ are usually 23, never less than 22. The middle digit or toe is always largest and symmetrical in form.

The *Tapirs* are short-haired animals of medium size, having four hoofs on the anterior legs and three on the posterior. There are 6 incisors, 2 canines and 6 molars in each jaw, while there are 8 premolars in the upper and 6 in the lower jaw. They have a short proboscis, eat leaves and young twigs, and live in South America and Southeastern Asia.

The *Rhinocerotidæ* are large, unwieldy, thick skinned animals bearing one or two epidermal horns on the nasal bones. In each jaw there are 4 rudimentary incisors, 8 premolars and 6

molars. They are natives of Africa and Southern Asia. They have hoofs on the 2d, 3d and 4th toes of each foot.

The *Equidæ* are as noted for their graceful, slender forms as the other members of the order are for their bulky, clumsy bodies. The dentition is 6 incisors, 2 canines, 8 premolars and 6 molars in each jaw. Each of the incisors has a little pit near the summit, which, filled with foreign matter, seems like a black spot, that wears away with age. This pit is peculiar to horses, and is not found in the teeth of geological ancestors of the horse. The canines are small, conical teeth and are usually present in both jaws only in the male. The knee and hock joints of the horse correspond to the wrist and ankle joints of man, the bones below to the middle bone of the hand, and the bones of the middle finger are represented by the bones below the fetlock joint.

The hoof in all the ungulates corresponds with the nails or claws of other animals. The slender form of the horse fits him for harder ground and more open country than that occupied by the tapir and rhinoceros, and his well developed incisors enable him to take different kinds of food. The zebra, wild ass and quaggas belong to the horse family. The present members of the horse family are natives of the Old World, but in comparatively recent geological times there were several species of horses in America. Some of these ancient horses had three and some four toes instead of one, as does the present species.

The *Artiodactyla*, are animals with paired hoofs, the third and fourth digits on each foot supporting the body, the second and fifth digits are generally present but are rudimentary and do not help support the body.

The dorsal and lumbar vertebræ are 19 or 20; the premolars are single, while the molars are two-lobed and the other teeth are variable. This order contains several families.

The *Suidæ* or swine family have an elongated mobile snout, and the skin is clothed with coarse bristles. There are 6 incisors, 2 canines, 8 premolars and 6 molars in each jaw, sometimes an upper incisor and a premolar are suppressed.

The canines in the male are developed into formidable tusks.

The wild boar of Europe, Africa and Asia was perhaps the progenitor of all the varieties of the domestic pig, but they are so widely distributed and vary so greatly that some have thought they must have originated from several sources. Besides these, there are the wart hogs of Africa, the peccaries of America, and the babyroussa or hog deer of Southeastern Asia. The domestic pig is one of the most important food-producing animals known to man.

The *Obesa*, or *Hippopotami*, are large unwieldy amphibians, vegetable eating animals, living in Southern Africa, that belong in this order.

The other members of this order are ruminants, distinguished by incomplete dentition and by the peculiarities of the digestive organs. The animal crops the food, and without much mastication it passes from the œsophagus into the paunch, where it soaks in the secretions for a time, then passes to the honeycomb bag, or *reticulum*, where it is made up into little balls and returned to the mouth by regugitation. After thorough mastication, the food passes to the third stomach, called "many plies" or "*psalterium*," because its lining membrane lies in many folds. From this cavity the food passes with little change into the *rennet* stomach, where the food is really digested by the secretion of the peptic glands.

The *Tylopoda* include the camel and dromedary of the Old World and the llama, alpaca, etc., of the New. The soles of the feet are covered with horny integument on which the animal walks, and there is no separate psalterium.

The Arabian camel has numerous large cells in its paunch which enable it to carry several days' supply of water. The giraffes and musk-deer belong to this order.

The *Cervidæ*, or deer, are characterized by a pair of solid dermal horns attached to a bony process of the forehead; they are cast off and renewed from year to year, the weight and number of parts usually increasing with each renewal. The red deer, the stag, the elk, the reindeer, used as a beast of burden in Lapland, and others, are members of this family. The deer and stag have

pointed horns, while the horns of the elk and reindeer are broad and flat at the extremities. The horns are borne only by the males, except in the case of the reindeer. The cervidæ have eight incisors in the lower jaw working against a callous pad in the upper jaw; occasionally canines occur in the upper jaw. There are twelve grinders in each jaw, which are separated on the lower by a little space from the incisors. The young of nearly all species are spotted. The spines of the dorsal vertebræ are long, better fitting them for the origin of the strong ligaments which support the head with its load of horns.

The *Cavicornia* have hollow horns in both sexes, no canines, but twelve grinders in each jaw with six incisors in the lower. In this group belong the antelope, gnu, gazelle and chamois; the sheep, goat, ibex, Rocky Mountain goat and others; the musk ox, the American bison, and the Indian buffalo and the domestic ox—the sheep and the ox, the horse and hog being the most important and valuable domestic animals of the temperate and warm temperate zones.

The *Proboscidea* include the elephants and several extinct animals, all of great size. They are characterized by a long flexible proboscis, which is an organ of touch and of prehension as well. The skin is very thick and sparsely covered with hair, though some of the extinct forms had an abundant coat of hair. They have several toes on each foot furnished with hoofs, but walk on thick pads of integument. The tusks are two upper incisors; some extinct forms had lower tusks as well. The grinders are seven on each side in each jaw, but they grow forward gradually so that never more than one or parts of two are in service at one time, the earlier ones dropping out and new ones coming in. The grinders of the elephant are considerably longer than wide, and are made up of thin alternate layers of enamel, dentine and cement, showing a flat surface, while the teeth of the mastodon show a tuberculated surface. The mammoth and mastodon seem to have been vegetarians, living in damp shady places, much like the elephants of Africa and Asia of to-day. One extinct form had tusks curving downward from the lower jaw.

The *Rodentia* are a numerous group of small animals characterized by their chisel-shaped incisor teeth and the broad compact skull furnishing attachment and leverage for the powerful muscles used in their work of gnawing. The dental formula is two incisors and six or eight grinders in each jaw. The hares and rabbits having four incisors in the upper jaw, and some Australian forms have only four grinders. The incisors are enameled on the anterior surface with dentine on the posterior, and as the dentine wears away faster the tooth is always sharp and chisel-shaped. The teeth grow continuously during life about as fast as they wear away, so that they are always the same length. When one incisor is destroyed in any way its opposite unopposed continuing to grow has been known to form a complete ring, sometimes causing the death of the animal by preventing the use of its other teeth. These animals are compactly built, very prolific, and often showing great intelligence in the building of homes and the storing of food. Some migrate at the beginning of winter; some take a winter sleep. They are vegetarians, feeding on roots, seeds, fruits, etc. The mammals already studied walked on their toes, were in general *digitigrada*, but the rodentia walk on the palm of the hand or sole of the foot, and are *plantigrada*. The digits are freely movable, having claws or nails. In this order belong the hares and rabbits with long ears, powerful hind legs and short tail; the guinea pig and agouti, the porcupine with blunt nose and sharp quills; the chinchillas and the jumping mice; the true rats and mice and their allies; the voles with their short hairy ears and tail, and the lemming, the beavers, dormice and squirrels.

The *Insectivora* are small plantigrade animals whose feet are furnished with strong claws; the elongated head often ends in a pointed snout and the jaws carry a full set of teeth; the dentition varies considerably, the most distinctive character being the tubercles or points on the crowns of the grinders and that the canines are not prominent. They feed on small animals, insects and worms.

The *Erinacidæ* or Hedgehogs with stiff bristles and spines.

The *Soricidæ* or Shrews, with a proboscis-like snout and a musty smell. And the *Talpidæ* or Moles with short, powerful digging feet, soft fur and small eyes constitute this order of insect eaters.

The *Pinnipedia* are aquatic animals with a somewhat spindle-shaped body, having two pairs of short legs ending in fin-like feet. They are covered with a fine close fur and are carnivorous. This order includes the *Phocidæ* or Seals and the *Trichechidæ* or Walruses. The seals live on fish, have short canines and rough molars. The walrus lives on crustaceæ and molluscs, having the upper canines developed into tusks.

The *Carnivora* are distinguished by their size, strength and quickness; by prominent canines and cutting molar teeth; by the massive skull furnishing the attachment and leverage for the powerful muscles moving the sturdy jaws, and they are all armed with strong cutting claws. This order is made up of the *Ursidæ* or Bears. Stout unwieldy plantigrades including the polar and grizzly bears, the black bear, the raccoon and others. Some of the ursidæ are omnivorous, eating roots, mast, honey, etc. They have strong non-retractile claws, and some take a winter sleep.

The *Mustelidæ* or Martens, as the badger, marten, skunk, weasel and otter. The *Viverridæ* or Civet-cats. The *Canidæ* or Dogs, which are digitigrades with non-retractile claws, including the dogs, wolves, jackals and foxes. The *Hyænidæ* or Hyænas; and lastly the *Felidæ*, the typical family of carnivorous animals. They are digitigrada, of slender but powerful build, with strong retractile claws, with powerful canines and sharp cutting teeth. This family includes the lion, tiger, leopard, panther, jaguar and other cats.

The *Cheiroptera* or Bats are characterized by long anterior limbs, with long digits, which are united by a delicate membrane extending from the fore to the hind limbs, and, being attached to the sides of the body, form true organs of flight. They are nocturnal animals; the eyes are small but the senses of hearing and touch are very acute. Some of the bats live on fruits, some on insects, and some on the blood of warm-blooded vertebrates.

The *Prosimiæ* or the Lemurs. These animals have hands and prehensile feet; live in trees and feed on insects and small animals, and are generally nocturnal in their habits.

The *Primates* or Apes. The apes are vegetarians, generally leading an arboreal life, for which their form, however varied, seems adapted. They are usually of slender build, having hands, prehensile feet and sometimes prehensile tails.

The jaws are much less prominent than with other animals, which, with the obtuse ear and projecting eyebrow gives the face something of a human appearance. They have two mammary glands situated in the pectoral region, and are covered with a complete coat of hair. The dentition is much like the human, only that the canines are relatively larger and the grinders more tuberculated. The clavicle is always present, and in general the structure is very like the human, differing most widely in the size and structure of the brain and cranium.

The *Hapalidæ* are South American monkeys of small size with long hairy, non-prehensile tails, and opposable great toes. The *Pitheciidæ* have more teeth than the last but are otherwise much the same.

The *Cebidæ* are South American monkeys with prehensile tails sometimes naked at the end.

The *Cynocephalidæ* or Baboons. The baboons are of stout build, semiterrestrial in their habits, with a dog-like face. Tail sometimes long, sometimes short, never prehensile. The anterior and posterior limbs sub-equal. The canine teeth are large and the disposition is fierce. They sometimes eat eggs and small birds; in captivity they are omnivorous. There are several species, but they are all inhabitants of Africa and Arabia.

The *Cercopithecidæ* are of slender build, having a long tail, with cheek pouches and a short muzzle. They are the common apes of North Africa, Gibraltar, India, and adjacent islands.

The *Semnopithecidæ* have longer pelvic limbs, no cheek pouches, thumb small, sometimes absent. They are mainly Asiatic.

The *Anthropomorphæ* have longer anterior limbs and without tail or cheek pouches. In this family are the gibbons, having

very long arms; the ourang-outang, a native of Borneo; the gorilla and chimpanzee of Africa.

Man. Man, in his physical structure, resembles the anthropoid apes in innumerable particulars. His hand may be more perfect; his pelvis, legs and feet may fit him for a firm and erect position, and he may differ in every particular detail of physical structure from the apes, yet the difference is only in degree not in kind. And not till we consider the size and development of the *brain* and *cranium* and the correlative greater intellectual capacity does the gap between man and other animals reveal itself.

CHAPTER XLI.

GEOLOGY—ASTRONOMICAL.

GEOLOGY is a general science which has the material world for its subject. It attempts to give a history of the earth, to trace its development from a mass of burning gases to a whirling sphere clothed with verdure and teeming with life. From the study of a manufactured article we may learn how it was made and gain some idea of its history. The geologist studies the earth as a planet in its relation to celestial bodies, he studies the rocky pages of the earth's crust, and the data gathered from these sources interpreted according to the principles of physics, and chemistry, botany and zoölogy enable him to work out a somewhat complete history of the development of the earth.

The Earth is a member of the solar system which consists of the Sun, Planets, Planetoids or Asteroids, Moons or Satellites, Comets and Meteors.

The Sun is the central and controlling member of the solar system. It seems to consist of a central nucleus of molten matter bounded by the photosphere, outside of which is an atmosphere composed largely of the vapors of iron, nickel, manganese, carbon, calcium, sodium, silicon, aluminium, potassium and several other substances known upon the earth. This envelope is called the chromosphere. Above this layer of vapors, rise flames and prominences composed largely of hydrogen. And beyond these is the solar corona. At times dark spots may be seen upon the sun that appear to be deep pits in the photosphere; they vary in size and in duration. The time of the minimum number of spots occurs every eleven years and the time of the maximum number occurs some four or five years afterwards. We know little about the cause of the spots but they seem in some way to

disturb the magnetic conditions of the earth, and possibly its climatic conditions as well.

The gaseous envelopes of the sun are subject to violent disturbances or storms, consisting largely of upward and downward movements of the gases. It is thought by some that the sun spots are in some way the result of these storms. The quantity and intensity of the heat of the sun is beyond comprehension and yet it must be diminishing as there seems to be no adequate means of supplying the enormous and continuous loss of heat by radiation. Others claim that while the sun is continuously sending out immense quantities of heat, it is actually increasing in temperature through condensation of material due to gravity. The sun is spherical in form and rotates once in about 25 or 26 days. Besides rotation, the sun with the whole solar system has a progressive motion in space toward the constellation of Hercules. Its diameter cannot be determined with accuracy, but is given as about 866,000 miles.

The Planets are spherical bodies which revolve around the sun from west to east in elliptical orbits. Named in their order from the sun the planets are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus and Neptune. Venus, Jupiter, Mars and Saturn appear as brilliant stars. The planets differ in size, time of revolution and in density. Mercury is more dense than the earth, but the sun and all the other planets are less dense. Venus seems to have an atmosphere, but Mercury is not known to have one. No permanent marks or features have ever been discovered on these planets so that it is not certainly known whether they rotate or not. Mars and the earth each has a solid crust, and somewhat similar atmospheric conditions and each rotates from west to east. Jupiter and Saturn seem to be masses of molten matter, each surrounded by a deep dense atmosphere, in which extensive changes and disturbances are known to occur, and somewhat permanent markings can be seen, from which it appears that each of these planets rotates from west to east. But little is known of Uranus or Neptune beyond some idea of their size, density and time of revolution.

The Planetoids or asteroids are a group of smaller bodies revolving around the sun between the orbits of Mars and Jupiter.

The Moons or satellites are bodies which revolve around some of the planets as these revolve around the sun. The Earth has one moon, Mars two, Jupiter four, Saturn has eight moons and in addition two rings, Uranus has four or more satellites, and Neptune at least one. We can know but little about the moons but they all seem to be spherical bodies and in general to revolve in the same direction as their primaries. The satellite of the Earth, one of the largest of the moons, is nearly a perfect sphere having a diameter of 2,160 miles. It rotates on its axis and revolves around the earth in about twenty-seven and one-third days, so that the same side is always toward the earth. Seen through a telescope the surface of the moon appears to be very rugged, not from mountain ranges but from great circular depressions in which there are sometimes conical elevations. The moon seems to be a great cinder-like body, devoid of air, water and every form of life. It is supposed that the rocky mass may have absorbed the air and water which were formerly abundant on its surface.

The Comets are interesting, but little known, members of the solar system. They are usually rather small bodies with an extensive atmosphere, revolving in much elongated orbits, moving with great velocity when near the sun.

Meteors are bodies, which, falling toward the earth, are heated to incandescence by friction in the air, and usually vaporized before reaching the earth. Sometimes they reach the earth as meteoric stones or meteorites. In general the meteorite is composed mainly of iron, sometimes of a stony substance.

The Stars are supposed to be bodies like our Sun, many of them, however, much larger than it. The spectroscope shows that many of them contain substances found to exist in the sun and well known on the earth. The stars vary in size, in distance from the earth, in temperature, in color, and apparently in composition as well. Some appear to be double stars, some revolve about others; others are variable in appearance, often changing

rapidly. They are all supposed to be in motion in definite directions but whether they move together as one system or as many distinct systems is not known.

The Nebulæ are cloud-like masses, similar to the milky way, which occur abundantly in different parts of the heavens. Many of these, when examined with a telescope, are shown to consist of distinct stars, others still appearing as clouds when viewed with the most powerful telescopes. Some of these, when examined with the spectroscope are shown to be star clusters, while others are shown to be incandescent gaseous bodies. They differ in size and in distance from the earth; some are formless masses, some ring-shaped and some spiral, as if the mass were beginning to rotate, but our knowledge of them is very meager. The constitution and conditions of the nebulæ and stars; the motions, conditions and relations of the members of the solar system have given rise to the Nebular Theory, which supposes that the sun was once a mass of burning gases, which filled the orbit of Neptune. The mass had a rotary motion which increased as it cooled and contracted, becoming at length so rapid that portions were thrown off, much as water and mud are thrown from rapidly turning carriage wheels, this process continuing until all the planets were formed, each assuming a spherical form, each revolving around the parent mass, some and probably all rotating in the same direction. Some of the planets rotated so rapidly that bodies were thrown off from them and thus the satellites were formed. This theory cannot be demonstrated but it harmonizes with most of the facts known of the solar system.

The nebulæ as burning gas, the sun and stars as molten masses surrounded by intensely heated gases, Jupiter and Saturn as molten bodies which have cooled below the point of incandescence, the Earth and Mars as bodies, over which at least a solid crust has been formed, are each supposed to represent different stages through which the earth has passed in developing from the primal fire mist, to its present condition. The moon probably represents a farther stage toward which the earth is approaching.

CHAPTER XLII.

MINERALS AND ROCKS.

THE greater part of geological work pertains to *rocks*. In geology everything that helps to make up the crust of the earth is rock, whether it be hard and enduring, like the limestone and granite, or loose earthy materials like sand, clay or dust. Rocks are sometimes simple chemical compounds, but generally they are composed of a mixture of several distinct compounds called *minerals*. There are a great many different kinds of minerals; all of them are interesting and many are valuable, but only a few are of much importance as rock-forming materials.

The most abundant and common of the minerals is *silica*, composed of oxygen and silicon. It crystallizes in six-sided prisms, appearing something like glass. It is hard enough to scratch glass, and this quality distinguishes it from all other minerals having a similar appearance. Silica is sometimes called quartz. It is the chief ingredient of sand, gravel and sandstone.

The *Feldspars*, often associated with silica, are a group of interesting and abundant minerals. *Orthoclase*, the most common feldspar, is a silicate of aluminium and potassium. It occurs in all colors from white to a fleshy-red. It sometimes has the appearance of glass, but is readily distinguished from quartz by its inferior hardness, as it will not scratch glass, and may be scratched with a good knife. It crystallizes in rhombic prisms, and splits easily and smoothly in two directions, but it sometimes has a massive or granular structure showing no signs of crystallization. Moonstone and sunstone, often used as jewels, are varieties of this feldspar. Sanadine, a glassy variety, is common in many lavas.

Albite, another species of feldspar, is a silicate of aluminium

and sodium, while *Anorthite* is a silicate of aluminium and calcium. Several other feldspars are thought to be only mixtures of the ones just mentioned. In general they are very much like orthoclase in appearance, but on a fresh surface their crystals seem like strips of glass on which fine lines may often be found that do not occur in the orthoclase. These are usually called triclinic feldspars. Broken down weathered feldspar is the basis of clays, shales and slate rocks.

Mica is a silicate of aluminium and potassium or magnesium, with iron and sometimes a little lime. It splits easily into thin flexible leaves, which are nearly transparent, and are frequently used in windows. It often occurs with silica and feldspar as an ingredient of some kinds of granite rock. Sometimes from their glistening appearance scales of mica are mistaken for gold.

Hornblende and *Pyroxene* are silicates of magnesium and calcium, containing oxides of iron and manganese. Some varieties contain in addition a little aluminium. They vary in color from white to black, but in general they are greenish-black or black. In general the darker varieties are the ones containing aluminium. The fibrous mineral asbestos is a variety of hornblende. The darker varieties are more common, and are easily distinguished from mica by their hardness and crystalline form, and are not liable to be mistaken for any other mineral. These are common minerals in basalt and lava, in trap and syenite, and sometimes the light-colored varieties occur in limestone.

Talc is a hydrated silicate of magnesium with a little oxide of iron. It is the softest mineral known, separating easily into thin scales. It has a light green color, a pearly luster and a greasy feel. It is best known as steatite or soapstone.

Serpentine is much like talc in composition and qualities but is a little harder and has a rich greenish color.

Chlorite contains more aluminium than talc and is harder than that mineral. It has an olive green color and often a granular structure.

Calcite, carbonate of calcium, is a mineral that crystallizes in several different forms. When pure it has a pearly luster and is

nearly transparent. It is the basis of the different kinds of limestone and marble, appearing in a great variety of forms. It is easily scratched with a knife, and effervesces vigorously when treated with any acid, even strong vinegar will decompose it.

Dolomite is a carbonate of calcium and magnesium. It is perhaps a little harder than limestone, and is not as easily affected by acids, but it is often difficult to distinguish between them.

Gypsum, the hydrated sulphate of calcium, often forms extensive beds of rock. It is easily cut with a knife, is white, sometimes variegated, in color and when burned to drive off water of crystallization becomes plaster of Paris.

Pyrite, the disulphide of iron, is of a pale brassy yellow color, crystallizing in cubes. It is very common in the neighborhood of coal banks, and is the source of the sulphur in the coal. From its color it is often mistaken for gold. Pyrite and the sulphides of copper, lead, zinc, and other metals are often associated with gold, and are abundant minerals.

Graphite, nearly pure carbon and the various ores of *iron* are widely disseminated minerals of value and interest.

Chloride of sodium, common salt; *corundum*, nearly pure oxide of aluminium; *apatite*, phosphate of lime, etc.; *leucite*, abundant in some lavas; *olivine*, a silicate of magnesium and iron, are all important minerals.

The minerals mentioned, either singly or variously combined, make up the greater part of the rocks which compose the earth's crust.

Granite is a crystalline rock composed of thoroughly mixed quartz, orthoclase feldspar and mica, the particles being of nearly uniform size. It is usually hard, light-colored and can generally be identified by the scales of mica. Sometimes the rock is very fine grained, containing large crystals of feldspar scattered through the mass when it is called *porphyritic granite*.

Quartz Felsite or *Felsite*. This rock consists of a fine granular or homogeneous ground mass, through which are disseminated crystals of quartz, feldspar, mica or hornblende. This rock varies widely in structure without much modification in composi-

tion. Felsite consists of the ground mass without the crystals, forming a tough compact rock.

Liparite has a similar composition but shows more evidence of a former molten or glassy state in its structure.

Syenite, a rock often associated with granite, is composed of orthoclase mixed with hornblende and occasionally some quartz and mica, and sometimes triclinic feldspar occurs. There is seldom any difficulty in identifying this rock after one learns to recognize feldspar and hornblende.

Trachyte is a volcanic rock composed largely of sanidine, a variety of orthoclase, with some triclinic feldspar, and usually hornblende, mica and iron, and sometimes with pyroxene, apatite, etc. It has much the same composition as syenite but has not become fully crystallized.

Obsidian is a volcanic glass, varying considerably in its composition, but in general it is rather like trachyte. It shows no trace of crystallization and may represent the first stage in the development of crystalline rocks, trachyte and syenite representing others.

Diorite, or *Green Stone*, is composed of triclinic feldspar and hornblende usually with apatite and iron.

Basalt is a dark-colored volcanic rock, composed of triclinic feldspar, pyroxene, olivine, iron and apatite. It often has a ground mass of glass through which crystals are scattered.

Schists are crystalline rocks of varied composition in which the materials are arranged in nearly parallel layers. Schist rocks may be composed of but one mineral, but they usually consist of two or more minerals in alternate layers or mingled in the same layer. They are usually named from the principal ingredient, as, mica schist, chlorite schist, and talcose schist, usually containing quartz, feldspar and other minerals besides the one naming the rock.

Gneiss. This rock is composed of quartz, feldspar and mica but the proportions and the arrangements are different from those in granite. It is schistose in structure but coarser than schist. There is a larger proportion of mica than in granite. It

varies widely in appearance but is usually recognized without difficulty.

Under the action of atmospheric influences the rocks are gradually pulverized, reduced to boulders, pebbles, gravel, sand and clay. We may find all kinds of rocks represented among the boulders and pebbles, while the gravel and sand are largely of quartz. The clay, dust, etc., making up the *soil* are from the feldspar, mica and other easily disintegrated materials. Much of the clay, sand and dust are eventually spread out over the sea bed as sediments. Great quantities of rocks are broken down and pulverized by the action of the waves along the sea coast and added to the sediments of the sea.

Pebbles or gravel, and sometimes boulders, may be cemented together into *conglomerate* rock, and it is called quartz, limestone or granite conglomerate, according to the nature of the material. Conglomerates differ also in the nature of the cement or paste, which may be of quartz, lime, clay or even iron.

The sand may be cemented into *sandstone*, which may vary much as the conglomerate varies. The typical sandstone, however, is composed of quartz grains united by a paste of quartz.

The clays are compacted into shales. They are easily cut with a knife, break into irregular blocks and vary greatly in purity.

The finer sands and coarser clays mingle in varying proportions so as to form clayey sandstones or sandy shales.

In deeper water, away from the shore, calcareous sediments are formed from materials furnished mainly by different forms of life; these at length become *limestone* rocks. Peat and soft coal are sediments.

The different kinds of sandstone, clay and limestone rocks are formed from sediments, and are known as *sedimentary* rocks.

Metamorphic rocks are sedimentary rocks that have been changed by heat, pressure and other agencies into a crystalline form. The sandstones become quartzites; the mixed sands and clays become gneiss, granites, etc. Limestone becomes crystalline limestone and marble, and the clays and shales become slate, which is but slightly crystalline. Peat and soft coal become

bituminous and anthracite. These rocks were formed from sediments that were deposited in layers or strata, and the rocks are often called stratified rocks.

Obsidian, propylite, trachyte, basalt and other volcanic products are called *igneous* rocks, and are unstratified. Doubtless many of the granites and gneisses had their origin in trachyte or basalt, and are strictly igneous rocks.

Granite, syenite and other crystalline rocks are the last terms in the series beginning with sediments, as well as in the series beginning with obsidian or basalt.

All rocks are divided by cracks or joints into irregular blocks of various sizes and shapes. In stratified rocks the bedding planes bound the blocks on two sides, and divisions nearly perpendicular to these and to each other bound the other sides. The last are called joints. In the case of igneous rocks the blocks are bounded on all sides by joints. These blocks vary in form in different rocks; in *limestones* they are regular and cubical; in *basalt* regular and columnar; in *slate*, small and indistinct; in *sandstone*, large and irregular, etc. The cause of joints is probably the shrinkage of the strata in consolidating from sediments. Similar joints or cracks may be seen in the dried mud of ponds that have been drained of water. Joints are confined to individual strata, but fissures are fractures passing through several or many strata, probably caused by movements of the earth's crust. Fissures 30 to 50 feet wide and many miles in length are known. Sometimes the rock on one side of a fissure is forced upward so as to change the relations of the strata, causing what is called a *fault*. In some cases the displacement is as great as 15,000 or 20,000 feet. Fissures in many cases have been filled with some rock-forming material, when they are known as veins. Much of the gold and silver of the world came originally from veins. In some cases these fissures were filled by an injection of igneous material from below; others are filled by matters deposited from water circulating through them. Joints and fissures are geologically interesting, as they facilitate erosion, determine the course of rivers and the location of valleys.

CHAPTER XLIII.

EARTHQUAKES AND VOLCANOES.

IN the geological history of the earth, two sets of forces have been active. Some which may be called plutonic, have been making the surface of the earth uneven, through them the continents had their origin and the mountains were formed. The others, which are eroding forces, mostly atmospheric, have been equally busy in cutting down the elevations and filling up the depressions, their action tending toward uniformity as the others toward variety.

The internal condition of the earth is not well understood. As we explore the crust by mines and wells, we find that heat increases rapidly with the depth below the surface, so that at a depth of thirty or forty miles, the heat must be intense enough to melt any known substance, if it were only under atmospheric pressure, but under the enormous pressures of such regions, substances would doubtless behave as solids, notwithstanding the great heat.

In relation to other celestial bodies the earth behaves as a solid, rigid as glass, so that while the interior of the earth is intensely hot, it is probably not a liquid.

In general the irregularities of the surface of the earth are supposed to be due to unequal contraction, the interior contracting more rapidly than the crust. This results in enormous horizontal pressures under which, along lines of weakness, the crust swells up into wrinkles, folds or corrugations. The lines of weakness are accounted for by supposing an irregular distribution of matter, or that there was more radial contraction, or settling over the area now occupied by the oceans. This idea is strengthened by the fact that the matter underlying the oceans is more dense than that underlying the continents. Whatever may have been the

origin, when the irregularity was initiated, the pressures due to unequal contraction would continue to intensify them.

Sometimes under this pressure the crust yields suddenly, is fractured for a great distance, the rocks on one side of the fracture being elevated or depressed with reference to the other. Thus an earthquake is caused, a fissure vein is opened and a fault is formed. The fault may be only a few feet at first, but it may increase to hundreds of feet as it slowly yields to the continued pressure. Other forces may cause earthquakes, as explosions of superheated water or of gas, possibly in connection with volcanic eruptions. These shocks cause vibrations of the crust, which are often transmitted for immense distances. These waves may be severe enough to overthrow buildings, produce avalanches and land slips, sometimes changing springs and streams of water. Again they cause great waves of the sea, which rush upon the shore with great violence; in fact, the greatest destruction of life by earthquakes has been from the ocean waves which they caused. A wave that destroyed Lisbon in 1755 was nearly sixty feet high. In 1868 an earthquake devastated the coast of Peru. And less than half an hour after the earth wave came several water waves from 50 to 60 feet high, adding greatly to the destruction already begun. These waves reached the Sandwich Islands, 5,580 miles, in 12 hours, and Japan, 10,000 miles distant, the next day. Such waves have been known to move at the rate of 450 miles per hour. An earthquake which occurred near Naples in 1857, by careful examination was shown to have originated in a fissure about nine miles long, through about three miles of rock, the center being about six miles below the surface. The velocity of the earth wave in this case was between nine and ten miles per minute.

No portion of the earth is free from earthquakes, but they are more common in volcanic regions.

Again, a fissure is formed as noted above, and from it is poured out vast quantities of molten matter or lava. Such fissure eruptions were frequent during Tertiary times in the Rocky Mountain region and other localities. At the present time a volcano is

usually an opening somewhere on the line of such a fissure, around which a somewhat conical hill has been built up from the materials thrown out.

In a volcanic eruption gases and vapors are the first materials to appear; they continue during the eruption of other material, and often for centuries after all other evidence of subterranean action has ceased. Aqueous vapor is probably most abundant; it is sometimes given off in such quantities as to result in heavy rainfall. Among the gases the most abundant are hydrochloric acid, sulphuretted hydrogen, sulphurous acid, carbon dioxide, free hydrogen and others. The typical volcanic material is molten rock called lava, which includes material varying considerably in composition and specific gravity. The lighter varieties contain a larger per cent. of silica, and are acid lavas, as trachyte and pumice. Others are basic lavas containing less silica and more iron and pyroxene, as basalt and leucite lava. Others again are intermediate between these groups. Lavas also vary in structure; some are wholly crystalline, as some liparites; some show a glassy or stony ground mass, with imbedded crystals, which is, perhaps, the most common structure. Again, others are pure volcanic glass, as obsidian. Then some, as basalt, are dense and compact, while others, as pumice, are vesicular.

Great quantities, a fine ash-like dust and coarser particles, called sand, usually accompany eruptions. The dust and sand are lava pulverized by escaping vapors and gases.

The quantity of dust formed and thrown out is sometimes enormous. Dust from volcanoes in Iceland has fallen abundantly in Sweden and Holland, and fell in such quantity at a distance of 600 miles as to destroy crops.

Large blocks of lava are frequently ejected. Water is sometimes a volcanic product, which, mingling with the dust and sand, forms a mud stream, and mud itself is a product of some volcanoes. A good idea of the flow of lava, and of the peculiar forms it often assumes, may be obtained by watching the flow of slag at a blast furnace.

Lavas differ in their fluidity; those of Kilauea in Hawaii, are

very liquid, while those of Vesuvius are viscous. The fluidity modifies the flow of the lava. That from Kilauea flows like molten iron; at first white hot, with a temperature of more than 2,000° F., it soon becomes red, growing darker till it assumes a black, cinder-like appearance. The viscous lavas of Vesuvius break in rough brown slags, which grind and grate over each other with a metallic sound. Occasionally the lava flows over the edge of the crater, but it often breaks through the side of the mountain, sometimes 2,000 or 3,000 feet below the surface of the lava in the crater, forming fountains of molten rock. Lava that is completely fused when cooled quickly forms volcanic glass obsidian; when cooled slowly crystals are formed and stony lavas result. In most lavas the crystallization is quite complete before the mass becomes solid.

A volcanic cone is, to a great extent, the work of the volcano, and its composition and form depend on the materials thrown out by eruptions. If the product is fluid lava, as in the case of the Hawaiian volcanoes, the cone will be broad and flat. If the lava is viscid the cone will be steeper and narrower. If the product is chiefly ashes, scorïæ and lava, the cone will be steep. The cones formed by successive eruptions have somewhat the structure of an exogenous tree. Sometimes the cone has been ruptured by radiating fissures, and these filled with lava dikes. Secondary cones are frequently formed inside the craters or on the sides of the main cone; there are some 200 such cones on the slopes of Mount Etna.

Volcanoes are mostly located in the mountain regions along the shores of the Pacific ocean, and many of the islands of that ocean are volcanic. Some are located about the Mediterranean Sea, in the West India islands and elsewhere.

The causes of volcanic action are not understood, but many theories have been advanced to account for the phenomena. It is generally agreed that the expansive force of steam is the chief force of eruption, but how the water reaches the molten rock is not explained. The source of the volcanic product and of the volcanic energy cannot be deep, as water could scarcely penetrate

to a depth of more than six or eight miles. Some think the crushing of the rocks under the great horizontal pressure develops heat enough to fuse the rocks and produce eruption. Others ascribe the molten matter to chemical action between the unoxidized interior and oxidizing agents, as air and water, from the crust; and again the action must be within reach of surface water. The source must be local, as volcanoes near each other yield different kinds of material, and sometimes with lava standing in their craters at widely different levels. And it frequently happens that the same volcano yields different material at different times. We know many things about the effects of earthquakes and volcanoes but very little about their causes.

Rocks and lava cool slowly, thick masses retaining high temperature for many years. It is said that cigars and sticks might be lighted at fissures in a lava stream from Jorullo, Mexico, 21 years after the out-flow. Water percolating through such material appears again as hot springs, and often with dissolved gases and minerals, as, sulphur springs, iron springs, etc., and doubtless the geysers of Iceland and Yellowstone Park are in a sense secondary volcanic phenomena.

A geyser appears to be a spring or pool of hot water, but when its depth is measured it is found to be more like a funnel-shaped well of hot water. At somewhat regular intervals eruptions of water and steam occur. The phenomena of an eruption are about as follows: Sounds like cannonading are heard below and bubbles rise through the water, then the water rises a little, overflowing the basin, and immediately afterward the water is thrown out as from a fountain, followed by a great quantity of steam. It is explained by supposing that water toward the bottom of the tube is converted into steam which throws out the water above it.

CHAPTER XLIV.

TEMPERATURE, WINDS, WAVES, TIDES AND CURRENTS.

THE forces active in early geological phenomena, had their origin for the most part in the earth itself. But as the outer portions cooled the initial heat became less effective, and the heat of the sun, causing most of the phenomena of climate, became an efficient geological agent, especially during the later stages of the earth's history.

The earth revolves around the sun and rotates on its axis. If the axis was perpendicular to the plane of revolution there would be no change in the distribution of heat over the surface of the earth during the year; there would be no zones; no changes of seasons. But the axis is declined from a perpendicular to the plane of revolution about $23\ 1-2^{\circ}$, and to this fact we owe the zones, the long cold winters in the polar regions, the winter and summer of the temperate zones, and the wet season and dry season of the tropics.

The crust of the earth is very uneven. The depressions filled with water we call the sea; those portions above the sea we call the land. The sea is divided into oceans and the land is divided into continents, and these into grand divisions.

Water is not a good absorber nor a good radiator of heat, hence does not gain heat rapidly during the day or the summer, and does not lose heat rapidly during the night or the winter, maintaining quite a uniform temperature during the year. The rough, dense land is a much better absorber and radiator than the water, so that it gets much hotter during the day and summer, and much colder during the night and winter than the water. The water, with its uniform temperature, tends to equalize the varying temperatures of the land, so that climates along the sea-shore are markedly different from inland climates. For this rea-

son the relative extent of land and water areas and the relative positions of the bodies of land and water are important climatic questions.

At first it seems as if there might have been more land; but on examination we find that only a portion of the present land surface can get water enough to be productive of plant or animal life. The land extends in two masses almost from pole to pole, and with such general form and irregular outline that very large portions come under the equalizing influence of the sea.

The land varies in elevation. There are low plains, plateaus and mountains. The important facts to be learned about mountains are their location, elevation and direction of extent; and in regard to plateaus their location, elevation and extent should be known. In general the mountain systems of the Western continent trend north and south, and so do those of South Africa and Australia, while in Europe and Asia the trend is more nearly east and west. The greater mountain systems border closely on the deeper oceans, as the Pacific and Indian.

The air is an invisible gas surrounding the earth, extending upward some 400 or 500 miles. It is composed mainly of oxygen and nitrogen, with varying quantities of water vapor, carbon dioxide, ammonia, nitric acid, etc. Variation in the temperature of the air is the principal cause of winds, rainfall, dew, frost and other phenomena, which together make up what we call *climate*, and which is generally discussed under the heads of temperature, winds and rainfall.

The temperature of the air depends mainly on the temperature of the earth's surface. The heat from the sun passes through the air and warms the earth, and the earth in turn warms the air mainly by convection, partly by radiation and reflection. It is estimated that the air absorbs more than one-third of the heat sent from the sun to the earth, the greater part being taken up by the water-vapor and carbon dioxide, as pure air is nearly diathermic. The air absorbs even a larger per cent. of the heat radiated from the earth and prevents the surface from cooling as rapidly as it would if the air were diathermic.

Thus the air serves the surface of the earth as a sun-shade by day and as a blanket by night, tending to equalize its own temperature. This effect is greatly increased by the presence of clouds in the air. If it were not for this property of the air it would be so hot in summer, and cold in winter as to destroy all such life as exists on the earth at present.

As the surface of the earth is the main source of heat for the air, the temperature of the air must decrease from the general surface upward. Mountains and high plateaus usually have a lower mean temperature than the general surface of the earth in the same latitude.

The difference in temperature between the tropical and polar regions is the chief cause of different pressures in the air, and the unequal pressures cause currents of air or winds.

Along the equator there is a belt of light pressure; at about 32° north and 25° south there are belts of heavier pressure, and at about 64° north and 70° south there are areas of light pressure. The movement of the air is from the heavy pressure toward the light pressure. Currents blow from the belts of light pressure at 32° north and 25° south toward the equator; these form an upward current, which, after rising some distance, spreads out toward the light pressures north and south.

Owing to the rotation of the earth these currents do not flow directly north and south, but those going toward the equator from 32° north, go southwest as *northeast* winds, and those from 25° south go northwest as *southeast* winds. And those toward the north pole go northeasterly as *southwest* winds; and those toward the south pole, go southeast as *northwest* winds. In general the winds of the tropics are easterly winds and those of the temperate zones westerly winds.

These winds represent the general movements of the air subject to many local exceptions, occurring in each grand division, especially in the coast regions.

The air always contains water vapor, the amount depending on the temperature of the air and on its distance from large bodies of water. The air does not hold the water vapor as the

sponge holds water, but they are two gases mingled together, each independent and sustained by the same force of heat. When there is mingled with the air as much water vapor as the temperature can sustain, the air is said to be saturated with moisture, while if it might contain much more it is called dry air. As the temperature of moist air is lowered the water-vapor at length begins to condense into dew, fog or cloud.

Air in tropical regions, near the sea, contains the most water-vapor. Nature's method of lowering the temperature of the air is by sending it upward or toward the poles. The winds from the equatorial regions are relatively warm and moist winds, and in general are rain-bearing winds. As winds rise over mountain chains their temperature is lowered and the water vapor falls as rain, as they move toward the poles the same thing occurs. The upward current from the tropical regions rises so high that moisture is condensed, forming the copious rains of those regions.

In South America the easterly winds of the torrid region coming from the ocean, leave some moisture on the low mountains near the eastern coast, but the greater part falls as they rise over the giant Andes, giving that region an exceptionally heavy rainfall and one of the most interesting river systems in the world.

In North America the westerly winds furnish a heavy rainfall for the region west of the mountains and north of San Francisco. And southwesterly winds that come over the regions of Arizona, as upper currents, are the main source of rainfall in the upper Mississippi valley, and westerly winds give Europe an abundant rainfall.

The eastern plateaus of Asia receive but little moisture on account of their high mountain borders; their surfaces are barren, and the air is nearly diathermic. During summer they become excessively hot, and the air over them so light that exceptional winds flow in from the east and south, which in rising over the mountains lose their moisture as heavy rainfalls, forming an extensive system of great rivers.

Africa furnishes a region of exceptional rainfall. The regular

easterly winds from the Indian Ocean furnish abundance of moisture, but during summer the central region becomes so hot and the air so light that exceptional winds from the Atlantic ocean flow into that portion of Africa. These winds both leave abundant moisture on the slopes of the plateau, but the greater part falls after the upward current is formed, condensed by cold from elevation.

Thus the winds carry the water from the sea to the land, where a portion becomes permanent in the rocks and soil, a portion evaporates and a portion forms springs, brooks and rivers. These inland waters are very efficient geological agents.

The sea, with waves, tides and currents, is also an important force in geological work.

Waves are caused by the wind and are common on the sea everywhere varying in elevation with the force of the wind. The wave has a forward movement, but the water only moves upward and downward. When waves advancing toward the shore reach shallow water, the motion is retarded at the bottom by friction, and the top moving on without support breaks over on the shore, thus forming breakers. During storms waves break on the shore with great force.

Tides are waves caused by the attraction of the sun and moon. There are four tidal waves, two of equal size on opposite sides of the earth caused by the moon, and two much smaller caused by the sun. As the moon revolves around the earth once in about 27 days, the waves caused by the moon make the circuit of the earth in the same time. Twice during this circuit the moon waves coincide with the sun waves, making higher or *spring* tides, and twice the lower part of one coincides with the higher part of the other, and a lower or *neap* tide is formed. As the earth rotates in the same direction that the moon revolves, a given place passes through the crest of both moon waves once in 24 hours and 52 minutes. In mid ocean the tide does not rise more than three feet, but along some coasts and in narrow bays they rise much higher. At the head of the Persian Gulf the tide rises 36 feet; at the Bay of St. Michael, France, 45 feet. In shoal

water and in narrow bodies of water these waves make strong to and fro currents.

Ocean currents are as common as the waves, but are not quite as manifest or as easily understood. They are caused mainly by the winds and by the tides. Unequal heating and evaporation would seem to be efficient causes of currents, but a little investigation shows that the effect of one tends to neutralize the effect of the other. The rotation of the earth and the form and arrangement of the land masses help to determine the direction of the currents. In general the currents have the same direction as the winds. The equatorial currents flow westerly with the easterly winds, and the Japan current and the Gulf stream flow northeasterly with the southwest winds, etc. Beside the surface currents there are strong under currents toward the equator. Thus the heat of the sun, the attraction of the earth, causes winds and streams of water, waves and currents in the ocean, and the attraction of the sun and moon cause the tides, all efficient agents active in geological phenomena.

CHAPTER XLV.

GEOLOGICAL ACTION OF AIR AND WATER.

AIR and water; winds, clouds and rain; frost, snow and ice; springs, creeks and rivers; waves, tides and currents, are the most common objects and phenomena of the material world. They are so common and familiar that most people fail to realize that they are important, efficient, essential agents in nearly all geological phenomena.

Quiet, dry air of uniform temperature is not an efficient agent, but changes of temperature, which may be mentioned here, are of great importance. The daily variation of temperature in some dry regions is very great. On the southwestern plateaus of North America the temperature varies from 90° F. at mid-day to 20° F. during the night, and the same is true of wide regions in Africa and Asia, a variation of 90° F. between day and night being by no means uncommon. The expansion and contraction due to such great and rapid change of temperature soon causes rocks to crack and flake off and rapidly disintegrate into sand. Dr. Livingstone, while in Africa, found that rocks heated up to 130° F. during the day, cooled so rapidly during the night that they cracked and split, throwing off angular fragments of all sizes up to those of a hundred pounds weight. In the dry regions the rocks are broken up in this way almost as rapidly as in regions where frost is the active agent.

The winds carry away the dust and sand formed, and the surface of the region is gradually lowered by this dry erosion. The sand carried in this way by the wind acts as a piece of sand-paper, polishing and cutting down the rocks. These natural sand blasts sometimes cut into the base of a cliff, and when undermined blocks fall, attack them in the same way, continuing the

process till the cliff is reduced to sand and carried away by the wind.

The combined action of wide and sudden variation of temperature and the wind, has removed a thickness of more than ten thousand feet of strata, from an area of thousands of square miles, of the plateau through which the Colorado river flows.

The sand and dust eroded by the wind from one locality is deposited in another. The dust is widely disseminated, and settling quietly is constantly adding to the growth of soil. In this way dust from the high plateaus of Asia has built up a formation of *loess* from 1,000 to 2,000 feet thick over regions between the plateaus and the ocean. The loess is unstratified, fine yellow calcareous clay, containing abundance of land shells and remains of vegetation. Other loess seems to have been formed with the aid of water, and is called *lake loess* or *river loess*. It is said in some places in Asia dust enough falls to serve as a fertilizer for the soil. This dust, which pervades the air everywhere, is of interest in the matter of rain-fall, for it seems that water-vapor condenses only on free surfaces, and the cloud and mist is formed by the condensation of moisture on the particles of cosmic dust.

The sand may be carried into rivers or lakes or into the sea, or may form sand hills or *dunes* on the margin of the dessicated region, as in northern Africa, Arabia and western United States. But the most interesting sand dunes are those formed along the margin of large bodies of water. When the prevailing winds are from the water toward the land they carry sand from the beach over the land till, meeting some obstruction, a dune is formed. It may be ridge-like or somewhat conical in form; the seaward slope is long and gentle, the other as steep as loose sand will stand.

The wind not only carries or rolls sand from the beach, up the gentle slope to the crest, but is continually carrying sand from the slope itself to the crest and letting it fall on the landward side, so that the dune travels inland, destroying forests and crops, covering buildings, filling ponds, damming up streams, etc. In time another dune forms between the first and the beach, which

follows the leader as waves follow each other. Where there is abundance of moisture not much sand can be moved during the year, and vegetation soon begins to grow on the dunes, and may in time so cover them as to stop the action of the wind and the dune becomes permanent. Sometimes these dunes interfere with drainage forming lakes, ponds, and marshes, as along the eastern shore of Lake Michigan and western coast of France. Dunes sometimes serve as barriers against the sea and sometimes as wind brakes. This action of the wind in moving sand can be studied almost anywhere on windy days, even in the street or schoolhouse yard.

Of the rain and snow that falls on the earth some is soon evaporated, some is taken up by the soil, some by plants, some sinks into the ground to reappear as springs, and some—from 25 per cent. to 30 per cent.—flows into the ponds, brooks and rivers. Water acts on the soils and rocks chemically and mechanically. Water, when it reaches the soil, contains a little air and carbon dioxide, dust, living germs, etc., so that one effect is to fertilize the soil as well as to moisten it. Pure water usually protects the rock it covers, but water in conjunction with air is an active oxidizing agent.

A thin pellicle of the oxide is formed on the surface, which if not washed away thickens from the inside until a thick crust covers the rock. The oxidation of iron and iron compounds is the most interesting and important. Sulphide of iron is widely disseminated through nearly all kinds of rock, and under the influence of air and water both the sulphur and iron are oxidized, sometimes forming ferrous sulphate; and sometimes other bases take the acid, leaving the iron free to become the ferric oxide. Thus many kinds of rocks are entirely broken up, some parts passing away in solution, allowing the whole to disintegrate rapidly. Carbonate of iron is also acted on in much the same way, the iron changing to the ferric oxide, allowing the rocks containing it to decay rapidly.

Water dissolves salt, sodium chloride, without aid, but in most cases of solution water is aided by carbon dioxide or

some other re-agent. In this way limestones, and feldspathic rocks, carbonates and silicates of calcium, potassium, and sodium, are disintegrated, the calcium and alkalies, becoming carbonates, are removed by solution and the rocks crumble down into sand and clay.

In this connection may be mentioned the action of freezing water. In northern latitudes the soils and rocks become saturated with moisture during the autumn. During winter the water in all the cracks, joints and interstices freezes, and by its expansion increases all these spaces, and so on from year to year till as the ice melts in the spring some of the outer particles becoming loosened are washed away; thus soils and rocks are broken up and pulverized in some cases with great rapidity. The work of water is somewhat increased by the mechanical action of falling rain.

The general effect of air and water aided by heat, frost, gravity, and vegetable acids on rocks is called *weathering*. This action varies with different rocks and in different climates; by this process nature transforms rocks into soil and carves out many strange and interesting forms on the rocky surfaces of the earth.

Soil is formed in various ways, but on level or gently sloping surfaces, much soil is formed by the decomposition of rock *in situ* by the process of weathering. Perhaps most of the work is done by carbonated water, but other agencies have more or less effect.

Nearly all rocks are more or less jointed or fissured, so that water charged with carbon dioxide from the air or decaying vegetation, readily finds its way deep into the rocky strata, reappearing at lower levels as springs. During its underground journey the water dissolves more or less material from the rocks over which it passes, so that the water of springs is seldom pure water. Sometimes the water may have passed over insoluble rocks, and issue from the earth as pure, *soft* water. Or it may have passed over limestone rocks, and loaded with calcium carbonate form a *calcareous* spring, supplying "hard" water. And according to the nature of the rocks through which the water flows, a spring will be ferruginous, sulphur, saline, alkaline, etc.

The effect on the rocks of this underground water is much the same as the effect of air and water on the surface rocks. Solution and disintegration are usually more rapid in limestone rocks, large channels and caves being common in such formations. Sometimes the roof of the cave falls in and the cave or underground channel becomes a gorge or narrow valley. The caves of Southern Indiana, Kentucky and Tennessee are remarkable for their size and the beauty of their stalactitic architecture. In these caves there are often interesting examples of reparative action. In cases where the bed of the stream has been lowered so as to leave some rooms practically dry, the dripping from the roof at length forms pillars, supporting the roof, and in time perhaps fills the room. Again, where quantities of rock have fallen, the drippings from above fill the spaces between the fallen rocks with stalagmitic material and at length build supporting columns, finally closing the cavity.

Sometimes the underground water, on sloping surfaces, dissolves away the union between large masses of rocks and the mountain side, causing land slips, rock avalanches, etc.

CHAPTER XLVI.

RIVER AND MARINE EROSION.

THE rain falling upon the uneven surface of the earth, forms little rivulets, which, uniting with others, form larger, and so on, till the brooks and creeks are formed ; which together constitute the river that receives all these little streamlets—each with its burden of sediment—and conveys them, at length, to the great and wide sea. Beside this surface water, the rivers receive the water from thousands of springs, spring water, in many cases, forming the greater part of the supply during the year. The region of country drained by a river is called the river valley, or basin, and is usually considerably longer than wide. The character of a river will depend on the nature of the rocks of its valley ; on the character of the climate of the valley and on the rapidity of its slope. Rivers vary in the amount of water and other material they carry. Nearly all rivers have an annual flood, and many are subject to change from exceptionally wet or dry seasons.

The Mississippi river, draining a wide valley embracing a variety of climate, is somewhat uniform in its flow, subject to its annual spring flood, and sometimes an exceptionally wet season will give a summer flood.

The Nile river depends for its water supply on seasonal rains in the upper part of its valley, and is very uniform in all its phenomena from year to year. In regions subject to great irregularities of rain-fall, the change from low water to flood is often very great, as rivers in south-east Australia, or even in the south-western part of the United States.

In general a river has three parts—the mountain portion, where formed by mountain torrents, it rushes noisily over its steep, rocky bed to the lower ground that forms its middle or valley course. In this part of its course the river flows through a more varied country, lower mountains, wide valleys, narrow gorges,

and sometimes spreading out into lakes, and in this region the largest tributaries are received. From this undulating country it passes into a broad alluvial plain, mostly deposited from its own waters, and winds sluggishly onward, and finally, amid marshes and banks of mud and sand, it empties into the sea. The great rivers of the globe probably have an average slope of less than 24 inches per mile. The Volga from source to sea has a slope of less than 4 inches per mile, while the Missouri has a slope of about 28 inches per mile. The water next the bottom and sides of the river channel is retarded by friction, so that water in the center and upper part of the river flows most rapidly. The fact that rivers flow more rapidly when in flood is explained on the theory of less friction and increased slope from high water in the upper courses.

Each little rivulet, each spring in the whole valley, brings to the river products of terranean and subterranean weathering, which the river carries out to sea with materials gathered up by erosion along its course. The amount of material carried by rivers in this way varies greatly; rivers flowing through cultivated regions usually carry great quantities of sediments. The Missouri river, flowing through recent, partially consolidated strata, is loaded with sediment, and so are the rivers of China that flow through the loess deposits; while the St. Lawrence system, with its rocky valley and lake basins, is nearly always clear and free from sediment. The water of rivers doubtless has some chemical effect on the materials over which it flows, but the chief work of flowing streams is mechanical. The matter carried by streams is partly in solution and partly in suspension, and partly coarse material pushed along the bottom. Of the substances in solution, calcium carbonate is most abundant, then calcium sulphate, sodium chloride, magnesium carbonate, and sulphate, etc. It is estimated that the quantity of calcium carbonate removed from the limestone areas of the Thames amounts to 140 tons per square mile annually.

The power of a stream to transport suspended matter is said to increase as the sixth power of the velocity of the current, so

that the power of the current is increased 64 times by doubling its velocity. A current of three inches per second will begin to work on fine clay, one of six inches per second will lift fine sand, and one of eight inches per second will move coarse sand, and one of one foot per second will move fine gravel; while a current of two feet per second, or a mile and a third per hour, will roll along pebbles an inch in diameter, while a current of two miles per hour will move stones the size of an egg. These figures are given for the bottom velocity, and it should be remembered stones are not more than two-thirds as heavy in the water as in the air, so that they are more easily transported.

In the upper course of the stream large angular blocks of rock, loosened by the frost, are urged down the steep slope by the rushing torrent; these, gradually abrading each other and the bed of the stream, in time reach the sea as gravel, sand or mud. Some fragments may have reached the sea within a year after leaving their mountain bed, while the last particles of some of the blocks may be thousands of years in reaching their final destination in the bed of the ocean.

The amount of solid matter conveyed by a large river to the sea each year is almost beyond comprehension. Many investigations have been made, but the most extensive and reliable are those made by Humphrey and Abbott, on the Mississippi river. They estimated that the amount pushed along the bottom of the river into the Gulf, was 750,000,000 cubic feet annually, and the amount in suspension was about 4,368,280,000 cubic feet, a total of 5,116,280,000 cubic feet per year, equal to a prism 268 feet high, with a base of one square mile. This means that the Mississippi moves about one foot from the surface of its valley in 6,000 years. Other rivers erode more rapidly, and some less rapidly, but the above, as an average rate, would carry North America into the sea within 4,000,000 years.

Rivers erode their channels, but clear water erodes very slowly, as shown in the case of the Niagara and St. Lawrence rivers, which have had very little effect on the glaciated rocks in their beds, during the 3,000 or 4,000 years since glacial times. The

work of erosion seems to be done by sand and gravel carried or pushed along the bed of the river. The rate of erosion will depend on the strength of the current, the amount and kind of sediment carried, and the nature of the rock through which the channel was located. In the Missouri river, in many places, there are from 40 to 50 feet of sand and mud between the bed rock and the water. When the river is low, or at a medium stage, this bed of mud and sand is quiet, and there is no erosion of the rock-bed; but when the river is in flood, the whole mass is in motion, sliding along like a rasp over the bottom of the rocky channel. Limestone rocks erode more easily than some others, and they are more easily soluble. Sometimes flint nodules in limestone rocks hasten erosive action. The limestone eroding, more rapidly, leaves the nodule as a projection; a piece of floating ice or a log strikes the nodule, knocking it from its bed, leaving a hollow. Sand and gravel collect in the hollow and, kept in motion by the water, soon form a pot-hole, which is an interesting and effective mode of erosion in rocks, where in any way little cavities are formed.

Another special form of erosion, is by water-falls, which are formed in various ways. The falling water splashing against the foot of the cliff gradually undermines the upper portions, which at length break down, and thus the falls recede and a gorge is formed. If the lower portions are easily eroded, the action is more rapid. At the Niagara Falls, the upper stratum is hard limestone, the lower shale—which are favorable conditions for rapid work. It is estimated that at the present time the falls are receding at the rate of about 2.4 feet per year. The Grand Cañon of the Colorado river about 300 miles long, and in some places 6,000 feet deep, is the work of the erosive forces of the river. Sometimes a fissure determines the course of a river, and helps to form its channel; but such cases are not as common as was formerly supposed. Ice in streams often adds considerably to their erosive power. Land ice, or glaciers, are efficient geological agents, which will be discussed in another place.

A stream of water carrying sediment begins to drop it when-

ever the current is checked. When a mountain torrent, with its burden of sediment, flows out upon a plain, it drops the greater part in a fan-shaped mass, the apex pointing up the stream; little streams flowing into ponds deposit sediments in the same shape; and the delta of the Mississippi is an enormous mass of sediment of the same form, and deposited in the same way, the current slackened by the waters of the Gulf.

A river seldom deposits any sediments along its mountain course, but when it enters its middle course the current is lessened and the sediments deposited sometimes raise the bed of the river above the level of the adjacent land. The same thing occurs frequently in rivers flowing through low plains or deltas. Some rivers in Northern Italy illustrate the first and the Mississippi river the second. During floods rivers often spread out over adjacent low lands which are covered with vegetation; the rough ground and the vegetation check the current and a layer of sediment results. Turbid rivers flowing into lakes drop their sediments, the water at the outlet being clear. In this way lakes are sometimes obliterated, entirely filled by the sediments of their inlets. The course of a stream consists of a system of irregular curves or bends, with occasional stretches of nearly straight channel. On the convex side of a curve the current is strong and erosive, while on the concave side it is weaker and depositing sediments. In this way streams change their channels, wandering about their valleys, eroding old sediments and depositing new, so that a bit of gravel may form a portion of scores of different gravel beds before it reaches the ocean. The whole matter of the geological work of streams can be studied in almost every phase along any little brook or creek in the country.

Marine erosion is very extensive, but is not as rapid or extensive as river erosion. The waves with their burden of sand or gravel gradually undermine the rocks so that they fall within reach of the waves; the smaller fragments are rolled backward and forward by the waves, hurled against the larger ones till at length they are broken up, and the fragments abrading each other become pebbles that slide up and down the beach with

every wave, and are soon worn to sand and mud. In the river the pieces of rock move forward, and are more nearly spherical in form, while on the beach they move backward and forward and soon become flattened, and are sometimes called shingle. The sand resulting may form sand bars parallel with the shore, or may be transported to other localities by ocean currents, or may be built into dunes by the winds.

The different forms of life often are of great importance as geological agents. Plants, as mosses and liverworts, by keeping the surface of rocks moist, promote their decay, and in the decay of their leaves and stems organic acids are formed which are active oxidizing agents. These acids, for the most part, become carbon dioxide, and in one form or the other are the great solvents of the mineral world, often penetrating rocks to a great depth. Plants and trees also aid erosion in a mechanical way, as their growing roots open cracks and seams in the rocks.

Turf and trees protect from erosion. Forests protect hillsides and sand dunes; the sand-grass and other plants also protect the same from the wind. Mangrove swamps along the seashore are especially effective in reclaiming and making land. While live plants protect, dead and decaying plants often open the soil to the erosive action of wind and rain. Decaying vegetation enriches soils, forms muck beds, peat bogs, etc., from which all the coal and much of the rock oil and natural gas were formed.

Burrowing animals of all kinds, earth worms, cray-fish, open the soil to the action of oxidizing agents, and often to the action of erosive agents as well. Beavers build dams, making ponds and swamps, while cray-fish, rats, etc., open holes through banks which lead to destructive erosion. Some mollusca bore holes in rocks and wood, thus promoting their disintegration. The shells of the mollusca, the framework of corals and other animal organisms have made up most of the calcareous or limestone rocks. And the coral polype, in the tropical sea, is building islands and reefs of coral limestone, while diatoms, and some forms of animal life, are furnishing material for silicious deposits of great extent.

CHAPTER XLVII.

THE ARCHÆAN AND ALGONKIAN ERAS.

ASTRONOMICAL studies lead us to suppose that our earth was once a sphere of glowing gas, and that as it gradually cooled, portions were condensed, forming a molten nucleus surrounded by intensely heated gases. That as the cooling process continued, the nucleus gradually increased in size and the temperature of the surrounding gases diminished until the mass ceased to be luminous. At length a solid crust began to form over the heated interior. It was doubtless broken up, remelted and reformed many times, but at last a continuous slag-like crust became permanent. From what we know of the composition of the rocks, this crust was composed mainly of the silicates of aluminium, calcium, potassium, sodium and magnesium, with iron manganese and other substances.

All the water of the present oceans, lakes, and rivers, all the mercury, sulphur, chlorine and other volatile matters with the air formed an atmosphere of dense, poisonous vapors. In time, portions of these vapors condensed, covering the crust with broad, shallow oceans of hot, acid water. As the earth continued to cool, the interior contracted more rapidly than the solid crust, and as the crust settled down with the inner mass broad, low swells and wide, shallow depressions were developed. These gradually increased in elevation and depth until the continents appeared, and the ocean boundaries were defined. Portions of these ancient continents may have been submerged from time to time for many hundreds of feet, but at no time have the continents and oceans changed places; their relative positions have probably always been substantially the same.

The reactions between the acid waters and the basic rocks re-

sulted in adding many soluble chlorides and sulphates to the sea-water and in the formation of sediments as silica, silicates of aluminium, potassium, calcium and sodium. These materials with the original crust make up a system of granites, gneisses and crystalline schists, which represent the oldest rocks of the earth. These rocks are doubtless of a mixed origin partly igneous, partly sedimentary, but they have been so completely changed by metamorphic agencies that all trace of lava, slag, and sediment has been obliterated.

These rocks, sometimes called the "Basement Complex," are found in Arizona, Nevada, and Texas, in the regions of Lake Superior and Hudson's Bay, including the greater part of the Laurentian rocks of Canada. These rocks were subjected to the folding, crumpling and faulting incident to mountain formation and to atmospheric erosion, and have been covered extensively by later rocks so that we can know little of their original form and extent. The time from the beginning of the crust to the time when rocks that are distinctly sedimentary began to be formed is called the *Archæan* or *beginning era*, and the rocks belong to the Basement Complex, or Laurentian Age.

The Algonkian Era.—Under the action of erosive agencies large portions of the Archæan rocks were broken down and distributed over adjacent sea bottoms as sediments, which afterward were changed into conglomerates, quartzites, quartz, mica and iron schists and limestones. These rocks vary considerably, passing from quartzite to quartz-schist; from conglomerate to conglomerate schist; from pure limestone almost like marble, to limestone containing great quantities of chert; and with the iron schists there are cherts and jaspers in abundance. These rocks are called the *Lower Huronian*. At the end of Lower Huronian time this region was raised above the sea, crumpled and folded, and subjected to erosive agencies, which in some instances carried away the whole series. After this period of erosion the surface was depressed and sediments were deposited on the eroded surfaces that afterward were changed into the conglomerates, quartzites, shales, schists, iron schists and slates, chert, jasper, etc.,

which make up a group of rocks known as the *Upper Huronian*. The exposed area of these rocks is much greater than that of the Lower Huronian, and they include the most of the rich iron ore deposits of the Lake Superior region.

These rocks in some places are as much as 13,000 feet in thickness. In general these rocks are not as highly metamorphic as the Lower Huronian. At the close of Upper Huronian time the surface was raised above the sea and exposed to erosive agencies again. After some time great floods of volcanic materials were poured out over this region. Later the region was covered by the sea and sediments were deposited which afterwards became conglomerates and sandstones. These volcanic and sedimentary rocks make up the *Keweenawan group* or *series*. In some cases the volcanic rocks are interstratified with the sedimentary rocks, which seems to indicate a subaqueous flow of lava. This series is very extensive, and in some places is estimated to have a thickness of 50,000 feet. These rocks include most of the rich copper deposits of the Lake Superior region. Rocks to the east of Lake Superior belonging to this or an earlier series contain thick beds of graphite as well as iron.

The reactions between the air, water, and land so purified the air and water that low forms of aquatic life began to appear, and soon became abundant, even acquiring new characters and spreading out over the rocks. Great quantities of insoluble iron ore were disseminated throughout the slag-like crust. Water containing carbon dioxide derived from decaying organic matter changed this insoluble peroxide into the soluble protoxide and carried it down to the ponds, lakes and marshes, where taking oxygen from the air, it again became insoluble, and settling to the bottom helped to form sediments which afterward became thick beds of iron ore. The immense beds of iron ore and graphite, indicate that some forms of life must have been very abundant; but there is no positive evidence as to its character, as all organic remains were destroyed when the sediments were changed to rocks.

Granitic, gneissoid, schistose and slate rocks make up the

Laurentian tableland extending from Labrador southwestward to the region of Lake Superior, thence northwesterly to the Arctic Ocean. They occur in the Adirondack and White mountain regions, at many localities in the Western mountain regions in the Alleghanies, in Arkansas and Missouri and in other places, but only in the region of Lake Superior and some western localities have the rocks of the two eras been clearly separated.

These rocks as exposed in the Laurentian tableland are from 40,000 to 50,000 feet in thickness. Their formation and their elevation into mountains is explained as follows: The area now occupied by these rocks was a shallow sea, adjacent to an extensive land surface, probably on the north in the region of Hudson's Bay. The sediments derived from the land were spread out over this sea bottom. For some reason this area of the crust was weak, so that it settled gradually, as the sediments were deposited, till they became more than 50,000 feet deep. At length the settlement was so great that the rocky masses underneath became softened by the internal heat, and the whole mass became so weak that it yielded to the lateral pressure of the sinking crust and the sediments were mashed together, the crumpled, folded strata slowly swelling up into mountains.

Under this great pressure, through the agency of heat and water, the organic matter of the sediments was destroyed and they were changed into metamorphic rocks.

Originally the substances which make up the earth's crust were widely disseminated, and the great bulk of the Archæan rocks were formed from a mixture of a wide variety of substances; but the assorting tendency of nature's operations is manifest in the beds of quartzite, slate, limestone, iron ore, and graphite.

The Laurentian tableland is the oldest portion of North America; it seems never to have been submerged. It has been subject to eroding agencies for untold ages; it has furnished materials for the rocks of all subsequent ages; yet rising by intervals or continuously, it has always kept pace with the degrading effects of the eroding forces.

CHAPTER XLVIII.

THE PALÆOZOIC ERA.

THE next period of the earth's history is called the *Palæozoic Era*, or era of old life. This era includes the Silurian age, the Devonian age, and the Carboniferous age.

At the beginning of this era, besides the Laurentian tableland, there seems to have been a large body of land occupying the region of the Atlantic coast plain; and another in the region now occupied by the Rocky Mountains. Between these bodies of land there was a broad, shallow sea, called by some the Palæozoic sea. The earliest rocks of this era are sandstones and slates, composed of materials that accumulated on the beach of this ancient sea, over a region extending from Canada to Georgia. They are known as the Cambrian rocks. In them we find the earliest remains of life, representing protozoans, cœlenterates, echinoderms, worms, and crustaceans, nearly all the invertebrate forms of life, besides several species of plants.

This abundance of the various forms of life, calls attention to the nature of the geological record. We know nothing about how much time elapsed between the formation of the primal crust and the formation of the Algonkian rocks, with their evidences of beginning life, and we know very little of what events transpired during the period.

The life of the Algonkian era must have consisted mainly of low forms of vegetation with some protozoans, as no other forms could exist under the conditions of those times; and yet in the next higher rocks that have been found there is evidence of an abundance of life of well-advanced forms. The early rocks had been strongly folded and deeply eroded before the later rocks were deposited. Thus the relations of the rocks and the forms of life show that after the formation of the Algonkian rocks there is an

immense period of the earth's history, of which no record can be found. Erosive forces were active; sediments inclosing remains of various forms of life were deposited and changed to rocks, and the whole submerged and covered from view by later rocks. The rocks of that era which we can examine seem to be mere remnants of great continents of rocks that have been cut away by erosion and submerged. They stand between great unknown periods in the history of the earth. Breaks in the geological record are numerous, but perhaps no other is as well marked as this one.

During the balance of the Silurian age thick beds of rock were deposited over a wide portion of the continent, as the Trenton, Niagara and Galena limestones, the Utica and Niagara shales and the Medina sandstones; the limestone largely exceeding the others in some regions, so that it is mentioned as the characteristic rock of the age.

All classes of invertebrate life were abundantly represented, but mollusks were most numerous and varied, so that this period is often called the Age of Mollusks. Some fossil fishes have been discovered in European rocks. More than 10,000 species of fossils have been described from the Silurian rocks; remains of seaweeds and of plants that were terrestrial, as ground pines and others, some like the yew and pine.

The area of Silurian rocks extends from Newfoundland to Missouri, from Lake Superior to Georgia, but they are thickest in the Appalachian region. In the west the limestones are most abundant, while in the Appalachians they only make up about one-half of the beds. The limestones were formed in quiet waters, largely from the shells of mollusks, the stems of crinoids, the framework of corals, etc. The sandstones and shales were generally beach deposits, sand bars, mud flats, etc. Some clayey iron ores and salt deposits indicate the existence of marshes and shallow salt lakes. The frequently alternating beds show many upward and downward movements of the crust. It takes but a few moments to make these statements of the events of this age, but they were the work of millions on millions of years. And in this study we need to keep constantly in mind that geological time units are

very, very long. It is said that no group of strata has been traced over a wider area of the earth's surface, and none are more uniform and well marked in their composition and in the character of their fossil remains than are the Silurian.

Following the Silurian age came the Devonian age, characterized by the "old red sandstone beds" of Great Britain. In North America the lowest formation is the corniferous limestone, one of the great limestones of the continent; the later strata were mainly sandstones and shales in the east, with shales and thin limestones in the west. The corniferous limestone is distinguished by seams of hornstone or flint and occurs in New York, Ohio, Michigan, Iowa, Missouri, Kentucky and adjacent regions. The Hamilton shales of New York and the black shales of Ohio and neighboring regions belong to this age.

During the Devonian age the different classes of invertebrate life were abundantly represented, but in general by different species from those of the silurian age. Fishes, however, were the characteristic and dominant life of the age. They were like the sharks and skates, garfish and sturgeons of the present, representing the lower orders of vertebrate life. They existed in great variety, and often attained a large size.

Plants were represented by seaweeds and other aquatic forms, but terrestrial forms, as equisetæ, ferns, lycopods, and the lower gymnosperms were abundant and characteristic, often attaining the size of trees, forming forests. The corniferous limestone indicates a quiet sea for a long time, but the later rocks were largely the products of erosion deposited on the sea bottom near the coasts. And the vegetation suggests extensive swamps and marshes. The character and relations of the rocks indicate no marked distinction or gap between the Silurian and Devonian ages, but the marked difference between the life forms of the two ages does suggest an interval of time not shown by the rocks.

The Devonian passed without violent changes into the carboniferous age. The rocks in many localities show changes of level and crumpling of strata indicating some difference of conditions between the Devonian and the following Carboniferous age; but the

difference is not very great. This age is divided into three parts, the *sub-carboniferous*, *carboniferous* and *permian*. The sub-carboniferous rocks are mainly limestone, but in Ohio, Michigan and Pennsylvania there are more sandstones and shales, all of marine formation. The lowest strata of the Carboniferous is a coarse sandstone called the *Millstone grit*. The other strata are thin beds of coal, shale, limestone, sandstone, clay, iron, stone and under clay. The permian rocks are an ill-defined group of sandstones, limestones, gypsum beds and shales, that mark a transition period from the palæozoic to mesozoic eras.

Coal occurs in separate areas or basins, as the Appalachian coal field, the greatest in the world, extending from Pennsylvania to middle Alabama, with an area of about 60,000 square miles of workable coal; the central field, covering the greater part of Illinois, part of Indiana and Kentucky, about 47,000 square miles. The western field includes southern Iowa, and portions of Missouri, Kansas, Arkansas and Texas, about 80,000 square miles. Then about 6,000 square miles in Michigan, about 500 in Rhode Island and about 18,000 in the region of the Bay of Fundy. The carboniferous and sub-carboniferous rocks have a much more extended area than the coal proper, as given above.

As in the two previous ages, the invertebrates were well represented, and in addition to the marine forms there were many terrestrial and fresh-water mollusks, and some spiders and insects. Fish were as large, abundant and varied as during the Devonian age, and toward the close some amphibians appeared. But the notable, the characteristic life of this age was its plants. Only the cycads, a group of gymnosperms, were added to those known in the Devonian age; but in general the plants of the carboniferous age were larger, more abundant and more varied in form; as many as 500 species have been described from American rocks, besides a large number of different ones from European rocks.

It is generally believed that coal is of vegetable origin, and that coal and its associated rocks were, in general, deposited under the following circumstances: A large, nearly level, somewhat basin-shaped area of land has been covered with a bed of

fine clay thick enough to hold water and support a growth of vegetation; a slight elevation makes shallow, stagnant or slow-moving water, in which springs up a dense growth of mosses, ferns, equisetæ, lycopodia, sigillaria, calamites, etc., forming a swamp. The stems and leaves of these plants, preserved from complete decay by the water, accumulate as peat. After a time the area is slightly depressed and currents of water flow over the peat, depositing on it sediments of clay or sand, and perhaps the depression may be enough to allow the sea to invade the region and deposit lime sediments. Again the region is elevated, a deposit of fine clay is made and the cycle of deposits begins anew. In Belgium, Nova Scotia and other localities there are more than eighty seams of coal, and as at least two strata of other material separate each seam from the next, we can form some idea of how many upward and downward movements, how many changes of condition have occurred in the formation of a group of coal strata. The layers of peat are changed by heat and pressure into bituminous coal, and the pressure and heat may be enough to change the beds of peat to anthracite coal, or even to graphite.

Iron in some form always occurs with coal. Nearly all the iron of England, and much of the iron of America, comes from the coal measures. It often occurs as the sulphide, which is of no value for iron, and is a damage to the coal; but it occurs most abundantly as clay iron stone, or kidney iron ore, which is a carbonate of iron. In some manner, not well understood, vegetation gathers up the iron from adjacent rocks, and concentrates it into these forms. Sand rocks and shales near coal seams are white or gray, not red—their coloring matter has become iron ore.

Besides coal, we find in the rocks of different ages, quantities of asphalt and bitumen, petroleum oil and natural gas. They are supposed to be of organic origin, as similar substances may be derived from coal by distillation; and while they might originate from any accumulation of organic matter, it is probable that, for the most part, they were the products of the carboniferous age, although they may have accumulated in cavities of rocks of other ages.

During the Algonkian era, the Laurentian tableland was raised above the sea level, as a permanent feature of the continent. During the Silurian age, the Green Mountains were formed; and the palæozoic era closed with the elevation of the Appalachians, extending the land surface of the continent westward to the region of the Missouri, and southward to the Tennessee. The elevation was doubtless slow, and possibly there were oscillations, but this area seems never to have been below the sea level since the carboniferous age.

The heat and pressure attending the elevation of the Appalachians, changed sediments to metamorphic rocks, as clays to slates, sands to quartzite, limestones to marbles, peat beds to anthracite coal, etc., the forces, the elevation and the metamorphism diminishing from the east toward the west. It is interesting to note the similarity of events in North America and in Europe; the practical identity of the Algonkian rocks, the occurrence of evidences of a lost period, the similarity of the Silurian and Devonian rocks, the identity of the millstone grit, the marshy areas and other conditions for the formation of coal, with similar forms of life, from beginning to end, including multitudes of identical species; and the eras of crumpling strata and mountain formation seem to have been coincident.

CHAPTER XLIX.

THE MESOZOIC OR SECONDARY ERA, AND THE TERTIARY AGE.

THE *Mesozoic Era* in Europe shows three well-marked divisions, which are known as the *Triassic*, *Jurassic*, and *Cretaceous* periods.

The triassic and jurassic are not as distinct in North America, but the three periods are recognized. The triassic rocks are mainly red sandstones, with some conglomerates, shales, and impure limestones. They occur in Nova Scotia, Connecticut, Pennsylvania, and North Carolina, and over wide areas in the Rocky Mountain region, extending far north into the Canadian provinces. Some quarries furnish a brown sandstone, much prized for ornamental building; but in general the rocks of this period are not of much economic value. The rocks seem to have been formed in shallow water, and the abundance of mud cracks, rain-drop impressions, and tracks of animals show that the sediments were often half-emerged sand flats.

Jurassic rocks are found near the Black Hills, and in the Uintah, Wasatch and Sierra Nevada mountains, usually sandstones, sandy limestones, etc.

The cretaceous rocks are beds of sand, clay, shells, green sand, limestone; all these beds usually loose, easily crumbled, but occasionally compact beds are found. They occur in detached areas along the Atlantic and the Gulf coasts, and north along the Mississippi almost to the Ohio river; along the slopes of the Rocky Mountains from Texas into Canadian territory quite to the Arctic ocean, the thickest beds being in Colorado, Utah, and Wyoming, where the rocks are fully 9,000 feet thick. The life forms were abundant. Among plants there were equisetæ, ferns, conifers, and others known during the coal period. The cycads, having the appearance of palms; with leaves that unrolled like ferns and wood like the pine, were characteristic and peculiar. In

the cretaceous the first dicotyledons appeared, as the oak, willow, maple, and sassafras, and became numerous, as many as 100 species having been discovered. And leaves of the redwood and of the palm have also been discovered.

The characteristic life of the age was reptilian, so that it is often called the Age of Reptiles. They practically appeared with the age, reached their culmination and passed into a decline. They were very large and very numerous, they dominated the water and the land, and some were furnished with wings for excursions in the air. Invertebrate life was abundant, and so were ganoid fishes and amphibians. In the cretaceous the *teleosts*, or bony fishes, and birds of different kinds appeared, and remains of mammals have been found in the triassic rocks.

The famous chalk cliffs of England, and the cretaceous beds of eastern North America, were doubtless formed at the same time, and were continuous. These localities were raised above the sea level, while chalk is still being formed in the ocean between.

At the close of the jurassic, there were some igneous eruptions in the Connecticut Valley, and other slight disturbances on the Atlantic coast; but the great revolution was the swelling up of the then marginal sea bottoms into the Sierra Nevada and Coast Range mountains, and doubtless the Uintah and Wasatch ranges began to rise about the same time.

At the close of the cretaceous, or soon afterward, the whole western half of the continent was elevated, the interior cretaceous sea disappeared, the Rocky Mountain region joined the tableland and the Appalachian region, completing the continent.

The *Cenozoic Era*, or Age of Mammals, is divided into the *Tertiary* and *Quaternary* Ages.

The *Tertiary Age* is divided into the *Eocene*, or lower, *Miocene*, or middle, and *Pliocene*, or upper tertiary.

The tertiary deposits constitute the Atlantic and Gulf coast plains, and extend from the Gulf up the Mississippi river to the mouth of the Ohio river. These are marine deposits of a somewhat varied character. In the Rocky Mountain region there are numerous basins of fresh-water deposits belonging to this

age, as the Green river and Uintah basins of the eocene; basins in Nebraska and Oregon belonging to the miocene; the Niobrara and White river basins and others containing pliocene deposits.

The rocks of the tertiary consist of beds of sand and clay, shell beds and marls, compact sandstones, calcareous sandstones and limestones. On the Pacific slope some metamorphic rocks are found, metamorphic agencies having been in force in that region after some of the tertiary sediments had been deposited. Some coal in the Western mountain system is referred to this period.

Among plants, the genera of the dicotyledons, palms and grasses were about the same as now, but most of the species were different from those of the present. Magnolias, palms and other sub-tropical plants grew in the extreme north of Europe and North America, indicating a much warmer climate than now prevails in those regions. Immense deposits of infusorial earth, composed largely of diatom shells, indicate an abundance of microscopic life.

Among animals, mollusks, insects, worms and fish were abundant; reptiles and birds were numerous, but mammals were the characteristic and dominant form of life. Herbivorous animals, like the rhinoceros, mastodon, elephant, camel, giraffe, tapir, antelope, hog and horse were common. From the Green river and adjacent basins more than 150 species of vertebrates have been described. Carnivorous animals, like the tiger, panther, wolf, fox and hyena were abundant, and remains of animals like the beaver and porcupine have been found.

Quite a series of the ancestors of the modern horse have been found in these rocks, beginning with one having four toes, and gradually diminishing till the present form, with one toe, is reached. The horse and camel seem to have originated on this continent; and the number of old-world forms found in the rocks of North America would indicate free communication between the continents through long periods of time. The nearly common forest vegetation prevailing through the northern

parts of Asia, Europe, and North America, testifies in the same direction.

The tertiary was the great mountain-forming period, and in connection with this work the continents were elevated and extended to their present limits; in fact, the boundary lines between the land and the sea were laid during the tertiary period.

The whole western mountain system of North America was elevated more or less, some of the eastern chains rising as much as 10,000 feet, and the coast ranges were formed at this time also.

Long cracks or fissures were opened and immense sheets of lava poured out; one sheet, cut through by the Columbia river, is over 3,000 feet thick and 150,000 square miles in extent. Elevations in the south-east exposed recent sediments and extended the continent to its present limits, except a portion of the Peninsula of Florida. "Throughout the old world, from the Pyrenees to Japan, the bed of the early tertiary sea was upheaved into a succession of giant mountains, some portions of that sea floor now standing at a height of at least 16,500 feet above the level of the sea" on the Himalayas. Along with these elevations of the land, there were doubtless depressions in the ocean beds, of which there are some indications in the Pacific ocean.

The movements of the crust of the earth during the tertiary, are among the most extensive of which we have any record, yet they were doubtless quiet and slow, in fact, rivers in the Rocky Mountains and in the Himalayas have deepened their rocky channels as rapidly as the mountains rose.

CHAPTER L.

GLACIAL PERIOD.

THE *Quaternary* Age is divided into the *Glacial*, the *Champlain*, and the *Terrace* periods.

The glacial, or ice period, like other geological phenomena, seems to have come on gradually. In the early part of the tertiary, the climate of Central Europe and North America was sub-tropical, and flowering plants and shrubs were growing within the Arctic circle. During the extensive changes in the crust of the earth which occurred in the tertiary, the northern parts of the continents seem to have been gradually elevated to a height of some 1,000 to 2,000 feet above the present level. With this elevation the climate gradually became more severe, until the ice and snow had crowded the shrubs and flowering plants far toward the south, and were occupying the greater part of North America, north of the Ohio river, and the northern and central portions of Europe, and parts of Asia—and the glacial period was in full progress.

Then followed periods when the ice seems to have retreated and advanced several times, as if the climate were alternately warmer and colder. One retreat was so great, that many speak of the next advance as a second glacier. But at length the ice retreated to the confines of the polar zone, and temperate climates prevailed over Central Europe and North America.

The glaciers of the Alps and the Pyrenees, those that linger in Norway and cover Greenland, the glaciers of Alaska and the Rocky Mountains, are but the remnants of the great ice sheet that dominated the northern part of both continents for untold centuries.

From a study of these existing remnants, and the work they do, we may gain some idea of what were the conditions of our

country during the glacial period; and may find some rational explanation of the interesting and peculiar surface features which were determined wholly, or in part, by glacial ice.

The study of surface features is somewhat complicated by the fact that coincident with the final retreat of the ice, the whole region sank slowly down almost to sea level, and was covered with the broad, shallow lakes, or seas, of the Champlain period, which greatly modified the surface left by the ice sheet. Then the surface rose to about its present level, the lakes drained away, still further modifying the old glacial surface, as the country gradually attained its present condition.

Ice seems to be a brittle solid, but as it accumulates in the mountains of Switzerland, it flows down those valleys like rivers, slowly but surely following every change in direction, every variation in slope, and every irregularity of surface almost as perfectly as water does.

As the ice moves down the valley loose fragments of rock are pushed forward, abrading each other as they roll along; sharp angles of rock are broken off, which, with rocks falling from cliffs above, jostle along between the ice and the sides of the valley abrading each other, till in time the whole mass of ice is filled with sand, gravel, pebbles and fragments of rock. Those along the bottom and sides, held firmly in the frozen grasp, make the ice a gigantic rasp scratching, striating and grooving its rocky bed, and smoothing out its sharper irregularities. Thus the ice river, like the river of water, flows toward the sea with its burden of mud, sand, pebbles, etc. At the end of the glacier the melting ice forms a stream which carries away much of the fine dust from the glacial mill; but the pebbles, boulders and rocks, with much of the finer materials accumulate, forming what is called a moraine. A few hotter seasons cause the ice to retreat from the moraine, covering the ground with clay, pebbles and boulders, which otherwise would have been heaped on the moraine. A few colder seasons and the ice advances again, pushing before it the loose material it dropped on its retreat, until it again reaches the moraine and perhaps crowds it forward.

As the continental ice sheet retreated, it left the whole country covered with clay that was so filled with pebbles and boulders that it has received the name of *boulder clay*, sometimes known as *hard pan*; it is so hard, and resists erosion so well that it is often mistaken for rock. The margin of the ice sheet can be traced across the United States with some degree of accuracy, but in many cases the location is doubtful, as the original deposits, doubtless thin toward the margin, have been so washed away and commingled with other material that the limit of the ice cannot be defined.

The line that marks in a general way the southern limit of the ice and drift, runs from Cape Cod along the south shore of Long Island to New Jersey, then northwesterly to near the headwaters of the Alleghany river, not far from Salamanca, thence southwesterly through New Lisbon, Danville and Winchester, Ohio, crossing the Ohio river near Cincinnati to Madison, Indiana, thence northwesterly a little beyond Martinsville, thence southwesterly through New Harmony to the Mississippi river near the mouth of the Big Muddy, thence up the river crossing to the Missouri below St. Louis, thence up the Missouri to the Osage, then up the Osage for a short distance, then westerly and northwesterly in a course generally parallel with the Missouri river to the Rocky Mountains, thence southerly nearly to the head waters of the Red river, thence across the mountains and northerly to about the Columbia river, thence southerly including most of the Sierra Nevada Mountains and the northern part of the Coast ranges. The mountain region was hardly covered by an ice sheet, but was rather the seat of numerous local glaciers, much as Alaska and Switzerland are to-day.

The greater part of this region had been above the sea and subject to erosion since Devonian times, and was deeply scored by drainage channels that in great measure determined the direction of the ice flow, tongues or lobes of ice flowing along the valleys in advance of the ice sheet; and these are sometimes called glaciers, as the Green Bay lobe or glacier, the Lake Michigan glacier, the Saginaw glacier, the Maumee glacier and several les-

ser ones farther east. During the time of most extensive glaciation these doubtless were all united into one broad sheet of ice that extended nearly or quite to the line already traced across the country; but for the most part they were separate bodies of ice. The moraines in many places are very distinct; they are readily traced on Long Island, across Pennsylvania, Ohio and Indiana. The moraine bounding the Lake Michigan glacier has been traced, the common portion between the Lake Michigan and the Saginaw glaciers being well marked, extending north and south just west of the center of Michigan. And the one between the Saginaw and Maumee glaciers is also well marked in the eastern part of Michigan. And the peculiar relation of the St. Mary's and St. Joseph rivers to the Maumee is due to a terminal moraine of the Maumee glacier along which these rivers flow to a common opening through the ridge. In Minnesota and Dakota there are numerous moraines, forming two systems of lobes or loops, the arrangement being more complicated than farther east.

At places over this area where bed rocks are exposed, they show marks of glaciation, as at Put-in-Bay in Northern Ohio, Niagara Falls, and other places, the striæ indicating the direction of ice flow; sometimes two or more systems of striæ occur on the same surface, indicating two or more invasions of ice flowing in different directions.

Boulders from the hard pan are often glaciated; sometimes specimens are found that have been striated in a dozen different directions, as they have turned in the loosening grasp of the ice. Many of the boulders and much other glacial material came from limestone and sandstone rocks whose original bed is not far away, but for the most part glacial débris came from the Laurentian tableland.

It is interesting to trace these boulders back to the native quarry, selecting well-marked varieties, so that there shall be no doubt as to the identity of specimen and quarry or ledge. In this way it is shown that the "*drift*" material of Iowa, in general, came from the northeast, of Indiana and Ohio from the north, of New England from the northwest. In Indiana, Ohio

and Michigan nearly all the varieties of granitic rocks may be found among the boulders of the hard pan. Large quantities of drift have been transported from 300 to 500 miles, but for the most part the transportation has seldom been more than 100 miles. But little is known about the thickness of the ice; it seems to have covered the mountains of New England, but was doubtless much thinner west and south, for in southwestern Wisconsin and vicinity there is a large area over which no glacial ice ever flowed; it is a "driftless area." The flow of ice over such low gradients as seemed to prevail during the glacial period is not well explained. It flows over similar gradients in Greenland, so that it is not impossible, only difficult to understand. It is also difficult to understand how the ice became so loaded through and through with rocks, boulders, etc.

The Laurentian tableland includes the oldest mountains, and the great lakes occupy the oldest valleys on the continent. Their great depth, some of them reaching two or three hundred feet below the level of the sea, is not only evidence of great erosion, but of the fact that the whole region for ages stood at least from 1,000 to 1,500 feet higher than now; for those old channels must have had outlets to the sea. The glacier smoothed up these old channels, perhaps changing their form somewhat, but not materially; and when it retreated, its load of clay and rocks filled many of them, and parts of many more, resulting in the formation of thousands of lakes, great and small, over some parts of the glaciated area.

The rocky bed of the Cuyahoga river, at Cleveland, is about 225 feet below the present level of Lake Erie. The beds of other tributaries of Lake Erie are at about the same distance below its level, which seems to indicate that the lake occupies an old valley, which formerly had an outlet to the sea at a much lower level. There is evidence of such a channel, now filled with glacial material, extending from Lake Erie to the head of Lake Ontario. The filling up of this old channel changed a portion of a river valley into a lake, and the waters of this lake, finding an outlet across the divide to Lake Ontario, formed the Niagara river, with

its famous rapids, gorge, and cataract. Some think the old outlet of the Ontario valley was by the Mohawk and Hudson river valleys, and that the St. Lawrence flows in a recent channel, at least for a portion of its course. Lakes Huron and Superior are supposed to have had their outlet by the Ontario valley, but many suppose Lake Michigan flowed toward the Gulf.

The glacier as it advanced southward drove before it all the plant and animal life of the region, carried away all the soil, and in many respects changed and modified the surface features of the country. Then retreating, it deposited material for a new soil, obliterated many old channels and changed many others, formed ridges, hills, and lakes, in fact changing the whole face of the country.

The cause of the climate of the glacial period is one of the questions which geologists have not satisfactorily answered. The elevation of northern regions with the advance of the ice, and their depression as the ice retreated, seems to connect the events in the relation of cause and effect. Such elevation might have closed Bering strait, and shut the Gulf stream from the Arctic ocean, and yet it does not seem to geologists generally as if such elevation was adequate to the effect. Some have attempted to find a cause in the changes in the eccentricity of the earth's orbit, combined with other astronomical causes, but this idea does not appear satisfactory. Others have supposed a depression of the Isthmus of Panama, allowing the Gulf stream to pass into the Pacific ocean, as an adequate cause; but there is no evidence of such depression during glacial times, and nothing to show that it would have affected the climate if there had been. Other theories have been advanced, but have not been received with favor. At present it can only be said that most geologists acknowledge elevation as a cause, but think that some other as yet unexplained cause must have acted in connection with elevation to have produced the results.

When did the glacial period begin, how long did it continue, and how many years has it been since the ice retreated? are questions often asked of the geologist. No very definite answer

can be given to the first or the second questions, but many attempts have been made to answer the third.

It is generally supposed that the gorge of the Niagara has been formed since the retreat of the ice, and that if we knew the age of the gorge we would know how long it has been since the glacier. Early estimates of the age of the gorge varied from 35,000 to 100,000 years, but later ones vary from 4,000 to 10,000 years. The river at the present time is cutting back at the rate of about 2.4 feet per year, or a mile in about 2,200 years, and the gorge in about 15,400 years. But there are evidences that the river found considerable work already done on the gorge when it began to flow, so that perhaps 7,000 years would be a safe estimate for the age of the Niagara gorge, and for the time that has elapsed since the ice retreated from the St. Lawrence valley.

The glacier was a very effective erosive agent, but whether more effective or rapid than air and water is very doubtful.

CHAPTER LI.

THE CHAMPLAIN AND TERRACE PERIODS.

AFTER a long period of elevation the northern portions of Europe and North America were slowly depressed and the ice began to retreat. The floods from the melting glacier opened many old drainage channels that had long been closed by glacial débris. But as the depression continued, the streams became sluggish and began to silt up their channels with clay, sand, gravel, etc. At length over great areas drainage almost ceased, and wide, shallow lakes and marshes and ponds were formed, their surplus waters carried away by broad, sluggish streams. The waters and waves of these shallow lakes dissolved and broke down much of the hard pan and assorted it into beds of sand and clay. There were several slight oscillations of the crust, giving rise to different conditions, so that in some localities there are as many as six or seven layers of different kinds of material lying over the boulder clay.

The Orange sand or bluff gravel, a thick deposit of glacial material along the Mississippi river as far south as Louisiana, may have been transported by glacial floods early in this period. Later the Erie, Champlain and other clays were deposited, and later still, over much of the glaciated area, reaching far down the Mississippi, thick beds of fine clay or loess were formed.

The ice seems to have retreated more rapidly in the west than in the east, so that when the region now occupied by the great lakes was free from ice, the natural outlet of the Ontario basin was still closed by the glacier. These valleys, filled with water from the melting ice, formed a great inland sea with shores of ice on the east and north, discharging its surplus waters toward the Gulf. An old beach ridge, nearly parallel with the shores of Lake Erie, shows the level of this old lake to have been at one

time at least 200 feet above the present level of Lake Erie. Other beaches, at lower levels, seem to indicate that the barrier was cut down at an irregular rate.

Icebergs were doubtless common on this inland sea, and perhaps on other lakes of this period. It is thought by many that they had much to do with distributing glacial material near the margin of the drift area in the southwest, as there is often no evidence of glacial ice having reached that region.

The Champlain period of Europe was much the same as in North America, and is often called the era of fresh water formations.

The glacial period merged gradually into the Champlain, and the Champlain as gradually into the terrace period. The northern regions began to rise again, sluggish rivers became narrower and more rapid, other rivers were formed, lakes and inland seas were drained away, carrying along great quantities of fine silts and sands; and at length the slender, rapid rivers began cutting out channels in the sediments that filled the older, deeper, wider valley. In this way bluffs and terraces were formed which gave name to the period. Sometimes several terraces have been formed, which are often known in common language as first bottom, second bottom, etc.

Where the drainage was not complete, extensive marshes or wet prairies and multitudes of little ponds or lakes are the only remains of wider bodies of water.

The life of the quaternary was interesting as being the culmination of the mammalian type.

The plants and marine mollusca that during the glacial period lived in what are now temperate regions, are represented at the present time by species living in polar or sub-polar climates. As the ice retreated both plants and mollusca migrated northward. Very little is known about the birds, fishes and reptiles of the period, but it is supposed that there was not much change, simply a migration southward as the ice advanced and a migration northward as the ice retreated.

The mammalia of this period were abundant, varied in form

and often of enormous size. Their remains are found in caves, in marshes, and sometimes in the drift and silt of streams. In Europe more have been found in caves, while in North America more have been found in swamps and bogs.

The mastodon, two species of elephants, two great bisons, a giant stag, large horses and beavers, the megalonyx and the tapir were the most interesting among the herbivorous animals; there were one lion and two bears to represent the carnivora. In South America there were several large edentates, a mastodon, with wolves, panthers and others. But Europe and Asia had the richest variety of species, especially among the carnivora. In the bone caves of Europe they have found remains of the cave bear, cave hyena, cave lion and two tigers, all of remarkably large size. Several elephants, a rhinoceros, a hippopotamus, horses, oxen, the great Irish elk and others represent the herbivora. The mammoth, a species of elephant, was over twice the bulk and weight of modern elephants. Some have been found frozen in the ice of Siberian swamps; they were covered with hair and wool, and the flesh, preserved by cold, was eaten with relish by dogs. In one cave the remains of 800 bears were found, and one contained the remains of at least 300 cave hyenas.

The difference between the plant life of the quaternary and the present was not great, neither was the difference between the lower animals of that time and the recent period, and while, at first, the difference between the mammalia seems great, yet the type is still the same; many species of mammals, some birds and others, have become extinct, but in general the change has been slight. There is no definite event that marks the close of the quaternary and the opening of the recent age, or age of man. The country rose out of the waters of the Champlain period, formed a soil, was clothed with vegetation, and entered upon the various lines of activity now in progress.

The Mississippi river is silting up its channel, which indicates that the region of its upper course is slowly settling. Old beach lines along the shores of Lake Ontario, that, when made, were level, have been raised considerably toward the east, so that the

two portions now differ in level. There are upward and downward movements in Norway and Sweden and along the Mediterranean sea. There are volcanoes and occasional earthquakes, showing that one group of geological forces is still in operation.

The formation of sediments along river beds and at their mouths, along the shores of lakes and of the sea, the formation of sand dunes, of bog iron ore, and bog limestone, and the action of rain and frost, etc., in furnishing the materials for the sediments, shows another set of forces at work also. The geological agencies are doubtless working just as vigorously at the present as ever in the history of the earth; but one set works so slowly that we do not notice them, and the others are so common that we do not think of them as geological.

The large and fierce animals that dominated the Quaternary age passed away, and those of a smaller size and more tractable disposition appeared in their stead. And the earth, with pure air and water, with temperate climate, with useful plants and animals, after ages of preparation at last became a fit place for the home of man.

Man has doubtless lived on the earth for many centuries, was contemporary with many of the large mammals, and with the later events of the Glacial and Champlain periods, but does not seem to have become the dominant type of life until quite recent times. Remains of man are found in caverns, lake beds, peat bogs and similar places, and we find the tools of bone, wood and stone which he used; and we may know something of how he lived from finding fragments of bones and shells with tools, etc., in caves, and at particular places along the shores of lakes and seas. But the story told by these remains is very fragmentary and not easily interpreted, but seems to indicate at least a low stage of culture for primitive man.

Considered as an animal, man's appearance on the earth was abrupt, as abrupt as the appearance of vertebrates in the Devonian, and this idea is intensified when we consider man's intelligence.

What is the age of the earth? This is an interesting question,

often asked, but seldom answered with any degree of satisfaction. The matter of geologic time bears on so many important questions that much time has been given to the investigation of all available data on the subject, and many estimates have been made. The early estimates in general were large. Sir Charles Lyell considered that the earth was at least 240,000,000 of years old. Dr. Charles Darwin thought that 200,000,000 of years could hardly be sufficient for the evolution of organic forms. Dr. A. Winchell, 1883, estimates the time since the crust was formed at 3,000,000 years. Mr. W. J. McGee, 1892, estimated the age of the earth at 15,000,000, and Prof. Warren Upham, 1893, thinks the time necessary for building up the stratified rocks and developing the plant and animal life of the world must be about 100,000,000 of years. These results would seem to indicate that the data were not satisfactory, or else that they were not correctly interpreted. Mr. Charles D. Walcott, Aug. 17, 1893, in an elaborate paper reviews the whole question, working out an estimate that seems conservative when compared with those given by other investigators. Confining his investigations mainly to the cordilleran region of North America, he shows that erosion and deposition of mechanical and chemical sediments have always been going on at substantially the same rate. While one foot in 3,000 years is usually considered an average rate of denudation, he assumes a rate of one foot in 200 years for the region under consideration. Then, carefully estimating the area of erosion, the area of deposition, and the thickness of sediments, both mechanical and chemical, he estimates the cenozoic, including glacial or pleistocene, at 2,900,000 years; mesozoic at 7,240,000 years; paleozoic at 17,500,000 years; algonkian at 17,500,000 years and archæan at 10,000,000 years, a total of 55,140,000 years. He concludes that the time since the archæan age lies between 25,000,000 or 30,000,000 of years as a minimum and 60,000,000 or 70,000,000 as a maximum time.

The physicist, calculating on the time necessary for the earth to cool to its present condition, limits the time to from 10,000,000 to 30,000,000 of years. These estimates may not be very

GEOLOGICAL DIAGRAM.

Eras.	Ages	Life.	Periods and Groups.	Rocks, etc.
CENOZOIC...	Quaternary...	Age of Mammalia and Man.	{ Recent or Terrace..... Champlain..... Glacial or Pleistocene.....	Sand, lime and clay sediments. Erie clays. Boulder clay and other drift.
	Tertiary.....		{ Equis Beds... { Sumpter Loup River. } or Pliocene Truckee..... } Yorktown White River } or Miocene Uintah..... } Alabama Wasatch... } or Eocene	Limestones. Marls and clays. Marls, sand with shells. Marls, sandy limestone.
	Cretaceous...	Age of Reptiles.	{ Laramie..... Fox Hills..... Colorado..... Dakota.....	Shales, lignite beds, etc. Sandstones and clays. Limestones and clays. Conglomerate, coal.
	Jurassic.....		{ Flaming Gorge, Wyoming.. White Cliff, Utah.....	Limestones, sandstones, shale. Silicious and calcareous shales.
MESOZOIC...	Triassic.....		{ Star Peak..... Koipato, Nevada.....	Limestones and quartzites. Quartzites and slaty rocks.

PALÆOZOIC	Upper Carboniferous	Age of Coal Plants.	{ Permian Coal Measures..... Conglomerates.....	Limestones and sandstones. Coal, shale, sandstones, limestones. Millstone grit.
	Lower Carboniferous		{ Upper Group Lower Group	Limestones, some sandstones. Sandstones, some limestones.
	Devonian.....	Age of Fishes.	{ Chemung..... Hamilton..... Corniferous..... Oriskany.....	Shales and sandstones. Shales and sandstones. Limestones and sandstones. Sandstones and limestones.
	Silurian.....		{ Helderberg..... Salina..... Niagara.....	Limestones. Marly sandstones, gypsum. Limestones and shales.
	Lower Silurian or Cambrian	Age of Lower Life and Age of Mollusks.	{ Trenton..... Canadian..... Primordial.....	Limestones and shales. Slates, sandstones and limestones. Sandstones, slates and limestones.
	Algonkian....		{ Keweenaw..... Upper Huronian..... Lower Huronian.....	Conglomerates, sandstones, felsites and porphyries. Conglomerates, slates, shales, jas- pers and igneous rocks. Conglomerates, quartzites, schists, limestones.
	Archaean.....	Begin- ning Life.	{ Upper Laurentian..... Lower Laurentian.....	{ Light-colored granites, gneissoid granites, schists.
Eozoic.....				

satisfactory, but they give us some idea of how difficult it is to say how old the earth is. Geological time is divided into eras, ages, and periods, and the rocks into systems and groups. And once there were primary, secondary, tertiary, and quaternary systems or ages. The primary and secondary have been subdivided, and the names dropped, while the terms tertiary and quaternary have been retained.

Geological studies began in Europe, and the names were derived from localities, as Devonian, from the town of Devon, and Silurian from the town of Silures, in England, Jurassic from the Jura mountains, etc. The first important geological work done in this country was in New York. Some European names were retained, but many local names were adopted, as Niagara, Hamilton, Chemung, and other states have followed the same custom, so that we have Knoxville, St. Louis, Keokuk, limestones, etc. The period or group names for the Mesozoic and early Cenozoic eras in this country are derived mainly from localities in the western mountain region, where those rocks are most abundant. With increasing investigation and knowledge the nomenclature and classification will change, but the diagram on two preceding pages represents in a general way the present condition of the subject.

CHAPTER LII.

THE THEORY OF ORGANIC DEVELOPMENT.

WE have learned something about the different kinds of matter, and of the forms under which they appear; and we have studied the forces acting upon matter, and the laws in accordance with which they are supposed to act. In this study we have learned that the molecular or atomic theory of matter, the law of definite proportions in chemical combinations, the undulatory theory of light and heat, the conservation of energy, and the theory of universal gravitation, are the great propositions or theories which determine the lines of scientific thought, and around which all the varied phenomena of the material world cluster for correlation and explanation. These theories may not stand the test of future investigation; they may prove inadequate, may be modified, may give place to others; but at present they are the best—the only working theories we have—and through them most of the activities of nature around us may be explained; hence, some knowledge of them is valuable in any system of education.

We have studied the different forms of life which occur on the earth. In them we found matter under the influence of a new force, displaying quite a different cycle of events. A group of molecules, endowed with life, comes into existence, is developed to maturity, reproduces its kind, and dies. The history of life forms, as individuals, is simply this and nothing more—all their energies are directed toward growth and reproduction. Primarily, their relations are to parents on the one side, and to offspring on the other; incidentally, they have a wide range of relations with other forms of life, and with the inorganic world. Living beings differ widely in form, structure, and intelligence, and in many respects the phenomena of life are more interesting than those of

the inorganic world; and the question is often asked, how do you account for, and explain this bewildering variety of life forms and the complex phenomena incident to their existence?

Until quite recent times, most people believed that the sun, moon and stars, the earth, with all its varied forms of life, and all material things, were created out of nothing. No one could comprehend the idea, but few doubted its truth. But as man became more intelligent, the idea of the creation of matter from nothing began to be questioned, not irreverently, but simply from a desire for the truth. This inquiry brought out the fact that the word creation, as used, had different meanings, and the idea began to grow that perhaps matter in its essence is eternal, was not created from nothing, but was moulded or shaped over into its present forms, something as the potter moulds the clay, or the workman makes a watch. And it was believed that every particular form of life was the result of a special act of creation. But a careful study of the phenomena of life has led students of botany, zoölogy and geology to the conclusion that special creation was not God's method in nature, but that some form of evolution or development was most probably the method employed. Organic development, then, is the great proposition or theory around which the facts and phenomena of the vegetable and animal kingdoms gather for correlation and explanation.

This theory may prove inadequate; may not stand the test of future investigation; but it is the only one now recognized by scientific men. No other theory ever promulgated has been as prolific of good results. It has stimulated thought in every department of human endeavor, not only in all lines of scientific work, but in all lines of social and historical work. Thus, whether true or false, every intelligent person should know at least something of the grounds for its existence. Evolution in its present form is a modern theory which required for its elaboration an amount of knowledge which could only be acquired gradually through years of scientific research. But the idea of evolution is by no means recent; some of its problems have been considered

in almost every system of philosophy. They were matters of speculation among the East Indians, the Arabs, the Jews, the Greeks and the Schoolmen, and they have been discussed by later philosophers, as Hobbs, Descartes, Locke, Kant, Hegel and others. But the honor of bringing the doctrine before the world in such a clear and forcible way as to command universal attention belongs to Charles Darwin and Russel Wallace, whose first publications were in 1858 and 1859.

One of the first steps toward this theory is the observed unity of all forms of life, as shown by the fact that plants and animals have about the same chemical composition; that plant and animal protoplasm appear to be identical; that the germinal vesicle and sexual reproduction are similar in each; the difficulty in distinguishing between the lower forms of animals and plants; that plants and animals are cellular in structure; that plants and animals, as individuals, develop from a bit of structureless protoplasm to a complicated organism, each growing by the simple multiplication of cells; and the fact that animals and plants are affected in much the same way by physical environment—all of which with many other things point toward the unity, the continuity of life on the earth; plants and animals possibly developing from a common germinal stock, plants through fixed forms, animals through motile forms.

Another is the fact that offspring inherit some of the characteristics of the parents, but not all. A number of children may be similar to their parents and to each other in many respects, the family features and traits may be well marked, yet each has his peculiarities, differing from all the others in some particulars. This fact is expressed in the phrase, "heredity, or descent with variation." Variation in size and activity is common among men and domestic animals, and among wild animals as well, variations in size sometimes amounting to as much as one fourth of the average size of the species. There may be variations in the length of legs, breadth of wings, size of fins and in other respects.

Then the fact that a pair of the slowest breeding animals, or plants if unchecked, would stock the earth to repletion within

1,200 or 1,500 years. Thus with the great numbers of different kinds of animals and plants there must be a continued struggle for existence, animals of the same kind struggling with each other, and with other kinds of animals and with plants, and plants struggling with each other and with animals, and all perhaps struggling against unfavorable climatic conditions. In this conflict many—in fact, most—perish, the few only survive. The strongest, the most active, the most intelligent, those that are in some way superior, survive and produce offspring. This process Darwin called “natural selection,” Spencer calls “survival of the fittest.” In this way Mr. Darwin believed new species were formed instead of by special creation, and that animals were descendants from at most only four or five progenitors, and plants from an equal or lesser number. Thus, he says, “From the war of nature, from famine and death, the most exalted object which we are capable of conceiving, namely, the production of the higher animals, directly follows.” “There is grandeur in this view of life with its several powers, breathed by the Creator into a few forms, or into one; and that from so simple a beginning endless forms most beautiful and most wonderful, have been and are being evolved.”

Many things seem to point toward the probable truth of the theory. There is no doubt about the fact of individual development; we are all descended from Adam by natural processes; each individual a complex organism, developed from structureless protoplasm. If evolution is God's method with the individual, there seems to be no reason why it may not be His method with the species, genus, etc.

In horses, the bone above the fetlock joint corresponds to the middle bone of the hand. On each side of this bone there is a little bone called a splint bone. These splint bones seem to be of no use or value to the horse, and on the theory of special creation they cannot be explained, but on the theory of descent they represent the second and fourth digits of some three or five-toed ancestor, and the geological record shows that the horse had such ancestors. Many similar cases might be mentioned. Most ani-

mals are able to move their ears freely and many can move portions of the skin; in general, man can move neither the ears nor skin and yet muscles for moving the ears and scalp exist in an aborted form, and occasionally individuals can use them. The presence of these muscles is not explained by special creation, but on the theory of descent with variation they indicate that some ancestor of man had use for such muscles.

The embryos of the higher animals in their development simulate the forms of lower animals; the embryo of the chick shows the gill slit of fishes and the teeth of reptiles, and it is not till quite late in its embryonic life that the human embryo takes on or begins to develop human characteristics. These phenomena, utterly unexplained on one theory, are at least partially elucidated under the other. According to the theory of evolution, the developmental history of the individual appears to be a short recapitulation of the course of development of the species. There seems to be a correspondence between the individual development of the higher animals and the progressive advance of organization in the whole animal series. The geological record gives interesting evidence in the case; it is necessarily an imperfect record, for, as a rule, only the hard parts of aquatic life would regularly be preserved, and only a small part of the record has been or can be examined. When the crust was first formed, no life of any kind could exist; but as the earth cooled water and other substances were condensed from the atmosphere, and the inter-actions between the atmosphere, water and crust removed impurities from the air and water, and put them away in permanent form, leaving the water and air in a condition favorable for the lower forms of life. And such forms of life appeared in great abundance, as the thick beds of iron ore and graphite in the older rocks are supposed to show. The life must have been of low form, as none other could have existed under the conditions which probably prevailed. As these chemical reactions continued, the plant and animal life also removing impurities, the air and water gradually became fitted for higher and higher types of life. The early forms of life seem to have been flexible and abundant, so that they

adapted themselves to changing conditions and crowded into every new addition to the domain of life. As conditions changed some forms could not adapt themselves, and, overcome in the struggle, passed away and others took their places. It is estimated that there were more than thirty complete changes of species during the paleozoic time. So that the principle of the "survival of the fittest" seems to have prevailed from the very beginning of life on the earth.

The graphite of the early ages, the limestones of the Silurian and later ages, the coal of the carboniferous, all represent impurities removed from air and water by different forms of life. It is interesting to note that each form of life has helped to prepare the way for other and higher forms, generally lessening the opportunities for their own existence. The coal plants not only rendered the air more pure, but so changed it as to allow the sunshine to reach the surface of the earth with vigor enough to promote the growth of flowering plants.

Every step in the history of the earth prior to the advent of life was in preparation for life, and every step afterward was in preparation for higher forms of life.

But the geological record at present is by no means continuous; the blank between the archæan and the Cambrian equals nearly one third of the whole record, leaving the origin of the protozoa, cœlenterata, arthropoda, echinodermata, mollusca, molluscoida and tunicata without record. Some of the rocks of this period have been found, and some fossils have been discovered, but the rocks are so highly metamorphic that there is little hope of ever finding anything like a complete record of the period. In this period the protophyta, zygomycota, oomycota, and carpophyta had their origin, of which no trace has been found in the rocks.

Fishes, the first of the vertebrates, appeared somewhat abruptly in the later part of the Silurian age. It is claimed that the first so-called fishes were of a comprehensive type, from which both fishes and reptiles were derived, but transitional forms are not numerous. And so on, the geological record in a general way

sustaining the development theory, new discoveries as a rule being favorable to that idea.

While the testimony is fragmentary, and the evidence incomplete, yet there is scarcely a botanist, zoölogist or geologist of note, who does not believe that some form of development was God's method of creation. Progress means the laying aside of ideas which are the result of limited knowledge, and the acceptance of other ideas, the result of wider information. The world had to give up the Ptolemaic theory, had to accept the theory of universal attraction, had to give up the idea that the earth was not more than 8,000 or 10,000 years old, had to give up the corpuscular theory of light, had to accept the theory of conservation of energy, had to change its theory as to the treatment of the insane. These and many other changes have been made, as the result of wider knowledge, and these changes were made without detriment to any, but rather resulted in benefit to all. So if we have to give up the idea of special creations, and accept the idea of development, no damage will be done.

Some persons object to the theory of evolution as atheistical. Dr. Asa Gray, a strict Presbyterian, Prof. Joseph Le Conte, an earnest Christian, Dr. Alexander Winchell, a Methodist, and hosts of others equally prominent as believers in God, would unite with Prof. John Fiske in saying, "The doctrine of evolution asserts as the widest and deepest truth, which the study of nature can disclose to us, that there exists a Power to which no limit in time or space is conceivable, and that all the phenomena of the universe, whether what we call material, or what we call spiritual, are manifestations of this infinite and eternal Power."

CHAPTER LIII.

SUGGESTIONS AS TO LINES OF STUDY.

THE first and perhaps the most important work to do in beginning the study of the geology of any locality is topographic. The topography of a place includes its actual location, its relative position as to mountains, hills, valleys and plains; as to lakes, ponds, swamps, marshes, rivers and other streams. It also includes a study of the soil and vegetation, and as these and other topographic features depend largely on climatic conditions, temperature, winds and rainfall need to be considered in topographic work.

This work is not only an important introduction to geological investigation, but the items considered in topography constitute the environment of the various forms of life, and need to be understood and considered in any good botanical or zoölogical work. Topographic work is not only important, but easy and interesting.

Actual location is readily ascertained in all those states where the rectangular system of survey was used. Under this system principal meridians were located with great accuracy, and the country on each side was divided into *ranges* six miles wide by secondary meridians, as nearly parallel with the primary meridian as the spherical form of the earth would permit. The first principal meridian is the boundary between Ohio and Indiana in longitude $84^{\circ} 51'$ west; the second runs through Indiana in longitude $86^{\circ} 28'$ west; the third through Illinois in longitude $89^{\circ} 10' 30''$ west; the fourth is in longitude $90^{\circ} 29' 56''$ west; the fifth is in longitude $90^{\circ} 58'$ west; the sixth in longitude $97^{\circ} 22'$ west, and the Michigan meridian in longitude $84^{\circ} 19' 9''$ west. Others were located as occasion required. A base line

was also run with great care perpendicular to the principal meridian, and then lines were run parallel to the base line at intervals of six miles on either side, dividing the ranges into *townships* about six miles square.

On account of the form of the earth it was necessary to establish correction, or secondary base lines at certain intervals. The base line for Indiana and Illinois is in $38^{\circ} 58' 12''$ north latitude.

(1) Township 2 north of range 2 east.	(6) Township 1 north of range 2 east.
(2) Township 2 north of range 1 east.	(7) Township 1 south of range 2 east.
(3) Township 2 north of range 1 west.	(8) Township 1 south of range 1 east.
(4) Township 1 north of range 1 west.	(9) Township 1 south of range 1 west.
(5) Township 1 north of range 1 east.	

The ranges are designated by number east or west of the principal meridian and the townships by number north or south of the base line; as shown in the above diagram.

A township is six miles square and is divided into thirty-six

square miles, or sections, which are numbered from 1 to 36, inclusive; as shown in the diagram below.

The township is not perfect in form, neither is the section, but the township is so divided as to throw most of the irregularity into the north and west tiers of sections which are often fractional, and there are fractional sections along lakes and large streams of water.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

A section contains about 640 acres. It is divided by lines through the center, parallel to its sides, into quarter sections of 160 acres each, and these into quarter quarters of 40 acres each, and so on as far as desirable.

A section is one mile, 80 chains, 320 rods, or 5,280 ft. square, the quarter section is one-half mile, 40 chains, 160 rods or 2,640 ft. square, and the quarter quarter is 80 rods or 1,320 ft.

square. The system is simply the application of latitude and longitude to land measurement, and was first used in Ohio.

The following sample description will show the practical working of the system: Five acres being the south half of the northwest quarter of the northeast quarter of the southeast quarter of section twelve (12), township ten (10), north of range nine (9), west of the second principal meridian. From the foregoing one can easily interpret the description of an ordinary deed. If you wish to locate a certain tract of land, hill, stream, or ledge of rock, borrow a deed of the land or of some in the immediate neighborhood; make a diagram of a township and locate the land described in the deed on the diagram. Sometimes the one description solves the whole question of location; sometimes one may have to consult several deeds, and may need to ask some one to point out a few section lines and corners before a given locality is fixed satisfactorily.

After locating a few prominent points, find out by measurement where the streams you wish to locate cross the section lines, and if very crooked, where they cross the quarter-section lines also, then map in the stream across the section as accurately as possible. In this work a pocket compass is useful. For measuring use the surveyor's chain or tape measure, if possible, but for much of such work many people can learn to step off the distance with sufficient accuracy. A little practice in walking over a measured distance, as 100 feet will enable one to walk with $2\frac{1}{2}$ -foot step. The field work for some of the finest geological maps I ever saw was done with a pocket compass and step measurement. The elevations were taken with an aneroid barometer. But the elevation of a moderately steep hill can be determined quite closely without instruments. Measure accurately the height of the eye from the ground, then practice in "standing straight" and "looking level" will soon enable one to stand at the foot of a hill and note on its side a point on the level of his eye, then advancing to that point, note another, and so on until the summit is reached, when the product of the number of stations by the elevation of the eye gives the approximate elevation of the hill.

Locate and map the streams, hills, outcrops of rock, and other prominent physical features, also the roads, farm lines, and houses of the neighborhood or district you are intending to study. In this work school children and their parents can render material aid. The children should make maps for themselves; in no way can map drawing be made more interesting and practical than when familiar ground is made the subject of study. While the map is in process of construction other work may be in progress. Perhaps the most important group of material phenomena affecting man is the one called the weather or climate. Many of these phenomena and their relations can be observed, and some idea of future manifestations can be derived, from an intelligent knowledge of the present. It is one of the latest deductions of science that it pays to collect and study "weather saws," to observe and note the relations of sunshine and cloud, wind, rain, etc. We have in the barometer an artificial weather glass, but among plants and animals there are many natural barometers or weather indicators. Cultivate the powers of observation by noting the aspects of the weather, and requiring the children to do the same; observe which way the wind blows, morning, noon and night; whether the day was clear, cloudy or rainy; any marked changes of temperature during the day or night should be noted, and the observations of each day should be made a matter of record. Collect "weather saws" and study them, some may be fanciful, but many will be found to stand on a scientific basis. In connection with this work note the habits of plants and animals that appear to relate to climate, also study the weather predictions from Washington and compare them with your own observations.

In winter corn and beans may be grown and each studied in different stages, gaining ideas of the seed embryo, cotyledons, ordinary leaves, etc., and noting the distinctions between the great classes of exogenous and endogenous plants. Much also may be learned from the study of the various house plants so common everywhere. Make a list of the different trees and shrubs of the neighborhood, studying carefully the peculiarities that distin-

guish them in winter. Get specimens of the wood of different trees and learn to distinguish them by the character of the wood.

Most insects die in autumn, being represented during the winter by eggs, larvæ, or some imperfect form, but a large number live through the winter, usually in a torpid state. They are perhaps more commonly found under decaying logs, in rotten wood, or between the bark and wood and similar places. A collection of such insects with notes of the circumstances under which they were found would be interesting and valuable. While looking for insects one may find salamanders, mice, snail shells and other things of interest. In every locality a number of birds, as owls, hawks, woodpeckers, shrikes, chickadees, blue jays and others are found during the winter; make a list of these winter birds, and note their habits, the food they eat, and the places in which they are found.

As spring approaches watch for signs of life in the trees and plants; note which trees and shrubs blossom before putting out their leaves, and the plants that send up the first flowers; study the trees and shrubs in their spring and summer vegetation, and note the colors the leaves of different plants and trees assume in autumn. Note the soil and surroundings in which the different plants and trees seem to thrive best; some will be found to have a wide range, others will be confined to narrow limits.

Observe, also, the returning summer birds, which come first, and when they come, and how soon after the first one is seen do the birds of its kind become common. Study the feeding and nesting habits of the birds, and note the localities the different kinds seem to prefer. Notice how completely the opening flowers and returning birds depend on the weather. At certain times in the spring birds visit us for a few days on their journey to more northern regions, and again in autumn on their return to the warmer regions. Make notes of these dates and of the birds passing.

The study of the smaller mammals, as mice, moles, shrews, ground squirrels, etc., is an interesting and neglected field of observation. The study of reptiles, batrachians, crustaceans, mol-

lusks and other forms of life well repays the time spent in making the investigations.

In connection with the topographic work make notes of geological features, the kinds of rock, thickness of beds, the effects of weathering upon them, and their relations to each other. Study water sheds and divides; you can find as typical examples of each in every township as you could find in the Rocky mountains. Study the valleys of the streams, the upper, middle and lower course. Notice the work done by the streams, eroding here, building up there—busy everywhere. Observe in how many different ways during the year material is removed from an eroding bank. Where the stream is making ground note the order in which different forms of vegetation occupy the new-made land. The study of fish and other life of the streams is interesting and profitable. Much of this study should be general, engaged in by the whole school, and a little time should be set apart each day for report of observations. Other work may be delegated to certain pupils according to their liking or aptitude. Do as much work as you can and do it as well as you can, and you will be astonished at the amount accomplished during a season.

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