FUNDAMENTALS
OF
BIOLOGY

BY
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PREFACE

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With an immense wealth of material from which to select, it has obviously been difficult to decide what to include. The choice made was based on the opinion that an orientation course should neither attempt to cover, in a necessarily superficial manner, an extremely wide range of subjects, nor to proceed too far into any one phase of biology. If the former is done, the course lacks unity—if the latter, it ceases to be general biology, but taxonomy, physiology, or something else.

Approximately half of the book deals with the morphology and physiology of both plants and animals, with some little attention being given to their classification, while the latter portion attempts to cover, in an elementary way, some of the more general phases of genetics, ecology,

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In treating a number of subjects as widely diverse as the course requires, it is difficult to achieve a proper organization of material without having some thread of continuity running throughout the book. The idea which has been kept in mind in its preparation has been that of the "unity of life." The conception that all life is one—that certain fundamental facts, processes, and principles are common to both plants and animals (including man)—seems to be worthy of emphasis in an elementary biology course.

In keeping with the general plan of the book, technical terms are reduced to a minimum. While a number are introduced, they are mostly those used a number of times and which serve to fix an important idea. The first time a term is used it is italicized and either defined or explained. This renders the inclusion of a glossary superfluous. The index, which has been carefully prepared, contains all of the technical terms used in the text, and definitions are easily found.

It goes without saying that the text is intended to be used in connection with laboratory work, for it is only in the laboratory that a student obtains a real acquaintance with the subject. Where it is not possible to do as much laboratory work as might seem desirable, as where classes are large or equipment is inadequate, satisfactory results may be obtained by reducing the amount of individual work and substituting demonstrations, for, after all, the aim of the course is cultural rather than to train students in laboratory methods. The demonstration method is especially applicable to physiological experiments, difficult dissections, and to certain phases of microscopic work. Museum material is very favorable for demonstrating adaptation, heredity, and evolution.

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UNIVERSITY OF CALIFORNIA AT LOS ANGELES,
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CHAPTER I

INTRODUCTION

Biology is the science of life. In its broadest sense, it includes all of the facts and principles which have been derived from a scientific study of living things. Except in the case of some of the lower forms of life, it is possible to assign all living things either to the plant or to the animal kingdom. Thus, the special study of plants, called *botany,* and of animals, called *zoology,* are to be regarded as the two great subdivisions of the larger science of biology. Plants and animals, whether simple or complex, are called *organisms,* and so biology may also be defined as the science of organisms.

Nature of Living Things.—The fact that both plants and animals manifest life is not generally appreciated. Most people think that plants are not alive in the same sense that animals are, or that there is some fundamental difference between plant and animal life. One reason for this misconception is that life is ordinarily associated with motion. While it is true that most animals move freely and most plants are stationary, this distinction is of slight importance, and has nothing to do with the actual state of living. In fact, there are many fixed animals, such as oysters, barnacles, sponges, sea anemones, etc., while, on the other hand, some of the lower plants are actively motile. Sensitivity is another quality associated with life and commonly thought to be lacking in plants, but this is not so. Plants react to external influences just as definitely as do animals, but ordinarily in a much slower way.

In beginning the study of general biology, we should realize that plants and animals have much in common. Their more important points of resemblance may be briefly stated as follows: (1) The substance which forms the living portions of organisms, called *protoplasm*, is essentially similar in all plants and animals. (2) This living matter is organized in both plants and animals into microscopic units called *cells*. (3) Certain vital processes take place in plant bodies in essentially the same manner as in animal bodies. These are respiration, digestion, assimilation, growth, and reproduction. (4) The same natural laws apply to all organisms, such as the laws of heredity and evolution.

Scope of Biology.—Biology, including all organized knowledge pertaining to living things, is a vast subject because organisms may be studied from a number of different aspects. Consequently, there are many special phases of biology, the more important of which will be briefly defined. (1) *Morphology* is the study of the form and structure of organisms. It includes a consideration of the gross features of plants and animals (*anatomy*) as well as the minute details which are seen only with the aid of a microscope (*histology*). (2) *Physiology* deals with functions—with vital processes and vital activities. The two great functions of all organisms are nutrition and reproduction; all others are mere phases of these. (3) *Taxonomy* deals with the naming and classification of organisms; it represents the oldest aspect of biological study. Plants and animals are named according to a system of binomial nomenclature devised by the great Swedish naturalist, Carl von Linné (1707–1778, Fig. 1). Every known species of plant and animal has been given a scientific name. The white oak is *Quercus alba*, the common potato, *Solanum tuberosum*, the dog, *Canis familiaris*, the English sparrow, *Passer domesticus*, etc. Organisms are classified according to their natural relationships into groups called families, orders, etc. (4) *Ecology* is a relatively new field of biology which deals with the life relations of plants and animals—their relations to each other, and to such factors of their physical environment as light, moisture, temperature, etc. (5) *Organic evolution* is a study of the descent of organisms. It is concerned with the history of life—with the changes which the various existing species have undergone during the past. (6) *Genetics* is a new field which has grown out of the study of evolution. It is concerned with the resemblances and differences between individuals, especially those due to heredity.

FIG. 1.—Carl von Linné, 1707–1778.

Applications of Biology.—An elementary study of biology is given a prominent place in college curricula for several reasons. (1) It is pursued for intellectual gratification. From a purely cultural standpoint biology is of value in giving one an appreciation of life itself, an acquaintance with the world of living things, and an understanding of some of the great fundamental laws and processes of nature. (2) Biology is a necessary prerequisite to further studies. There are many special fields of knowledge and many phases of human activity which are largely based on biological facts and principles, and to which an elementary training in general biology is essential. These include medicine, psychology, sociology, agriculture, horticulture, forestry, sanitation, dietetics, hygiene, and many others. (3) Because man is an organism subject to the same laws which govern all living things, and is built according to the same plan as other higher animals, an elementary knowledge of biology gives one a basis for an understanding of his own body, and thus directly contributes to health and comfort. (4) Plants and animals are of inestimable value to man; in fact, they make human life possible. From living things man derives all of his food. All of the nourishment which enters the human body comes from either a plant or an animal source. Man makes his clothing from both plant fibers (cotton and linen) and animal fibers (wool and silk). Medicines are derived largely from plants, and serums, vaccines, etc. come from animals. Wood has always been a building material of first importance. Wood, coal, and petroleum, man's principal fuels, are organic in origin. An understanding of plants and animals is essential to the most efficient utilization of all of these products.

CHAPTER II

PROTOPLASM AND THE CELL

When any small isolated portion of an ordinary plant or animal is examined with a microscope, it is seen to be composed of a great many minute organized masses of living matter. These are known as *cells.* Cells may be seen whether we look at a piece of frog or salamander skin, a drop of blood, a moss leaf, a thin section of a rootlet, or any other part of a plant or an animal (Fig. 2). Continued observation convinces us that these tiny cells are the units of which all living things are constructed, just as individual stones are the components of a stone wall. Cells are not only units of structure, but also units of function; that is, all vital activities—all of the processes which go on in the body of an organism—are performed by cells of various kinds. Recognition of the fact that the cell is the unit of structure and function is fundamental to an understanding of much of the subject matter of biology, and so it is appropriate to begin our studies of organisms with a general consideration of the cell and of the living matter of which it is composed—*protoplasm.*

A Generalized Cell.—Although there are many different kinds of cells in plants and animals, some very peculiar in appearance, all have certain basic features in common. These are readily seen in Figs. 2 and 3, where several kinds of simple cells are shown. A cell consists of a dense spherical body, the *nucleus,* surrounded by a mass of less dense material called *cytoplasm.* Both the nucleus and the cytoplasm are living, that is, consist of protoplasm, but each of a different kind, the nuclear material being, in general, more complex. The nucleus is enclosed by a delicate *nuclear membrane,* the cytoplasm by a *plasma membrane.* Almost all plant cells have, in addition to the plasma membrane, a thicker covering composed of a non-living substance called *cellulose*. This is deposited by the protoplasm

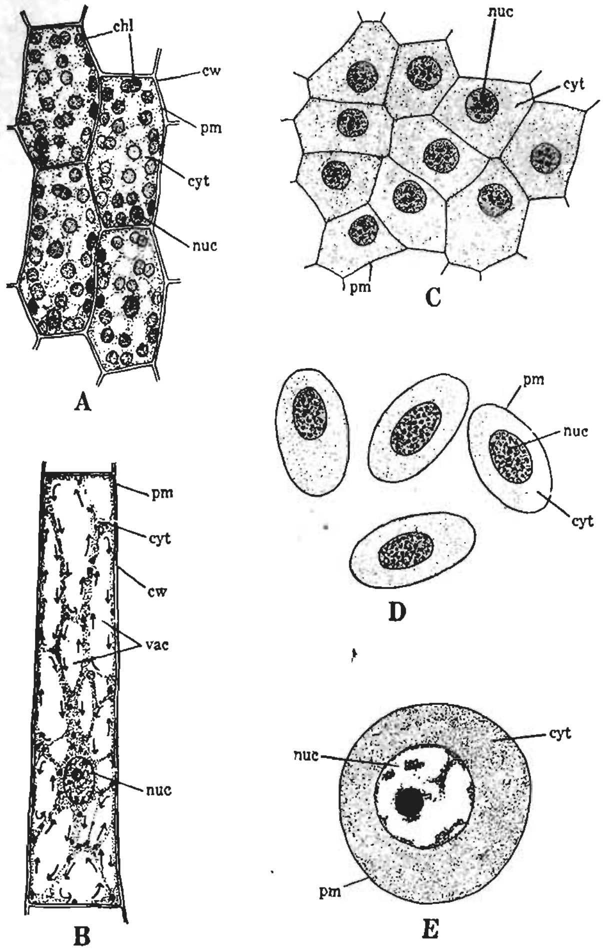
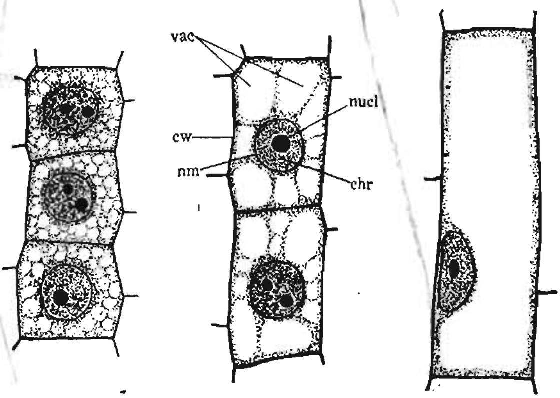


FIG. 2.—Some generalized plant and animal cells; *A*, cells from a moss leaf, × 350; *B*, cell from a hair of a squash leaf, the arrows indicating the streaming of the cytoplasm, × 150; *C*, a piece of the outer skin of a salamander, × 250; *D*, red blood corpuscles of a salamander, × 500; *E*, section of an unfertilized egg of a starfish, × 750; *nuc*, nucleus; *cyt*, cytoplasm; *cw*, cell wall; *pm*, plasma membrane; *vac*, vacuoles; *chl*, chloroplasts.

which it encloses, and is considered part of the cell, constituting the *cell wall*. Thus, in plants the living material occupies little rigid box-like compartments; that is, the protoplasmic units are separated from each other by partitions of non-living matter. In animals, however, this is not the case. For the most part their cells lack cell walls, each mass of protoplasm being separated from the others merely by its thin, living plasma membrane.

The nucleus consists principally of a fluid, the *nuclear sap,* in which is imbedded a coarsely granular substance called *chromatin.* Generally in plant cells, and less commonly in animal cells, one or more small dense spherical



A B C

FIG. 3.—Cells from a longitudinal section of an onion root tip, showing the enlargement of vacuoles which accompanies growth of the cell, × 750; *A*, young cells; *B*, older cells; *C*, mature cell; *vac*, vacuoles; *cw*, cell wall; *nm*, nuclear membrane; *nucl*, nucleolus; *chr*, chromatin. The plasma membrane is in close contact with the cell wall.

bodies known as *nucleoli* (singular, nucleolus) are also present. The cytoplasm is finely granular and ordinarily less dense than the nucleus. The minute granules may surround clear spaces called *vacuoles* which are filled with a fluid designated merely as *cell sap.* Vacuoles are generally larger and, consequently, more striking in plant cells than in animal cells; in fact, in the latter the cytoplasm often appears entirely homogeneous.

The cytoplasm of very young plant cells is relatively dense and contains many very small vacuoles, but, as the cell enlarges, the vacuoles coalesce, and finally there is often just one large central vacuole around which the granular portion of the cytoplasm occurs as a thin layer (Fig. 3). Cells from the green parts of plants, as from the inside of a leaf, contain specialized bodies called *chloroplasts*, which are usually spherical or ellipsoidal in form (Fig. 2*A*). Chloroplasts are dense masses of protoplasm colored by the green pigment, *chlorophyll*. They carry on a very important function which we shall consider later.

Cells which do not carry on a definite kind of work are most nearly like the generalized cell which has been described. Most cells, however, are specialized for particular functions, and, hence, have various structural peculiarities. The nerves and muscles of animals, for example, and the woody parts of plants, are made up of such highly specialized cells.

Structure of Protoplasm.—Although by no means identical, protoplasm, the only substance which is alive, is essentially similar in all plants and animals in structure, composition, and behavior. In view of the enormous diversity among organisms, this is a remarkable fact.

Living protoplasm, under the microscope, ordinarily presents the appearance of a colorless, transparent, semifluid substance more or less gelatinous and viscid in consistency. It is nearly always distinctly granular in appearance, and usually contains vacuoles of various sizes, as already noted. On account of the colorless, transparent quality of living protoplasm, methods of staining have been devised so that its structure may be more clearly studied. Protoplasm, whether living or properly stained, ordinarily presents an appearance similar to that of a foam or an emulsion,[1] the granules being distributed throughout a liquid or semiliquid medium which surrounds fluid globules of various sizes, the globules being vacuoles.

Composition of Protoplasm.—Although often spoken of as "the living substance," protoplasm is really not a simple

[1] This structure can be simulated by adding a small quantity of lampblack to an emulsion of olive oil and water. The carbon particles represent the protoplasmic granules, the oil globules the vacuoles, and the water the medium in which the granules are suspended.

chemical compound, but a mixture of many substances, some of which are extremely complex. Numerous analyses of protoplasm have shown three things: (1) that it does not contain any elements which may not be found in non-living matter; (2) that its most abundant elements are few in number; (3) that these elements are very common ones. Of ordinary protoplasm, 97 per cent consists of the following four elements in the proportions indicated: oxygen, 65.0 per cent; carbon, 18.5 per cent; hydrogen, 11.0 per cent; nitrogen, 2.5 per cent. The remaining 3 per cent is made up of minute amounts of sulphur, phosphorus, chlorine, potassium, sodium, magnesium, calcium, and iron. Only rarely are traces of other elements present. These 12 elements form a large number of compounds, both organic and inorganic, the most important of which deserve brief consideration.

The most abundant constituent of active protoplasm is water, commonly forming 85 to 90 per cent or more of its weight. Without this large proportion of water, living matter cannot carry on its ordinary functions. The most abundant and most important organic substances in protoplasm are proteins of many different kinds. White of egg and lean meat are examples of substances consisting almost entirely of protein. Proteins always contain the four elements carbon, hydrogen, oxygen, and nitrogen, but usually sulphur and often phosphorus also. These elements are combined in so complex a manner that chemists have never been able to analyze any of the proteins satisfactorily. It is known, however, that they are built up from simpler compounds called *amino-acids,* the composition of which is accurately known in many cases. In addition to the proteins, protoplasm usually contains other organic compounds, such as carbohydrates and fats (both of which are composed entirely of carbon, hydrogen, and oxygen), organic acids, etc. In addition to water, there are also other inorganic substances present, such as gases and salts in solution, but these are not abundant.

The above facts regarding the chemical composition of protoplasm must be accepted with three reservations: (1) When protoplasm is subjected to chemical analysis, it must necessarily be killed, and thus its composition may be altered. It should be realized that all of our knowledge of its composition has been derived from a study of protoplasm no longer living. (2) The composition of living matter is constantly fluctuating as a result of chemical changes which go on all the time. In fact, the instability of protoplasm is one of its most characteristic attributes. In view of this fact, it is apparent that we can know what substances are present in a given cell only at the particular moment when analyzed. (3) Protoplasm is not merely a *collection* of various substances, some simple and some complex, but is undoubtedly an *organization* of substances. The constituents of protoplasm are related to each other in ways that are extremely intricate, and so living matter is a system. It is this organization which makes it possible for what we call life to express itself; that is, life may be merely a result of the organization itself.

Behavior of Protoplasm.—It is not difficult to distinguish between animate and inanimate things because we recognize the presence of life by certain sharply defined criteria—by certain peculiarities in the behavior of living matter. Protoplasm is not only the most complex material in existence, but exhibits a very remarkable and unique set of properties. The peculiarities in the behavior of protoplasm are manifested as follows:

1. It has the power of *independent motion*, supposed to result from some cause inherent in the living matter itself. In many one-celled organisms and in certain free cells of both the higher plants and animals, protoplasmic movement results in locomotion. The contraction of muscle, and the consequent movement of some part of the body, depend upon the ability of special contractile cells to change their shape. In certain other cells, especially those of plants, a rotation or streaming of the cytoplasm occurs within the cell boundary (Fig. 2B), but

the cell as a whole does not move or change its shape as raesult.

2. Protoplasm exhibits *irritability,* which is the capacity of responding to such external influences as gravity, light, heat, contact, chemical action, electricity, and certain others. When stimulated by these influences, various cells react in characteristic ways. This is one of the most distinctive features of protoplasmic behavior.

3. By the process of *assimilation,* living matter takes up inanimate substances and from them increases its mass. The new particles are interposed among the old ones and become part of the living organization. It is this property which makes growth and reproduction possible.

Nature of Life.—Although it is recognized that the powers of independent motion, irritability, and assimilation are distinctive of protoplasm, practically nothing is known about their nature or causes. Since they form the basis of all vital activity, this means that we cannot explain life itself. In fact, it is impossible to define the word except in its own terms. Protoplasm, which Huxley called "the physical basis of life," is nothing but ordinary matter in a peculiar state—matter with a unique set of properties. But because so little is known about the causes underlying the distinctive behavior of protoplasm, we are in complete ignorance regarding the real nature of life.

Regarding the causes of vital phenomena, two views have been held: the *mechanistic* and the *vitalistic* theories. According to the mechanistic conception of life, there is really very little difference between animate and inanimate things. It maintains that living matter owes its peculiar properties to the highly complex composition and interaction of the various substances composing it. This theory contends that life is merely the expression of certain physical and chemical laws which are still very imperfectly understood.

The vitalistic view of life claims that protoplasm owes its peculiar behavior to the presence of some kind of special force or "vital principle" as it is called—that life is something which enters into protoplasm and enables it to function. This "vital principle" has never been identified or analyzed, and perhaps, from its very nature, never can be. Consequently, the vitalistic theory is not conducive to research, for, if true, it is useless to attempt to solve the problem of the nature of life—the greatest problem of all time. For this reason, vitalism does not have much support among modern biologists.

It is apparent that the chief point of difference between these two theories is that the mechanists regard life as a result, the vitalists, as a cause. The strongest argument in favor of vitalism is that protoplasm has never been made artificially in the laboratory. To this the mechanists reply that perhaps some time it will be. It was once thought that all organic compounds could be formed only within the bodies of organisms, as their name itself signifies. But since 1828, when urea was first made synthetically, thousands of different organic substances have been made in chemical laboratories, and each year finds new ones being added to the list. Thus, even though there may be such a thing as a "vital principle," it is only by accepting the mechanistic point of view that progress can be made toward a fuller understanding of the nature of life.

Spontaneous Generation.—Because of the great abundance and rapid multiplication of certain forms of life, many strange ideas have been held in the past concerning their origin. One of the most widespread theories has been that of *spontaneous generation,* which has had many supporters, even among scientific men. This idea was prevalent from the time of Aristotle (384–322 B. C.) until the middle of the nineteenth century. It held that many low forms of life can arise directly from inorganic matter or from dead organic remains. Frogs and toads were supposed to develop from mud at the bottom of ponds under the influence of the sun, horsehairs falling into water were thought to give rise to worms, and maggots were claimed to come directly from decaying meat. Many other similar ideas were common.

In 1668, Redi, an Italian, conducted a set of experiments in an attempt to disprove spontaneous generation. He showed that maggots do not arise from decaying meat *de novo,* but always develop from the eggs of flies deposited there. Redi placed three jars of meat in an open window. One was left uncovered, one covered with gauze, and the third with parchment. All of the meat decayed, but maggots developed only in the jar which had been left uncovered. Redi observed flies depositing their eggs in the meat contained in the uncovered jar and on the gauze of the second jar, but no eggs were laid on the parchment because no odors could pass through it to attract the flies.

These and other similar experiments did a great deal toward dispelling the theory of spontaneous generation. But with the invention of the microscope in the seventeenth century, a world of minute forms of life was discovered, and the theory was revived. If a small quantity of hay be boiled and the liquid placed in a covered vessel, great numbers of microorganisms soon appear. These were seen with the microscope, and it was rather naturally thought that they arose directly from the decaying organic matter in the "hay infusion." Several investigators attempted to disprove the spontaneous origin of these minute forms of life by showing that they enter from the air, but their efforts met with only partial success. It was not until 1864 that the theory was completely overthrown. It was then that the great Frenchman, Louis Pasteur (1822–1895, Fig. 4), demonstrated conclusively that microorganisms do not appear in sterilized organic matter, even if exposed to air, provided that the air is entirely free of dust. In one of his experiments, he boiled liquids containing material capable of yielding microorganisms, and then admitted air to them after filtering it through cotton. Since no decay resulted, this proved that dust particles carry microorganisms to the liquids. As a result of Pasteur's experiments to disprove the theory of spontaneous generation, he laid the foundations for the great modern biological science of bacteriology.

There is now no reliable scientific evidence that living things, as we know them, ever arise by spontaneous generation. As far as we can tell, protoplasm comes only from antecedent protoplasm; *omne vivum ex vivo*. Every kind of plant and animal originates from preexisting individuals of its own kind, and life presents an unbroken chain from the beginning. In regard to the origin of the first forms of life, there is no scientific evidence whatsoever. Nothing is known as to how the first protoplasm came into existence.

FIG. 4.—Louis Pasteur, 1822–1895.

The origin of life, like the nature of life, is an unsolved problem, the secret of which science may or may not be able to reveal.

The Cell Principle.—The fact that the cell is the fundamental unit of all plant and animal structure has been recognized only since 1838–1839. The discovery of cells was made much earlier, however, being credited to the Englishman, Hooke, who first described them in 1665. He perceived with a simple microscope of his own manufacture, that ordinary bottle cork is composed of minute compartments to which he gave the name of cells. Cork tissue forms the outer bark on old stems, commercial cork coming from a species of oak. It consists entirely of dead cells, the protoplasm having completely disappeared and left only the cell walls. Although Hooke saw and described empty cells, the meaning of the term he introduced has been gradually extended to include the protoplasm as well, and where there is no cell wall, the protoplasmic unit itself is called a cell.

Other observers saw and studied cells in many kinds of organisms, but their importance was not appreciated for nearly 175 years after Hooke's discovery. It was then that the "cell theory" was announced, based on the thorough investigations of two Germans, Schleiden and Schwann, who claimed that all organisms are composed of cells. Schleiden established the cell theory in the plant kingdom in 1838, Schwann in the animal kingdom the following year. Subsequent investigators have fully substantiated their results, and today the cell theory is a fully established biological principle. Several important additions have been made to it, however, which should be recognized. The essential feature of the cell theory of Schleiden and Schwann was that the bodies of all plants and all animals are made up entirely of cells. To this statement must now be added, "and their products," because it is apparent that much of the material in the bodies of the higher organisms consists of substances formed by cells but not living themselves, as for example wood and cork in plants, shells and hair in animals, the outer part of the skin, mineral matter in the teeth and bones, the fluid portion of the blood, etc.

The earlier investigators considered the cell wall to be the most important part of the cell, while the contents were considered unessential and largely ignored. This is shown by the word "cell" itself, indicating a box-like compartment, as a cell in a prison. The Frenchman, Dujardin, was the first to appreciate the importance of the cell contents and to give a name to the living substance.

In 1835, he applied the term *sarcode* to the material composing the bodies of microscopic animals, but thought it limited to them and did not regard it as the basis of life. In 1846, von Mohl gave the name protoplasm to the living contents of plant cells, although it had been used earlier in a different sense. It was not until 1861, however, that the work of Schultze established the similarity between the living matter of both plants and animals. Since that time the term protoplasm has been applied to all living matter.

CHAPTER III

UNICELLULAR ORGANISMS

Although, in the preceding chapter, cells have been considered as structural units composing the bodies of plants and animals, many kinds of cells can carry on an independent existence, and thus live entirely apart from other cells. A cell may be merely a very small part of an organism, or it may exist as a separate, complete organism in itself. This means that a plant or an animal may consist of many cells or of just one cell. The lowest organisms are *unicellular,* each individual being a single unit of protoplasm. Obviously, this represents the simplest possible condition of structural organization; yet a single cell, living alone, is a complete organism—it can carry on all of the functions which many-celled organisms perform, although doing its work in a much simpler way. Several kinds of common representative unicellular plants and animals will now be studied, and the resemblances and differences between them carefully noted.

Protococcus.—There is often present on the shaded side of damp tree trunks, rocks, walls, etc., a bright green stain. If we scrape off a bit of this material, mount the scraping in a drop of water, and examine with a microscope, we see innumerable small spherical green cells averaging about 0.01 millimeter ($\frac{1}{2,500}$ inch) in diameter. Each cell is an individual plant—a complete, independent organism. This plant, known as *Protococcus viridis,*[1] is one of the simplest forms of plant life (Fig. 5).

Each cell consists of a small central nucleus surrounded by a mass of cytoplasm, and is enclosed by a cell wall composed of cellulose. In the living condition, the nucleus is difficult to see. The green coloring matter, called

[1] Often called *Pleurococcus vulgaris.*

chlorophyll, is a pigment which appears to be uniformly diffused throughout the cytoplasm, but, in reality, is confined to a single large peripheral chloroplast, the limits of which are difficult to make out in the living cell. In the presence of sunlight and by virtue of its chlorophyll, the cell carries on a very important function—the manufacture of sugar. It makes sugar by combining two very simple inorganic substances: water and carbon dioxide. Not only *Protococcus*, but all green cells, when illuminated,

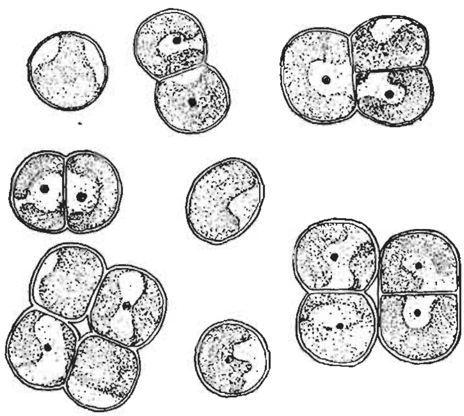


FIG. 5.—*Protococcus viridis*, a simple one-celled plant, × 1,000. Some of the cells have divided to form small groups of cells. Each cell contains a nucleus, cytoplasm, and a single large chloroplast.

can carry on this process. The making of sugar in a green cell under the influence of light is called *photosynthesis*. It is one of the most important processes in nature.

The sugar made by photosynthesis is used by the cell as a source of nourishment, that is, it is *assimilated* by the living protoplasm. Thus, the presence of chlorophyll enables *Protococcus* to makes its own food, and this ability it shares with all green cells. The inorganic substances from which sugar is made—water and carbon dioxide—are both absorbed through the cell wall. The cell also absorbs oxygen, a substance which enables it to carry on *respiration*. This process goes on constantly in all living cells, and is entirely distinct from photosynthesis, which proceeds only in the daytime and only in green cells. These two processes should not be confused.

Protococcus not only performs photosynthesis, assimilation, respiration, and other processes directly concerned with the great work of *nutrition*, but, like all other organisms, it also carries on *reproduction*. New individuals come into existence by a method called *fission*. After a cell has reached a certain definite size, if external conditions are favorable, it undergoes division into two cells. First the cell elongates slightly and its nucleus divides. Then a cell wall forms between the two nuclei which cuts the cell in half. The two new cells then increase in size, and either immediately separate or frequently remain together until each has again divided. Thus, from a single individual a group of four cells may arise, sometimes even more, but separation usually occurs shortly after division, each cell taking up an independent existence. Fission is the simplest method of reproduction. It merely involves an approximately equal division of an individual into two new ones which become independent organisms.

Yeast.—There are a number of kinds of yeasts, one of the commonest, called *Saccharomyces cerevisiae*, being used in making bread. Like *Protococcus*, the common yeast plant is unicellular, but is ovoid in form and about 0.008 millimeter ($\frac{1}{3,100}$ inch) in length (Fig. 6). It has a nucleus, cytoplasm, and a cellulose wall, but there is no chloroplast, and so the cell is entirely colorless. Each cell contains one or more large vacuoles and many small oil globules. The nucleus is very small and not visible in the living unstained condition. Reproduction occurs by *budding*, a modified form of fission. A bud arises as a small outgrowth, usually appearing at one end of the cell; the nucleus divides to form two nuclei, one going into the bud. The bud now enlarges and becomes abstricted, or pinched off, from the parent cell, and may either separate at once or remain attached for awhile, often giving rise to another bud. In this way, short chains may be formed, each arising from a single cell, but they soon break up, each cell carrying on a separate existence.

The yeast plant lives in fruit juices and other sugar solutions. It resembles *Protococcus* in utilizing sugar as a source of nourishment, but differs in that it cannot make its own food. Lacking chlorophyll, it is unable to carry on photosynthesis. It simply lives on sugar which is already made, absorbing it through the cell wall. *Protococcus* is said to be an *independent* plant because it has the power of making its own food and is thus self-sustaining. Yeast is a *dependent* plant, requiring an external source of food.

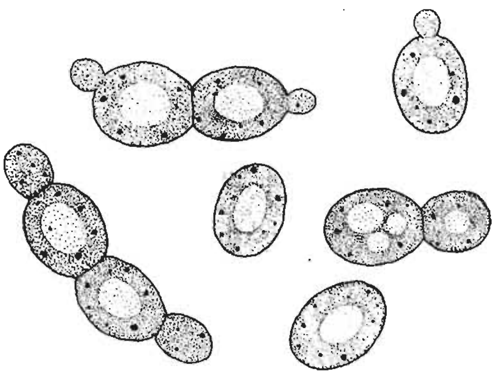


FIG. 6.—Yeast, a unicellular colorless plant. × 1,500. Reproduction occurs by budding, short chains of cells being formed.

Because it lives on dead organic matter, taking in its food by absorption, it is called a *saprophyte*. Yeast cells use as food only a very small proportion of the sugar which they absorb. The rest is broken down into carbon dioxide, alcohol, and small amounts of several other substances. This process is called *fermentation*.[1]

Bacteria.—The bacteria are at once the smallest and the simplest of all known organisms. They are found under all conditions where life may exist—in water, soil, air, and in the bodies of other organisms. They are of tremendous

[1] Fermentation in yeasts is accomplished by the production of an enzyme called *zymase*. It is most active in the absence of free oxygen, and serves as a means of releasing energy when the ordinary type of respiration cannot be carried on.

importance to man, not only because of their relation to disease, but because of their beneficial activities as well. *Bacteria are unicellular plants lacking chlorophyll*, and live either on dead organic matter as *saprophytes*, or on other organisms as *parasites*, in both cases absorbing food directly through the cell wall as in the yeast plant. Their cells are of three general types: spherical (*coccus*) forms; rod-shaped (*bacillus*) forms; or curved or spiral (*spirillum*) forms (Fig. 7). Some are non-motile while others bear slender protoplasmic threads called *cilia* by means of which

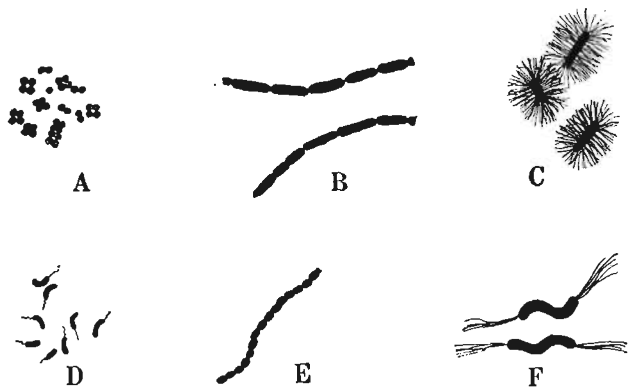


Fig. 7.—Group of common bacteria, × 1,500: *A*, *Sarcina lutea*; *B*, *Bacillus subtilis*; *C*, *Bacillus proteus*; *D*, *Spirillum cholerae*; *E*, *Streptococcus pyrogenes*; *F*, *Spirillum undulatum*.

they move rapidly. The rod-shaped types average about 0.0025 millimeter (1/10,000 inch) in length, while some of the spherical forms are only 0.0005 millimeter (1/50,000 inch) in diameter. It would take 800 of the former and 4,000 of the latter, placed end to end, to stretch across the head of an ordinary pin (which is about 2 millimeters in diameter).

The cells of bacteria are so simple that they might almost be said to be structureless. A thin cell wall surrounds a mass of homogeneous protoplasm. There is no organized nucleus—merely a few scattered granules of chromatin. Bacteria reproduce entirely by fission. In some the two cells separate after division, while in others they remain together permanently to form chains, plates, or irregular masses. These are called *colonies.* Under favorable conditions the cells divide with great rapidity, so that, in the course of 24 hours, a single bacterium may give rise to millions. While all bacteria are active only in the presence of moisture and other favorable conditions, if these fail many can pass into a resting stage, remaining inactive for long periods of time. Bacteria which are present on dust particles in the air, are in a dormant state, and can resist drying and great extremes of temperature.

Protococcus belongs to a group of plants called *algae* (singular, alga), of which there are about 20,000 different species. While most of the algae are multicellular and hence more complex than *Protococcus*, they are all relatively simple plants living in water or in wet places. All of the algae have chlorophyll. The yeasts and bacteria are plants known as *fungi* (singular, fungus), which number about 60,000 species. In contrast to the algae, all fungi lack chlorophyll and hence must obtain their food from an external source, living either as saprophytes or as parasites.

Amoeba.—This is one of the simplest types of unicellular animals. There are a number of species of *Amoeba*, the best-known one being commonly called *Amoeba proteus* (Fig. 8), which is widely distributed in stagnant water. Its body consists of a single cell with finger-like lobes extending in all directions. It is a relatively large cell, being about 0.25 millimeter ($^1\!/_{100}$ inch) in diameter, but most other species are considerably smaller. As in a typical cell, there is a spherical nucleus surrounded by cytoplasm, and a very thin plasma membrane on the outside, but a cell wall and chloroplasts are lacking. The nucleus is rather difficult to see in the living condition, but is very distinct after the cell has been killed and stained, when it is seen to consist of many coarse granules. With the exception of a comparatively thin layer on the surface, which is clear, the cytoplasm is finely granular. A large clear *contractile vacuole* is present which suddenly contracts and then slowly expands, this action taking place regularly at short intervals.

The finger-like extensions of the cell are termed *pseudopodia* (singular, pseudopodium). They are the means by which locomotion is accomplished. When the animal is active, its outline is continually changing due to the extension and withdrawal of these finger-like lobes (Fig. 9). When one or more pseudopodia are thrust out in a given direction, the cytoplasm is seen to flow into them, and at the same time other pseudopodia are retracted. As a

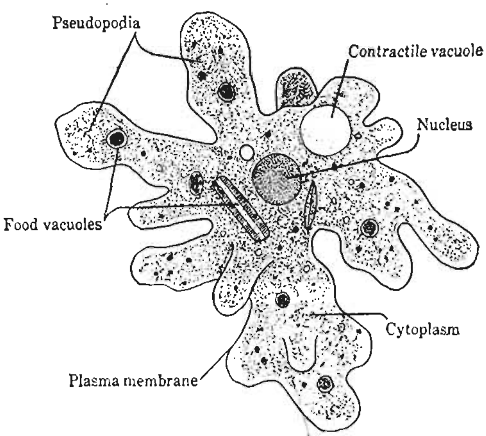


FIG. 8.—*Amoeba proteus*, a simple unicellular animal, × 250.

result of this behavior, the animal slowly moves from place to place. The streaming of the cytoplasm is a very striking thing to observe, and is a beautiful demonstration of the power of independent motion, which has been mentioned as one of the unique features of living matter.

The food of the amoeba consists of small algae, bacteria, other smaller animals, and of both dead vegetable and animal matter. As the animal slowly creeps along, if it comes in contact with a food particle, the protoplasm flows around the food and engulfs it. A small amount of water is taken into the cell with the food particle, forming what is called a *food vacuole*. The work of *digestion* now begins. Fluids pass into the food vacuole from the surrounding cytoplasm, and the food is gradually changed chemically in such a way that it can be absorbed and thus be made part of the living cell. This is the process of *assimilation* which we have seen to be characteristic of all living matter. The digested food material, by assimilation, increases the amount of protoplasm in the cell. Indigestible matter is expelled from the body at any part of the surface; it is merely left behind as the animal moves on.

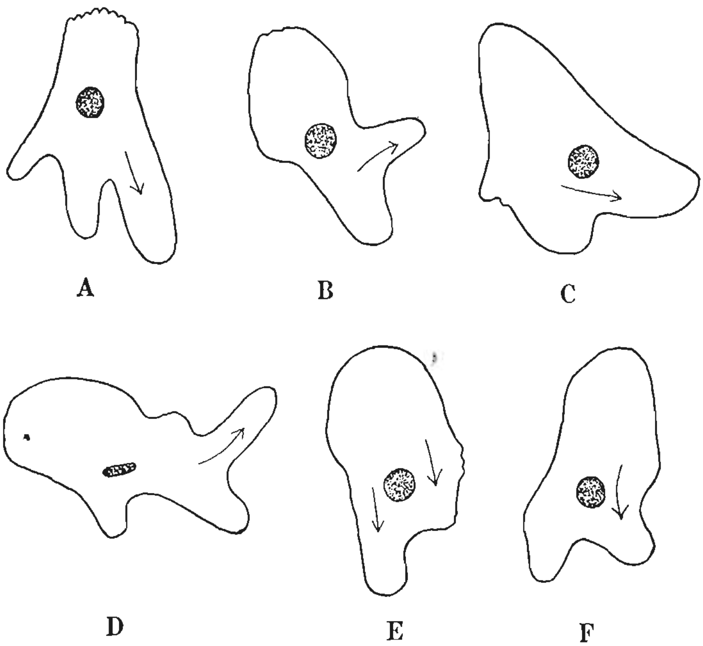


FIG. 9.—Locomotion in *Amoeba proteus*; *A*, *B*, *C*, *D*, *E*, *F*, outlines of a moving individual sketched at successive intervals to show the formation of pseudopodia. (*Redrawn after Calkins.*)

As in one-celled plants and all other living cells, oxygen is absorbed from the surrounding medium in order that the process of *respiration* may go on, for otherwise life cannot exist. The oxygen combines with the protoplasm with the result that energy is liberated, just as when a piece of coal is burned. The oxidation of organic matter in the cell causes waste products to be formed. These are chiefly water, carbon dioxide, and urea (a nitrogenous substance resulting from the decomposition of proteins). Some of this waste matter passes out of the cell directly through the plasma membrane, while the rest apparently flows into the contractile vacuole and is expelled by it through the plasma membrane into the surrounding water. Thus this structure plays a part in the work of *excretion.*

If the amoeba gets plenty of food, more protoplasm is built up by assimilation than is destroyed by respiration, and as a result *growth* takes place. A size limit is soon reached, however, beyond which the animal does not go,

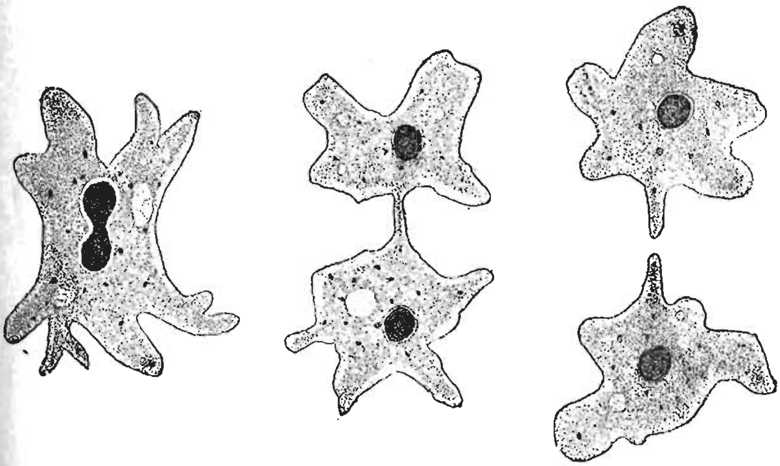


FIG. 10.—Fission in *Amoeba*, showing the division of the nucleus, constriction of the cytoplasm, and separation of the two new cells. (*From Shull, "Heredity," McGraw-Hill Book Company Inc., by permission.*)

and then *reproduction* occurs. The amoeba, like most other unicellular organisms, reproduces by fission, the cell dividing into two parts which separate and take up an independent existence (Fig. 10). In the presence of adverse conditions, as during a drought, the animal passes into a quiescent state, becoming spherical and secreting a protective layer around itself. Such an individual is said to be *encysted;* it remains in this state until revived by the return of favorable conditions. In some types of amoebae, the nuclei increase in number within the cyst. When the cyst hatches, several amoebae are produced by the division of the cytoplasm around each nucleus. This process is known as *multiple fission,* in contrast to the ordinary kind of reproduction, termed *binary fission.* It is also called *sporulation.*

Paramoecium.—This is another kind of unicellular animal, very common in stagnant ponds and streams (Fig.

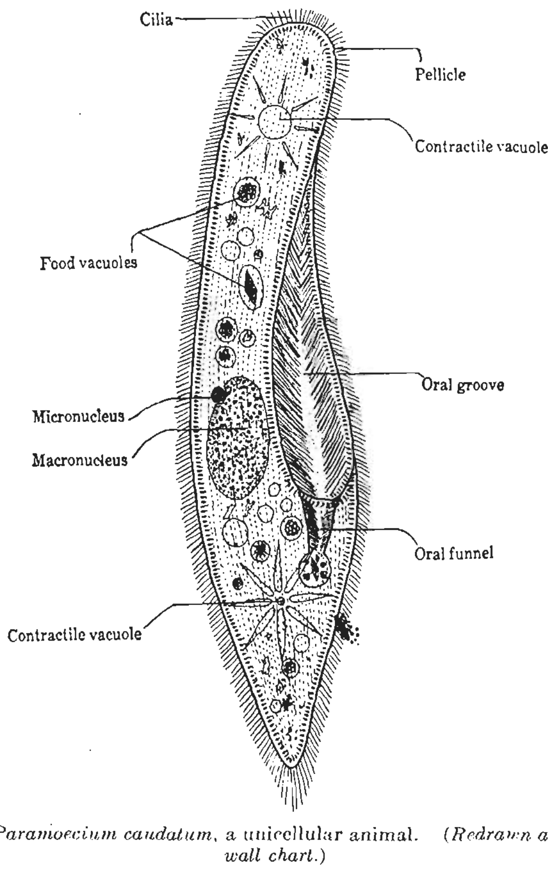


FIG. 11.—*Paramoecium caudatum,* a unicellular animal. (*Redrawn after Schmeil wall chart.*)

11). It is also a large form, being about 0.2 millimeter (1⁄125 inch) long; a single individual is just barely visible to the naked eye when seen against a black background. Due to the presence of a firm outer membrane called the *pellicle,* the cell has a definite and constant form, but there is no cellulose cell wall. One of the commonest species, *Paramoecium caudatum*, is more or less slipper shaped, being rounded at the forward (*anterior*) end and pointed at the rear (*posterior*) end. The cell is entirely covered over with very short, fine, protoplasmic threads called *cilia* which beat against the water and rapidly propel the animal forward. Thus the method of locomotion in *Paramoecium* and *Amoeba* is very different. Ordinarily, the animal swims with the rounded end forward, but under special circumstances, as when an obstacle is encountered, the cilia may reverse their action and send the animal backward. *Paramoecium* does not take a straight course through the water, but swims in a spiral path, at the same time rotating on its long axis from right to left (Fig. 12).

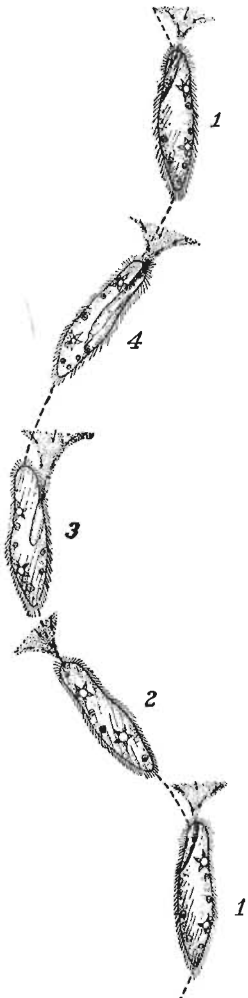


FIG. 12.—Diagram showing spiral path taken by a paramoecium and rotation on its long axis from right to left. 1 to 4, successive positions. The shaded areas represent currents of water drawn into the oral groove. (*From Jennings, "Behavior of the Lower Organisms," Columbia University Press, by permission.*)

The cell contains a large nucleus (the *macronucleus*) and a very small one (the *micronucleus*); these are in contact with each other, and have a constant position near the center of the cell. There are also two contractile vacuoles, one located at either end of the body. Usually these alternate in contracting at intervals of 10 to 20 seconds. Extending radially into the cytoplasm from each contractile vacuole are a number of minute canals. These seem to collect liquid waste products which are emptied into the vacuole and are finally discharged to the outside.

In the anterior half of the animal is a shallow depression called the *oral groove*, at the lower end of which is a funnel-like opening into the cytoplasm, termed the *oral funnel.* The oral groove is lined with long cilia; their beating creates currents which sweep food particles, consisting of smaller one-celled animals and of bacteria, into the lower end of the oral funnel. A number of food particles enter the cell in a drop of water, forming a food vacuole. This breaks loose from the end of the funnel and passes into the cytoplasm. By the movement of the cytoplasm, the food vacuoles pass to other parts of the cell. The processes of digestion, assimilation, respiration, and excretion are

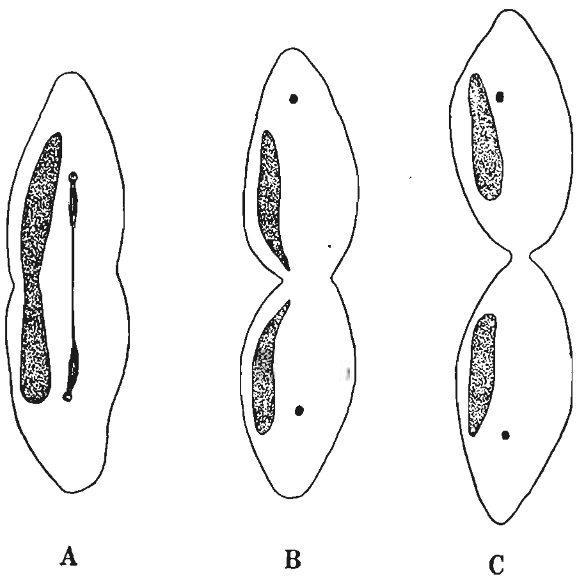


FIG. 13.—Fission in *Paramoecium*, showing successive stages in the division of the macronucleus and micronucleus, and the constriction of the cytoplasm.

carried on in essentially the same ways as in *Amoeba*, but in *Paramoecium* there is a definite spot on the surface of the body where indigestible matter is expelled. Reproduction[1] occurs by fission, the cell dividing transversely (Fig. 13).

Amoeba and *Paramoecium* belong to a group of animals called *protozoans*, which includes over 10,000 different species. Many of the protozoans are relatively simple animals, although some are much more complex than the

[1] The peculiar behavior known as *conjugation* is briefly described elsewhere (see p. 159).

two forms which we have studied. Protozoans are all unicellular and are nearly all microscopic in size. The cells are mostly solitary, but in some cases are arranged in colonies. Protozoans are found both in fresh and salt water and in the soil, while many are parasites, living within the bodies of other organisms.

Euglena.—While it is possible to assign most organisms to either the plant or the animal kingdom, there are some groups which have mixed affinities, combining the charac-

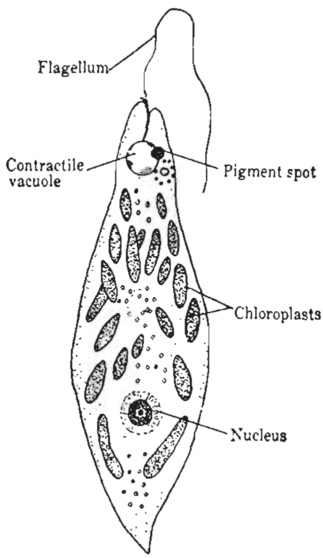


FIG. 14.—*Euglena viridis*, an organism showing both plant and animal characters. (*Redrawn after Doflein.*)

ters of both plants and animals. One such group of organisms is the *flagellates*, often represented in stagnant pools and ditches by a form known as *Euglena viridis* (Fig. 14). Like *Paramoecium*, this organism has a rather definite form, due to the presence of a thin pellicle, but some flagellates are amoeboid, putting out slender pseudopodia. In most cases, no cell wall is present. *Euglena* is blunt at its forward end, gradually tapering behind. It swims by means of a single long whip-like cilium (usually called a *flagellum*) which lashes back and forth and pulls the organism through the water. At the base of the flagellum is a red *pigment spot* which is thought to be sensitive to light, as the organism tends to swim toward the best illuminated part of the water. Near the pigment spot is a large contractile vacuole. A single nucleus is present near the middle of the cell.

At the anterior end of the body is a small oral funnel, but, strangely enough, no food ordinarily is taken in through it. Instead of engulfing food particles like unicellular animals, *Euglena* makes its own food, for within the cell are a number of small chloroplasts which enable the organism to carry on photosynthesis. Thus its nutrition is distinctly plant-like. Reproduction occurs by fission, the cell dividing longitudinally. One half keeps the old flagellum, the other forming a new one. As in *Amoeba* and many other unicellular organisms, encystment, in the presence of unfavorable conditions, is a common occurrence.

While *Euglena viridis* has chloroplasts and carries on photosynthesis, there are other flagellates which are colorless. Some of these forms are parasites while others are saprophytes, absorbing liquid organic matter like the yeast plant. Some flagellates take in solid particles of food through the oral funnel, while others engulf food like an amoeba. Some species of *Euglena* carry on photosynthesis in the light, but if kept in darkness and supplied with organic material, they become colorless and saprophytic. Most of the flagellates live in fresh or salt water, but, as noted above, some are parasitic in the higher animals. They are all unicellular forms characterized by the presence of one or two flagella (rarely more), but the cells may be either solitary or grouped into colonies.

CHAPTER IV

THE MULTICELLULAR ORGANISM

It has been seen that the bodies of the lowest organisms consist of one cell, and that, when it divides, two new individuals are formed. Unicellular organisms may be *solitary* or *colonial*, depending on whether the cells separate following division or remain permanently together. Such organisms as *Protococcus* and yeast are somewhat intermediate between these two conditions, in that the cells formed by fission show a tendency to remain in contact for awhile before separating. A *colony* is merely an aggregation of organisms, each maintaining its individuality and having little or no dependence upon the others. Many of the simpler algae are colonial, many bacteria and flagellates, but only a few protozoans.

The cells forming a colony may be arranged in chains, filaments, plates, spheres, irregular masses, or otherwise (Fig. 15). The simplest colonies consist of groups of cells very loosely held together by a mucilaginous matrix, by stalks, or some other mechanical means. In more highly developed colonies the cells are in contact with each other, and so there is organic union between them. Some colonies consist of only a few cells, others of many thousands.

All of the higher plants and animals are multicellular, the individual consisting of many cells closely associated in structure and function. Here each cell is but a small part of the individual. Another feature of multicellular organisms is that the cells of the body cooperate in the performance of their functions and are more or less dependent on each other. It is only under special circumstances that a cell may become separated from the organization and carry on an independent existence; ordinarily, this is not possible.

It is a fact of great significance that one cannot draw a hard and fast line between colonies of unicellular individuals

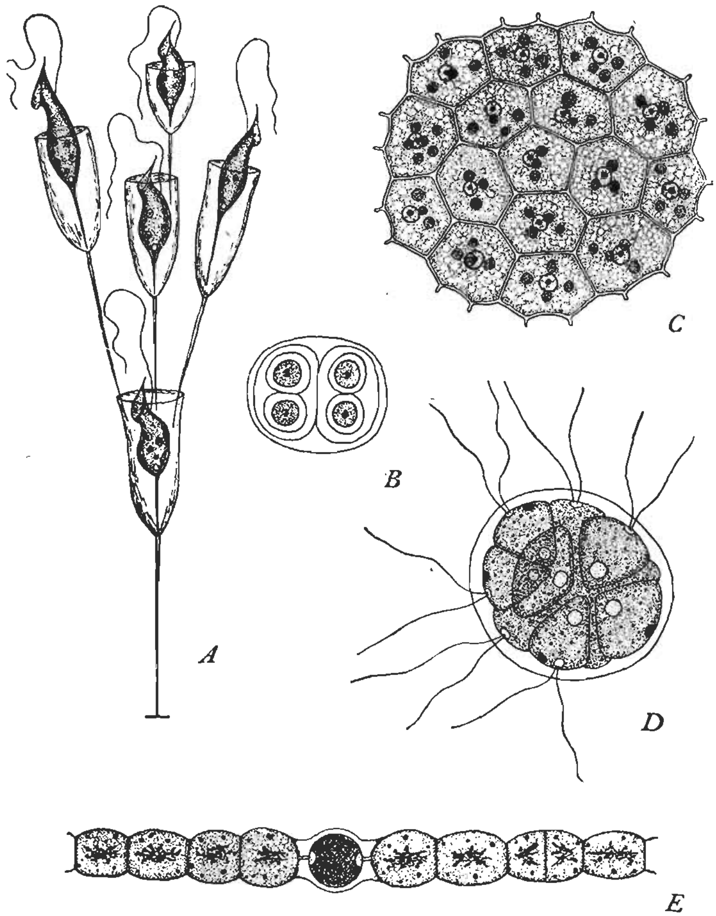


FIG. 15.—Some simple colonies, showing various kinds of cell arrangement. *A*, *Poteriodendron*, a flagellate, the individuals held together by means of stalks; *B*, *Gloeocapsa*, a simple alga, the cells imbedded in a mucilaginous matrix; × 750; *C*, *Pediastrum*, a plate-like algal colony with cells definitely in contact with each other, × 750; *D*, *Pandorina*, a spherical, 16-celled, motile algal colony enclosed in a mucilaginous sheath; *E*, *Anabaena*, a simple alga, the members of the colony forming a chain, × 1,000. (*A*, *redrawn after Stein*; *D*, *redrawn after Pringsheim*.)

and simple multicellular organisms. The fact that they grade imperceptibly into each other may indicate that the latter represent a modification of the former. In the evolution of the early forms of life, the tendency for cells to remain together after division led to the formation of colonies. A closer association of the cells in the colony may have led to a dependence of the cells on one another, resulting in a multicellular organism.

Differentiation of Cells.—In the simpler multicellular algae the body commonly has the form of a simple filament, a branching filament, or a plate of cells (Fig. 16), while nearly all of the fungi have a filamentous type of body. In the simplest cases all of the cells of the body are essentially alike in form and structure, but there is often a tendency for some of them to become different. For example, one or more of the basal cells may become modified to serve as a means of attachment to objects in the water (Figs 16*C*). In many of the branching forms, the cells show a differentiation in size, those of the branches being smaller than those of the main filament (Fig. 16*B*). The tendency for cells to become differentiated is well marked in all of the higher plants and animals.

Differentiation in structure has come about through a specialization of a cell or group of cells for a particular function. In unicellular organisms one cell performs all of the functions of the body, and this is also true of each cell in the simplest multicellular algae, as stated above. In the higher multicellular organisms, however, there exists a *division of labor* between various groups of cells, each group carrying on a particular kind of work. A group of similarly differentiated cells performing a definite function is called a *tissue*. In all of the higher plants and animals, the cells are organized to form tissues. In the simpler multicellular organisms there are only a few kinds of tissues, but in the more complex forms there are many. Among animals, the sponges constitute a group of primitive multicellular forms whose cells are but slightly differentiated; consequently they have very simple tissues of only a few different kinds. We shall now consider the chief kinds of tissues which occur in the higher plants and animals.

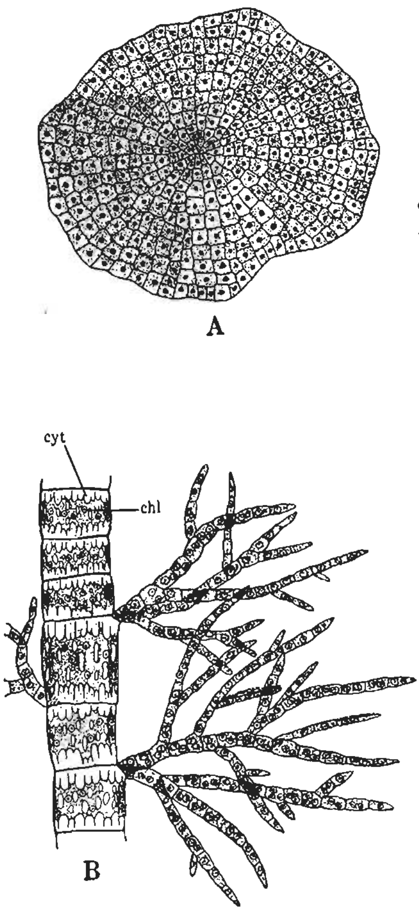


FIG. 16.—Some simple multicellular algae; *A*, *Coleochaete*, the cells in a plate like arrangement, × 150; *B*, a portion of the body of *Draparnaldia*, which consists of a branching filament, the cells of the branches being smaller than those of the main filament, × 250; *C*, *Ulothrix*, a simple unbranched filament with a differentiated basal cell which serves as a holdfast, × 350; *D*, *Spirogyra*, an unbranched filament with spiral chloroplasts, × 250. In *B* and *C* the peripheral band-like chloroplast obscures the central nucleus. The small bodies on the chloroplasts are centers of starch formation; *cyt*, cytoplasm; *chl*, chloroplast; *nuc*, nucleus.

Chief Tissues in Plants.—A layer of cells called the *epidermis* forms a covering on the surface of all leaves, flower parts, fruits, young stems, and young roots (Fig. 17*A*). It is distinctly a protective tissue. Epidermal cells covering all aerial parts of the plant have their outer cell walls more or less thickened with a waxy substance (*cutin*) which serves to check evaporation from the underlying tissues. They have living contents and are mostly without chloroplasts.

Another kind of tissue is *parenchyma*, which forms the bulk of the living parts of the plant (Figs. 17*A*, 17*B*). It is characterized by living, thin-walled cells which are but slightly differentiated in structure. They may or may not have chloroplasts. Frequently, parenchyma is a rather loose tissue, characterized by intercellular spaces.

The woody portion of plants consists of *xylem tissue* (Fig. 18). There are several different kinds of xylem elements, but all are greatly elongated tubes with thick cell walls. At first they are alive, but, for the most part, soon lose their protoplasm. Some xylem elements have peculiar local thickenings on the cell wall, forming spirals, rings, etc., while in others the thickened wall has numerous circular or elongated pits. Xylem tissue gives strength to plants and serves as a path through which fluids pass, thus being both supporting and conductive in function. It is developed most extensively in roots and stems, but occurs in nearly all parts of the plant to some extent. Some kinds of xylem elements represent several or many cells which have fused together.

The outer part of old roots and stems becomes covered with *cork tissue*, which forms the outer bark (Fig. 17*B*). Cork is composed of many layers of somewhat cubical cells which lack protoplasmic contents when mature. The cell walls are slightly thickened by a waterproof substance (*suberin*). Cork is obviously a protective tissue, replacing epidermis on older roots and stems.

Mechanical tissues are often developed in many parts of the plant, especially in the stem. Their purpose is to give

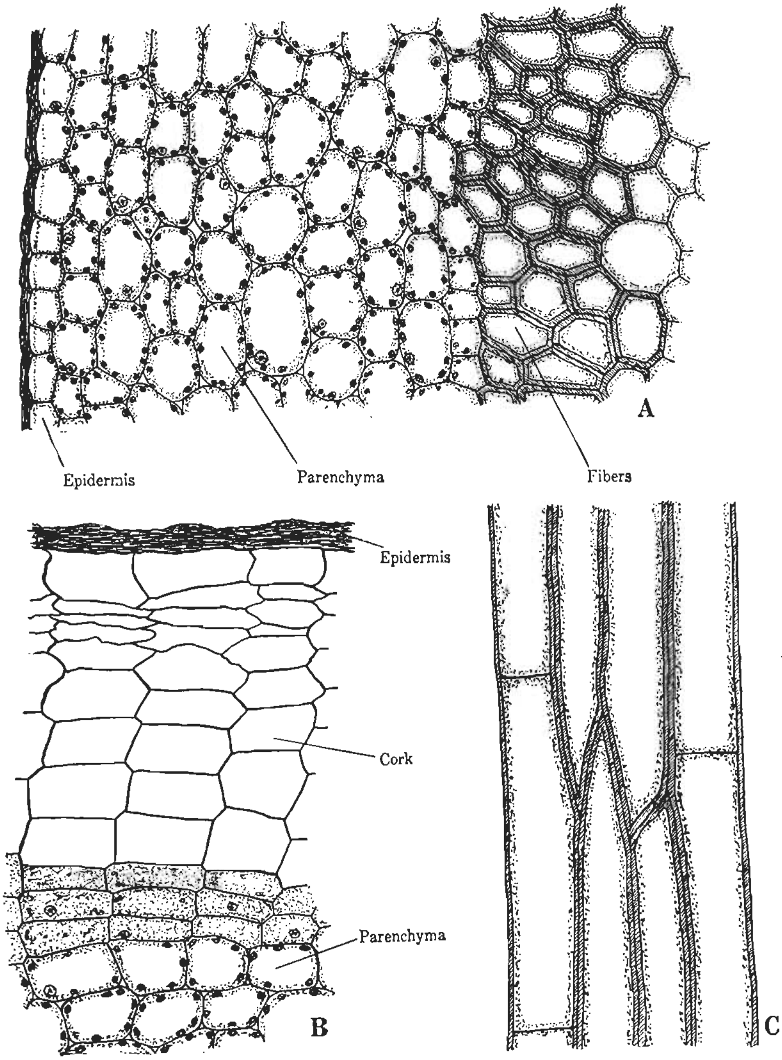


FIG. 17.—Tissues from a young stem of ivy geranium (*Pelargonium peltatum*), × 250; *A*, cross-section of a small portion of stem, showing epidermal cells with cutinized outer walls, parenchyma, and fibrous mechanical tissue; *B*, cross-section of older part of stem, showing development of cork tissue between the epidermis (now disorganized) and the parenchyma; *C*, a small group of fibers as seen in longitudinal section.

rigidity, toughness, or hardness, and so are commonly present where there is a weak development of xylem, as in many herbs. There are several different kinds of

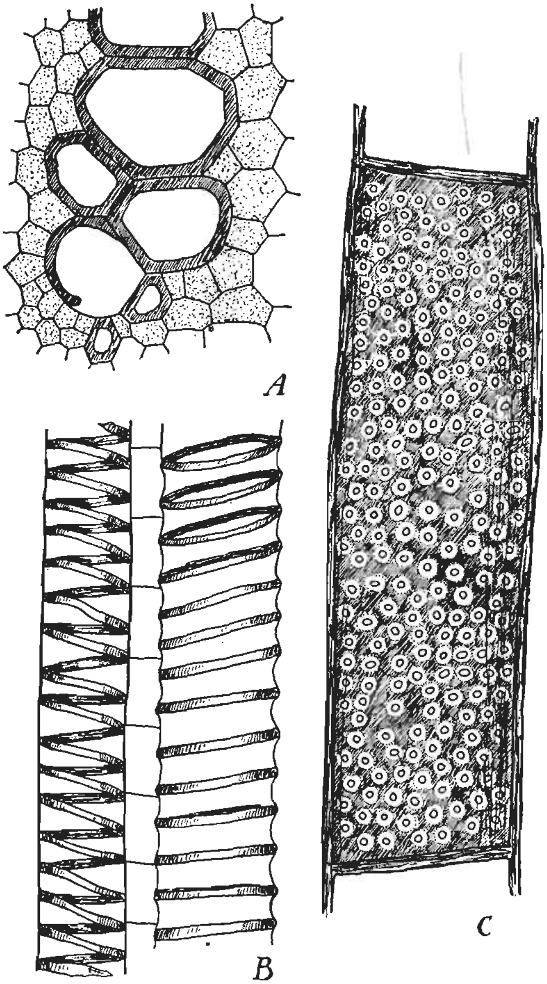


FIG. 18.—Xylem elements from the stem of castor bean (*Ricinus*), × 250: *A* and *B*, portion of spiral and ringed vessels as seen in cross- and longitudinal section; *C*, a pitted vessel.

mechanical tissues, but commonly they have the form of long fibers with greatly thickened walls (Fig. 17*C*). When mature they usually are not living.

Chief Tissues in Animals.—Comparable to the epidermis of plants, we find in animals a tissue called *epithelium* which covers the external and internal surfaces of organs (Fig. 19). The simplest multicellular animals are composed almost entirely of but slightly specialized epithelial cells. In more complex animals they are modified, however, in accordance with the function they perform, such as protec-

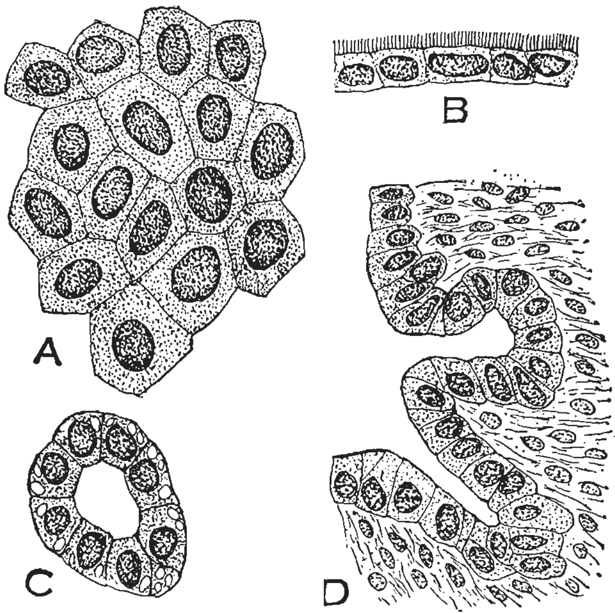


FIG. 19.—Several types of epithelial tissue from larval salamander, × 300; *A*, surface view of flat epithelium from skin; *B*, ciliated epithelium from pharynx; *C*, cubical epithelium from kidney tubule; *D*, columnar epithelium from intestine. (*From Wieman, "General Zoology," McGraw-Hill Book Company, Inc., by permission.*)

tion, absorption, secretion, etc. Epithelium commonly consists of a single layer of cells, but in some cases, as in the outer skin of man, there are several layers. Epithelial cells may be either flat, cubical, or columnar, and are often ciliated.

Muscle tissue is composed of cells which are specialized for contraction (Fig. 20). There are two kinds of muscle: *smooth* and *striated*. The former consists of elongated, uninucleated cells pointed at either end. They compose the muscles of most of the lower animals and nearly all of the involuntary muscles of the higher animals. Voluntary muscles are made up of bundles of long fibers, each fiber representing a row of cells which have fused together. Thus each fiber has many scattered nuclei. A peculiarity of voluntary muscle is the presence of numerous transverse striations.

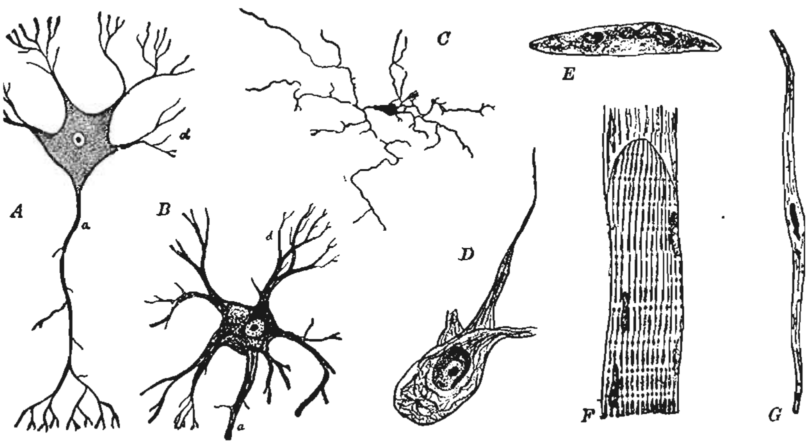


Fig. 20.—Nerve and muscle cells; *A*, diagram of a typical nerve cell; *B*, cell from human spinal cord; *C*, nerve cell from the eye; *D*, nerve cell of an earthworm; *E*, young voluntary muscle cell; *F*, portion of mature voluntary muscle cell, showing striations; *G*, involuntary muscle cell from intestine. (*From Sharp, "Introduction to Cytology," McGraw-Hill Book Company, Inc., A and B, after Obersteiner and Hill; C, after Lenhossék; D, after Kowalski; E to G, after Piersol; by permission.*)

Nerve tissue is also highly specialized. Its functions are to receive and carry sensations and to stimulate activity in other cells. Most nerve cells have protoplasmic fibers extending from them which carry the impulses (Fig. 20); these often become extremely long. A *nerve* consists of a bundle of these fibers.

Connective and supporting tissues include a variety of kinds of cells whose function is to bind together various parts of the body or to give rigidity and support. They form tendons, ligaments, cartilage, bone, etc. Blood is usually classified as connective tissue also. These tissues are all characterized by the presence of some kind of intercellular substance which is mostly non-living itself, but is formed as a secretion from the living cells. Thus the

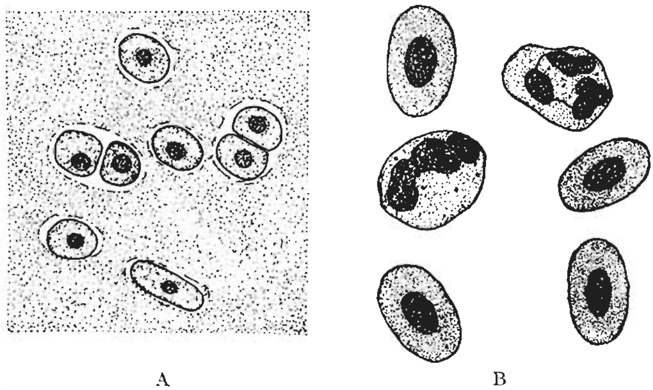


FIG. 21.—Cartilage and blood; *A*, section of cartilage, showing the cells imbedded in a non-living matrix. × 500; *B* frog blood corpuscles, the two white corpuscles with several nuclei, × 750.

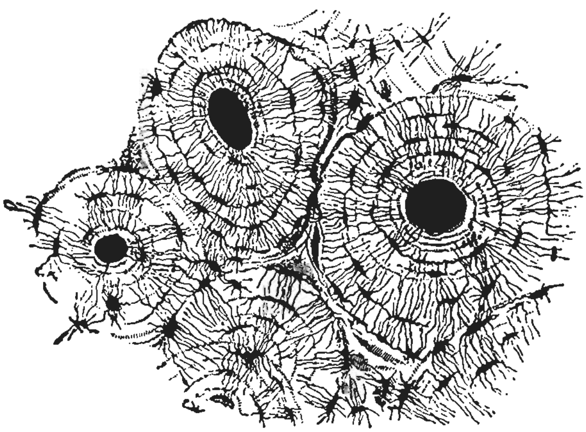


FIG. 22.—Cross-section of bone, the intercellular substance in white. The large black areas are occupied by blood vessels, the bone cells lying in the smaller spaces arranged in concentric circles, × 150. (*From Schäfer, "Textbook of Microscopic Anatomy," Longmans, Green & Co., after Sharpey; by permission.*)

cells are imbedded in a matrix of some sort, but are themselves little specialized. In cartilage (Fig. 21*A*), the intercellular substance is tough and more or less elastic; in bone it is very hard because of the accumulation of mineral matter (Fig. 22); in blood the cells float freely in a liquid (Fig. 21*B*).

Organs and Systems.—Among the higher plants and animals, the body shows certain highly organized parts, each of which is ordinarily associated with some particular function or set of functions. Such differentiated parts of the body are called *organs*. In the higher plants there are six primary organs: the root, stem, leaf, flower, fruit, and seed. In the higher animals there are many organs, examples being the brain, heart, lungs, stomach, liver, kidneys, eyes, ears, limbs, etc. An organ is usually composed of more than one kind of tissue, although in most cases one kind predominates, as parenchyma in the leaf, xylem in the stem, nerve tissue in the brain, muscle in the heart, etc. There are no organs in the simplest multicellular plants and animals. The algae and fungi have a *thallus* body, that is, a body with little or no differentiation into root, stem, and leaf. The sponges have simple tissues but no definite organs.

A *system* is a group of organs performing some general bodily function. The following systems occur in the higher animals: digestive, circulatory, respiratory, excretory, nervous, muscular, skeletal, and reproductive. In plants, systems are not well developed because there are no internal organs. The roots are collectively termed the root system, while the stem with its branches and leaves constitutes the shoot system. There is no blood in plants, no nerves, muscles, or digestive, circulatory, or excretory organs. While plants do not have internal organs, and consequently no internal organ systems, we often speak of the conducting tissues collectively as the "conducting system."

Plants and Animals Compared.—While it is an easy matter to distinguish between plants and animals if we confine our observations to the higher organisms, our study of unicellular forms has shown that it is difficult to separate all living things into these two conventional groups. Some of the more constant differences are given below, but it should be understood that there are numerous exceptions to any general statement that could be made.

1. *Structure.*—Most plant cells are surrounded by a cell wall of non-living material, while most animal cells are not. The organs of plants are mostly external, of animals both external and internal. For this reason, and because of the presence of more highly differentiated tissues, animals are, in general, much more complex than plants.

2. *Locomotion.*—While most plants are stationary and most animals active, some of the algae and fungi have the power of locomotion while many animals do not, as, for example, the sponges, barnacles, oysters, etc.

3. *Growth.*—Most plants grow continually throughout life, while animals grow only during early life. Thus, the maximum limit in size for any given species is more quickly reached in animals than in plants.

4. *Irritability.*—For the most part, plants are slower to respond to stimuli than animals, and, consequently, their movements are performed more slowly. Yet when the leaves of the sensitive plant (*Mimosa*) are touched, the leaflets close together almost instantly.

5. *Nutrition.*—Green plants have the power of photosynthesis, while animals and dependent plants do not. In general, animals ingest solid food while dependent plants absorb food in liquid form, but there are many exceptions.

CHAPTER V

THE GREAT PLANT GROUPS

There are nearly 250,000 different species of plants which have been named and described by botanists. This vast assemblage of forms, collectively constituting the *plant kingdom*, includes not only the various kinds of familiar plants of field, forest, and garden, but also many simple ones largely unknown to most people. The plant kingdom is divided into four major groups, each group representing a certain definite condition of structural complexity. The general characteristics of each of these four great plant groups will be briefly considered.

Thallophytes.—The lowest group of plants includes the thallophytes, a large assemblage of simple forms numbering about 80,000 species. Although many are unicellular, most thallophytes, like all of the members of the higher groups, are multicellular. The body of the thallophytes is not differentiated into distinct vegetative organs—root, stem, and leaf—such as characterize the higher plants, and it is chiefly to this feature (the presence of a *thallus* body) that thallophytes owe their simplicity.[1]

The two outstanding groups of thallophytes are the *algae* and the *fungi*. Algae are independent plants, and nearly all of them live in water. They include the pond scums, kelps and other seaweeds, and many other less familiar forms (Figs. 23 and 24). Fungi are dependent plants, living either on dead organic matter or on living organisms. Familiar kinds of fungi are bacteria, yeasts, molds, mildews, blights, rusts, and mushrooms (Figs. 25 to 27).

[1] In many of the marine algae, however, the body is differentiated into parts which bear a superficial resemblance to the roots, stems, and leaves of the higher plants, but are structurally very different (Fig. 23*A*).

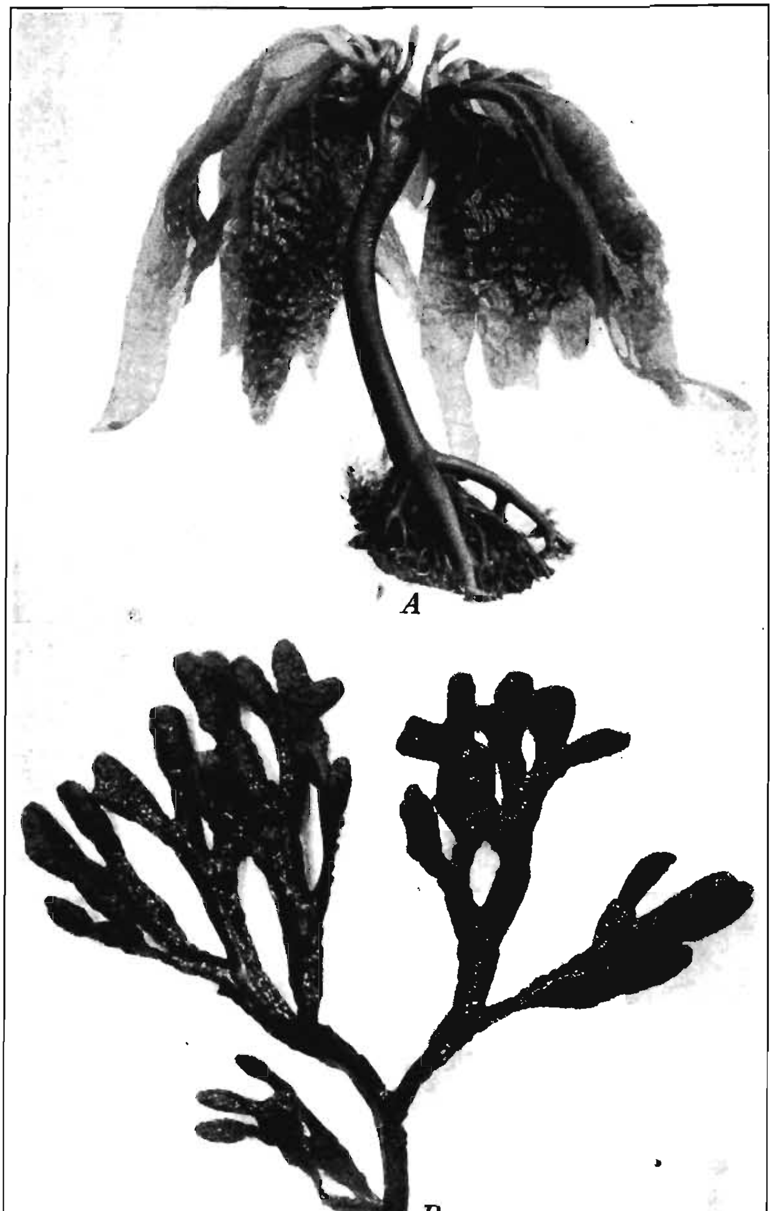


Fig. 23.—Two marine algae from southern California; *A*, a small kelp (*Eisenia arborea*), $\times \frac{1}{2}$; *B*, a rockweed (*Hesperophycus harveyanus*), $\times \frac{7}{8}$.

FIG. 24.—One of the many species of red algae (*Pleonosporium dasyoides*, × 1), nearly all of which are marine in distribution. (*Courtesy of Professor N. L. Gardner.*)

Bryophytes.—The second great plant group, including the liverworts and mosses, numbers about 16,000 species. It is distinguished from the thallophytes chiefly by greater complexity in reproductive structures. Bryophytes are small, inconspicuous, green plants which live mostly on moist soil, rocks, tree trunks, etc. They are of considerable scientific interest in that they are intermediate in structure

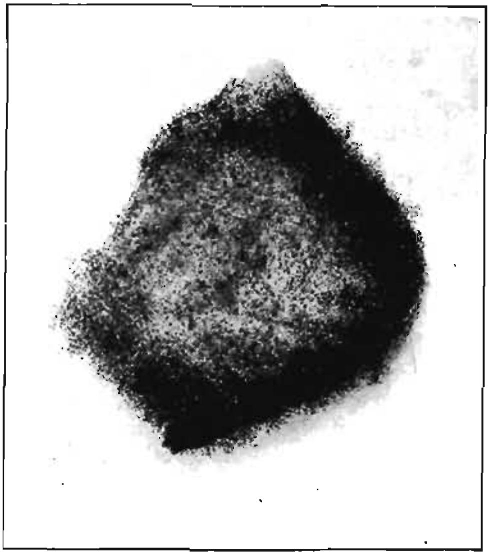


FIG. 25.—Bread mold (*Rhizopus nigricans*), a saprophytic fungus growing on a piece of stale bread, × ¾. The white, filamentous, vegetative body of the fungus produces many black, globular, reproductive bodies.

between the algae and the higher plants. It is noteworthy that the simplest green plants, the algae, are aquatic, while the bryophytes, but slightly more advanced structurally, grow on land, but mostly in wet places. Some of the liverworts have a thallus body (Fig. 28), but in most bryophytes very simple stems and leaves are present (Fig. 29). They are not, however, like those of the higher plants, and in none of the bryophytes are true roots present.

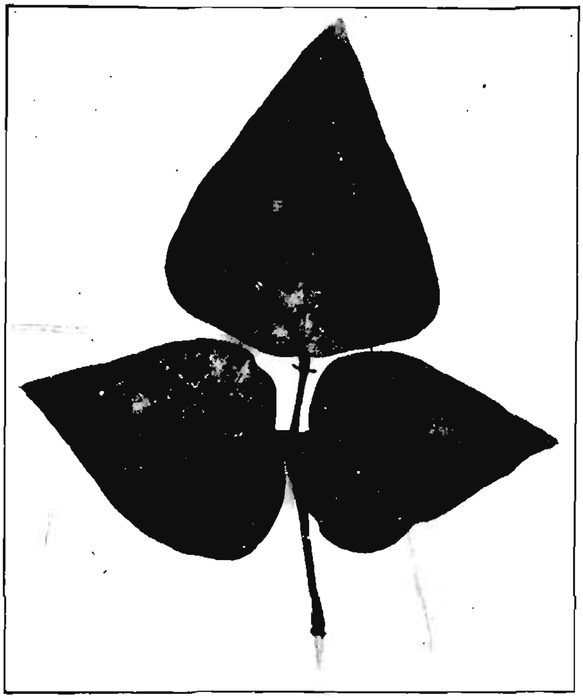


FIG. 26.—A mildew (*Erysiphe polygoni*), a parasitic fungus growing on a leaf of scarlet runner bean, × 3/4. The white, filamentous, vegetative body of the fungus absorbs nourishment directly from the epidermal cells of the leaf.

FIG. 27.—A mushroom (*Amanita muscaria*), × 1/3. The white, filamentous body of the fungus lives saprophytically on organic matter in the soil, sending these complex, fleshy, reproductive bodies to the surface.

FIG. 28.—A common liverwort (*Marchantia polymorpha*), × ⅞.

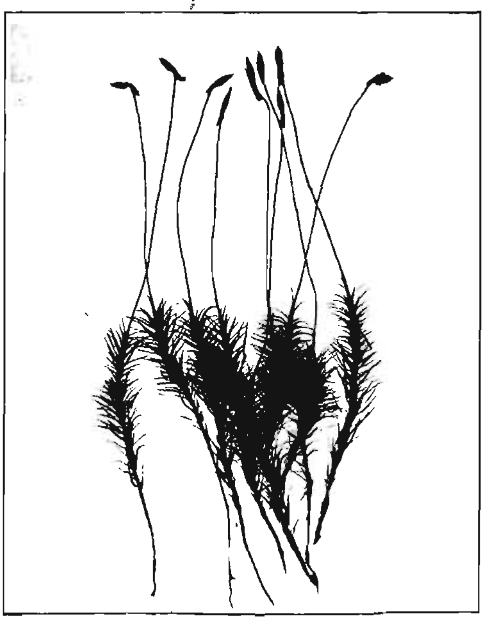


FIG. 29.—A moss (*Polytrichum commune*), × ½.

FIG. 30.—A lycopod (*Lycopodium obscurum dendroideum*), × ½.

Pteridophytes.—The ferns and their relatives (the lycopods and equisetums) are represented today by only about 5,000 species, but in past geologic times they were a much larger and more conspicuous group. The pteridophytes show a great structural advance over the bryophytes in having complex, highly developed roots, stems,

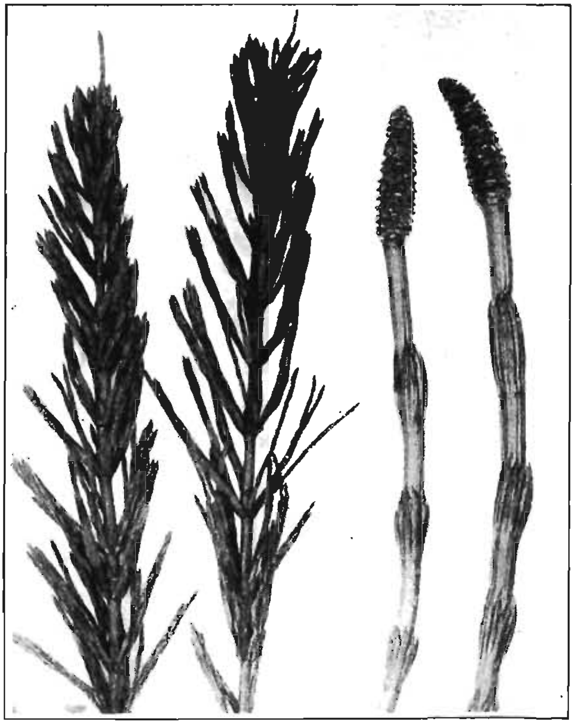


FIG. 31.—An equisetum (*Equisetum arvense*), × ⅗.

and leaves (Figs. 30 to 32). They also have a conducting system consisting of specialized tissues which support the plant body and transport fluids from one part to another.

Spermatophytes.—The name of the highest plant group means "seed plants," as they are the only plants which bear seeds. They are also the most highly specialized in regard to the structure of their vegetative organs. The spermatophytes not only surpass the other groups in structural complexity, but are the most numerous, there being about 135,000 species. There are two subordinate groups of spermatophytes, *gymnosperms* and *angiosperms*. The former number only about 500 living species, and include the pines, firs, spruces, hemlocks, cedars, etc.

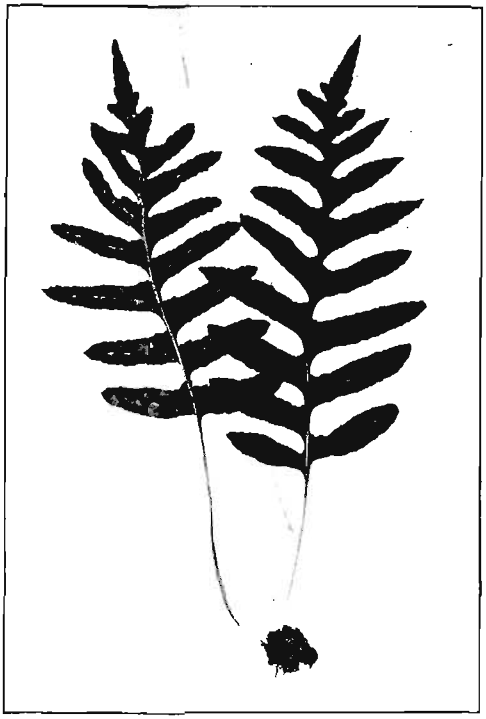


FIG. 32.—A fern (*Polypodium californicum*), $\times \frac{1}{3}$.

(Fig. 33). The name gymnosperm means "naked seed," in reference to the fact that the seeds are borne freely exposed on the face of a cone scale (Fig. 35). Angiosperm means "enclosed seed," signifying that the seeds are produced in a closed vessel which becomes the fruit. Nearly all of the common plants of everyday experience are angiosperms (Fig. 34).

FIG. 33.—Mature cone and leafy branch of white pine (*Pinus strobus*), a gymnosperm, × ½.

FIG. 34.—White trillium (*Trillium grandiflorum*), an angiosperm, × ½.

Summary.—A summary of the general features[1] of the four great plant groups will serve to fix them in mind.

Thallophytes.—Mostly aquatic; no true vegetative organs; no conducting system; no seeds.

Bryophytes.—Terrestrial but living in wet places; no roots, but simple stems and leaves usually present; no conducting system; no seeds.

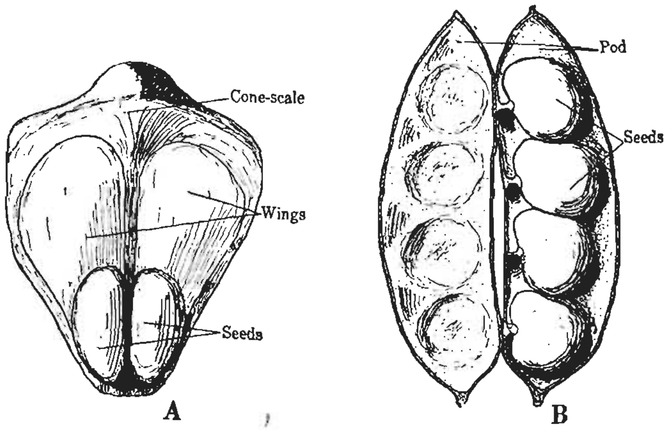


FIG. 35.—Gymnosperm and angiosperm compared. *A*, cone scale of sugar pine bearing two naked seeds at base of upper surface. × 1; *B*, pod of lima bean split open to show the enclosed seeds. × ½.

Pteridophytes.—Terrestrial; complex roots, stems, and leaves; conducting system; no seeds.

Spermatophytes.—Terrestrial; complex roots, stems, and leaves; conducting system; seeds.

[1] It should be understood that the great plant groups are characterized by more fundamental differences than those mentioned in this chapter, but these we are not yet ready to appreciate. Among these differences, those relating to reproductive features are presented in Chap. VIII.

CHAPTER VI

VEGETATIVE ORGANS OF SEED PLANTS

There are three distinct kinds of vegetative organs in seed plants: roots, stems, and leaves. They are called vegetative organs because their chief functions are concerned with the work of nutrition, that is, they provide for the continued existence of the plant body of which they are a part. In fact, it is only through the work of the root, stem, and leaf that a plant is able to live.

THE ROOT

The roots of a plant, collectively constituting the *root system*, place it in intimate relation with the soil. The welfare of the plant demands that this be maintained at all times, for, as everyone knows, when a plant is removed from the soil, it soon wilts and eventually dies. This happens because its source of water has been cut off. Roots not only absorb water from the soil, but also gases and mineral salts dissolved in the soil water. These are necessary to the welfare of the plant in ways which will be explained in the next chapter. Roots not only perform this important function of *absorption*, but also provide the plant with a means of *anchorage*, holding it firmly in the soil.

Organization of Root Systems.—Some root systems consist of a primary root, called the *taproot*, from which a number of smaller and smaller branches arise. In other plants one large root does not dominate the others, but the root system consists of a cluster of highly branched *fibrous roots*. Between these two extremes, however, are many of intermediate character, and so these "types" are of little significance. The important point is that all roots give rise to successively smaller and smaller branches which penetrate the soil in all directions. It should be noted that there is no regularity to the way in which branch roots arise, the smaller ones springing from the larger ones indiscriminately. Another fact of importance is that the tips of all roots are constantly elongating, pushing their way out into the soil. Furthermore, it is only these delicate rootlets which carry on the work of absorption, and so, as a root system grows, its absorbing region moves farther and farther out into the soil.

Structure of Root Tip.—The structure of a root tip can be studied to good

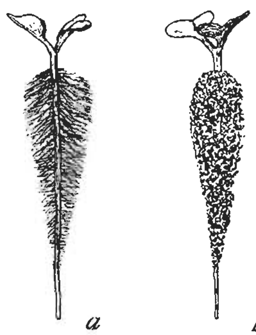


Fig. 36.—Radish seedlings grown in moist air (*a*) and in soil (*b*), showing root hairs, × 1.

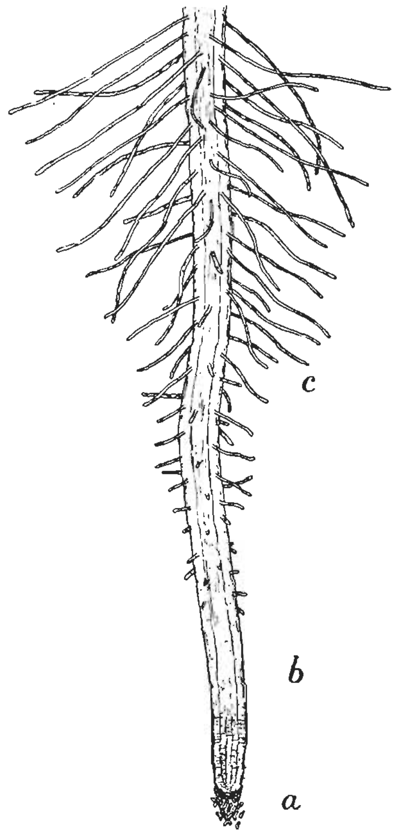


Fig. 37.—Root tip of a grass seedling grown in water, × 35; *a*, rootcap; *b*, growing region; *c*, root-hair zone.

advantage by examining with a microscope the young rootlets put out by sprouting seeds (Figs. 36 and 37). Fitting over the end of the root tip is a mass of cells forming the *rootcap*, a structure which serves as a buffer to the rootlet as it pushes through the soil, thus protecting the delicate cells which lie immediately behind.

Just back of the rootcap is the *growing region,* where the cells are constantly undergoing division and increasing in

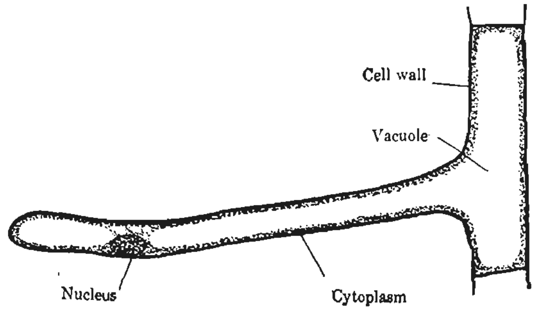


FIG. 38.—Enlarged view of one of the root hairs shown in Fig. 37, × 350.

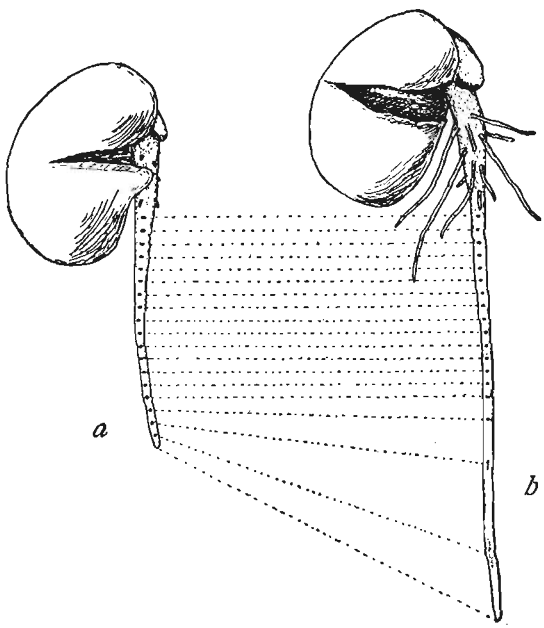


FIG. 39.—Growth of the root in length; *a*, seedling of scarlet runner bean with equidistant dots placed along the rootlet; *b*, the same seedling 24 hours later, showing elongation only near the tip, × 1. The older seedling shows the development of branch roots; root hairs are not indicated.

size. The growing region is about 2 to 3 millimeters (⅛ inch or less) in extent, but it is only here that roots increase in length. This can be demonstrated readily by placing a number of equidistant dots along a young root and a day or two later observing which ones have moved apart (Fig. 39). Behind the growing region is the *root-hair zone*, characterized by the formation of slender extensions from the outermost cells (epidermis) of the root (Figs. 37 and 38). Thus, root hairs are epidermal outgrowths, each one representing a single cell, and their presence very effectively increasing the absorbing surface of the rootlet. When roots are grown in soil, the root hairs become closely united with the soil particles (Fig. 36).

Structure of Mature Root.—The root-hair zone extends back only a short distance and gradually merges into the mature root. All of the cells of the growing region are essentially alike, but in the root-hair zone they become gradually differentiated to form tissues. In the mature root, differentiation is complete. A cross-section of a root taken behind the root-hair zone shows two distinct regions: an outer *cortex*, and a central *vascular cylinder* (Fig. 40). The cortex consists of relatively large, uniform, parenchyma cells. The root hairs have disappeared from the epidermis, and soon this is replaced by cork tissue. The vascular cylinder consists mostly of cells specialized for the conduction of liquids. There are two kinds of conducting tissues in plants: *xylem* and *phloem*. As already stated, the former consists of greatly elongated, thick-walled cells, most of which do not have protoplasm. The xylem tissue in a root is arranged in the form of a star, usually forming a solid central strand, and between its rays are the smaller strands of phloem surrounded by more or less parenchyma. Phloem consists of small, slightly elongated, thin-walled cells containing living contents. Water passes upward through the xylem tissue, while food in solution travels downward through the phloem.

In plants which live from year to year, the roots increase in thickness through the activity of a special layer of cells called the *cambium*, situated between the xylem and phloem. Cambial activity will be given detailed consideration in connection with the stem.

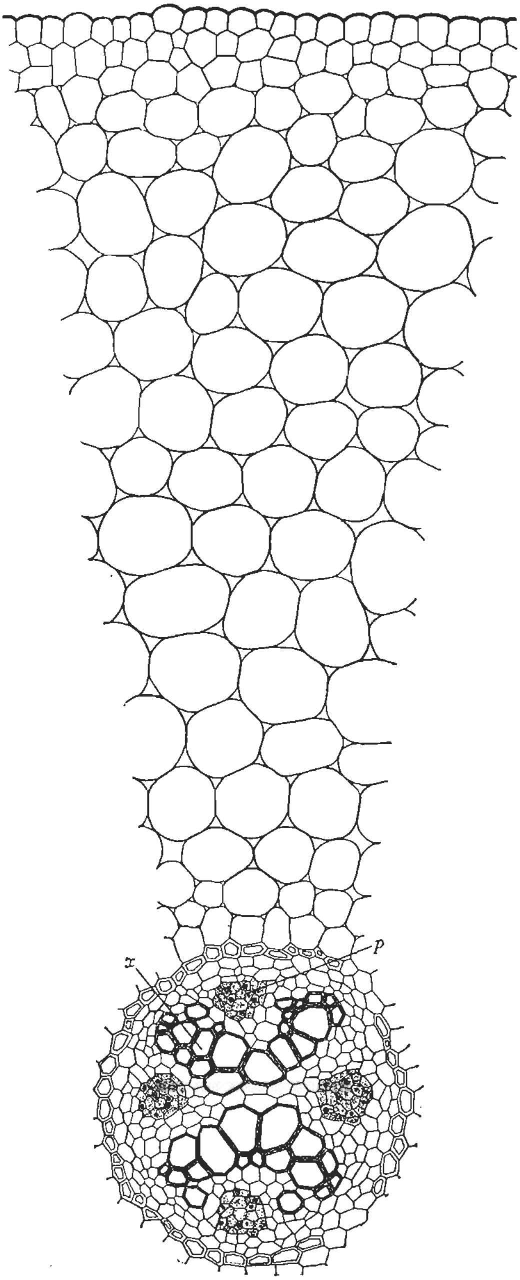


FIG. 40.—Portion of a cross-section of a buttercup root (*Ranunculus acris*), showing the outer cortex and the central vascular cylinder, the latter containing two kinds of conducting tissues: xylem (x) and phloem (p). × 150.

Duration of Roots.—Plants which live through but one growing season are said to be *annuals*. *Biennials* live through two seasons, while *perennials* live from year to year. It is apparent that a plant can live only as long as does its root system. While the roots of annuals die at the end of the first summer, the underground parts of biennials and perennials accumulate food. The portion above ground may then die down, but the roots live over the winter, a new shoot system arising the next spring. Storage roots are seen in such common plants as dandelion, radish, turnip, beet, carrot, parsnip, and sweet potato (Fig. 41). Their food is mostly in the form of starch, but there is also a large amount of water present—commonly 80 to 90 per cent. The accumulation of food and water in their roots enables these plants to make a vigorous growth above ground the following spring. In the case of biennials this food is entirely consumed during the second season, the plant produces seed, and then dies. In perennials, however, food accumulates during every growing season, the roots living from year to year, while the shoot system may or may not die back to the ground in the autumn.

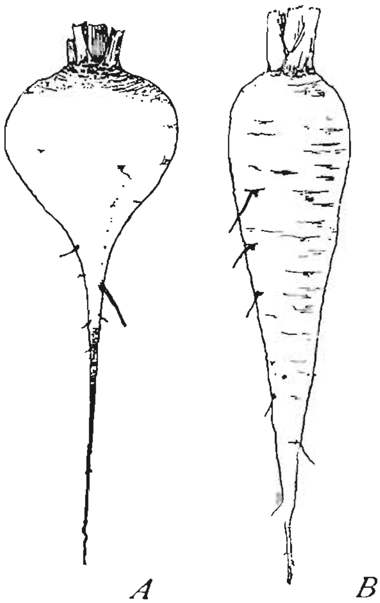


FIG. 41.—Storage roots of beet (*A*) and of carrot (*B*). × ½.

THE STEM

Stems are concerned chiefly with the bearing of leaves, and it is to this fact that they owe their distinctive features. The stem has two primary functions: to *support* the leaves, and to *conduct* substances in solution to and from them. Thus it serves to connect the roots with the leaves both structurally and functionally. A leafy stem is called a *shoot*, while all of the stems and leaves of a plant constitute its *shoot system*. Just as the root system is related to the soil, so is the shoot system related to the air and light.

FIG. 42.—Three types of leaf arrangement, × ½; *A*, alternate leaves of *Cotoneaster*; *B*, opposite leaves of *Salvia*; *C*, whorled leaves of *Abelia*. A bud is present in the axil of every leaf. Note that in each case one leaf does not stand directly over another.

Arrangement of Leaves.—Leaves are not scattered over a stem promiscuously, but are always borne according to a definite arrangement. The point on the stem where a leaf is attached is called a *node*, while the regions between successive nodes are known as *internodes* (Fig. 42). In most plants just one leaf is borne at a node, but in many cases there are two, one standing opposite the other. The former constitutes an *alternate*, the latter an *opposite* arrangement. In a few plants the leaves are *whorled*, there being three or more at a node. It is generally true that, regardless of the number of leaves at a node, leaves tend to be arranged on a stem in such a manner that one leaf does not stand directly over another and thus shade it, for the chief work of leaves demands that they be freely exposed to the light.

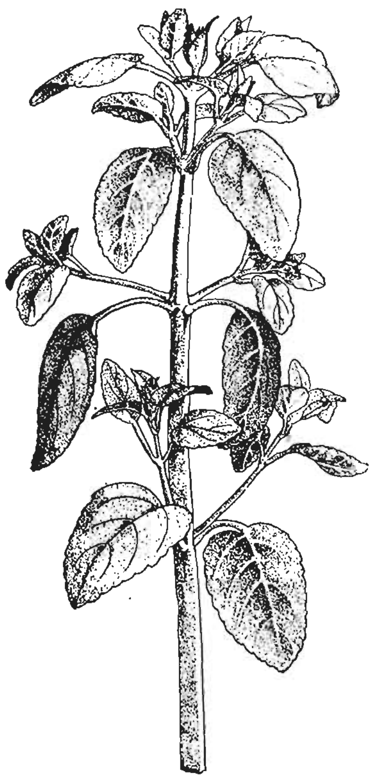
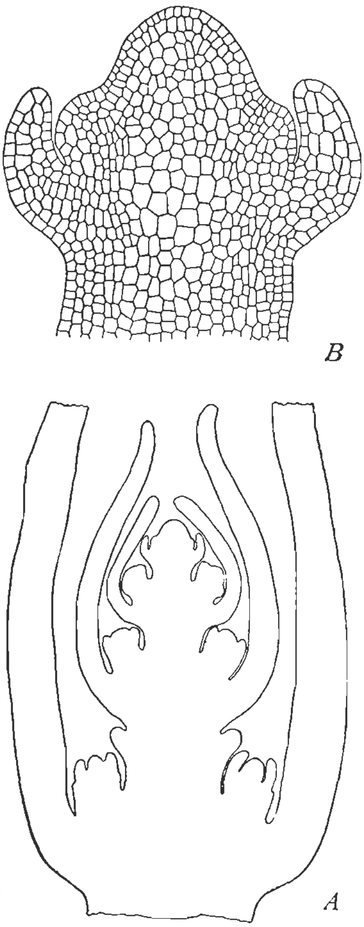


Fig. 43.—Older shoot of *Salvia* (*cf.*, Fig. 42*B*), showing the development of branch shoots from axillary buds, × ½.

Buds and Branches.—Not only are leaves borne at the nodes, but ordinarily a bud is formed in the *axil* of each leaf (Fig. 42*B*). The axil is the upper angle formed where the leaf is attached to the stem. A bud is merely an embryonic or undeveloped shoot; that is, it has the capacity for developing into a leafy stem (Fig. 43). It consists of a very short stem tip, which gives rise to minute lateral outgrowths, the latter being undeveloped leaves (Fig. 44). A bud expands into a leafy shoot merely by the elongation of its internodes and the enlargement of the leaves. The leaf in whose axil a bud is formed may fall off before the branch shoot develops or it may persist for a longer or shorter period.

Winter buds are buds which remain dormant during the winter, the delicate internal parts usually being protected by a covering of scales (Fig. 45). In the spring they develop into new shoots, the scales dropping off. While branches of the main stem always arise from *axillary buds*, the main stem itself usually increases in length by the growth of a *terminal bud*. The growth of the shoot system by the formation and development of buds is in striking contrast to the method of growth of the root system.



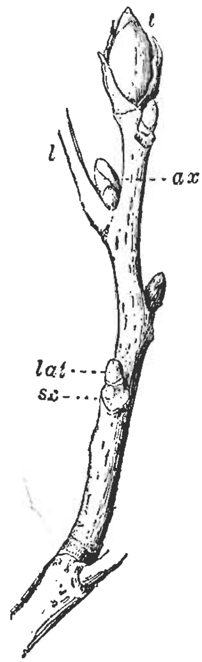


FIG. 44.—Stem tip of the opposite-leaved plant shown in Figs. 42*B* and 43 (*Salvia grahami*); *A*, longitudinal section of terminal bud, showing leaves and axillary buds arising at the nodes, × 35; *B*, upper portion of same, × 335.

FIG. 45.—Twig of hickory in winter condition; *t*, terminal bud; *l*, a last year's leafstalk still remaining on the twig; *ax*, a lateral bud in the axil of the leafstalk; *lat*, another lateral bud; *sc*, leaf scar. (*From Bergen and Caldwell, "Practical Botany," Ginn and Company, by permission.*)

Habit.—The general aspect of a plant, called its *habit*, is determined by such features of the shoot system as its growth direction, duration, and branching. While the stems of most plants support themselves and grow erect, in some cases they are creeping or climbing. Some plants have underground stems, such as *rhizomes*, *tubers*, or *bulbs* (Fig. 46). These serve as food-storage organs, resembling storage roots in this respect. According to the duration of the shoot system, plants are said to be either

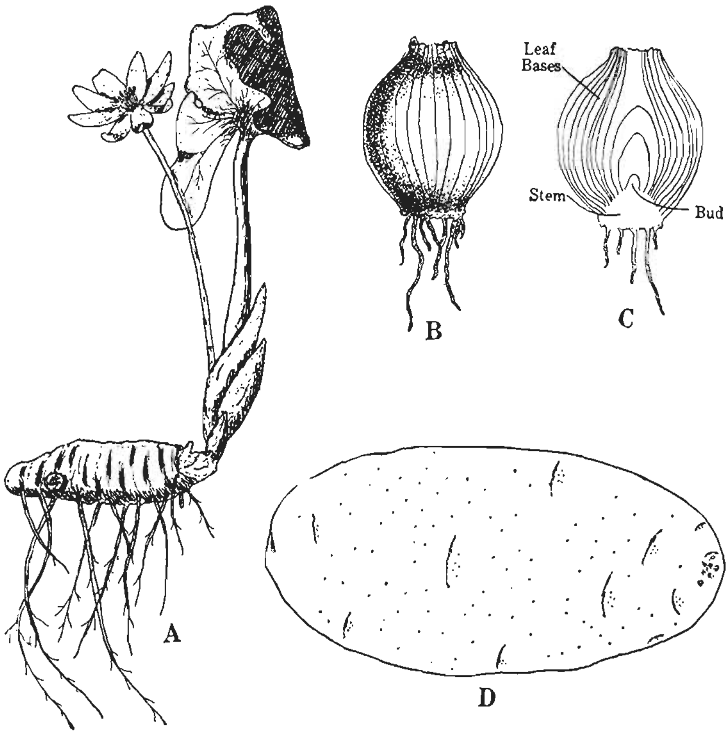


FIG. 46.—Types of underground stems, $\times \frac{1}{6}$; *A*, rhizome of bloodroot (*Sanguinaria*); *B*, bulb of narcissus; *C*, the same cut lengthwise; *D*, tuber of potato.

herbaceous or *woody*. An herb is a plant whose shoot system dies at the end of the growing season, while woody plants—shrubs and trees—have stems which live from year to year. All woody plants are necessarily perennial, as the root system must continue to live if the shoot system does. Most herbs, on the other hand, are annuals, the entire plant dying at the close of the first season, but some are biennial and some perennial. An *herbaceous perennial* is a plant whose underground parts live from year to year, but whose shoot system dies back to the ground at the end of each growing season. Common plants of this sort are asparagus, rhubarb, iris, dahlia, canna, tulip, gladiolus, etc.

The manner in which a plant branches is an important factor in determining its habit. In some plants the main stem is unbranched, elongation occurring by the growth of a single terminal bud. Although common among herbs, this type of shoot system is rare among trees, but is seen in the palms, whose habit is said to be *columnar.* In many herbs, and in such trees as the pine, spruce, fir, and others, the main stem continues to the top as a straight vertical shaft, the branches growing out horizontally; such a habit is designated as *excurrent.* In such trees as the elm and oak, the main stem soon gives rise to large branches and does not continue to the top, thus producing a spreading crown; this type of branching is called *deliquescent.*

Exogenous Stems.—Based on their internal structure, the stems of seed plants belong to two general types. The first, called the *exogenous* type, is characteristic of all gymnosperms and most angiosperms. A cross-section of a typical young exogenous stem shows three general regions: an outer *cortex,* a hollow *vascular cylinder,* and a central *pith* (Fig. 47). Both the cortex and pith are composed chiefly of parenchyma; the pith is colorless, but most of the cortical cells contain chloroplasts. As in a young root, the cortex is bounded externally by the epidermis. The vascular cylinder is usually a continuous tube, consisting chiefly of xylem tissue, but surrounding the xylem there is always a narrow zone of phloem. As in the root, both xylem and phloem are conductive in function, but the former also gives strength to the stem. Traversing the vascular cylinder are a number of narrow plates of cells called *vascular rays* which extend from the pith to the cortex. Between the xylem and phloem, and forming a complete ring, is a layer of cells constituting the *cambium*. In some stems, notably those of many herbs and woody vines, the vascular cylinder is not continuous,

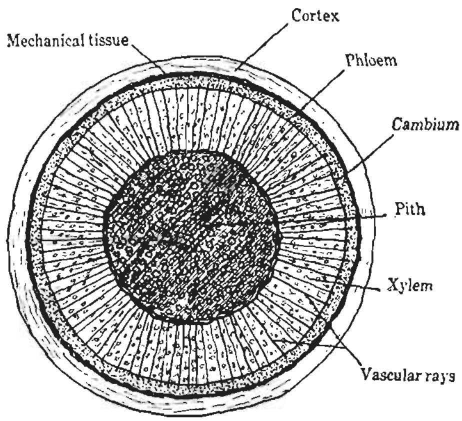


Fig. 47.—Cross-section of a one-year-old twig of box elder (*Acer negundo*), a typical woody exogenous stem, × 10. The xylem, cambium, and phloem tissues collectively constitute the vascular cylinder.

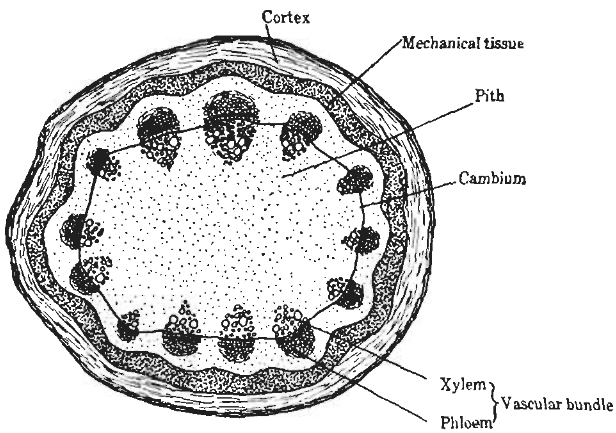


Fig. 48.—Cross-section of a one-year-old stem of Dutchman's pipe (*Aristolochia*), a woody vine, showing a vascular cylinder composed of isolated vascular bundles separated by wide extensions of the pith, × 10.

but is broken up into separate *vascular bundles* by wide extensions of the pith which may or may not be traversed by the cambium (Fig. 48).

During the growing season the cells forming the cambium are constantly undergoing division, giving rise to new vascular tissues—new xylem outside the old xylem, and new phloem inside the old phloem (Fig. 49). In woody plants the old phloem gradually disappears, but the xylem

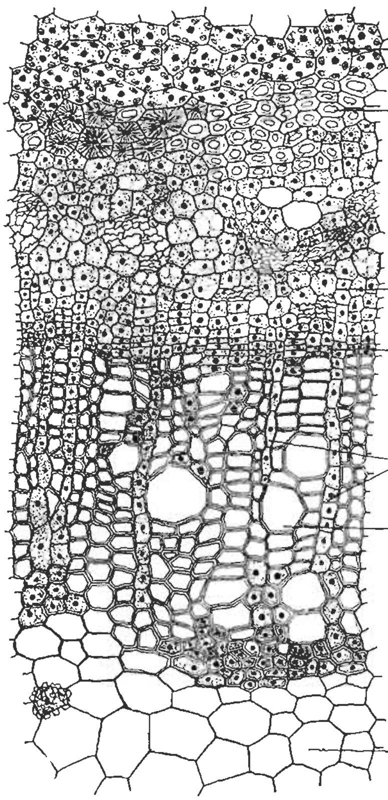


FIG. 49.—Portion of the vascular cylinder of a box elder stem in its first year of growth, showing details of structure, × 250.

persists from year to year. Thus the age of an exogenous stem can be estimated by counting the successive layers of xylem, as each year's growth is usually more or less sharply delimited from the rest by an *annual ring* (Fig. 50). As the vascular tissues increase in amount through cambial activity, cork tissue develops outside the cortex, forming a waterproof external covering of dead tissue (Fig. 17*B*). The cork layer contains many small openings called *lenticels* through which communication is maintained between the cortical cells and the atmosphere. These can be seen on almost any woody twig. After a number of years the cortex disappears, and because the

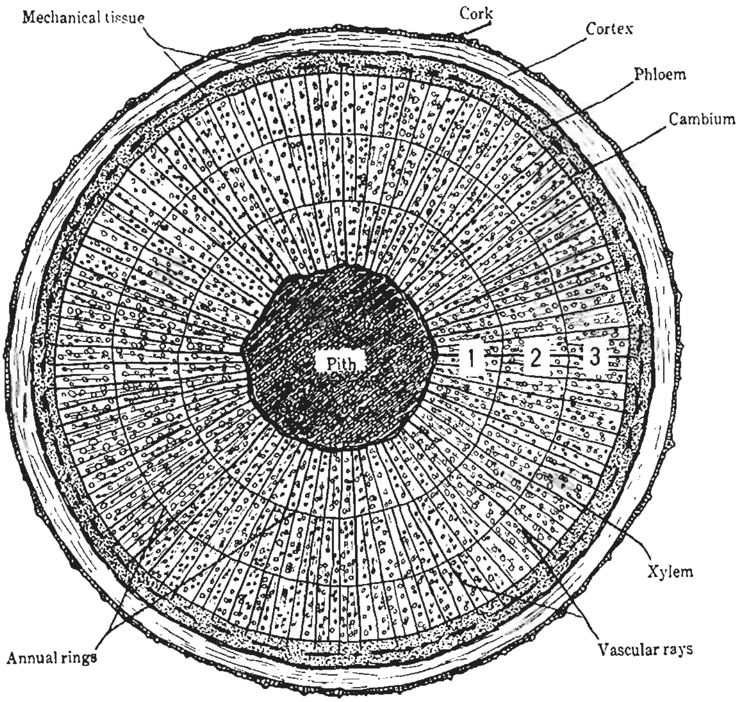


FIG. 50.—Cross-section of a three-year-old stem of box elder, showing increase, through cambial activity, in the amount of xylem and phloem, and the formation of cork, × 10; 1, 2, 3, successive layers of wood formed during the three growing seasons of the stem's existence.

pith always remains relatively small, an old woody stem really consists only of the following regions: *outer bark* (cork), *inner bark* (phloem and cambium), and *wood* (xylem). It should be realized that nearly all of the living cells are confined to the inner bark.

Endogenous Stems.—The endogenous type of stem is found among such angiosperms as grasses, lilies, palms, and orchids. A corn stalk, an asparagus stem, or a piece of bamboo or sugar cane would serve as an excellent example. The endogenous stem has separate vascular bundles like the exogenous stem shown in Fig. 48, but, instead of being arranged in the form of a hollow cylinder, they are scattered irregularly through the parenchyma tissue (Fig. 51). Thus, an endogenous stem shows no differentiation

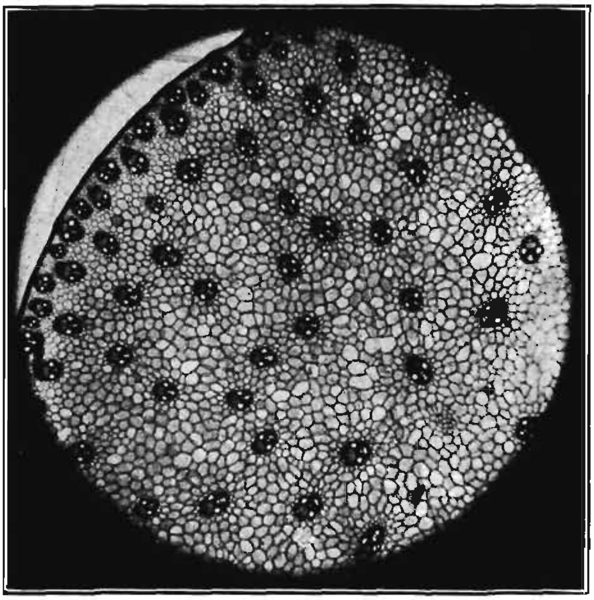


FIG. 51.—Photograph of a portion of a cross-section of a young corn stem (*Zea mays*), showing the scattered arrangement of the vascular bundles, × 13.

into pith and cortex. Each vascular bundle consists of a small group of xylem and phloem cells. Most endogenous stems do not have a cambium, and consequently the vascular tissues, once formed, do not increase in amount. Increase in diameter takes place entirely through a multiplication of the parenchyma cells.

THE LEAF

Leaves are the most conspicuous organs of the plant, and carry on the major part of the work of nutrition. Their chief function is the manufacture of food under the influence of sunlight.

External Features.—Most leaves are differentiated into a flat expanded portion, the *blade*, and a slender leafstalk or *petiole*. The blade, being characteristically broad and thin, serves as a means by which green tissue is exposed to the light, while the petiole merely supports the blade. In many plants, however, the leaf does not have a petiole, the blade then being attached directly to the stem. Some leaves

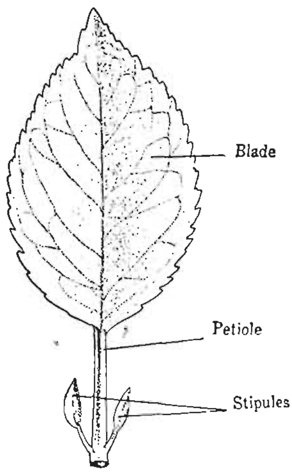


FIG. 52. Apple leaf, showing blade, petiole, and stipules, × 1.

possess a pair of *stipules*—small, scale-like appendages formed at the base of the leaf (Fig. 52).

A noteworthy feature of all leaves is the elaborate system of *veins* which extends to all parts of the blade. Veins represent a continuation of the vascular system of the root and stem, and so are channels for the transport of water and dissolved substances which pass into and out of the leaf. The larger veins of most leaves are conspicuous, especially on the lower surface, but the small veinlets can be seen only with the aid of a lens (Fig. 53). It is then evident that the veins form an elaborate network of smaller and smaller branches.

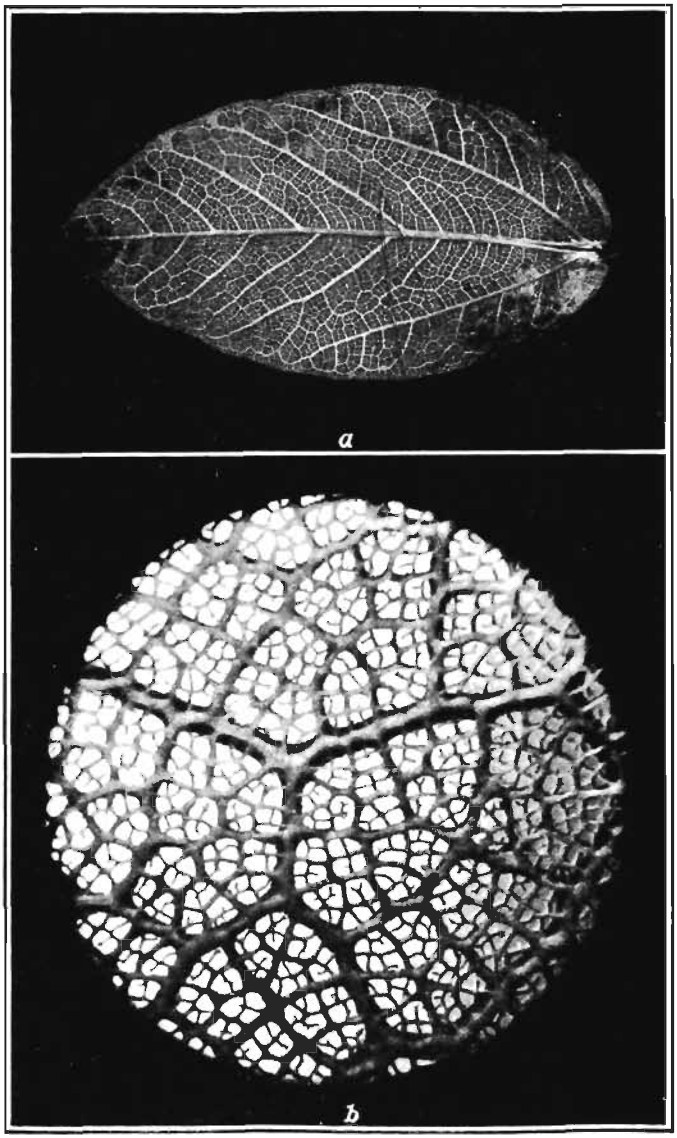


FIG. 59.—Leaf of climbing fig (*Ficus pumila*) which has been "skeletonized" by removal of the epidermis and mesophyll; *a*, entire leaf, × 1; *b*, portion of same, × 15. Note that the smallest veinlets end freely.

In size, leaves vary from minute scales to those as large as in the banana and palms. In form some of them are more or less circular, as in the geranium and nasturtium, others are long and narrow, like a grass blade or a pine needle, but most leaves are of some intermediate shape. The leaf margin may be smooth and even, or variously toothed, notched, or lobed. In some cases the lobes are so deep that the blade is divided into separate *leaflets* (Fig. 54). Leaves also show great variation in thickness, texture, character of the surface, arrangement of the principal veins, and other features.

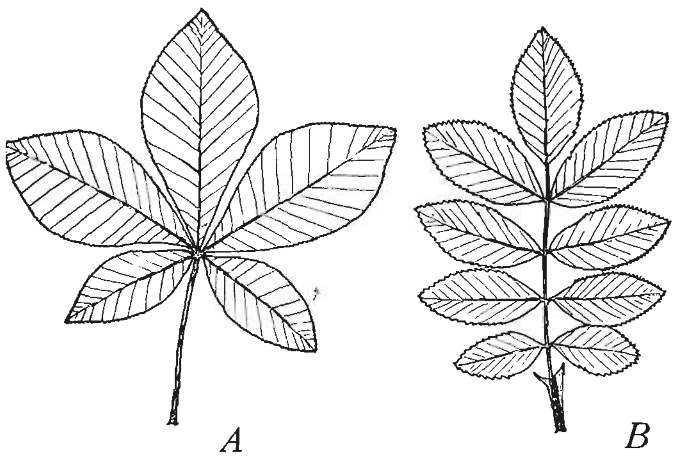


FIG. 54.—Divided leaves of horse chestnut (*A*) and of rose (*B*), × ½.

Internal Structure.—A cross-section of a typical leaf shows three kinds of tissues: an outer transparent *epidermis;* green tissue called *mesophyll*, comprising the bulk of the internal portion; *vascular bundles*, or veins, passing through the mesophyll (Fig. 55). Typically, a single layer of colorless epidermal cells is found both on the upper and lower surfaces of the leaf. Their outer walls are covered with a thin waxy deposit which forms a waterproof layer known as the *cuticle;* this renders them impermeable to water and gases, and thus serves to check evaporation from the inner tissues. Here and there are peculiar structures called *stomata*, which are usually more numerous on the lower surface. They can be easily studied by stripping off a piece of lower epidermis from an ordinary leaf and examining under the microscope (Fig. 56). A stoma consists of a slit-like opening bounded on either side by a crescentic *guard cell,* which differs from the other epidermal cells in containing chloroplasts. It is through the stomata that gases pass from the atmosphere into the leaf and *vice versa.* In many leaves the size of the stomatal opening can be altered by a change

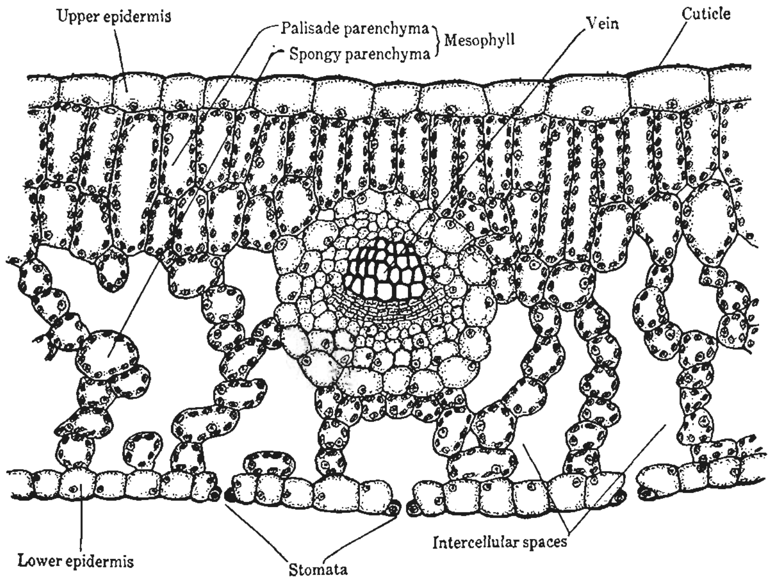


FIG. 55.—Cross-section of a leaf of privet (*Ligustrum vulgare*), × 250

in the shape of the guard cells, thus affecting the rate of gas exchange. Stomata are also present in the epidermis of young stems.

The mesophyll is the great food-manufacturing region of the leaf. It is typically differentiated into two kinds of tissues: *palisade parenchyma* and *spongy parenchyma,* the former usually forming a single layer beneath the upper epidermis. The two kinds of parenchyma differ from each other in the form and arrangement of the cells, but both have chloroplasts. The mesophyll is characterized by large intercommunicating air passages known as *intercellular spaces,* which are especially conspicuous in the spongy portion. They communicate with the outside air through the stomata, and provide for a movement of gases throughout the leaf.

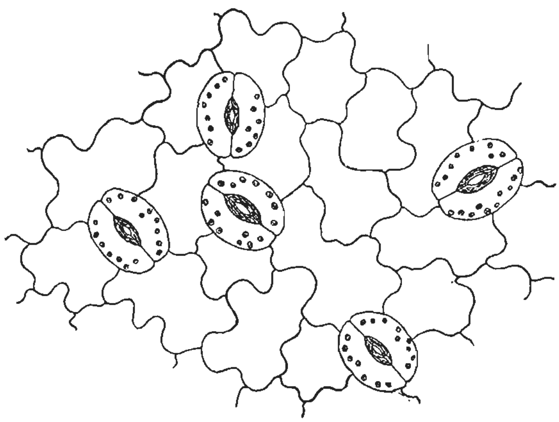


FIG. 56. -Portion of lower epidermis removed from a geranium leaf (*Pelargonium*), showing four stomata scattered among the ordinary epidermal cells, the latter having wavy outlines, × 500. Each stoma consists of a slit-like opening bounded by a pair of guard cells.

Each vein consists of a single vascular bundle in which the xylem occurs on the upper side, the phloem underneath. Around each bundle there is usually a sheath of parenchyma cells, its thickness being proportionate to the size of the vein.

CHAPTER VII

METABOLISM IN PLANTS

The term *metabolism* is applied to all processes in plants and animals which are concerned either with the building up or with the breaking down of protoplasm. In other words, it is the totality of physical and chemical changes by means of which the life of an organism is maintained. All processes in plants concerned with the manufacture and utilization of food, the release of energy, and the elimination of waste products are phases of metabolism. In general, we speak of any metabolic process as being either constructive or destructive, depending upon whether it contributes to the building up or breaking down of living matter.

Independent and Dependent Plants.—It has already been pointed out that all green plants have the power of making food by photosynthesis, and that plants which lack chlorophyll are unable to carry on this important function (see Chap. III). Green plants are said to be *independent* because they nourish themselves, while *dependent* plants must absorb their food from some external source. All plants are independent except the fungi and a very few angiosperms, such as the dodder and mistletoes (see pp. 256–258). Dependent plants which absorb food from dead organic matter are *saprophytes*, while those which subsist on other living organisms are *parasites*.

Independent plants support themselves. They build up food within their own bodies from water, carbon dioxide, and mineral salts—inorganic substances which they absorb from their environment. These are not foods themselves, but raw materials from which foods are constructed in the plant body. Foods are organic substances which contain stored energy and which are thus capable of yielding nourishment to organisms. Inorganic substances cannot do this. Protoplasm, whether plant or animal, can derive energy only from three classes of substances: carbohydrates (starch, sugars, etc.), fats, and proteins. These are organic substances; they alone yield nourishment; they alone can sustain life. Thus, the food of all organisms is the same, the difference between green plants on the one hand, and animals and dependent plants on the other, arising from the manner in which they obtain their food. It is only green plants which can make food from inorganic materials. Animals and dependent plants must obtain it from an external source—food which was originally formed in the body of a green plant. Consequently, without green plants no other forms of life could exist, for they are the ultimate source of all nourishment.

Absorption.—A green plant has two sources from which it derives substances essential to its existence: the air and the soil. Through its shoot system, especially the leaves, it obtains oxygen and carbon dioxide. Through its root system it absorbs water with oxygen and small quantities of mineral salts dissolved in it. The oxygen is used in respiration, the other substances in food manufacture. Oxygen and carbon dioxide enter the leaves and young stems through the stomata; they enter the older stems through the lenticels. Water, with its dissolved substances, is taken into the roots through the root hairs. Oxygen, carbon dioxide, water, and mineral salts are the only substances which a green plant absorbs from its environment. Organic matter in the soil, called *humus*, is not absorbed. That this contains nourishment is evidenced by the fact that such organisms as mushrooms and earthworms can live on it, but it is not a source of food for green plants. After humus is completely decayed, it adds to the mineral content of the soil and thus enriches it for green plants, but while it is still in organic form it is not utilized.

Diffusion.—All substances enter the plant by diffusion, a physical process which can be easily understood. When a crystal of copper sulphate is dropped into a glass of water, minute particles of the salt escape, as is evidenced by the dark blue color assumed by the water around the crystal. Gradually the colored area becomes larger and larger, until finally the entire liquid is uniformly light blue, indicating that a complete mixing of the two substances has taken place. This spontaneous intermingling of the particles of one substance with those of another is called *diffusion* (Fig. 57). The direction of movement is always from a region of higher to a region of lower concentration. Diffusion is exhibited only by soluble sub-

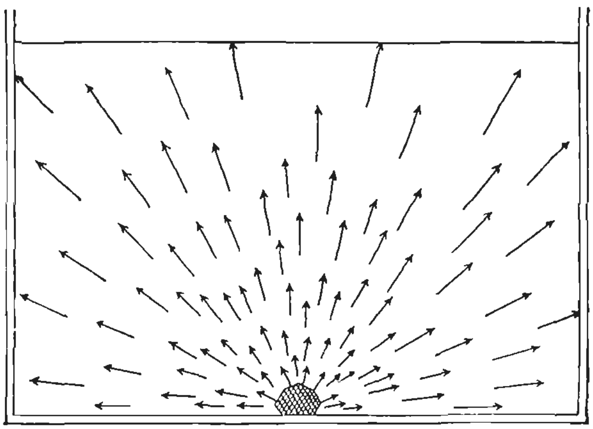


FIG. 57.—Diagram illustrating the diffusion of the molecules escaping from the surface of a soluble crystal placed in a vessel of water. (*From Sinnott, "Botany; Principles and Problems," McGraw-Hill Book Company, Inc., by permission.*)

stances. A lump of starch will not dissolve in water, and, consequently, there is no movement of its particles. If the liquid is shaken, a mechanical mixing occurs, but the starch soon settles to the bottom.

Osmosis.—When a salt solution is separated from pure water by a membrane through which the particles of both substances can pass, the salt particles diffuse into the water as if no membrane were present. This movement continues until the concentration is the same on both sides of the membrane, that is, until there are approximately the same number of salt particles per unit volume on one side as on the other. With respect to any given substance, a membrane is said to be *permeable* if the substance can pass through it, and *impermeable* if it cannot. The diffusion of a substance through a membrane is called *osmosis*. While all osmotic membranes are permeable to water, any given one is usually permeable to some substances and impermeable to others. Thus, a thin piece of parchment, placed between a salt solution and pure water, while permeable to the water particles almost completely checks the free diffusion of the particles of salt. Under these conditions, practically no salt passes through the membrane, but a great deal of water moves in the opposite direction (Fig. 58).

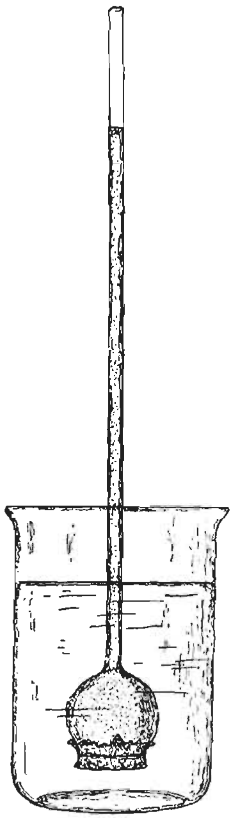


FIG. 58.—Demonstration of osmosis. A parchment membrane is tied over the lower end of a thistle tube, the tube partially filled with a strong salt solution, and immersed in a beaker of distilled water. Water passes into the tube, causing a dilution of the salt solution and rise in its level.

An osmotic movement of water occurs whenever a strong solution is separated from a weaker one by a membrane which is impermeable to the dissolved substance, the direction of movement always being from the less dense to the more dense solution. A familiar illustration is seen in the swelling of prunes or raisins when placed in water. The skin of the fruit, if unbroken, is impermeable to the sugar contained inside, and thus water enters. But if the swollen fruit is then put into a strong syrup or a strong salt solution, water is withdrawn and it again shrinks.

It is by osmosis that all substances enter and leave all living cells. The cell wall which surrounds most plant cells is permeable to free gases, water, and dissolved substances, but the plasma membrane is permeable to some substances and impermeable to others. Thus, sugar in a root hair cannot pass out of the cell, but any given soil salt can enter as long as its concentration is greater in the soil water than in the cell sap. The entrance of water depends upon the total concentration of dissolved substances on each side of the plasma membrane. If a cell is in contact with water or a weak solution, water enters, but if placed in a strong salt solution, water passes out of the cell, and, as a consequence, the elastic plasma membrane shrinks away from the cell wall (Fig. 59). This behavior is known as *plasmolysis*.

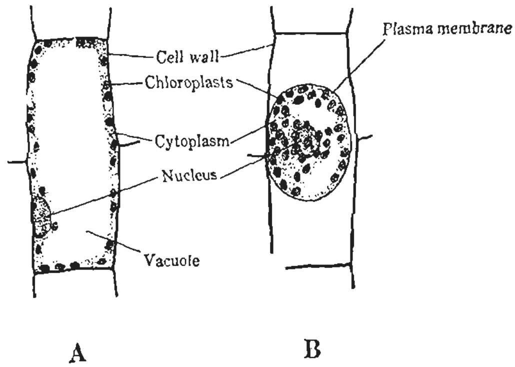


FIG. 59.—Demonstration of plasmolysis: *A*, normal cell of leaf of *Elodea* × 250; *B*, the same after 5-min. *immersion in a 2 per cent solution* of sodium chloride, showing the contraction of the plasma membrane caused by a withdrawal of water from the cell.

Conduction and Transpiration.—The cell sap of the root hairs, containing various dissolved substances, is relatively much more highly concentrated than the soil water, and thus water enters in response to the law of osmosis. Dissolved substances also diffuse into the root if the plasma membrane is permeable to them. After entering the root hairs, the soil water passes through the living cells of the cortex by osmosis. Upon reaching the vascular cylinder, it moves upward through the xylem tissue into the stem and out into the leaves. Water travels very rapidly through the vascular system, as xylem tissue, it will be recalled, consists almost entirely of cells which have no protoplasm. They are greatly elongated, thick-walled tubes, and thus the ascending water (sap) moves through cavities in dead cells.

Upon reaching the leaves, nearly all of the water which has traveled up the stem is evaporated through the stomata (Fig. 60). Water vapor is constantly being given off into the air from leaves; in fact, the chief value of the water which a plant absorbs from the soil is to replace that which is evaporated. If this were not constantly replaced, the plant would wilt and eventually die. The giving off of

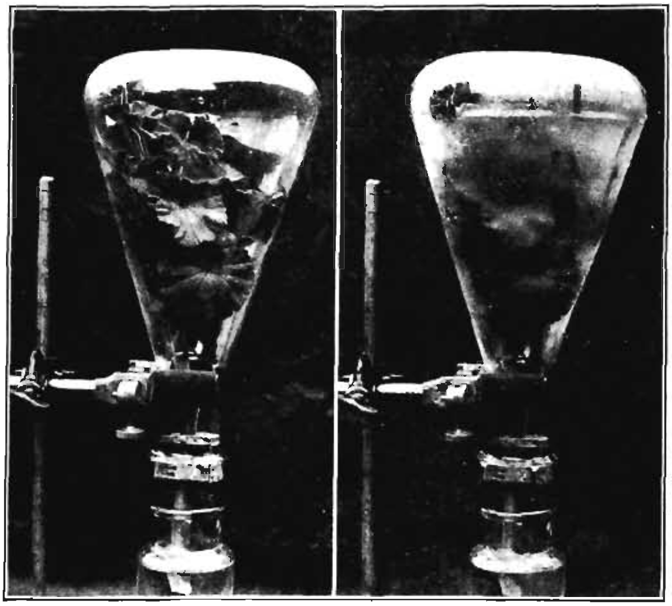


FIG. 60.—Demonstration of transpiration. A geranium shoot, held in an inverted flask by means of a split cork, has its lower end in a bottle of water. The photograph to the right, taken an hour later, shows condensation on the inside of the flask of water vapor given off by the shoot.

water vapor from leaves is termed *transpiration*, but it is merely evaporation through stomata. This water loss, always a danger to the plant, is unavoidable because the stomata must be kept open so that respiration and photosynthesis may go on.

The causes governing the upward movement of water in the plant have been extensively investigated, but as yet a thoroughly satisfactory solution of the problem has not been reached. It is apparent that an enormous amount of energy is required to force or lift water to the height of tall trees. The source of this energy is still a very uncertain matter. One of the most widely accepted theories seeks to explain the ascent of sap in terms of the lifting force of transpiration and the cohesive strength of water. Evaporation exerts a tremendous pull on the innumerable threads of water in the xylem tissue, and yet the particles of water in these threads seem to hold together.

Photosynthesis.—We have seen that green plants make carbohydrate food from water and carbon dioxide. The latter is a gas present in the atmosphere in very minute quantities—ordinarily in the proportion of about 0.03 per cent. It enters the leaves through the stomata, diffuses into the intercellular spaces, and is absorbed by the mesophyll cells. The chloroplasts have the power of combining carbon dioxide with water in such a way that a carbohydrate is formed and free oxygen is liberated. The process of photosynthesis is represented by the following equation:[1]

$$\underset{\text{Carbon dioxide}}{6CO_2} + \underset{\text{Water}}{6H_2O} \rightarrow \underset{\text{Grape sugar}}{C_6H_{12}O_6} + \underset{\text{Oxygen}}{6O_2}$$

This means that six molecules of carbon dioxide combine with six molecules of water to produce one molecule of grape sugar and six of free oxygen (each molecule of oxygen being composed of two atoms). The primary product of photosynthesis is commonly a simple carbohydrate known as grape sugar. Most of the free oxygen passes out of the leaf through the stomata, although some may be immediately used in respiration (Fig. 61).

The manufacture of carbohydrate food is dependent upon two special factors: chlorophyll and light. Photosynthesis can go on only in green tissues—only under the influence of

[1] Actually, the process of photosynthesis is not as simple as this, the equation representing only the end products of a series of intermediate changes which are incompletely understood. It seems that the water and carbon dioxide are first decomposed by the chloroplast, their constituent atoms then being recombined, first into one or more simpler compounds, and finally into the carbohydrate.

chlorophyll. While the mesophyll region of the leaves is the great center of photosynthetic activity, the process goes on in all green parts of the plant, as in the cortex of young stems. Carbohydrates can form in green cells only in the presence of light; at night photosynthesis ceases. Energy is absorbed from the sunlight and utilized by the chloroplasts to bring about the union of water and carbon

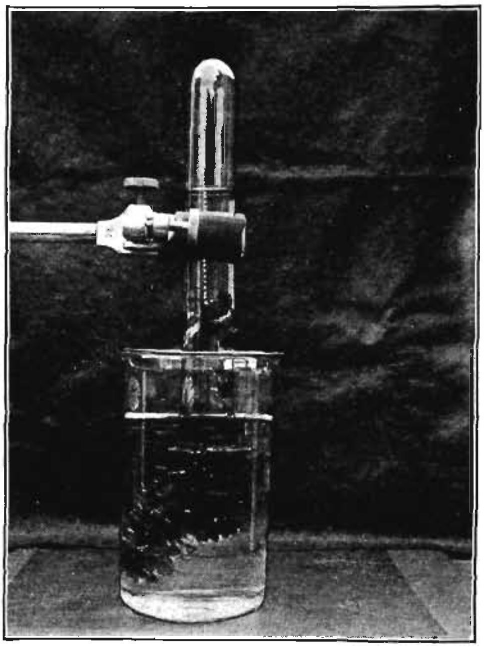


FIG. 61.—Experiment illustrating the release of oxygen in photosynthesis. Bubbles of oxygen are arising from the cut end of the stem of the water plant (*Elodea*), and are gradually displacing the water in the test tube. The apparatus is standing in weak sunlight.

dioxide. This energy is stored in the carbohydrate just as energy is stored in a wound watch spring. The storage of energy is really the most significant phase of photosynthesis, for it is the potential energy contained in all foods which makes them capable of sustaining life.

Sugar constitutes the chief food of plants. After being formed it may be immediately used by the leaf cells as a source of nourishment, or transported through the vascular system to other parts of the plant and there utilized. Ordinarily, sugar is formed in a leaf more rapidly than it can be removed. The excess is then changed to starch, which temporarily accumulates. At night, after photosynthesis has ceased, the starch is reconverted to sugar and transported to other parts of the plant. It should be recalled that, for the most part, food is conducted through the phloem tissue.

Formation of Fats and Proteins.—These are more complex foods than carbohydrates. They are not made by photosynthesis directly from inorganic substances, but are transformation products derived from carbohydrates. Fats contain only carbon, hydrogen, and oxygen, the same elements which are present in carbohydrates, but here they are combined in a different way. In carbohydrates the hydrogen and oxygen are combined in the same proportion as they occur in water, but in fats the proportion of oxygen to hydrogen is much less. Fats usually occur in liquid form in plants, that is, as oils. They can be formed in any part of the plant where there are carbohydrates, not merely in green parts.

All organisms require some protein food because protoplasm itself is largely composed of proteins. Proteins are compounds of carbon, hydrogen, oxygen, and nitrogen, while most of them contain sulphur and some phosphorus as well. They are elaborated carbohydrates to which new elements are added to form very complex compounds. The elements nitrogen, sulphur, and phosphorus enter the plant through its root system in the form of nitrates, sulphates, and phosphates, that is, as salts. Although approximately 78.2 per cent of the air consists of free nitrogen, green plants are unable to utilize atmospheric nitrogen in the synthesis of proteins, and thus must depend upon nitrates in the soil for their supply. The manufacture of proteins may take place at any time and anywhere in the plant, as it is not dependent upon light or chlorophyll.

In addition to nitrogen, sulphur, and phosphorus, all green plants require four other elements which occur in the soil. These are potassium, calcium, magnesium, and iron. They are not used in protein synthesis, but in other ways. Thus, there are ten essential elements which the plant must have in order to carry on its normal functions: carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, and iron. It should be realized that all except the first three enter as salts from the soil, but that by far the greater part of the plant is composed of carbon, hydrogen, and oxygen.

Food Storage.—Food made by the plant and not immediately used accumulates in various parts of the body. This *reserve food,* as it is called, most frequently is stored in the form of starch, although often sugars, fats, and proteins accumulate in varying amounts. It has already been seen that roots are common storage organs, while, in many plants, underground stems (rhizomes, tubers, or bulbs) serve as organs of food accumulation. All seeds contain reserve food, and, because they contain little water, the food is highly concentrated. The amount of food stored in fleshy fruits, leaves, and ordinary stems is usually small. Reserve food represents nourishment to be used at some future time, either by the plant itself or by its offspring.

Digestion and Assimilation.—Before reserve food can be utilized it must undergo *digestion,* a process which may go on in any living part of the plant. The conversion of starch to sugar is an example of a digestive change. Digestion in organisms is accomplished through the action of substances called *enzymes,* of which there are many kinds. The commonest starch-digesting enzyme in plants is *diastase.* Reserve foods are mostly in an insoluble condition, that is, they cannot be dissolved in water. The process of digestion is merely a means of rendering foods soluble, and this is necessary in order that they may pass by osmosis from cell to cell, and so that they may be eventually made into living matter. *Assimilation* is the transformation of digested food into protoplasm; it represents the final stage in constructive metabolism. Thus.

sugar itself and all of the other kinds of foods made from sugar contribute to the actual organic substance of the plant, which is constantly being built up. Growth can occur only through assimilation, which, in turn, is dependent upon food manufacture.

Respiration.— Plants and animals are machines in the sense that they utilize energy in the performance of their functions. This energy is derived from the breaking down of their own living substance. If a green plant is kept in darkness so that photosynthesis cannot go on, its dry weight decreases because its protoplasm is slowly being destroyed. If a paramoecium is kept in water containing no food, we can actually observe a gradual decrease in size until death finally ensues. All organisms are constantly consuming energy in carrying on their vital activities, and, as a consequence, living matter is always undergoing decomposition so that energy may be available. Unless renewed by the assimilation of additional food, there is a steady loss of weight. Protoplasm must be built up because it is constantly being broken down; the constructive phases of metabolism must counterbalance the destructive if the life of an organism is to be maintained.

The ultimate source of all vital energy is the sunlight, for, as previously explained, solar energy is absorbed when carbohydrates are made by photosynthesis. This energy becomes stored in the food, and when the food is assimilated it becomes incorporated in the protoplasm. The potential energy contained in living matter is liberated by respiration. which is essentially an oxidation process. When oxygen combines with protoplasm, the latter breaks down into simpler products with an accompanying release of energy for use by the living machine. Thus we see why all organisms must have constant access to oxygen in order to live. Ordinarily, most of the oxygen is absorbed from the air (of which it forms about 20.8 per cent), entering the plant through the stomata and lenticels, but some also diffuses into the roots from the soil water in which it is dissolved. It is carried to all of the living cells of the plant, diffusing chiefly through the intercellular spaces. The chief products resulting from the decomposition of protoplasm through oxidation are water and carbon dioxide. The latter passes out of the plant through the stomata and lenticels into the air, and through the roots into the soil.

Respiration goes on at all times—in all living cells—in all plants and animals. It involves the absorption of oxygen and the liberation of carbon dioxide. The fundamental feature of respiration, however, is not this gas exchange, but the destruction of organic matter within living cells in order that energy may be released for use in carrying on vital functions. Much misunderstanding often arises from failure to appreciate the significance of the gas exchanges which occur between green plants and the atmosphere. Therefore it should be understood that in photosynthesis, which proceeds only in the daytime, carbon dioxide is absorbed and oxygen is liberated, while in respiration, which goes on all the time, the gas exchange is just the reverse. At night only respiration is carried on; in the daytime both processes take place simultaneously. Under favorable conditions, however, when photosynthesis is active, there is much more oxygen given off than carbon dioxide; in fact, the latter may not even pass out of the plant but be immediately utilized in the manufacture of sugar.

Photosynthesis and respiration may be contrasted as follows:

Photosynthesis	Respiration
Organic matter is constructed	Organic matter is destroyed
H_2O and CO_2 are raw materials	H_2O and CO_2 are waste products
Oxygen is liberated	Oxygen is absorbed
Energy is stored	Energy is liberated
Occurs only in green tissues	Occurs in all living tissues
Occurs only in daytime	Occurs at all times

Irritability.—In order that the various metabolic functions of the plant may be carried on most advantageously, it is necessary that all of the vegetative organs be brought into the most favorable relations to their environment. This is accomplished chiefly through the property of irritability. It has already been stated that the power of response to external influences, or *stimuli*, is an inherent property of protoplasm, and hence is common to all organisms (see p. 11). In general, plants react to stimuli much more slowly than do animals, and the mechanism of response is much different; yet the response itself is just as definite. Young parts of plants, such as root tips and

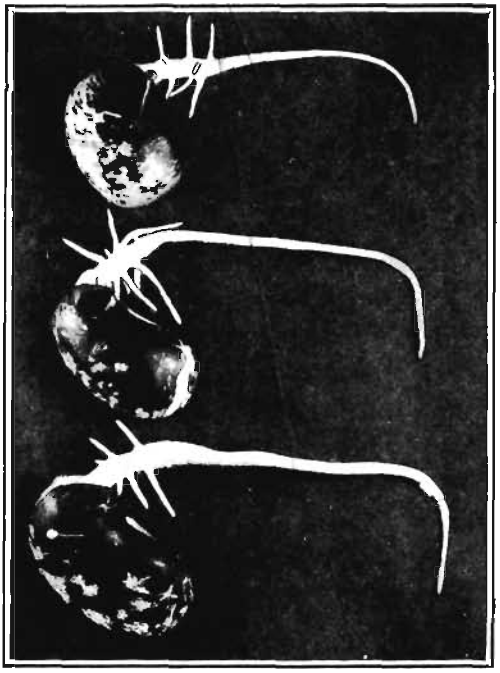


FIG. 62.—Response to gravity. Three seedlings of scarlet runner bean placed in a horizontal position and photographed 12 hours later. The root tips have developed a curvature in response to the stimulus of gravity.

elongating stems, are most sensitive to stimuli, but older parts often respond as well. Irritability in plants is manifested chiefly by the direction of growth and orientation which the various organs assume. Under ordinary conditions, the primary root grows downward, the main stem grows upward, while the branches and leaves are held in a more or less horizontal position. The chief stimuli which call forth these responses are gravity and light.

The action of gravity can be seen to advantage in seedlings. It is a well-known fact that, no matter in what position a

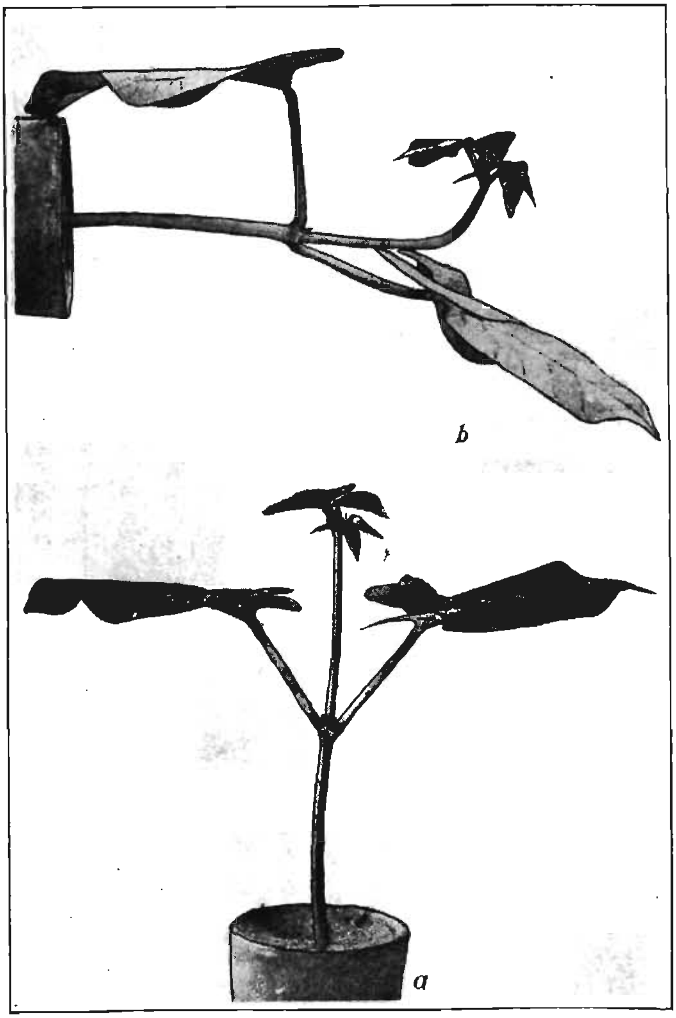


FIG. 63.—Response to gravity. A seedling of scarlet runner bean photographed under normal conditions (*a*) and after having been placed in a horizontal position for several hours (*b*). Note the response, both on the part of the leaves and of the stem.

seed is placed in the soil, when it sprouts the primary root always grows downward, forcing its way through the soil, while the stem pushes upward toward the light and air. If a seedling is placed in a horizontal position, however, the root tip soon begins to turn downward again and the stem in the opposite direction (Figs. 62 and 63). The chief stimulus involved in these reactions is gravity. It is evident that the root and the stem respond to the same stimulus, but in an exactly contrary manner, the root growing toward the

A B

Fig. 64.—Response to light. A young mallow plant (*Malva*) which has been exposed to one-sided illumination for several days; *A*, side view; *B*, face view.

stimulus, the stem away from it. Leaves react to gravity also, becoming oriented in a horizontal plane, that is, at right angles to the direction in which the stimulus is acting (Fig. 63).

The mechanism of response is important to understand. When an organ is placed in a different position from that in which it has been growing, so that the stimulus of gravity acts from a new direction, it responds by a curvature. This is brought about by an unequal acceleration of growth on opposite sides of the organ. Thus, in Fig.

63, the lower side of the stem is stimulated to grow faster, and in Fig. 62, the upper side of the root. The leaf is oriented by a growth curvature of the petiole, or a twisting of the base of the blade itself. If a plant is placed in a horizontal position and slowly rotated so that the stimulus of gravity can act upon it with equal intensity from all sides, there is no reaction.

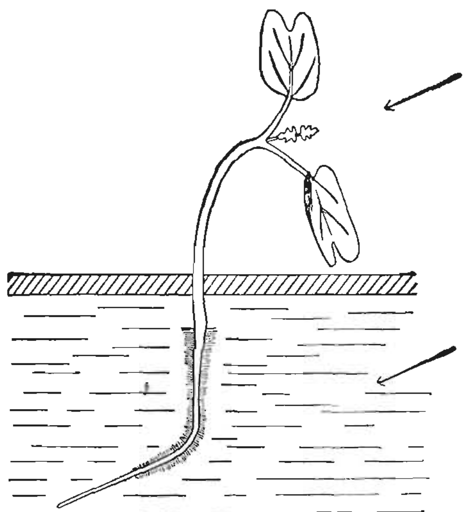


FIG. 65.—A mustard seedling growing with its root in water. The plant was at first illuminated from all sides, but later from only one side (shown by direction of arrows). Note that the stem has bent toward the light and the root away from it, while the leaves have taken up a position at right angles to the light. (*From Sinnott, "Botany, Principles and Problems," McGraw-Hill Book Company, Inc., after Strasburger, by permission.*)

The response of the shoot to light is one of the most obvious expressions of irritability in plants. Under ordinary conditions, most leaves assume a horizontal position, their orientation manifestly being such that the rays of light strike the flat surface of the blade at right angles (Fig. 42). This permits them to absorb a maximum amount of solar energy for use in photosynthesis. With a change in the direction of the light rays, the leaves assume a new position. This is apparent when a house plant is placed near a window, the stem tips tending to grow toward the source of light, while the leaves bend so that the blades are perpendicular to the direction from which the light is coming (Fig. 64). Thus the growth direction of the stem and the orientation of the leaves represent a definite response both to the stimuli of gravity and of light, the latter being the stronger influence. If a

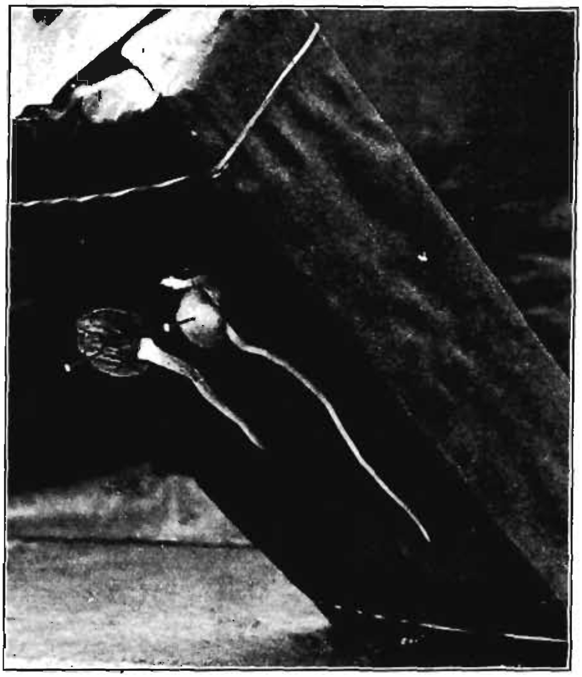


FIG. 66.—Experiment illustrating the response of roots to moisture. The seedlings are pinned to the underside of a sloping board covered with wet paper. The stimuli of gravity and of moisture are acting from different directions, and the latter proves to be the stronger.

plant exposed to one-sided illumination is slowly rotated, there is no response to light, as the intensity of the stimulus is then equalized.

While, ordinarily, roots do not react to the stimulus of light, under appropriate conditions, and in some cases, they are seen to grow away from its source (Fig. 65). Roots are very sensitive, however, to the stimulus of moisture. While this is usually not apparent by reason of the fact that commonly the stimuli of gravity and moisture act from the same direction, an experiment can be readily *arranged in which the two act from* different directions (Fig. 66). Then it is seen that the influence of moisture is stronger than that of gravity. It is obviously an advantage to the plant for its roots to grow from drier to more moist parts of the soil.

CHAPTER VIII

REPRODUCTION IN PLANTS

It will be recalled that nutrition and reproduction are the two great functions of all organisms, the former maintaining the individual, the latter, the race. The root, stem, and leaf are concerned chiefly with the nutrition of the plant body; they provide for its growth and continued existence. The flower, fruit, and seed, on the other hand, are related to the work of reproduction. They have nothing to do with the welfare of the plant body of which they are a part; their functions are associated with the coming into being of new individuals. Reproduction may be defined as the production of a new organism; it may occur either sexually or asexually. Just as vegetative structure shows a progressive advance in passing from the lower to the higher plants, so do the parts associated with reproduction exhibit an increase in complexity. For this reason, we shall first consider reproduction in some of the algae and fungi, as here it is relatively simple.

Fission.—The direct division of an organism to form two independent individuals is obviously the most primitive method of reproduction possible. In fact, it is the only method among many of the lowest plants and animals (see Chap. III). In unicellular organisms, fission is merely reproduction by cell division. All cells divide, but among multicellular organisms cell division results not in reproduction, but in growth. Because of this fact, reproduction can take place only by the separation of a cell or group of cells from the parent individual, the new organism developing from this fragment. A common way in which this process operates in plants is by the production of spores.

Spore Reproduction.--A *spore* may be defined as a cell having the capacity of developing directly into a new plant. In many of the simpler algae, the contents of any one of the vegetative cells of the body may give rise to one or more uninucleate swimming spores (Fig. 67). These escape

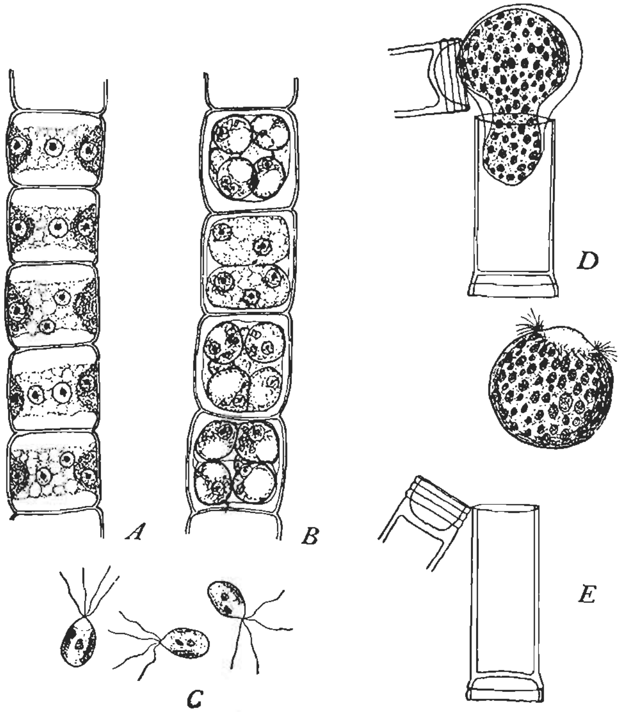


FIG. 67.—Spore reproduction in *Ulothrix* and *Oedogonium; A*, portion of a vegetative filament of *Ulothrix*. Each cell contains a peripheral, band-like chloroplast which obscures the central nucleus. Numerous starch-forming bodies are seen on the chloroplasts. *B*, formation of spores inside the cavity of the vegetative cells. *C*, free-swimming spores of *Ulothrix* which have escaped from the vegetative filament. *D* and *E*, formation and escape of a swimming spore in *Oedogonium*. The spore in this alga is provided with a crown of cilia. (*D and E, redrawn after Hirn.*)

from the cell cavity as naked cells (lacking a cell wall), and swim through the water by means of cilia. Swimming spores resemble the flagellates, not only in being motile, but also in having a contractile vacuole and a pigment spot (see pp. 29 and 30). After coming to rest, each spore gives rise to a new plant by cell division, this behavior being called *germination*. In some of the algae and many of the fungi, spores are produced in specialized structures called *sporangia* (singular, sporangium), which are formed for the sole purpose of spore production, a feature which becomes established in the higher plants (Fig. 68). It is only in the algae and a few of the fungi

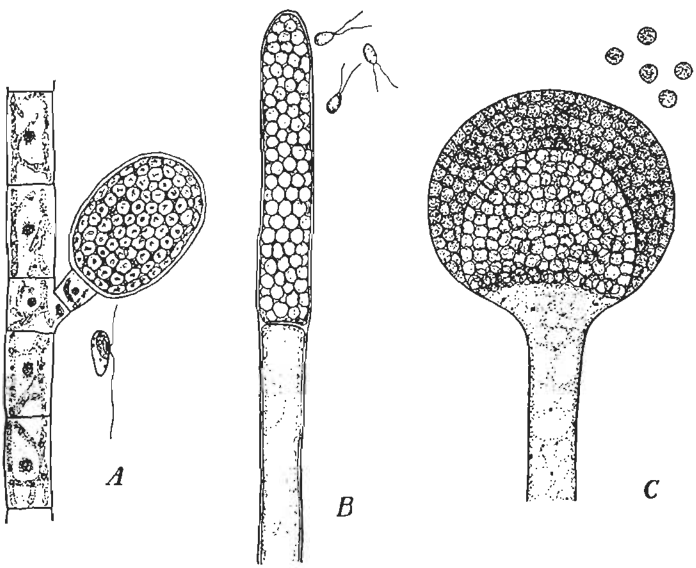


FIG. 68.—Spore reproduction in *Ectocarpus*, *Saprolegnia*, and *Rhizopus*; *A*, sporangium of *Ectocarpus*, a marine alga, arising as a branch of the vegetative filament; also a single swimming spore; *B*, sporangium of *Saprolegnia*, a water mold, and several escaped swimming spores; *C*, spore formation in *Rhizopus*, the common bread mold; the sporangium contains a great number of aerial spores.

that swimming spores are produced. In most of the fungi, and in all of the higher plants, except as noted below, the spores are shed into the air, and no swimming spores are formed (Figs. 68*C*, 73, and 74). Aerial spores have a cell wall, which prevents their drying up, and, of course, lack cilia. In a few pteridophytes and in all of the spermatophytes, there are two kinds of spores which differ in size: *microspores* (small) and *megaspores* (large). Only the microspores are shed into the air, the megaspores being retained within their sporangia.

Vegetative Multiplication.—In many plants reproduction takes place by the separation of whole groups of cells, a method which occurs in all four of the great plant groups, but is most familiar in seed plants. Vegetative multiplication merely involves the isolation of some vegetative portion of the plant. For example, in the strawberry

FIG. 69.—Strawberry, showing vegetative multiplication by means of runners, × ½. The dying away of the runners isolates the new plants which have arisen at the nodes. Note that only every other bud develops, the others remaining dormant.

horizontal stem branches called "runners" are produced which send out roots and buds at the nodes, the older parts later dying away (Fig. 69). In this way many new plants arise. The formation of tubers in the common potato, of rhizomes in the iris and lily-of-the-valley, and of bulbs in the tulip and onion are all means by which vegetative multiplication is accomplished. The planting of "slips" or "cuttings" is a method of plant propagation extensively used by gardeners (Fig. 70). A slight modification of this method is seen in the practice of *budding* and *grafting*, whereby a detached bud or twig of one plant is inserted into another in such a way that the former continues to grow and produce the same kind of leaves, flowers, and seeds that it would had it not been removed.

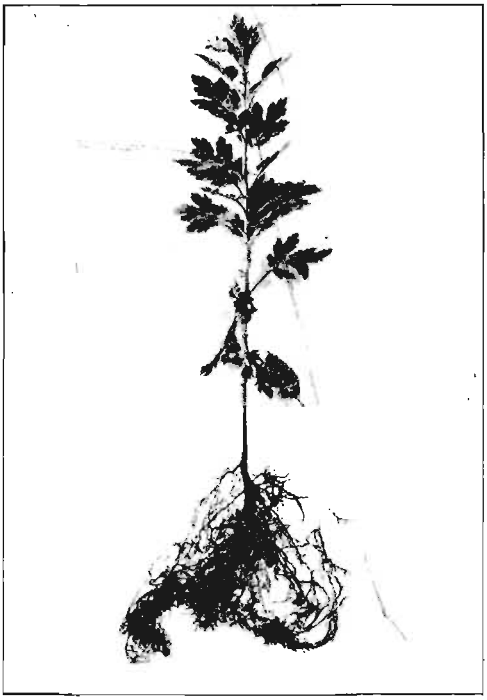


FIG. 70.—Cutting of chrysanthemum, illustrating the formation of roots at the lower end of an isolated branch.

Sexual Reproduction in Lower Plants.—Sexual reproduction among the lower algae is a relatively simple process. Detached cells called *gametes* are formed which resemble swimming spores in appearance, but are usually smaller (Fig. 71*A*). Although gametes arise in the same way that spores do, they are incapable of directly forming a new plant. Instead of germinating, they come together in pairs and fuse. The essential feature of sexual reproduction in all organisms is the fusion of two gametes.

The pairing cells become one, and then their nuclei unite. The cell which arises from the union of two gametes is

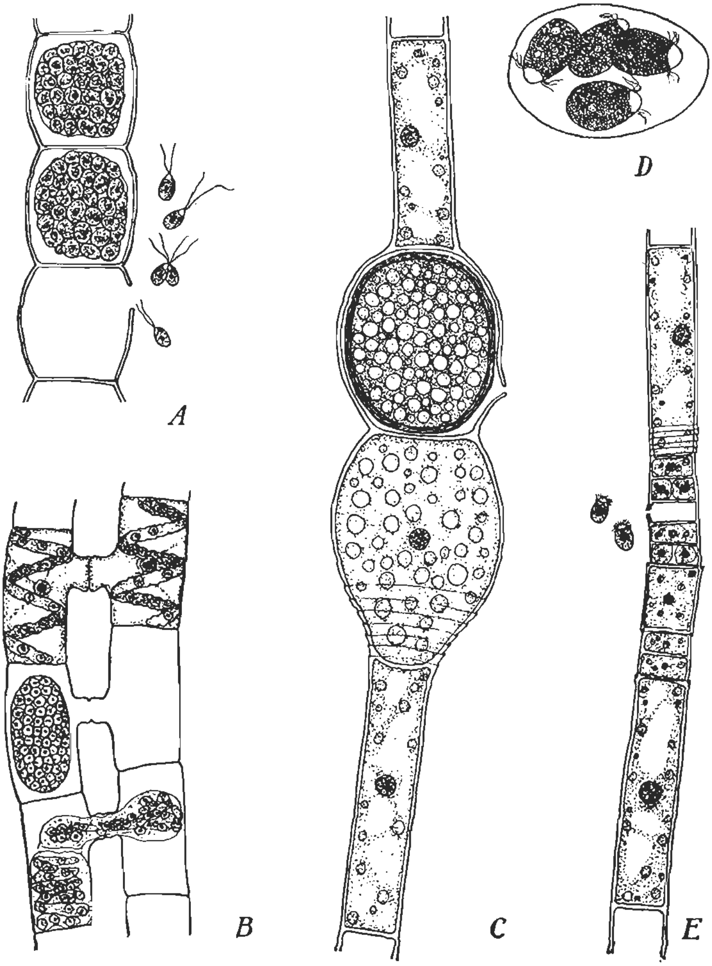


FIG. 71.—Sexual reproduction in some common fresh-water algae; *A*, *Ulothrix*, showing vegetative cells giving rise to numerous free-swimming gametes which pair and fuse; *B*, *Spirogyra*, illustrating an unusual form of sexual reproduction where the cells of adjacent filaments put out tubes through which the contents of the one fuse with those of the other; *C*, a developing egg (below) and a heavy-walled zygote (above) of *Oedogonium*; *D*, group of four swimming spores produced by the zygote of *Oedogonium*; *E*, formation of sperms in *Oedogonium*. (*D*, *redrawn after Juranyi*.)

called a *zygote*. In the algae it usually secretes a heavy wall around itself and goes into a dormant condition.

It is only in the lower algae that both of the fusing gametes are alike in size and behavior. In most plants gametes are of two different kinds: one remains small and active, while the other becomes large and passive, being retained within the cell from which it arises (Figs. 71*C* and 71*E*). The smaller gamete is called the *sperm* or *male gamete;* the larger one is called the *egg* or *female gamete.* The large size of the egg is due to the accumulation of reserve food in the cytoplasm, its motility being sacrificed for an increased nutritive capacity. The sperm swims to the egg and fuses with it, this act being called *fertilization.*

In the algae and fungi the zygote is commonly a resting cell. Later it gives rise either to a new plant body directly or to spores which germinate (Fig. 71*D*). In the bryophytes and the two higher plant groups, the zygote does not rest, but divides soon after fertilization has occurred, producing a new plant body directly. Although, as stated above, no plants above the thallophyte level have swimming spores, motile sperms are retained throughout all of the bryophytes and pteridophytes. In fact, even some of the lower gymnosperms have ciliated male gametes—a most remarkable fact.

The gametes of the lower algae, whether they are differentiated into sperms and eggs or not, arise directly from ordinary vegetative cells just as the spores do (Fig. 71). In the higher algae, however, and in bryophytes and pteridophytes, gametes are produced in specialized *gametangia* or *sex organs* (Figs. 73 and 76). In the spermatophytes, sex organs are not present, but reproduction is complicated by the development of other special features, and so a consideration of reproduction in the seed plants will be deferred.

Alternation of Generations.—In a few thallophytes and in all of the higher plants, there exists a phenomenon known as *alternation of generations.* It is seen to best advantage in the bryophytes and pteridophytes. Briefly stated, alternation of generations means that there are two kinds of individuals involved in every life cycle—one producing spores, the other gametes (Fig. 72). The zygote gives rise to a plant body which produces spores, and is thus known as the *sporophyte.* When a spore germinates, however, it produces a different kind of plant body which bears gametes, and so is called a *gametophyte.*

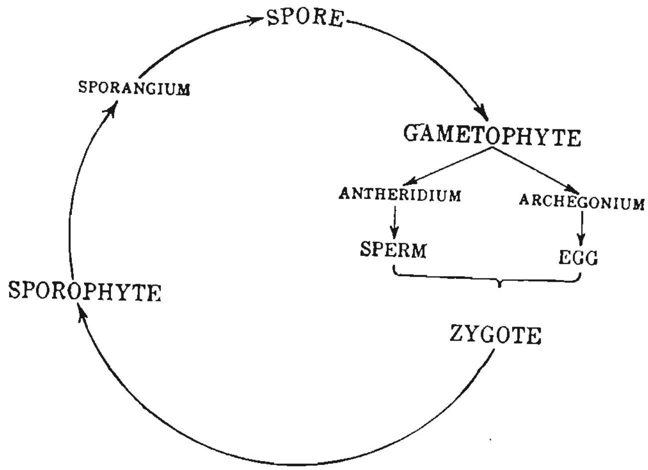


FIG. 72.—Diagram illustrating the general scheme of alternation of generations in a moss or a fern.

Life History of Moss.—An ordinary moss plant consists of a small leafy stem bearing filaments at its lower end, called *rhizoids,* through which water and mineral salts are obtained from the soil (Fig. 73). True roots, such as characterize the seed plants, are lacking. The stem does not have a vascular system, while the leaves consist mostly of just a single plate of cells. At the upper end of the stem, groups of complex sex organs are borne—one kind (*antheridia*) producing a great many sperms, the other (*archegonia*), each containing a single egg. Thus this plant body is a gametophyte. The sperms are discharged when the plants are wet, and swim by means of a pair of cilia. They enter the female sex organs, and fertilization is accomplished when a single sperm penetrates the egg and their nuclei fuse.

The zygote does not escape from the female sex organ and pass into a resting stage, but germinates immediately.

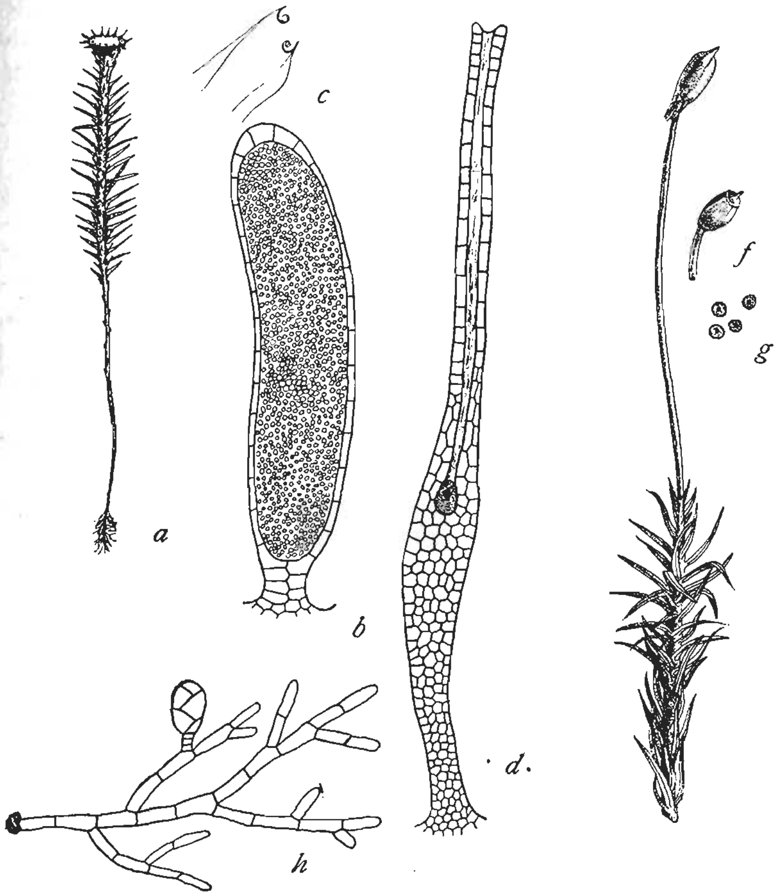


FIG. 73.—Life history of a moss (mainly *Polytrichum*); *a*, male plant bearing a cluster of antheridia at its upper end, × 1; *b*, longitudinal section of a single male organ (antheridium) containing a great number of sperms, × 150; *c*, enlarged view of two moss sperms; *d*, longitudinal section of a single female sex organ (archegonium), × 150. Note the single egg and the long narrow passage down which the sperm must swim to effect fertilization; *e*, female plant with a mature sporophyte arising from its tip, × 1; *f*, a sporangium from which the outer covering has been removed; *g*, enlarged view of several spores; *h*, the filamentous protonema giving rise to a bud from which an erect leafy shoot will be developed, × 75.

By repeated cell division, the zygote gives rise to a sporophyte which arises from the top of the gametophyte. It consists of a long stalk bearing a terminal sporangium

(Figs. 29 and 73*e*) in which a great many thick-walled spores are produced. The spores are dispersed into the air, and, upon germination, give rise to a delicate, green, branching filament (the *protonema*) from which the erect leafy shoots arise (Fig. 73*h*). Thus, in the life history of a moss there are two distinct plant bodies involved which alternate with one another, one representing a sexual generation, the other an asexual generation. An important feature of the mosses is the fact that the gametophyte is an independent plant, but the sporophyte is not because it derives its nourishment from the gametophyte.

Life History of Fern.—Alternation of generations in the ferns follows the same general scheme as in the mosses, but the structures involved are very different. An ordinary fern plant consists of a perennial underground stem (a rhizome) which sends out roots into the soil and leaves into the air (Fig. 74). As in the seed plants, a well-developed conducting system is present. A fern leaf is peculiar in that the blade is divided into a number of small leaflets; otherwise it has most of the structural features of a typical leaf already studied.

On the back of the leaflets, small groups of sporangia are borne (Figs. 32, 74). Each sporangium contains a number of thick-walled spores which are discharged into the air. Thus the familiar fern plant is a sporophyte, although obviously very different from the moss sporophyte. When a spore falls upon moist earth, it gives rise to a flat, green, heart-shaped body about 6 millimeters (¼ inch) in diameter (Fig. 75). From the lower surface numerous rhizoids are put out into the soil. Sex organs are also borne on the lower side, the male organs (antheridia) being scattered among the rhizoids, the female organs (archegonia) occurring near the notch. Thus, this little green body is a gametophyte. The sperms, which are large, coiled, multiciliate cells, are discharged from the male organs and swim toward the eggs (Fig. 76). Fertilization occurs by the fusion of a single sperm with an egg. As in the mosses, the zygote does not escape, but germinates immediately,

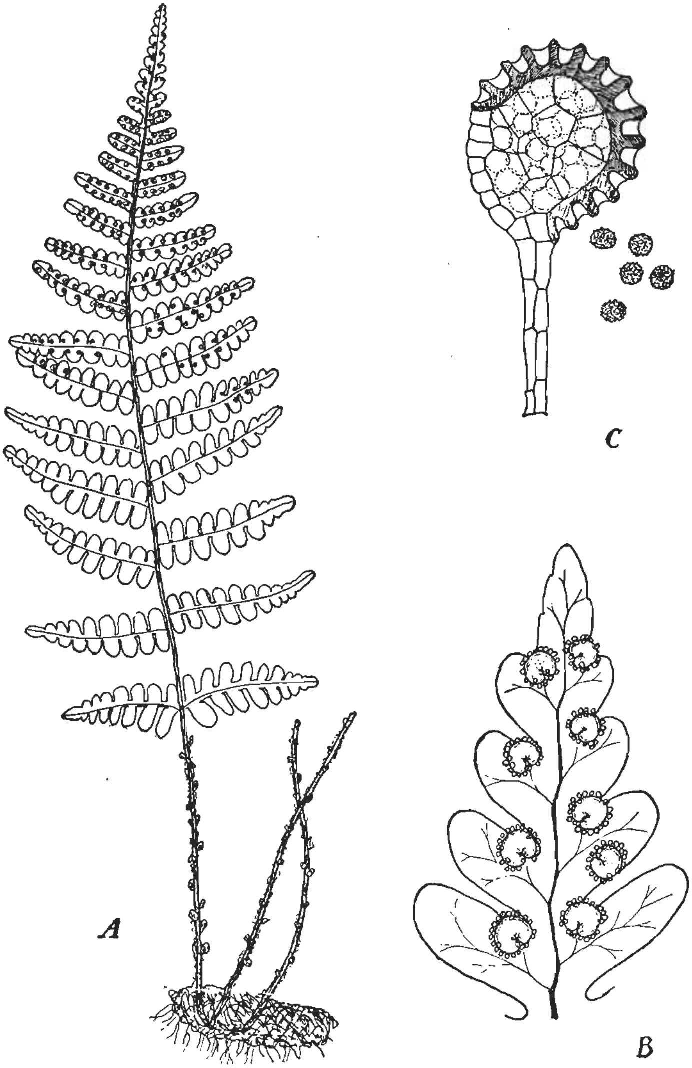


FIG. 74.—Spore-bearing structures in a fern (*Aspidium marginale*); *A*, the sporophyte, consisting of an underground stem bearing large divided leaves, × ½; *B*, portion of the under side of a leaflet enlarged to show the groups of sporangia, each group in this case covered by a membrane; *C*, a single sporangium and several spores, × 150.

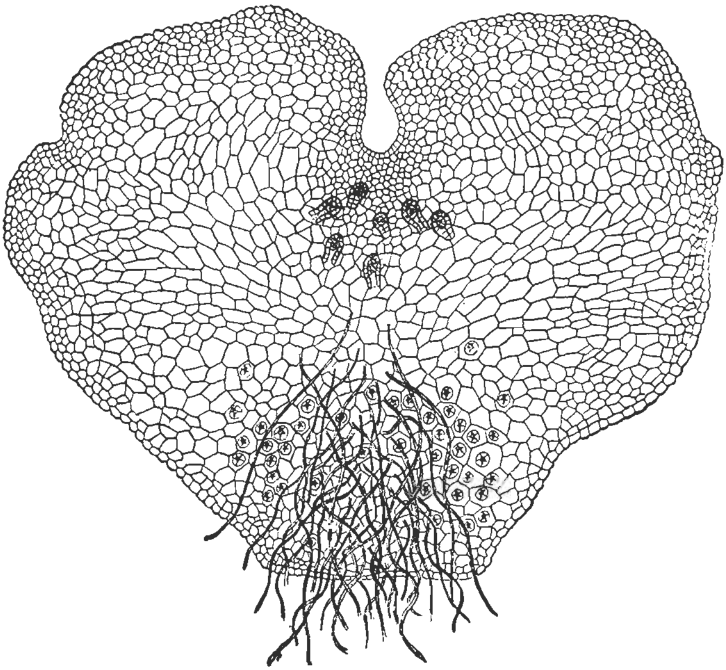


FIG. 75.—The gametophyte of a fern. View of the lower surface, showing rhizoids with male sex organs scattered among them, and female organs near the notch. *(From Sinnott, "Botany; Principles and Problems," McGraw-Hill Book Company, Inc., by permission.)*

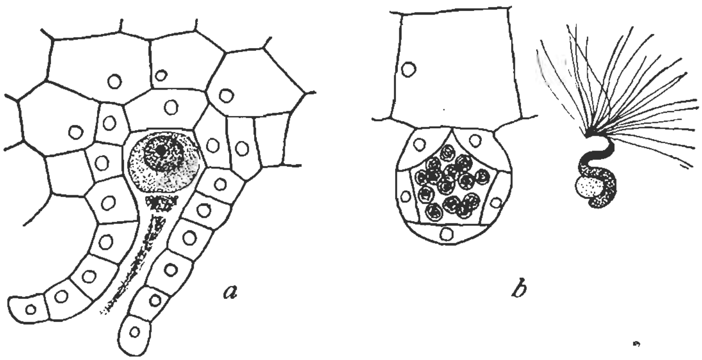


FIG. 76.—Sex organs of a fern, × 350; *a*, longitudinal section of a female organ (archegonium) containing a single large egg; *b*, longitudinal section of a male organ (antheridium) containing a number of sperms; also a single escaped sperm greatly enlarged.

forming a young sporophyte. The latter derives its nourishment from the gametophyte for a while, but soon develops a rhizome, roots, and a leaf, thus becoming independent (Fig. 77).

It is apparent that the conspicuous difference between a moss and a fern is the presence of an independent sporophyte in the latter. In all of the bryophytes the gametophyte bears leaves and does practically all of the work of photosynthesis, the sporophyte being dependent upon it for nourishment. In the pteridophytes, on the other hand, by developing highly differentiated organs, the sporophyte attains independence and becomes the dominant generation. The fern gametophyte is consequently a greatly reduced structure concerned with the production of gametes and not primarily with the manufacture of food. In the spermatophytes the sporophyte is also the conspicuous generation, the gametophyte being very greatly reduced and obscure.

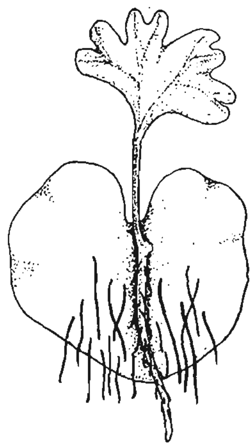


FIG. 77.—Young fern sporophyte, developed from a zygote, still attached to the gametophyte.

Seed and Fruit Formation.—Reproduction in the spermatophytes is complicated by the development of a number of special structures necessary to the formation of seeds, and for this reason is very different from reproduction in the lower groups. It has already been pointed out that there are two groups of spermatophytes—gymnosperms and angiosperms—and that the chief difference between them is whether the seeds are exposed on a scale or enclosed in a fruit (Fig. 35). The following account will deal with reproduction in angiosperms.

The Flower.—Preparatory to the ultimate production of seeds is the appearance of the flower. A typical flower consists of a *calyx*, a *corolla*, *stamens*, and a *pistil* (Fig. 78). The calyx is composed of individual *sepals*—green leaf-like parts which form an outer covering for the young flower bud. The corolla, occurring just inside the calyx, is made up of *petals*, which are usually either white or conspicuously

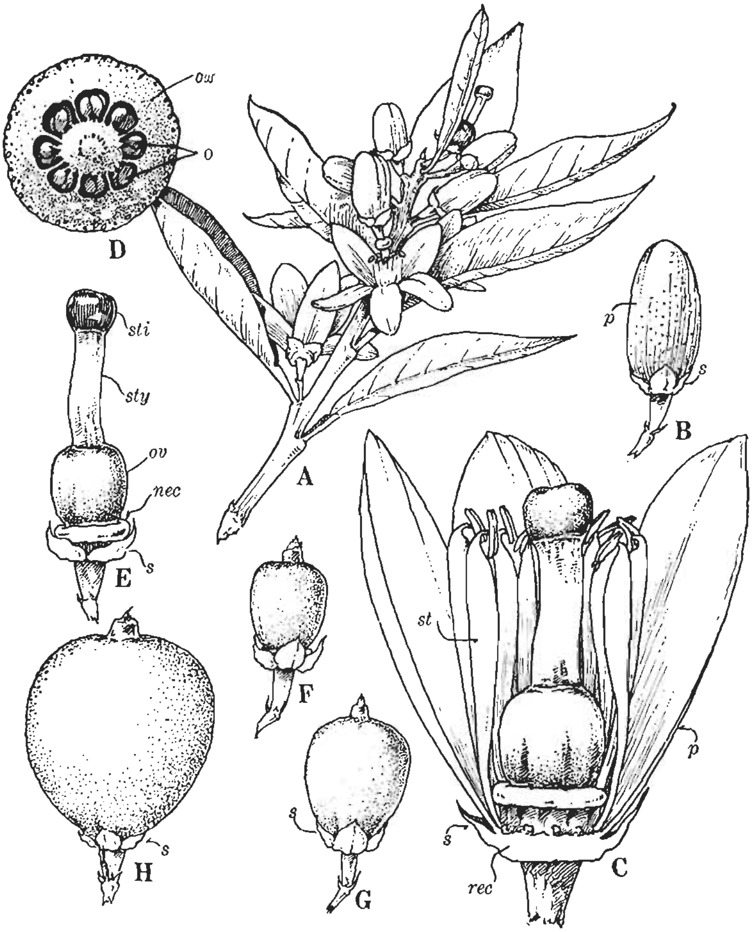


Fig. 78.—Flower and fruit of orange (*Citrus sinensis*); *A*, flowering shoot, × ½; *B*, unopened flower bud, × 1; *C*, single flower with two of the petals and several stamens cut away, × 2; *D*, cross-section of the ovary, × 3; *E*, pistil just after fertilization has taken place, the petals and stamens having fallen off, × 1½; *F*, *G*, *H*, early stages in development of the fruit, × 1½; *p*, petal; *s*, sepal; *st*, stamen; *rec*, receptacle; *ow*, ovary wall; *o*, ovules; *sti*, stigma; *sty*, style; *ov*, ovary; *nec*, nectary.

colored. The petals, as well as the sepals, may be entirely separate and distinct from one another, or united to form a tube, as in the morning glory and petunia. The stamens, situated inside the corolla, produce a yellow powder called *pollen*, which consists of minute grains. Each pollen grain is a single cell—really an aerial microspore. The pistil,[1] in the center of the flower, consists of an enlarged basal portion called the *ovary*. Arising from the top of the ovary is a slender stalk-like *style*. A portion of the style, usually its tip, ordinarily is modified in some way for the reception of pollen. This is termed the *stigma*. The ovary is a hollow vessel containing small bodies known as *ovules*, each one of which is an incipient seed. The number of ovules in an ovary varies among angiosperms from one to many.

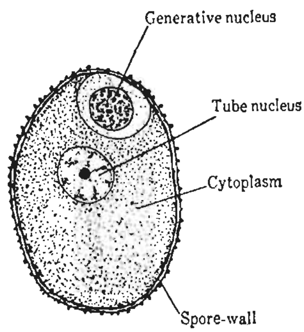


FIG. 79.—Section of a pollen grain of a lily (*Lilium*) in the shedding condition, × 500. The generative nucleus is surrounded by a small amount of cytoplasm and a plasma membrane, and is thus organized as a naked cell. The tube nucleus lies free in the general cytoplasm of the spore.

In order that ovules may become seeds, pollen must first be transferred from a stamen to the pistil. This act of *pollination*, as it is called, is accomplished in various ways (see pp. 229–232). The stamens and pistil are called the *essential organs* of the flower because they are primarily involved in reproduction. The sepals and petals, on the other hand, are known as *accessory organs*, because seeds may be produced whether they are present or not. At first, each pollen grain contains a single nucleus, but this soon gives rise to two: a *tube nucleus* and a *generative nucleus* (Fig. 79). After the pollen grains have come in contact with the stigma, they germinate. From each there is put out a long tubular extension called the *pollen tube*. This grows down the inside of the style and enters the cavity of the ovary, finally penetrating one of the ovules. Only one pollen tube enters each one of the ovules present in the

[1] In some flowers, the pistil is simple, but in most cases it is compound, being made up of two or more simple pistils which are more or less united. In other flowers there may be several simple pistils entirely separate from one another.

ovary. While the tube is developing, the generative nucleus gives rise to two *male nuclei;* these may or may not be organized as naked cells. The tube nucleus soon degenerates.

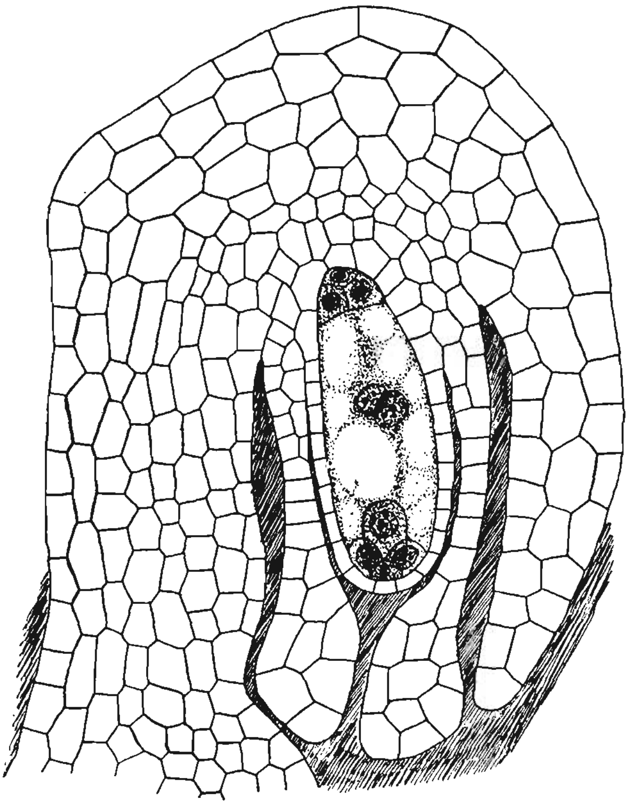


FIG. 80.—Longitudinal section of a lily ovule containing a mature embryo sac ready for fertilization, × 250. The egg is the middle one of the three lower cells. In the center are the two nuclei with which one of the male nuclei will fuse to form the primary endosperm nucleus.

Within the ovule is a structure called the *embryo sac,* which was originally developed from a megaspore (Figs. 80 and 81).[1] The embryo sac is a relatively large cell which

[1] In the angiosperms there are two kinds of gametophytes, both greatly reduced and entirely dependent upon the sporophyte for nourishment. The contents of the pollen tube, formed by a *microspore,* represent the *male gametophyte,* while the embryo sac, developed from a megaspore, is really a *female gametophyte.*

is organized in a peculiar way. At each end there are three small naked uninucleate cells, one of which is the egg, while in the middle are two nuclei in contact with each other. These eight nuclei have arisen by three successive divisions from the nucleus of the megaspore. The pollen tube discharges the two male nuclei (or male cells, as the case may be) into the embryo sac; these are really sperms, but do not have cilia. One of them fuses with the egg to form the zygote, while the other unites with the two nuclei in the center of the embryo sac to form the *primary endosperm nucleus.* The other cells in the embryo sac are functionless and soon disappear.

The Seed.—The zygote immediately germinates without leaving the ovule, giving rise to a group of cells which finally forms a diminutive plant called the *embryo* (Fig. 81). At the same time, the primary endosperm nucleus gives rise to a tissue called *endosperm.* The embryo consists of three main parts: a very short stem, the *hypocotyl;* a minute bud arising from its upper end, the *plumule;* and one or two lateral leaf-like parts called *cotyledons* (Fig. 82). An interesting correlation is seen in the fact that angiosperms whose seeds have two cotyledons have exogenous stems, while those with one cotyledon have endogenous stems (see pp. 65–69).

The growth of the embryo proceeds only to a certain point, and then is checked. At the same time respiration and all other vital processes become almost entirely suspended, the embryo going into a dormant condition. This makes it possible for the seed to become separated from the parent plant, to be disseminated, and to endure conditions unfavorable for vegetative activity. Dormancy is brought about chiefly by the withdrawal of water, most ripe seeds containing only about 10 to 12 per cent of moisture. Seeds and fruits are commonly adapted to be distributed by some mechanical means, as by animals or by currents of air or water (see pp. 226–229).

Thus a seed is really a ripened ovule, consisting typically of three parts: an outer covering called the *testa;* a diminutive undeveloped plant in a dormant condition, the *embryo;* and a special region of food storage, the *endosperm.* All seeds have a testa and an embryo, but many lack endosperm, the reserve food then being stored in the cotyledons. In such

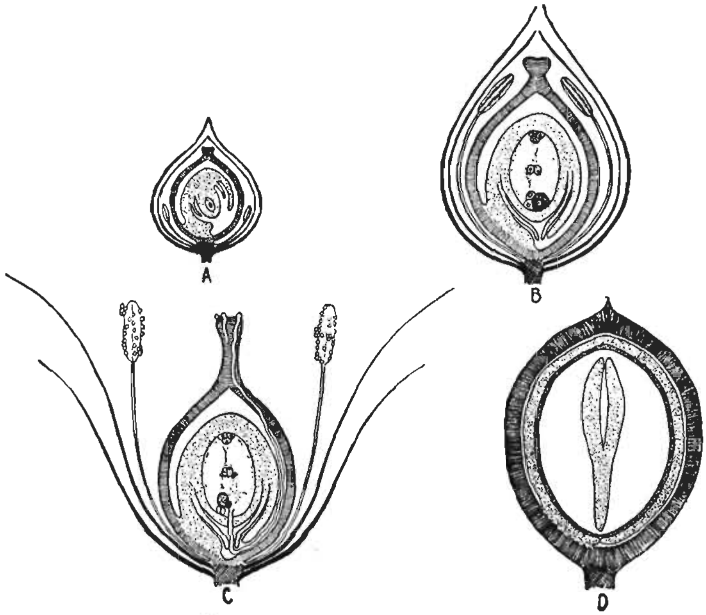


FIG. 81.—Diagrams illustrating the formation of the fruit and seed. The calyx and corolla are shown in solid black; the ovule, testa, and embryo dotted; the ovary wall and style lined. The ovary contains a single ovule; *A*, young bud, the ovule containing a single megaspore; *B*, bud ready to open. The megaspore has produced an embryo sac with its egg cell below the two naked nuclei in the center; *C*, fully opened flower. The anthers have burst and pollination has taken place. Two pollen grains have germinated, and the pollen tube from one of them has penetrated the ovule and discharged its two male nuclei into the embryo sac. One male nucleus is shown uniting with the egg, the other with the two naked nuclei; *D*, ripe fruit. The calyx, corolla, and stamens have dropped off; the ovary wall has formed the wall of the fruit; the outer portion of the ovule has formed the testa of the seed; the zygote has given rise to the embryo, the endosperm nucleus to the abundant endosperm tissue (shown in white) which surrounds the embryo. *(From Sinnott, "Botany; Principles and Problems," McGraw-Hill Book Company, Inc., by permission.)*

seeds as the pea, navy bean, sunflower, and squash, the endosperm is entirely absorbed by the embryo during its development, while in the corn, wheat, morning glory, buckwheat, and castor bean, it becomes a permanent food-storage region in the mature seed (Fig. 82).

After a longer or shorter period, the embryo resumes its growth and other vital activities, that is, the seed sprouts.

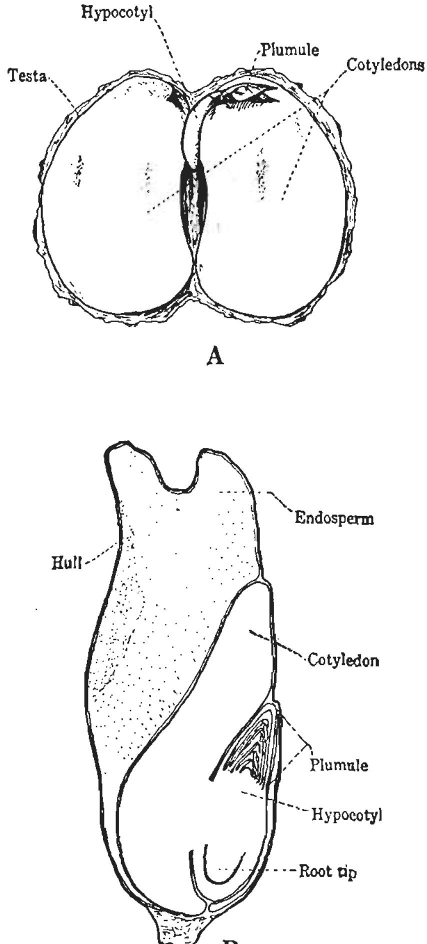


FIG. 82.—Seed structure; *A*, a lima bean laid open to show the three parts of the embryo; × 1. There is no endosperm, the food being stored in the large cotyledons; *B*, longitudinal section of a grain of corn, showing a seed with endosperm and a monocotyledonous embryo, × 5. The outer covering consists of the ovary wall fused with the testa, and so the grain is really a one-seeded fruit.

This happens, however, only if three external conditions are satisfied: there must be an adequate supply of oxygen, abundant moisture, and a favorable temperature. These

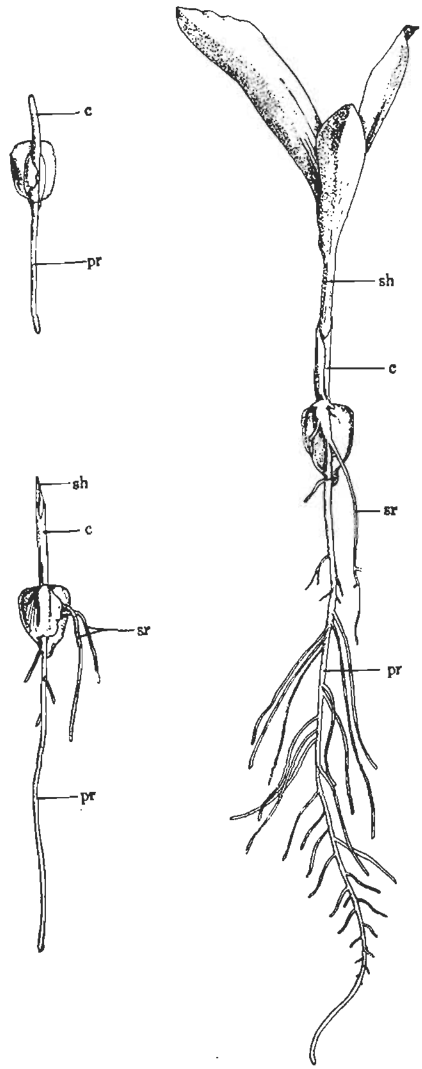


FIG. 83.—Successive stages in the development of a corn seedling, × ½; *c*, sheath (*coleoptile*); *pr*, primary root; *sr*, secondary roots; *sh*, shoot developed from plumule. The hypocotyl does not elongate, while the cotyledon remains within the seed, acting as an absorbing organ through which food passes from the endosperm to the developing root and shoot systems.

conditions are necessary for the renewal of respiration, digestion, food transfer, assimilation, and growth. When

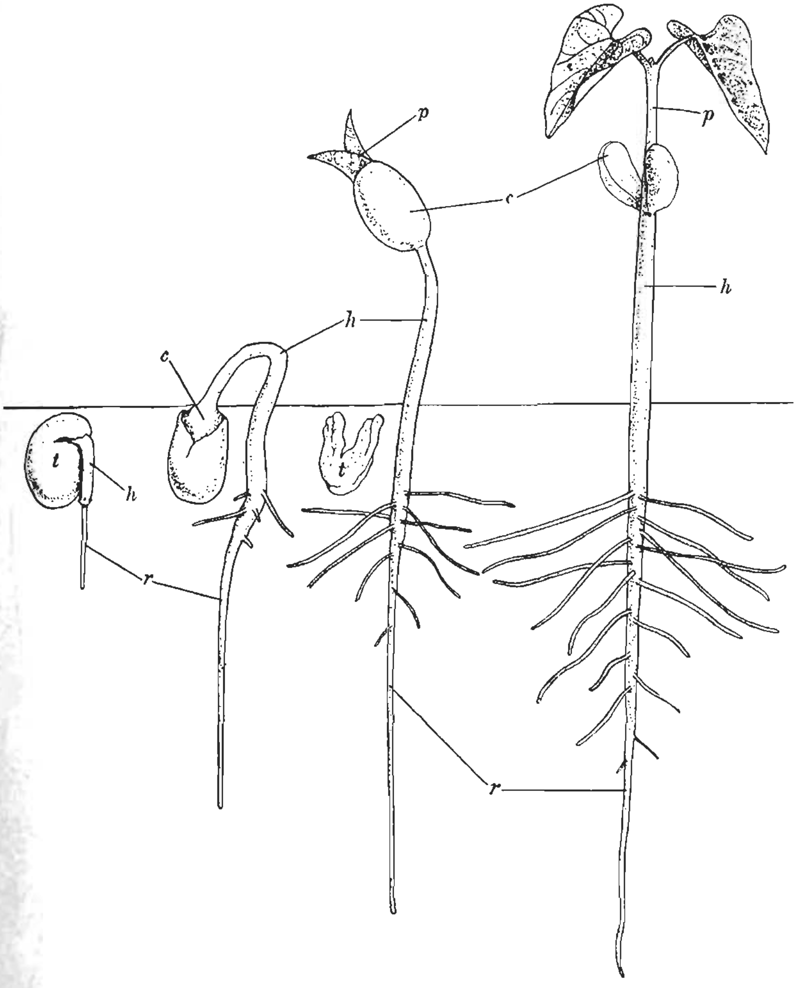


FIG. 84.—Successive stages in the development of the seedling of navy bean, × 1; *t*, testa; *h*, hypocotyl; *r*, primary root; *c*, cotyledons; *p*, plumule developing into shoot. By the elongation of the hypocotyl the cotyledons are pulled out of the soil, the development of the plumule being delayed until this is accomplished.

the seed sprouts, the hypocotyl forms a root at its lower end, the plumule gives rise to an erect leafy stem from which the entire shoot system of the plant develops, while the cotyledon (or cotyledons) may either remain within the testa under the ground (Fig. 83) or be raised into the air by the elongation of the hypocotyl to form the first leaves of the young plant (Fig. 84). Until the plant becomes independent of the food stored in the seed, it is called a *seedling.*

The Fruit.—After pollination has taken place and the ovules are ripening into seeds, changes also occur in the ovary itself which result in the formation of a fruit (Figs. 78 and 81). Thus a fruit consists essentially of a ripened ovary, but in some cases other floral parts, as well, become involved in its formation. At maturity fruits may be fleshy, as in the plum, or dry, as in the peanut. They may split open, as a bean or pea pod, or remain closed, like an acorn. Sometimes a group of fruits ripen together, becoming more or less consolidated, and thus forming an *aggregate fruit,* as in the blackberry and raspberry.

CHAPTER IX

STRUCTURE OF REPRESENTATIVE METAZOANS

Only two animals have been dealt with thus far: *Amoeba* and *Paramoecium*. Both of these forms are protozoans. All animals which are not protozoans, that is, all multicellular animals, are called *metazoans*. We shall now study in some detail three representative metazoans: a very simple one, the hydra; one of moderate complexity, the earthworm; and a complex metazoan, the frog. Each of these three animals represents a different degree of progress—a different stage in structural organization.

THE HYDRA

The hydra is one of the simplest of multicellular animals. There are two common species: the brown hydra (*Hydra fusca*) and the green hydra (*H. viridis*). Both are found in fresh-water ponds and streams where they live attached to aquatic vegetation or to other objects in the water.

Structure.—The body of a hydra consists of a cylindrical hollow stalk which bears five to ten slender finger-like *tentacles* at its unattached end (Fig. 85). The length of the brown hydra varies from 2 to nearly 20 millimeters (about $\frac{1}{8}$ to $\frac{3}{4}$ inch), this difference being due to its power of contracting and expanding itself. The green hydra is somewhat smaller. Because the parts extend outward in all directions from a common center, the body of the hydra is said to exhibit *radial symmetry*. Although attached, the animal can move from place to place by slowly gliding along on the base of the stalk.

The tentacles surround a conical elevation (the *hypostome*) in the center of which is the *mouth*. This opens directly into a single large internal cavity, called the *coelenteron*, which not only fills the stalk but extends out into the tentacles as well (Fig. 86). Surrounding the central cavity is a body wall consisting of only two layers of cells, the outer layer being called the *ectoderm* and the inner one the *endoderm*.[1] Both layers are composed largely of epithelial cells, but these have the ability to contract and expand, and so also function as simple muscle cells. There are also present in both ectoderm and endoderm a few simple *nerve cells*. The *ectoderm* contains peculiar structures called *stinging cells*, each of which discharges a long poisonous thread which can penetrate other animals. They are used both for defending the hydra and for capturing prey.

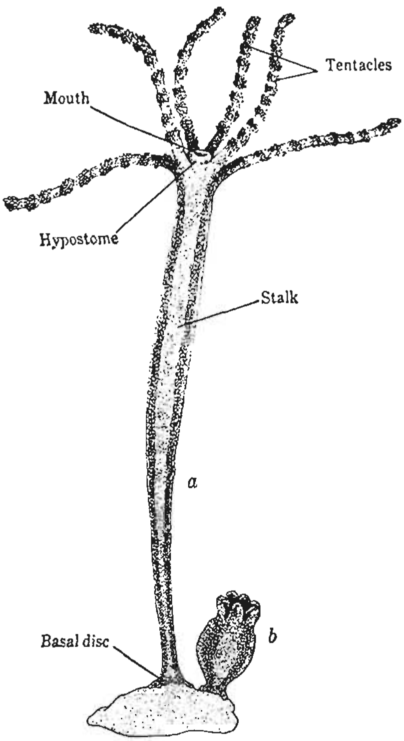


FIG. 85.—External view of a hydra in expanded (*a*) and contracted (*b*) conditions.

The hydra feeds on smaller aquatic animals which come in contact with the tentacles and are benumbed by the stinging cells. The tentacles then convey the food to the mouth. Digestion takes place within the coelenteric cavity into which digestive fluids are secreted by the cells which line it. The endodermal cells, however, by thrusting out pseudopodia, can engulf small solid particles of food, and so digestion occurs in two ways—both inside the coelenteron and within individual cells, the latter representing the primitive protozoan method. The food digested within the coelenteric cavity is absorbed by the cells of

[1] Between the ectoderm and endoderm, however, is a thin gelatinous noncellular layer, called the *mesogloea*, which, in jellyfishes, becomes very thick.

the body wall. Indigestible matter remains in the cavity, and is finally expelled through the mouth. Each cell of the body, being in contact with water, absorbs oxygen and gives off carbon dioxide, thus carrying on respiration directly.

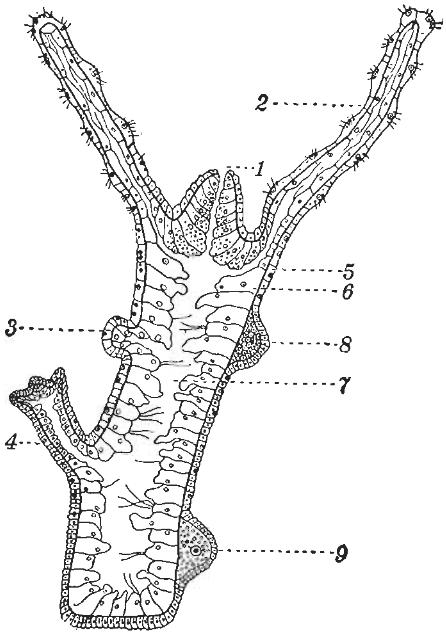


FIG. 86.—Longitudinal section of *Hydra;* 1, mouth; 2, tentacle; 3, bud just appearing; 4, older bud; 5, ectoderm; 6, endoderm; 7, coelenteron; 8, testis; 9, ovary. (*From Linville and Kelly, "A Text-book in General Zoology," Ginn and Company, after Parker. By permission.*)

Reproduction.—The hydra reproduces both asexually and sexually. A bud may grow out from the stalk, develop a set of tentacles, and later become detached to form a new individual (Fig. 86). In the marine *hydroids*, animals related to the hydra, the new individuals produced by budding do not become separated, but remain permanently attached, and, as a result, a colony is formed (Fig. 87). The hydra may also reproduce by fission, either longitudinal or transverse, but this method occurs rarely (see p. 158).

Sexual reproduction in *Hydra* is a simple process. Sperms and eggs are borne on the same or on different individuals, depending on the species. The male organs, called *testes* (or *spermaries*), arise in groups of two or three as conical elevations near the upper end of the stalk. They are ectodermal in origin. Each testis produces a great many sperms which are discharged into the water as free-swimming cells. The *ovary* is a knob-like organ formed

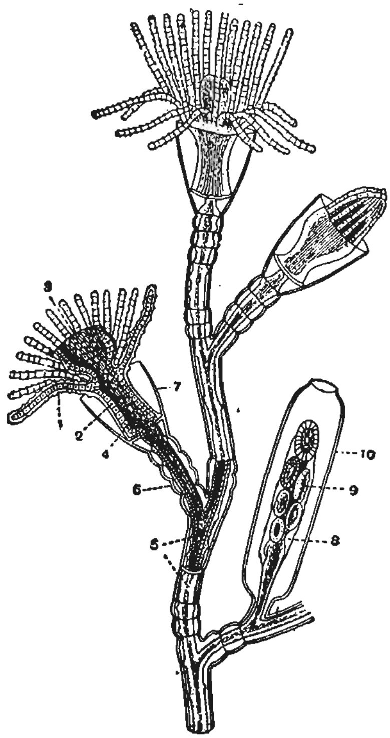


FIG. 87.—Portion of a colony of *Obelia*, a marine hydroid; 1, ectoderm; 2, endoderm; 3, mouth; 4, coelenteron; 5, stalk of colony; 6, 7, 10, enveloping sheath; 8, reproductive branch; 9, bud which becomes detached and gives rise to a free-swimming individual (*medusa*). (*From Shipley and MacBride, "Zoology," Cambridge University Press, after Parker and Haswell; by permission.*)

in the ectoderm near the base of the stalk. It produces a single egg. One of the free-swimming sperms penetrates the ovary and fertilizes the egg. The zygote gives rise to an embryo which undergoes part of its development within the ovary, but soon becomes free and grows to the adult condition.

THE EARTHWORM

The earthworm is a much more highly developed animal than the hydra. There are several common species, the one most often studied being called *Lumbricus terrestris.* It burrows in moist sandy soil, coming to the surface only at night or after a heavy rain.

General Features.—The cylindrical body is pointed at either end and slightly flattened on the lower surface. Unlike the hydra, the earthworm exhibits *bilateral symmetry.* This means that its longitudinal axis divides the animal into two approximately similar halves. Animals which are bilaterally symmetrical have an *anterior* (forward) and a *posterior* (rear) end, as well as a *dorsal* (upper) and a *ventral* (lower) surface.

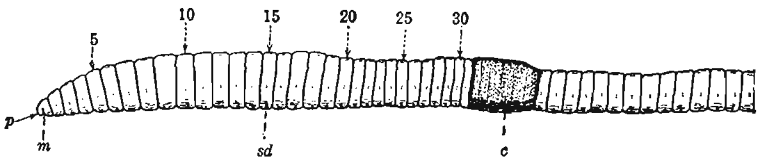


FIG. 88—External view of the anterior half of an earthworm as seen from the side, × 1; *p*, upper lip (*prostomium*); *m*, mouth; *sd*, external openings of sperm ducts; *c*, clitellum. Every fifth metamere is numbered as far back as the clitellum.

The body of the earthworm consists of a series of ring-like segments, called *metameres,* all of which are essentially alike (Fig. 88). Located about one-third of the length of the body from the anterior end is the *clitellum,* a thickened band-like portion of the body wall comprising six or seven metameres. It functions in reproduction. Each metamere (except the first and last) bears four pairs of short bristles called *setae.* They form four double rows—two lateral and two ventral ones. The setae assist in locomotion by sticking into the earth as the animal contracts. The body wall of the earthworm is made up of many layers of cells organized into complex tissues, such as epithelium, muscle, nerve, connective tissue, etc., but the muscular tissues predominate. The body wall surrounds a large cavity called the *coelom,* which is divided by transverse partitions (*septa*), each one corresponding to a metamere.

Digestive System.—Within the coelom and passing through the transverse partitions is a long digestive tube, or *enteron*, which extends the entire length of the body. It has an opening at either end, the anterior opening being

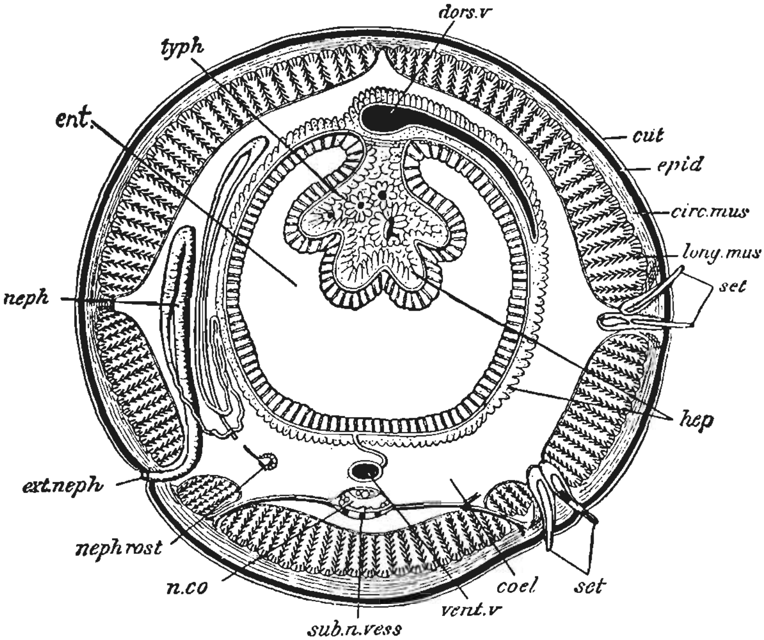


FIG. 89.—Cross-section through the middle portion of the body of an earthworm; *cut*, cuticle; *epid*, epidermis; *circ. mus*, circular muscle fibers; *long. mus*, longitudinal muscles; *set*, setae; *coel*, coelom; *dors. v*, dorsal blood vessel; *vent. v*, ventral blood vessel; *sub. n. vess*, subneural vessel; *n. co*, nerve cord; *typh*, typhlosole; *hep*, gland cells; *ent*, enteron; *neph*, nephridium; *ext. neph*, external opening of nephridium; *nephrost*, internal opening of nephridium. (*From Parker and Haswell, "Textbook of Zoology," 3rd ed., copyright 1921 by The Macmillan Company, after Marshall and Hurst; reprinted by permission.*)

the *mouth* and the posterior one the *anus*. Thus the body of the earthworm has two separate cavities, the coelom and the enteron, being built on the plan of a "tube within a tube" (Fig. 89). This is an important feature carried on into all of the higher animal groups.

The food of the earthworm consists of bits of dead vegetable and animal matter often mixed with soil. After being taken in through the mouth, it passes through the various organs of the digestive system (Fig. 90). These are as follows: (1) the *pharynx,* a muscular sac which draws food through the mouth by suction; (2) the *esophagus,* a narrow tube leading backward from the pharynx; (3) the *crop,* a thin-walled enlargement of the digestive tube in which food is temporarily stored; (4) the *gizzard,* a thick-walled muscular organ in which the food is ground up; (5)

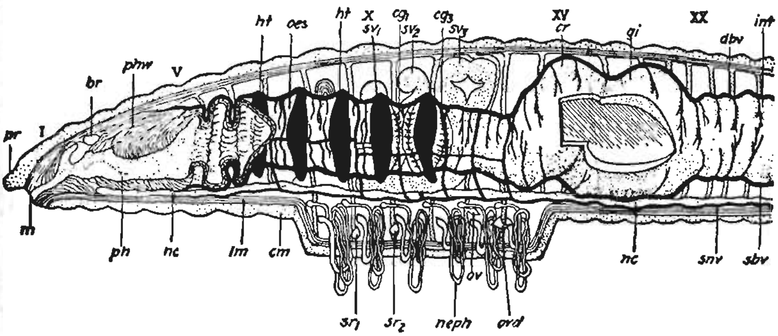


FIG. 90.—Dissection of the anterior end of the earthworm (*Lumbricus terrestris*), side view; I, V, X, XV, XX, number of metamere. Digestive system includes the mouth (*m*), overhung by the prostomium or upper lip (*pr*), pharynx (*ph*) with thick muscular wall (*phw*), esophagus (*oes*), digestive glands (cg^1 to cg^3), crop (*cr*), gizzard (*gi*), and intestine (*int*). Circulatory system includes aortic arches (*ht*), dorsal blood vessel (*dbv*), ventral blood vessel (*sbv*), subneural vessel (*snv*), and certain other vessels not here named. Excretory system includes nephridia (*neph*). Muscular system includes circular muscles (*cm*) and longitudinal muscles (*lm*). Nervous system includes suprapharyngeal ganglion (*br*), ventral nerve cord (*nc*), and other parts not shown. Female reproductive system includes ovary (*ov*), oviduct (*ovd*), and seminal receptacles ($sr,^1$ sr^2). Male reproductive system includes seminal vesicles (sv^1 to sv^3) which enclose testes not shown, and sperm ducts not shown. (*From Shull, LaRue, and Ruthven, "Principles of Animal Biology," McGraw-Hill Book Company, Inc., after Linville and Kelly, reprinted by permission.*)

the *intestine,* a long straight tube constituting most of the digestive system. It is in the intestine that most of the work of digestion takes place; the cells forming the inner lining of the intestinal wall secrete digestive enzymes into the enteric cavity. The dorsal wall of the intestine is infolded so as to form a median ridge (the *typhlosole*), the purpose of which is to increase the digestive and absorptive surface (Fig. 89). Following digestion, the soluble food passes through the intestinal wall by osmosis and is absorbed by the blood.

Circulatory and Respiratory Systems.—In the hydra there is no need for a circulatory system because the digested food can easily reach all the cells of the body. In animals as complex as the earthworm, however, this is not possible without the aid of a special system of blood vessels and blood. The two chief blood vessels lie above and below the digestive tube; they are called, respectively, the *dorsal* and *ventral blood vessel.* These are connected near the anterior end by means of five pairs of *aortic arches* which pass around the esophagus (Fig. 90). Blood flows forward through the dorsal vessel, down through the arches, and backward through the ventral vessel, this movement being caused by pulsations set up both in the dorsal blood vessel and in the aortic arches. These principal vessels give rise to many smaller branches which go to all parts of the body. The blood from the various parts of the body is returned to the dorsal vessel by means of a series of vessels encircling the body posteriorly, the *parietal vessels.*

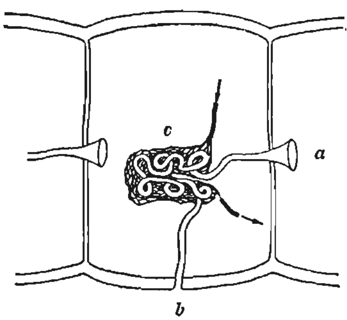


FIG. 91—Diagram to show the main structural features of a nephridium of the earthworm, anterior end toward the right; *a*, internal opening of nephridium; *b*, external opening; *c*, network of capillaries about the coiled glandular portion. (*From Woodruff, "Foundations of Biology," copyright 1922 by The Macmillan Company; reprinted by permission.*)

The blood carried to the moist outer skin takes up oxygen from the air and gives off carbon dioxide. Thus the blood not only carries digested food, but also oxygen, and so permits respiration to go on. In addition to the blood, there is a colorless fluid in the coelom which also transports food.

Excretory System.—Each metamere (except the first three and last one) has a pair of excretory organs called *nephridia.* These are long coiled tubes which collect waste products from the coelom, and directly from the blood vessels by osmosis, and convey them outside the body. Each nephridium has a ciliated funnel-like opening in one metamere, and passes through the transverse partition into the next metamere behind, where it opens to the ventral side of the body by means of a small pore (Figs. 90 and 91). Excretion in the earthworm is also effected by the activity of small amoeboid cells (*amoebocytes*) which occur in the coelomic fluid. These engulf solid waste products and destroy them.

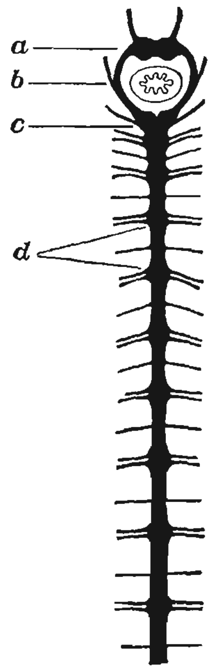


FIG. 92.—Diagram of dorsal view of the anterior portion of the nervous system of the earthworm; *a*, supra-pharyngeal ganglion; *b*, circumpharyngeal connectives; *c*, sub-pharyngeal ganglion; *d*, ganglia of the ventral nerve cord with nerves emerging. (*From Woodruff, Foundations of Biology, copyright 1922 by The Macmillan Company. Reprinted by permission.*)

Nervous System.—The nervous system of the earth-worm consists primarily of a fused double cord of nerve tissue extending the length of the body and located just beneath the ventral blood vessel (Fig. 92). An enlargement of this cord, called a *ganglion*, occurs in every metamere except the first two. From the ganglia small nerves pass to the body wall and to the principal organs. The largest ganglion (the *suprapharyngeal ganglion*) is a bilobed mass of nerve tissue located in the third metamere, just above the pharynx. Below the pharynx in the fourth metamere is a slightly smaller ganglion (the *subpharyngeal ganglion*). These first two ganglia are connected with each other by means of a pair of nerve cords (the *circumpharyngeal connectives*), one of which passes around either side of the pharynx.

Reproductive System.—The earthworm is *hermaphroditic;* that is, both male and female organs occur in the same individual (Fig. 90). The former consist of two pairs of testes located in the tenth and eleventh metameres. The sperms are carried to the surface of the body by means of a pair of *sperm ducts*. The female organs comprise a pair of ovaries in the thirteenth metamere. A pair of tubes called *oviducts* carries the eggs to the outer surface of the body. There are also some accessory reproductive organs which need not be considered. Although the earthworm is hermaphroditic, it is not self-fertilizing. Two individuals come together and make an exchange of sperms, so that the eggs of one earthworm are fertilized by the sperms of the other, and *vice versa.* The embryos develop in the earth within a gelatinous capsule, the *cocoon,* formed by the clitellum.

THE FROG

The frog belongs to the highest group of metazoans, the vertebrates, animals which are characterized by the possession of a *vertebral column,* or backbone. Like the earthworm, it is bilaterally symmetrical and metameric, but there are no external evidences of metamerism in the adult stage of development. It also has both a coelom and an enteron.

External Features.—The body of a typical vertebrate is divided into head, trunk, and tail, but the frog has a tail only in the tadpole stage (Fig. 93). The head bears a pair of large *eyes,* a pair of *nostrils,* and a pair of *eardrums.* The

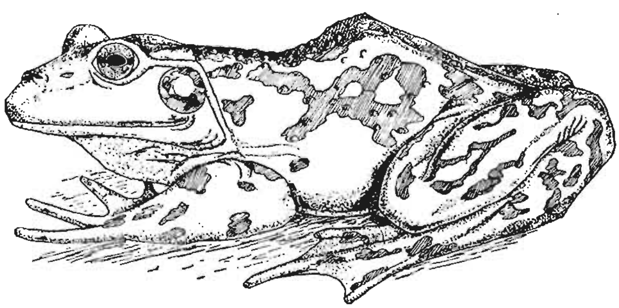


FIG. 93.—The bullfrog (*Rana catesbiana*), × ½. The head, trunk, limbs, mouth, nostrils, eyes, and ear drums are easily recognizable.

nostrils open into the large *mouth cavity.* The body is covered with a moist smooth skin without scales. Two pairs of *limbs* are present, which in the typical vertebrate are *pentadactyl*—having five toes. The hind limbs of the frog have five toes, but the fore limbs have only four, the fifth being present in a very rudimentary condition. The hind feet are webbed. The short fore legs merely support the body, but the hind legs are long and powerful, being used both in jumping and in swimming.

Digestive System.—Teeth are borne only on the roof of the mouth and on the upper jaw. They are not used for chewing, but merely for holding food. The frog catches worms and insects by thrusting out its large fleshy tongue. The extensive mouth cavity leads into a short *esophagus*

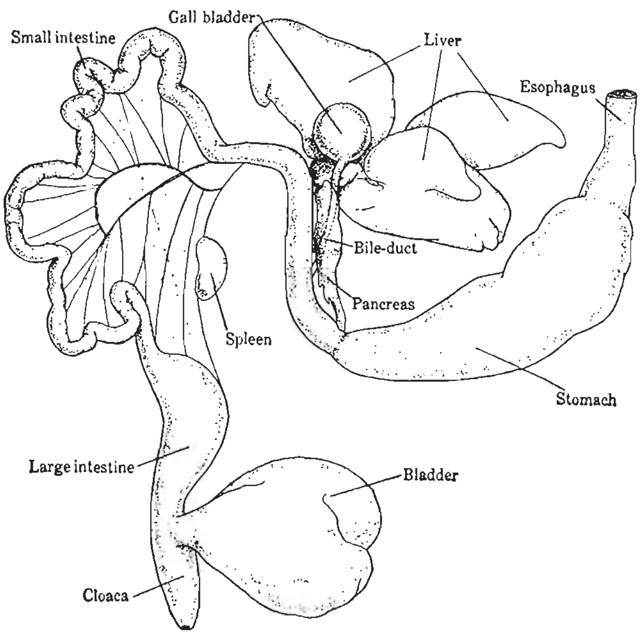


FIG. 94.—Digestive system of the frog. The stomach has been moved to the right, the three lobes of the liver turned back, and the small intestine spread out to the left.

which joins the thick-walled, sac-like *stomach* (Fig. 94). Then follows the long, coiled *small intestine,* and finally the short *large intestine.* The latter opens into a cavity termed the *cloaca,* where waste products accumulate. The cloaca communicates with the *anus.* It receives products from the kidneys and the reproductive organs, as well as from the digestive tract. All of the vertebrates have a cloaca except some fishes and most mammals.

The digestive system of the frog includes not only the digestive organs mentioned above, but also several *digestive glands*. The largest of these is the red three-lobed *liver*. Attached to the liver is the small green *gall bladder* which stores *bile*, a substance which the liver produces. The bile is carried from the gall bladder to the anterior end of the small intestine by a slender tube called the *bile duct*. Another digestive gland is the *pancreas*, a white irregular body lying next to the stomach. It secretes a digestive fluid into the small intestine through the bile duct. A third gland should be mentioned, the *spleen*, a small red globular body located at the point where the small and large intestine join. It is not connected with the digestive system, however; in fact, it has nothing to do with the work of digestion.

Respiratory System.—The frog has a pair of lungs located in the anterior part of the coelom close to the dorsal body wall (Fig. 95). Air is inhaled through the nostrils into the mouth cavity. It then passes through a slit in the esophagus, called the *glottis*, to a pair of *bronchial tubes*, one of which goes to each lung. In the higher vertebrates a *trachea*, or windpipe, extends from the glottis to the bronchial tubes. In the lungs there is an elaborate network of small blood vessels by means of which oxygen is taken up and carbon dioxide given off. A considerable amount of respiratory gas exchange also takes place through the moist skin, which is abundantly supplied with small blood vessels. This feature makes it possible for the frog to remain under water for a considerable length of time without using its lungs.

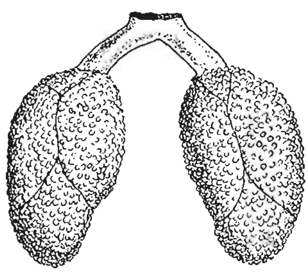


FIG. 95.—Respiratory organs of the frog, comprising the lungs and bronchial tubes.

Circulatory System.—The circulatory system of a vertebrate consists of a *heart*, and of *arteries*, *veins*, and *capillaries*. Blood is carried away from the heart by the arteries, the larger ones giving rise to smaller and smaller branches which finally end in capillaries. These transfer nourishment and oxygen to the living tissues and remove waste products from them. The capillaries are connected with the veins, through which the blood returns to the heart. Vertebrates which breathe with lungs have a more complicated circulatory system than the more primitive gill-breathing forms. For this reason we shall first consider the circulation of blood in a fish.

The heart of a fish consists of two chambers: an *auricle* and a *ventricle* (Fig. 96). Impure blood from all regions of the body is carried to the heart by the veins and poured into the auricle. After passing into the ventricle it is

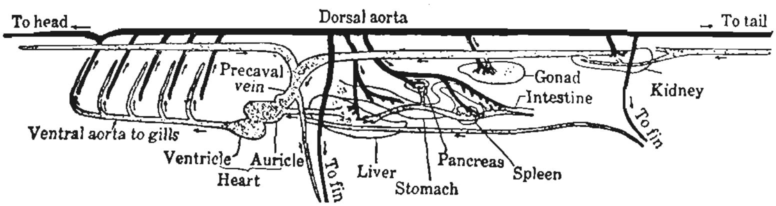


FIG. 96.—Diagram of the circulatory system of the dogfish. The capillaries and finer arteries and veins are omitted. (*From Shull, LaRue, and Ruthven, "Principles of Animal Biology," McGraw-Hill Book Company, Inc., after Parker and Haswell; by permission.*)

forced forward through the *ventral aorta* which gives off branches to the gills. There it absorbs oxygen from the water and gives up carbon dioxide. From the gills the pure blood passes into the *dorsal aorta,* which gives off branches to all of the principal organs of the body. After passing into the capillaries, it then returns to the heart through the veins. The most important feature of circulation in the fishes is that the heart pumps only impure blood, and consequently the blood makes a single circuit in going from the heart to the various organs and back again.

The frog's heart is three chambered, there being a *left auricle,* a *right auricle,* and a *ventricle* (Fig. 97*A*). The venous system collects impure blood from all parts of the body and empties it into the right auricle. Pure blood coming from the lungs enters the left auricle. Both auricles force blood into the ventricle at the same time, which then contracts before much mixing of pure and impure blood is possible. Because the arterial system arises from the right side of the ventricle, the first blood to leave the heart is largely impure. It goes to the lungs and skin to be aerated. The rest of the blood which is largely pure, goes to other parts of the body. The frog

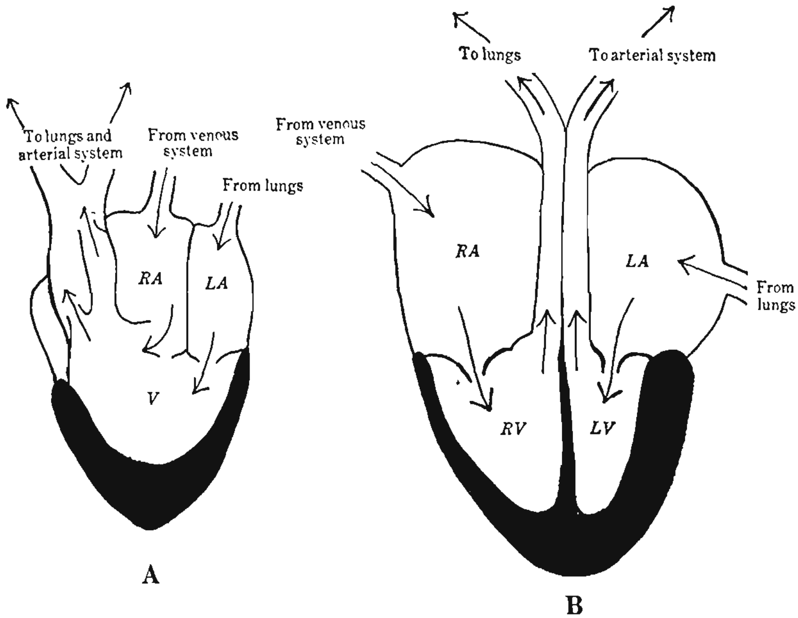


FIG. 97.—Diagram of heart of frog (*A*) and of mammal (*B*); *RA*, right auricle; *LA*, left auricle; *V*, ventricle; *RV*, right ventricle; *LV*, left ventricle. The arrows indicate the direction of the blood. (*B, redrawn after Shull, LaRue, and Ruthven.*)

has a *double circulation;* that is, the blood, after leaving the various organs, goes to the heart, then to the lungs, then back to the heart, and finally to the various organs again. Thus it makes two complete circuits.

In the highest group of vertebrates, the mammals, the heart is four chambered, there being two auricles and two ventricles (Fig. 97*B*). The impure blood, poured into the right auricle from the venous system, goes into the right ventricle and then to the lungs to be aerated. Returning to the heart, the pure blood enters the left auricle, passes into the left ventricle, and thence out through the dorsal aorta into the arterial system and to all parts of the body. It is evident that the mammals have a more perfect scheme of circulation than the frog. Because the right and left halves of the heart are entirely separate from each other, there are two distinct circulations with no mixing of pure and impure blood in the heart. Thus the circulatory system of the frog is intermediate between that of the fish and the mammal.

Excretory System.—A pair of oval, dark-red kidneys lies in the coelom close to the dorsal body wall (Fig. 101). In the frog some of the veins, in going to the heart, pass through the kidneys and give up waste products to them. The kidneys are connected with the cloaca by means of a pair of tubes called *ureters*. The *bladder* is a sac which stores the liquid wastes. In the frog it is a lateral outgrowth from the cloaca, but in the higher vertebrates it is a very different organ.

Skeletal System.—The body of the frog is supported by an internal framework of bones and cartilages (Fig. 98), as in all vertebrates except the lowest fishes (the cyclostomes and the sharks and rays) where it is entirely cartilaginous. The skeleton of the frog consists of an *axial portion* and an *appendicular portion;* the former includes the *skull* and *vertebral column*, the latter the *limbs* and *limb girdles*. The fore limb consists of an *upper arm, fore arm, wrist,* and *hand,* the latter having four *digits*. The hind limb is made up of a *thigh, shank, ankle,* and a *foot* with five digits. There are two limb girdles: the *pectoral* (shoulder) and *pelvic* (hip). The frog does not have true ribs, but nearly all of the higher vertebrates do.

Nervous System.—As compared with the lower animals, all vertebrates have very complex brains. The brain has certain highly specialized parts, the chief ones being a pair of *olfactory lobes*, a pair of *cerebral hemispheres*, a pair of *optic lobes*, a *cerebellum*, and a *medulla oblongata*. While

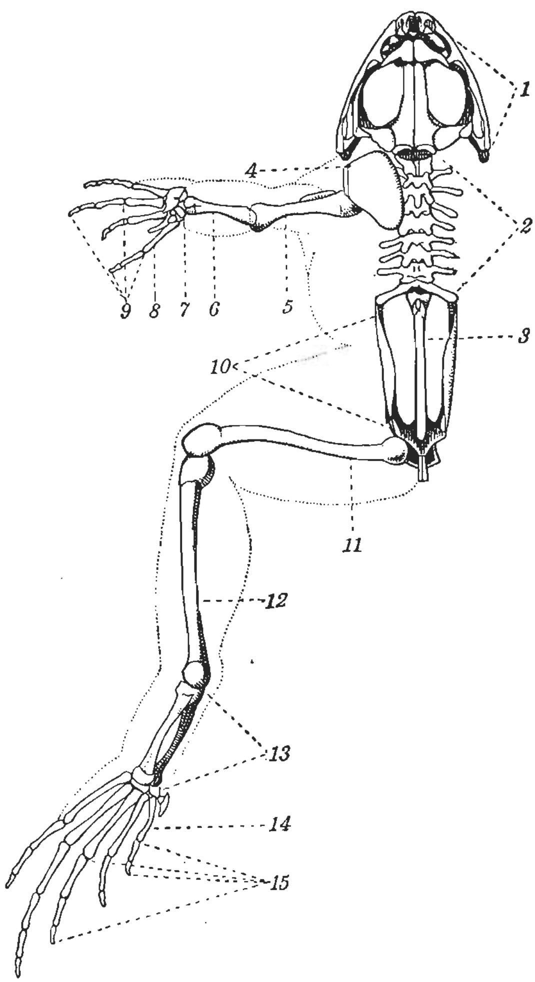


Fig. 98.—Skeleton of frog, dorsal view, with right limbs removed; 1, skull; 2, vertebral column; 3, urostyle; 4, shoulder blade; 5, upper arm; 6, forearm; 7, wrist; 8, 9, hand; 10, pelvic girdle; 11, thigh; 12, shank; 13, ankle; 14, 15, foot. (*From Linville and Kelly, "A Text-book in General Zoology," Ginn and Company, after Duges; by permission.*)

these parts are present in all vertebrates, each group exhibits differences in their degree of development. Thus, in the frog (Fig. 99) the cerebral hemispheres and cerebellum are relatively small, while in the mammals these parts are very large. Vertebrates also have a *spinal cord*, a tube of nerve tissue extending backward from the brain and enclosed by the vertebral column (Fig. 100). The location of the nerve cord above the enteron is in

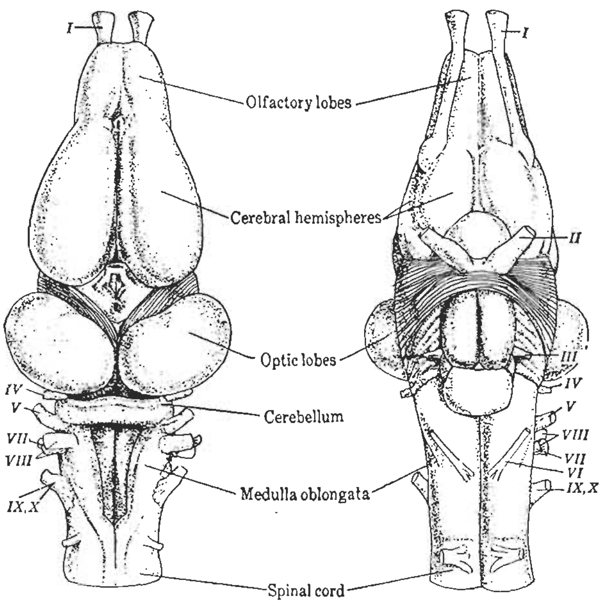


Fig. 99.—Brain of frog; *A*, dorsal aspect; *B*, ventral aspect. *I to X*, cranial nerves. (*Drawn from Jewell model.*)

striking contrast to its position in the earthworm. The brain of the frog gives rise to ten pairs of *cranial nerves* which go to the sense organs and other important parts of the body, while the spinal cord gives rise to a number of pairs of *spinal nerves*. All of the principal nerves have many branches. Vertebrates also have a *sympathetic nervous system*, consisting of a chain of ganglia on each side of the spinal cord and connected with branches of the

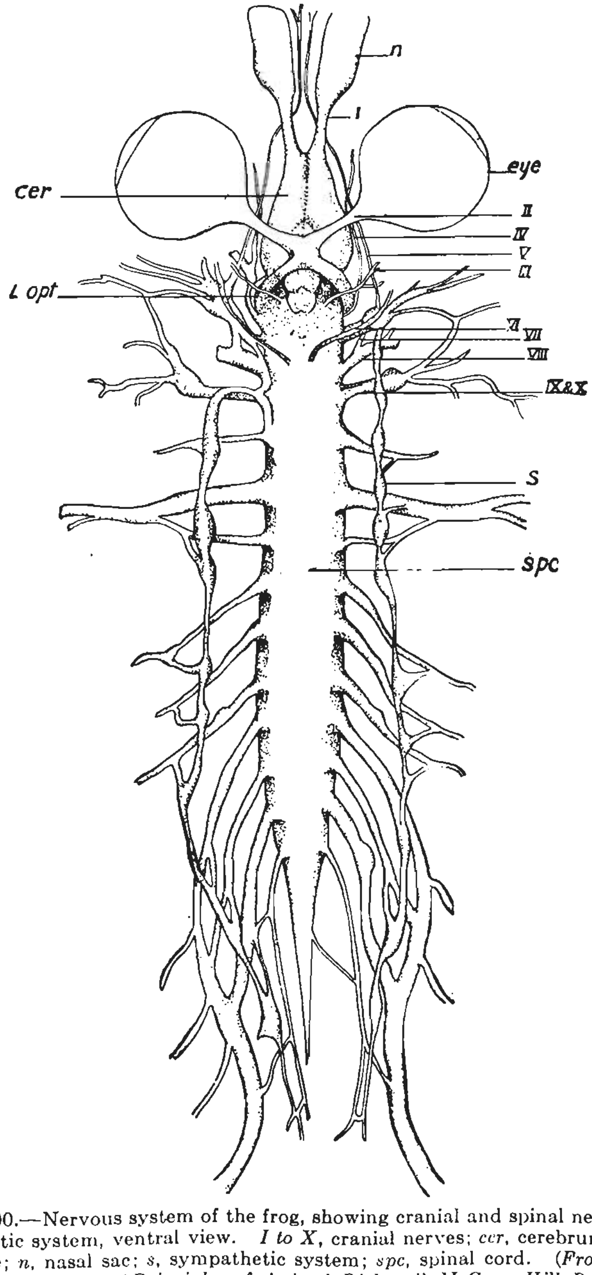


FIG. 100.—Nervous system of the frog, showing cranial and spinal nerves and sympathetic system, ventral view. *I to X*, cranial nerves; *cer*, cerebrum; *L opt*, optic lobe; *n*, nasal sac; *s*, sympathetic system; *spc*, spinal cord. (*From Shull, LaRue, and Ruthven, "Principles of Animal Biology," McGraw-Hill Book Company, Inc., after Wiedersheim; by permission.*)

spinal nerves. From these ganglia, nerves extend to the various internal organs, chiefly the organs of digestion and circulation, controlling their activities.

Reproductive System.—In the male frog a pair of small yellow oval testes lie beneath the kidneys and are connected with them by means of a number of slender sperm ducts (Fig. 101). Through these the sperms pass, leaving the body by way of the ureters and the cloaca. In the

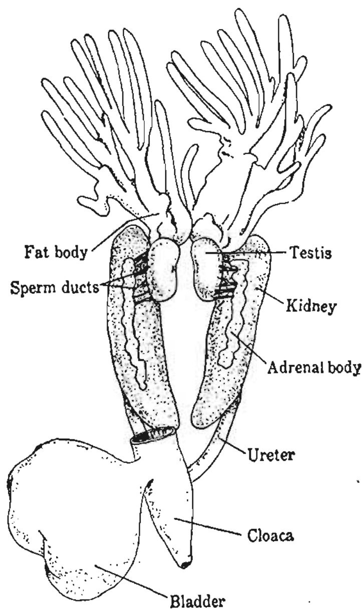


FIG. 101.—Excretory and male reproductive systems of the frog.

higher vertebrates the excretory and reproductive ducts are separate, and consequently the sperms do not pass through the kidneys and ureters. The female frog has a pair of sac-like irregular ovaries which nearly fill the coelom when they are full of ripe eggs (Fig. 102). The pair of long, coiled oviducts through which the eggs leave the body are not connected with the ovaries, but open into the coelom. The eggs are liberated by a rupturing of the ovary wall. Passing into the coelom, they find their way to the open ends of the oviducts which are funnel-like and ciliated.[1] The lower end of the oviduct is dilated to form a *uterus* where the eggs are temporarily stored. As the eggs leave the body through the cloaca, they are fertilized by the male frog. Thus the embryos develop entirely outside the body.

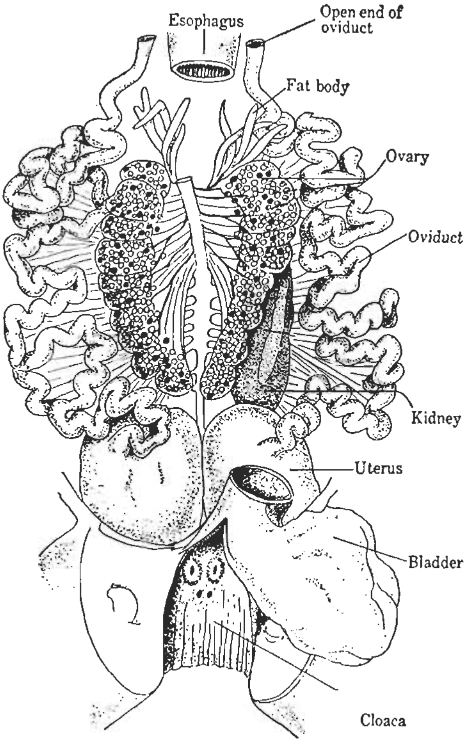


FIG. 102.—Female reproductive system of the frog. (*Redrawn after Pfurtscheller wall chart.*)

In both sexes finger-like *fat bodies* are attached to the anterior end of the sex organs. Their exact functions have not been accurately determined. They contain a great amount of fat and always decrease in size during the breeding season; for this reason, it is thought that they contribute nourishment to the reproductive organs.

[1] In most of the higher vertebrates, the oviducts, similarly, have no direct connection with the ovary, but because the mouth of the oviduct lies very close to it, the eggs do not remain in the coelom.

Development.—The eggs of the frog are always laid in water. They occur in gelatinous masses, each mass containing thousands of eggs. In about a week or 10 days after fertilization the embryo becomes a tadpole (Fig. 103). When first hatched, the eyes, mouth, and gills have not yet fully developed, but these soon become visible. The first gills are external, but these later disappear and are replaced by internal gills. The tadpole not

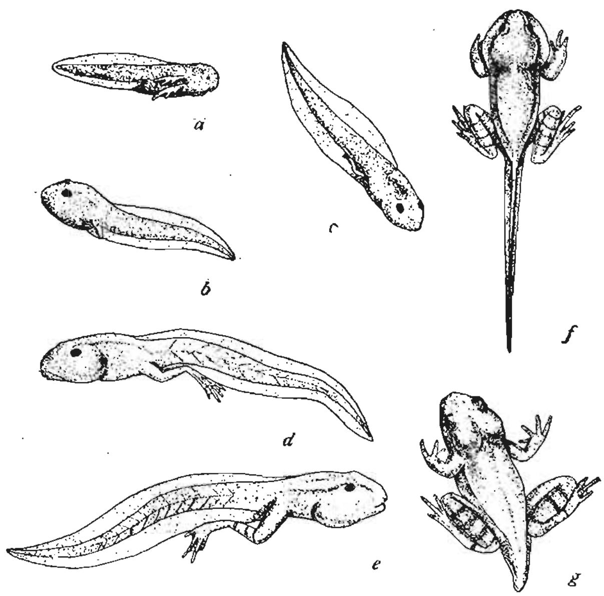


FIG. 103.—Stages in the later development of the frog. (*Redrawn after Leuckart-Nitsche wall chart.*)

only has gills, but a typical fish-like circulatory system with a two-chambered heart. A long tail is the organ of locomotion. Limbs are not developed until the tadpole has reached its full size. Gradually the hind limbs make their appearance, then the fore limbs, and as both grow the tail is absorbed by the body. To complete the metamorphosis, the gills are replaced by lungs, the heart becomes three chambered, the intestine shortens, the mouth cavity enlarges, and other changes take place which result in the transformation of the tadpole into a frog.

CHAPTER X

THE CHIEF GROUPS OF ANIMALS

The *animal kingdom* includes about 600,000 named and described species. Like the plant kingdom, it is divided into a number of major groups, the members of each group having certain fundamental structural features in common. These animal groups represent different stages in complexity and will be considered in an ascending sequence.

FIG. 104. —A simple sponge (*Sycon*), × 2. (*From Minchin, in Lankester's "Treatise on Zoology," A. & C. Black, Ltd., by permission.*)

Protozoans.—These constitute the simplest and probably the oldest group of animals. They number over 10,000 species[1] living in the soil, in fresh water, in the ocean, and as parasites. All of them are unicellular and most are microscopic in size. Some are colonial.

Sponges (Porifera).—The sponges comprise the simplest group of metazoans (Fig. 104). They are mostly marine in distribution, but a few occur in fresh water. The group numbers about 2,500 species. Sponges grow permanently attached to objects in the water; they may be solitary or form colonies. The body wall, consisting of only two layers of cells (separated by a non-cellular mesogloea), is perforated by many minute pores, and is usually supported by a framework of lime, silica, or organic material. The body wall encloses a single cavity. Sponges have simple tissues but there is little cooperation between the cells of the body, and there are no

[1] Statements of number of species in this chapter refer to described species. The actual number, which includes undiscovered species, is very much greater in some phyla, as in protozoans, roundworms, and arthropods.

definite organs. As in the protozoans, each cell engulfs food particles and carries on its own digestion. Sponges are radially symmetrical animals.

Coelenterates.—This group includes the hydroids, jellyfishes, corals, sea anemones, etc. (Fig. 105). There are about 4,500 species, mostly marine, the fresh-water hydra being one exception. Some of the coelenterates are attached, others are free-swimming; some are solitary, others colonial. As in the sponges, the body wall has only

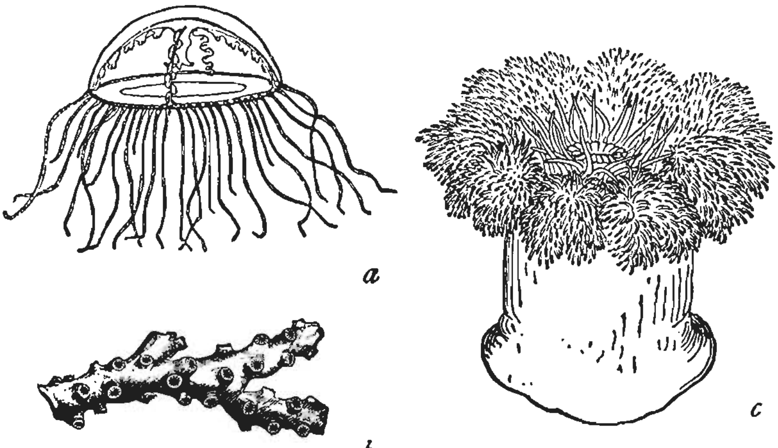


FIG. 105.—Representative coelenterates; *a*, a hydrozoan jellyfish (*Gonionemus*); *b*, a coral (*Oculina*); *c*, a sea anemone (*Metridium*). (*a*, *from Washburn, "The Animal Mind," copyright 1908 by The Macmillan Company, after Hargitt, reprinted by permission; b, from Sedgwick, "A Student's Textbook of Zoology," by kind permission of the publishers, George Allen & Unwin, Ltd., London; The Macmillan Company, New York; c, from Emerton.*)

two cell layers (but with a mesogloea between them). The single body cavity has just one opening—the mouth. The tissues of the body are simple, but are more highly developed than those of the sponges. Organs are present, but there are no systems. Digestion takes place not only within the single central cavity, but also inside individual cells. All of the coelenterates exhibit radial symmetry.

Flatworms (Platyhelminthes).—There are about 5,000 species of flatworms living in fresh water, in the ocean, and as parasites (Fig. 106). Two well-known parasitic forms are the liver fluke and the tapeworms. The tissues and organs are more complex than those of the coelenterates, and definite systems are present, as in all of the higher animals. Like the coelenterates, the body has a single cavity with just one opening, but the cavity is usually highly branched. The body wall is many cells thick, and this feature persists in all of the higher animals. The flatworms are the simplest animals with bilateral symmetry. As the name implies, the body is flat.

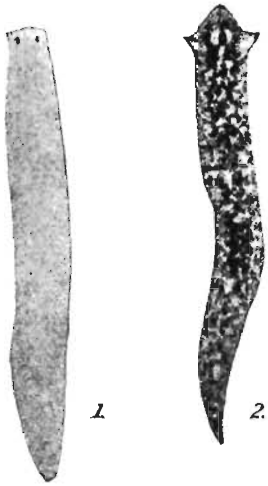


FIG. 106.—Two species of fresh-water flatworms; 1, *Dendrocoelum lacteum;* 2, *Planaria maculata.* (*From Davenport, "Elements of Zoology," copyright 1915 by the Macmillan Company, after Woodworth reprinted by permission.*)

Roundworms (Nemathelminthes).—The roundworms comprise over 1,500 species of fresh-water, marine, soil, and parasitic forms, the trichina and hookworm being as well known as any. They are similar to the flatworms except in two important respects: (1) both a coelom and an enteron

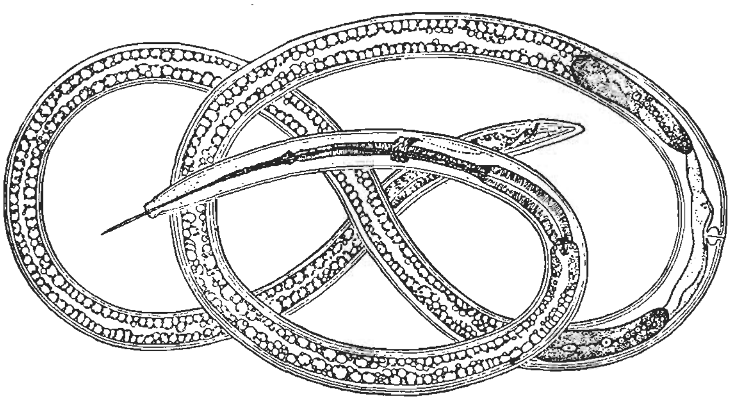
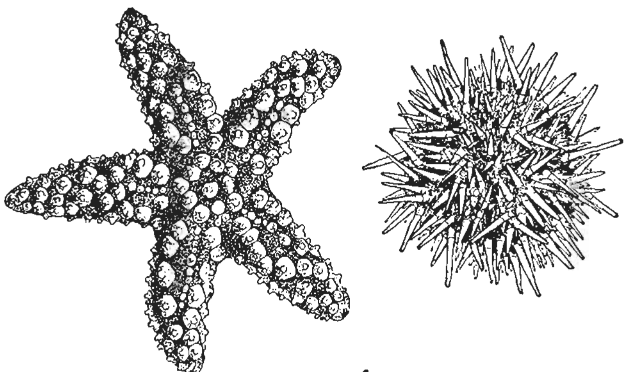


FIG. 107.—A nematode worm (*Xiphinema*) which lives on the roots of plants. Greatly magnified. (*From Cobb, in Yearbook U. S. Department of Agriculture,* 1914.)

are present; (2) the enteron has two openings—mouth and anus. These two features are characteristic of all of the higher groups. The form of the body is mostly thread-like or cylindrical (Fig. 107).

Echinoderms.—This is a peculiar group of marine animals numbering about 4,000 species. It includes the starfishes, sea urchins, brittle stars, sea cucumbers, etc. (Fig. 108). The echinoderms are a highly developed group of radially symmetrical animals having a number of special features: a spiny skin, the occurrence of the organs in fives, a peculiar system of locomotor organs, etc. The organs and systems are more highly developed than in the lower groups.



A B

FIG. 108.—Two common echinoderms, × ½; *A*, a starfish (*Pisaster*); *B*, a sea urchin (*Strongylocentrotus*).

Annelids.—These animals are known as "segmented worms," a group to which belong the earthworms, sandworms, leeches, etc. (Fig. 109). There are about 4,000 species. The annelids are like the roundworms in being bilaterally symmetrical and in having both a coelom and an enteron, but they make a great advance in having a metameric body. The organs and systems show a still higher degree of complexity than those of the preceding groups.

Arthropods.—This is by far the largest group in the animal kingdom, including over 500,000 species. Arthropods are closely related to the annelids, but are much more highly developed, differing from them in three important respects: (1) The metameric body bears appendages

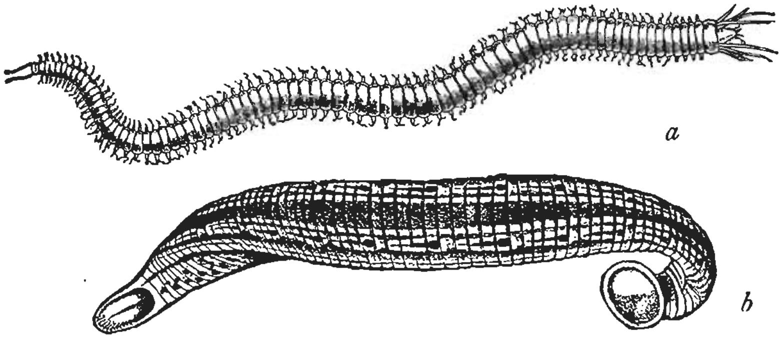


FIG. 109.—Segmented worms; *a*, the sandworm (*Nereis*), a marine annelid; *b*, a leech (*Hirudo*). (*From Shipley and MacBride, "Zoology," Cambridge University Press, a, after Oersted; by permission.*)

(such as feelers, legs, mouth parts, etc.) which are jointed. (2) The segments are more or less specialized and grouped into body regions; there is always a head, but the rest of

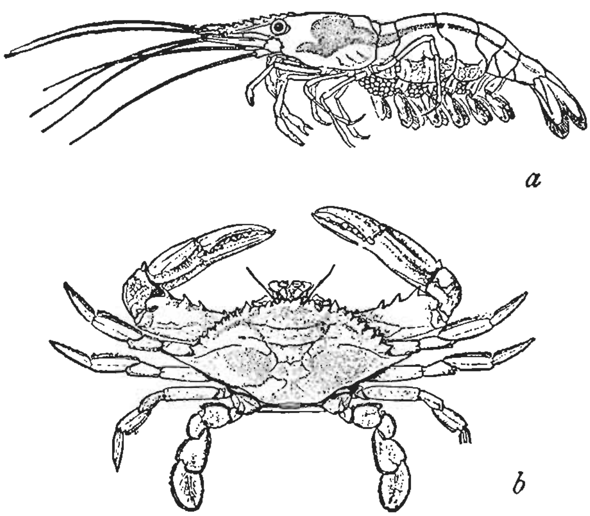


FIG. 110.—Typical crustaceans; *a*, a shrimp (*Palaeomonetes*); *b*, the blue crab (*Callinectes*). (*a, from Davenport, "Elements of Zoology," copyright 1915 by The Macmillan Company, reprinted by permission; b, from Paulmier, after Rathbun.*)

the body may or may not be differentiated into a thorax and abdomen, while in some cases the head and thorax are fused. (3) A hard outer covering is present. In other respects, the group resembles the annelids. The four chief classes of arthropods are as follows:

1. *Crustaceans.*—Mainly an aquatic group, numbering about 16,000 species, and including crabs, lobsters, crayfishes, shrimps, barnacles, etc. (Fig. 110). Most of the other arthropods are terrestrial. In many crustaceans the head and thorax are fused to form a *cephalothorax.*

2. *Myriapods.*—A small group of about 1,000 species, comprising the centipeds and millipeds (Fig. 111). These

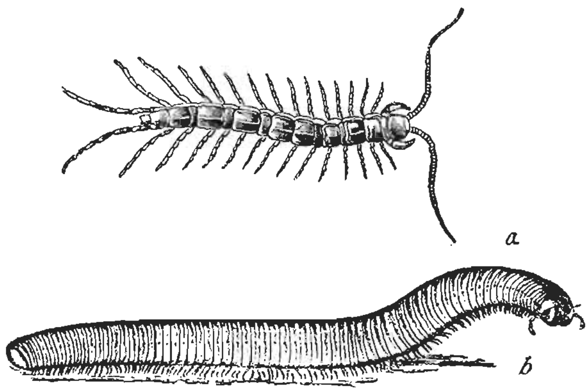


FIG. 111.—Myriapods; *a*, a centiped (*Lithobius*); *b*, a milliped (*Julus*). (*a*, *from Sedgwick, "A Student's Textbook of Zoology," after Koch, by kind permission of the publishers, George Allen & Unwin, Ltd., London: The Macmillan Company, New York, b. from Shipley and MacBride, "Zoology," Cambridge University Press, after Koch, by permission.*)

forms are more worm-like than the other arthropods, having a head but no differentiation between the thorax and the abdomen. They have one or two pairs of legs on each metamere.

3. *Insects.*—The insects, numbering over 450,000 species, constitute the largest group of arthropods, and include the locusts, dragon flies, bugs, beetles, butterflies, moths, flies, mosquitoes, wasps, ants, bees, and many others (Fig. 112). The body is divided into a distinct head, thorax, and abdomen. Insects have six legs and two pairs of wings.

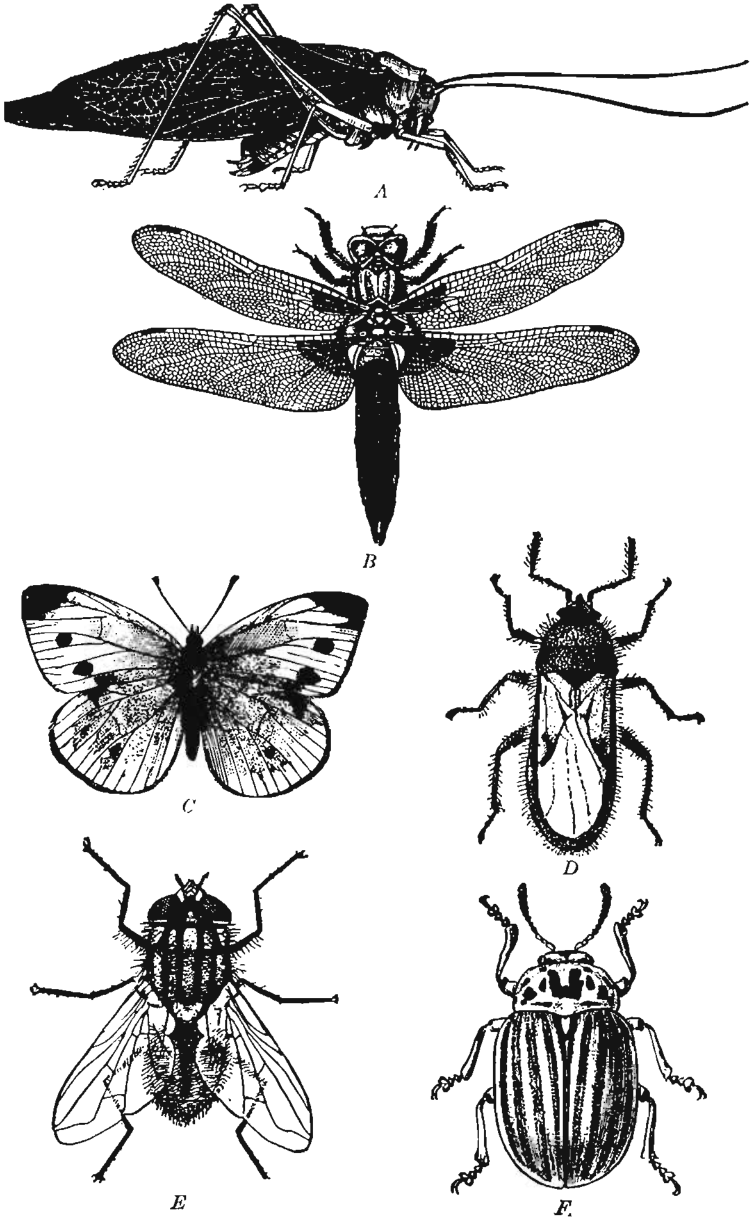


FIG. 112.—Representative insects; *A*, katydid (*Microcentrum*); *B*, dragonfly (*Libellula*); *C*, cabbage butterfly (*Pieris*); *D*, chinch bug (*Blissus*); *E*, house fly (*Musca*); *F*, potato beetle (*Leptinotarsa*). (*From Newman, "Outlines of General Zoology," copyright 1924 by The Macmillan Company, after various authors; reprinted by permission.*)

4. *Arachnids.*—A group including about 20,000 species of spiders, scorpions, mites, and ticks (Fig. 113). The head and thorax are fused to form a cephalothorax, as in some of the crustaceans. Arachnids have eight legs and no wings.

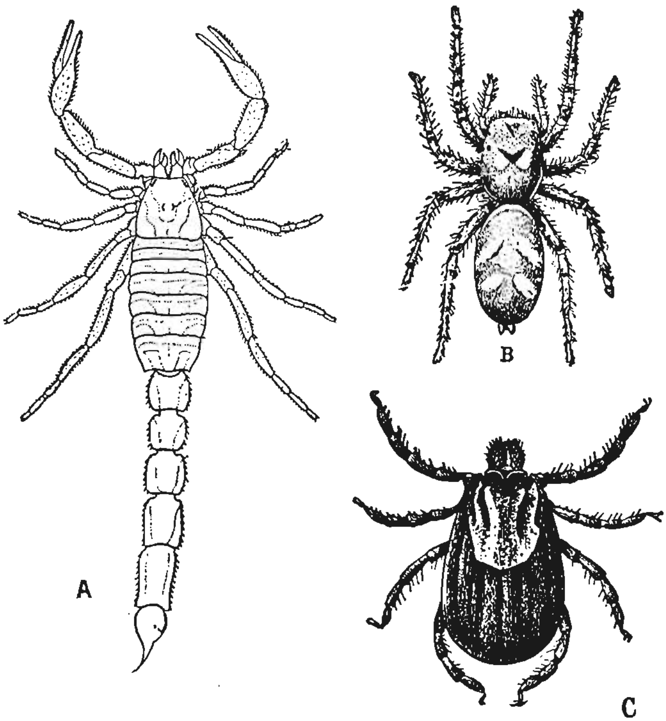


FIG. 113.—Typical arachnids; *A*, a scorpion (*Buthus*); *B*, jumping spider (*Attus*); *C*, cattle tick (*Boophilus*). (*A*, *from "Cambridge Natural History," copyright 1909 by The Macmillan Company, after Kraepelin; reprinted by permission; B, from Emerton; C, from Packard.*)

Mollusks.—There are about 60,000 species of mollusks living in fresh water, in the ocean, and on land. They are represented by such familiar forms as oysters, clams, mussels, snails, slugs, squids, cuttlefish, and octopi (Fig. 114). Mollusks constitute a highly developed group of non-metameric animals with soft bodies which are usually encased in a shell. All of them have a characteristic organ, the *foot*, which is variously modified. They are bilaterally symmetrical.

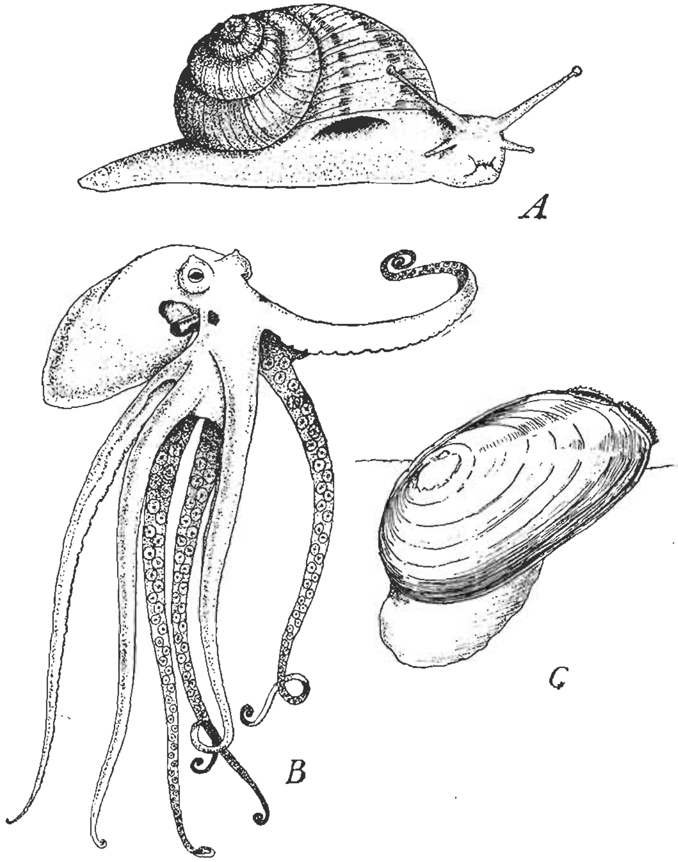


FIG. 114.—Representative mollusks; *A*, a land snail (*Helix*), $\times \frac{5}{4}$; *B*, an octopus (*Polypus*), $\times \frac{2}{5}$; *C*, fresh-water mussel, $\times \frac{3}{4}$. (*C*, *redrawn after Linville and Kelly, "A Text-book in General Zoology," Ginn and Company, by permission.*)

Chordates.—This is the highest group of animals, numbering about 38,000 species. They resemble the annelids and arthropods in being bilaterally symmetrical and metameric, but in most cases there are no external evidences of metamerism in the adult stage of development. The three distinctive features of chordates are as follows: (1) All chordates have at some stage of growth a rod of supporting tissue called a *notochord.* In the lower forms (the *Provertebrates*) this persists throughout life, but in most chordates (the *Vertebrates*) it is replaced in the adult by a series of vertebrae forming the vertebral column. No animals other than chordates have a notochord. (2) All chordates have paired *gill slits* at some stage of growth. These are clefts in the wall of the pharynx. In the lower aquatic forms they persist throughout life, permitting the outward passage of water from the mouth cavity over the gills. In the air-breathing chordates, however, the gill slits disappear before the adult stage is reached, being solely embryonic or larval structures. (3) The nerve cord is hollow (in reality a tube) and invariably dorsal to the enteron, never ventral as in the annelids and arthropods. The five chief classes of vertebrates are as follows:

1. *Fishes.*—These are cold-blooded,[1] aquatic vertebrates having functional gills throughout life (Fig. 115). There

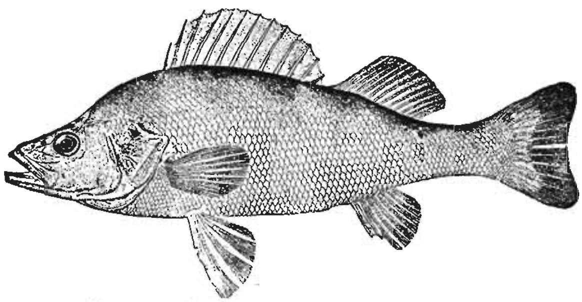


FIG. 115.—The yellow perch (*Perca flavescens*), a typical fish. (*From Dean, after Goode.*)

are no limbs, movement through the water being accomplished by fins. The skin is covered with scales. The heart is two chambered. There are about 15,000 species.

2. *Amphibians.*—This class includes about 1,500 species of salamanders, newts, frogs, and toads (Fig. 116). They are all cold-blooded vertebrates with functional gills in early life; in most amphibians these are later replaced by

[1] In cold-blooded animals the body temperature varies with the surroundings; in warm-blooded animals it is constant and relatively high, in man being about 37° C. (98.6° F.).

lungs. Nearly all have four limbs, the toes being without claws. The skin is smooth and entirely without scales. The heart is three chambered.

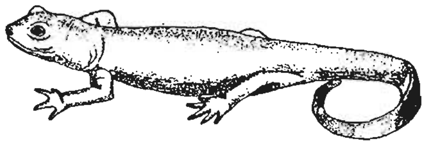


FIG. 116.—A salamander (*Triturus torosus*), a typical amphibian, × ½.

3. *Reptiles.*—To this class belong the lizards, snakes, turtles, tortoises, crocodiles, and alligators (Fig. 117). There are about 3,500 species. Like the two lower vertebrate groups, reptiles are cold blooded, but are entirely without functional gills at any stage of development. Some live in the water, but all reptiles have lungs. Nearly

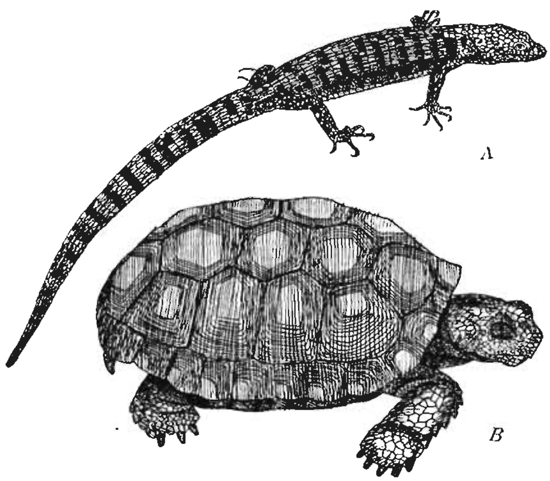


FIG. 117.—Reptiles: *A*, a lizard (*Gerrhonotus scincicauda*), × ¼; *B*, desert tortoise (*Testudo agassizi*), × ⅙.

all have four limbs (snakes being a notable exception), the toes ending in claws. The skin is covered with scales, hard plates, or both. The heart is three chambered, but the ventricle is incompletely divided. In the crocodiles and alligators, however, the heart is four chambered.

4. *Birds.*—The 13,000 species of birds form a very distinct class of vertebrates (Fig. 118). Like the reptiles,

they lack functional gills, but are warm blooded. There are two pairs of limbs, but the fore limbs are modified to form wings. The skin is covered with feathers, scales

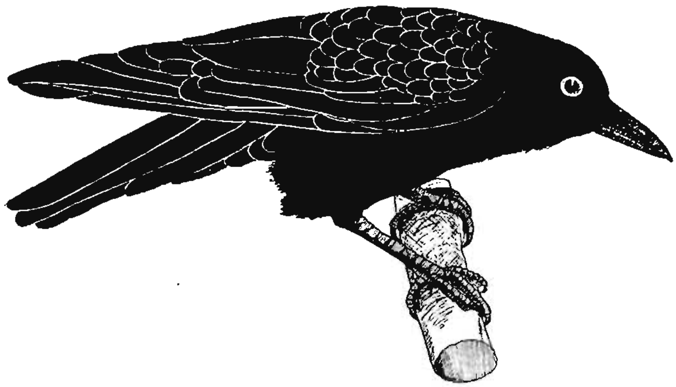


FIG. 118.—Crow (*Corvus brachyrhynchos*), × ⅕.

occurring only on the feet. The heart is completely four chambered.

5. *Mammals.*—The highest class of vertebrates numbers about 3,500 species and includes such well-known forms as

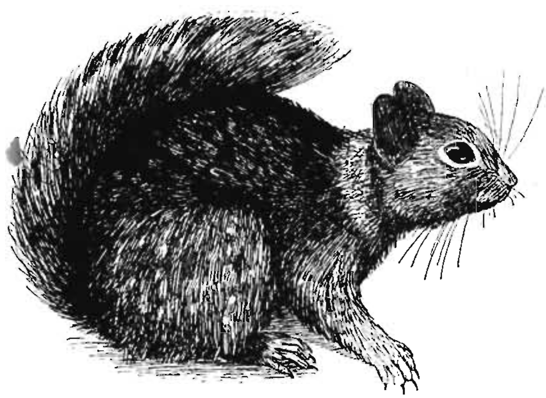


FIG. 119.—Ground squirrel (*Citellus beecheyi*).

man, apes, monkeys, cattle, sheep, horses, dogs, cats, seals, rats, mice, squirrels, moles, bats, whales, and many others (Fig. 119). Like the birds, mammals are warm blooded and lack functional gills. Two pairs of limbs are present in nearly all cases. The skin is covered with hair. The heart is completely four chambered. A distinctive feature of all mammals is the fact that the young are nourished by milk produced by the *mammary glands* of the female. The development of the brain far surpasses that seen in any of the lower animals.

CHAPTER XI

METABOLISM IN ANIMALS

Through our study of plants, we have become acquainted with a number of aspects of metabolism which are fundamental to all living things (see Chap. VII). We have learned what food is, and how it is formed in green plants. We have seen that all organisms use the same kinds of foods—carbohydrates, fats, and proteins—and that these are utilized by both plants and animals in exactly the same ways, *viz.*, in the building up of body substance (both protoplasm and its derivatives) and as a source of energy. It has been seen that the processes of digestion, assimilation, respiration, and their accompanying energy relations, are essentially similar in both plants and animals. Therefore our present interest is not so much in the nature of these metabolic processes as in the ways in which they are carried on in animal bodies.

In contrast to plants, animals are active; their functions are performed in a more accelerated manner. Having a higher rate of metabolism, therefore, they require a much greater amount of energy, and this necessitates a correspondingly larger consumption of nourishment. In fact, most of the activities of animals are concerned primarily with procuring food.

Digestion.—It has previously been pointed out that the ingestion of solid food is a distinctive feature of animal nutrition. Some of the food taken into the animal body, such as simple sugars, can be directly absorbed without undergoing chemical change, but most nutritive substances must be digested before they can be utilized by the living tissues. Complex foods must be broken down into simpler forms which can pass into solution. As in plants, digestion in animals is accomplished by *enzymes*, substances of unknown chemical composition which the organism itself produces. In the protozoans and sponges, and to a certain extent in the coelenterates, as already stated, digestion is *intracellular;* that is, it is carried on inside of individual cells, each cell engulfing its own food. In all other animals, however, digestion is *extracellular*, the food entering and being digested within a distinct digestive cavity. Enzymes are secreted into the cavity either by the surrounding cells or by accessory digestive glands which are connected with it by ducts.

For an understanding of the way in which the digestive processes are carried on in the higher animals, in a very general way the more important aspects of human digestion will be considered. Contrary to those animals whose diet is more or less restricted, man is *omnivorous*, using foods which come from a great variety of sources. Food is broken up in the mouth and mixed with *saliva*, a secretion from the salivary glands. Saliva contains an enzyme called *ptyalin* which acts upon starch, but little digestion occurs in the mouth because food remains there only a short time. The principal value of chewing is to reduce the size of the pieces of food so that fluids in the stomach and intestine can reach them quickly.

The stomach is a muscular sac in which food is temporarily stored, reduced to a semifluid consistency, thoroughly mixed, and partially digested (Fig. 120). The stomach secretion, called *gastric juice*, contains about 0.4 per cent of hydrochloric acid and an enzyme called *pepsin*. The acid plays no direct part in the work of digestion; it merely serves to activate the pepsin, as this enzyme can do its work only in an acid medium. Pepsin acts upon some of the proteins, changing them to peptones. The gastric juice also contains the enzyme *rennin*, the sole function of which is to coagulate milk. There is no starch digestion in the stomach except from the saliva mixed with the food, but as ptyalin acts only in an alkaline medium, this soon ceases in the presence of the hydrochloric acid. There is also little or no digestion of fats in the stomach.

Upon entering the small intestine, the partially digested food is acted upon by other enzymes, the chief ones being in the *pancreatic fluid*. These are three in number: *amylopsin*, which converts starch to sugar; *trypsin*, which changes proteins to peptones and simpler products; *steapsin*, which breaks down fats into glycerin and fatty acids. In man the pancreatic duct joins the bile duct, near its lower end, the latter thus discharging both bile and pancreatic fluid into the upper portion of the small intestine. As the food

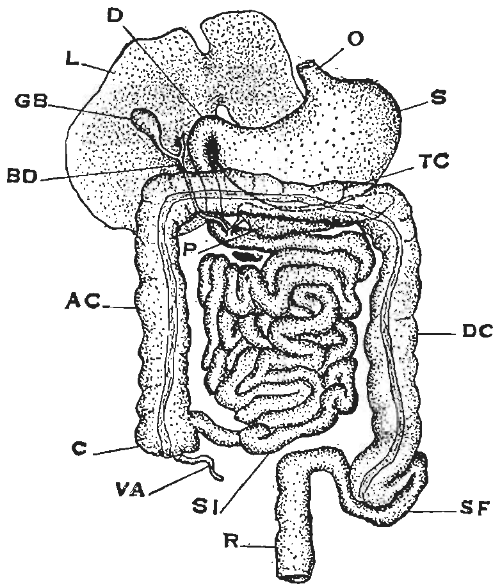


Fig. 120.—Diagram of the human digestive system; *O*, end of esophagus; *S*, stomach; *D*, duodenum (beginning of small intestine); *SI*, small intestine; *VA*, vermiform appendix; *C*, caecum; *SF*, sigmoid flexure; *R*, rectum; *L*, liver; *GB*, gall bladder; *BD*, bile duct; *P*, pancreas. (*From Wieman, "General Zoology," McGraw-Hill Book Company, Inc., by permission.*)

leaves the stomach it is acid, but is soon neutralized by the pancreatic fluid and bile, both of which are alkaline. This is necessary because the intestinal enzymes act only in a neutral or alkaline medium. Bile, the secretion from the liver, contains no enzymes, but its presence makes conditions favorable for the action of the pancreatic fluid, especially in its digestion of fats. As the food passes through the small intestine, it is also acted upon by several enzymes contained in the *intestinal juice*, one of which, called *erepsin*, supplements the action of trypsin in the digestion of proteins.

There are no enzymes in the large intestine. Nearly all of the work of digestion is carried on in the small intestine, the other parts of the digestive tract doing comparatively little. Certain portions of the material eaten, such as the cellulose of vegetable food and the fiber of meat, are not capable of digestion in the human body. Hence, the large intestine acts chiefly as a reservoir for the accumulation of this indigestible matter. Because of the presence of large numbers of bacteria in the lower end of the large intestine, the indigestible residue undergoes partial decomposition before leaving the body.

Absorption.—With the exception of sugars and a few other substances, most of the foods taken into the digestive tract are incapable of being dissolved in water. Foods like starch and proteins, for example, cannot pass through an osmotic membrane, while sugars and other soluble substances can. The real purpose of digestion is to render food substances diffusable by changing them from an insoluble to a soluble form that they may thus pass by osmosis through the layers of cells which compose the intestinal wall. The absorption of food takes place almost entirely in the small intestine, very little going on in the stomach or large intestine.

Assimilation.—The digested food is taken up by the blood and carried to all parts of the body to be assimilated. It should be recalled that assimilation is simply the transformation of food into protoplasm. Some of the sugar carried by the blood is taken to the liver, converted to an insoluble carbohydrate called *glycogen*, and temporarily stored in this form. Chemically, glycogen is very similar to starch; in fact, it is often referred to as "animal starch." When a great excess of food is habitually eaten, much of it is stored permanently as fat in what then becomes *adipose tissue*. Fat accumulates in thick layers beneath the skin and around such organs as the heart, liver, kidneys, and intestines, often interfering with their normal activities.

Respiration.—The breaking down of organic matter in the body to liberate energy has been adequately discussed in connection with plants (see Chap. VII). We have seen that respiration is essentially the same process in all organisms. In the lower animals oxygen is absorbed by all the cells of the body directly from the surrounding medium, the water or the atmosphere, as the case may be. In the higher forms, however, this is obviously not possible, and so oxygen must be transported to the tissues in some way. In the insects, air is brought directly to the cells through a system of highly branched, delicate tubes (*tracheae*) which communicates with the atmosphere by means of small openings in the body wall (*spiracles*), no oxygen or carbon dioxide being carried by the blood (Fig. 121). In the higher groups of animals, however, air does not come in direct contact with the tissues. Instead, oxygen is brought to them by the blood from definite *aerating organs*, such as gills or lungs, or in some cases from the moist outer skin.

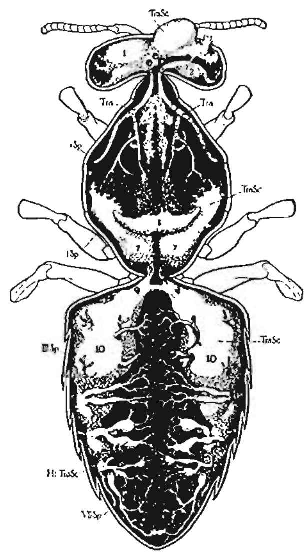


FIG. 121.—Respiratory system of the honeybee. (*From Snodgrass, "Anatomy of the Honeybee," McGraw-Hill Book Company, Inc., by permission.*)

Circulation.—The blood of vertebrates consists chiefly of two kinds of cells—*red* and *white corpuscles*—suspended in a colorless liquid called the *plasma*. The plasma carries most of the dissolved food to the tissues and removes wastes from them. The red corpuscles are oval or circular, disk-like cells which owe their color to the presence of a substance known as *haemoglobin* with which oxygen readily combines. In the earthworm and many other invertebrates this substance is dissolved in the plasma, all of the corpuscles being colorless. In the mammals the red corpuscles lose their nuclei, but in all other vertebrates they remain nucleated (Figs. 21*B* and 122). The white corpuscles are slightly larger than the red ones, but are only about one five-hundredth as numerous (in man), and never contain haemoglobin. They are often amoeboid in form, moving by pseudopodia, and contain one or several nuclei. A peculiar feature of the white corpuscles is their ability to pass through the walls of capillaries into the surrounding tissues. Their function consists partly in engulfing small solid particles, such as bacteria, waste particles, and wornout cells, which they destroy by digesting them. They also aid in the transportation of fats to different parts of the body.

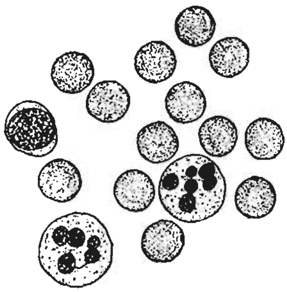


FIG. 122.—Human blood corpuscles, drawn from a stained preparation, × 750. Three white corpuscles are shown, the smaller one with a single large nucleus, the larger ones with several smaller nuclei. The red corpuscles lack nuclei.

In addition to the blood, vertebrates have a colorless fluid called *lymph* which circulates through the body in delicate vessels called *lymphatics;* these eventually connect with the closed system of blood vessels. Lymph contains mainly plasma and white corpuscles which have escaped from the blood vessels. It supplements the work of the blood, especially in the transportation of nourishment.

Excretion.—The breaking down of protoplasm results in the formation of carbon dioxide, water, and other waste products. These are collected by the blood stream and eliminated through the aerating organs, the skin, and the excretory organs. In mammals most of the carbon dioxide is given off through the lungs—the water, from the lungs, skin, and kidneys. When proteins are decomposed, a nitrogenous substance called *urea* always results. In the higher animals it is formed chiefly in the liver, and is then carried by the blood to the kidneys where it accumulates. The urea, with a smaller quantity of other waste products, is dissolved in water to form a fluid called *urine.* This passes from the kidneys through the pair of ureters to the bladder where it is stored before passing out of the body. In most mammals the skin contains innumerable small *sweat glands* which give off large quantities of water and leave a residue of solid waste matter on the skin.

Nerve Control.—We have already considered in plants the general fact of irritability and have seen that the capacity to react to stimuli is universal among living things. While response in animals is no more definite than it is in plants, ordinarily it is far more rapid and is brought about by a very different mechanism—chiefly through the cooperation of nerves and muscles. In the two lowest groups of animals—protozoans and sponges—the cells which react to external influences are stimulated directly, there being no nerve cells. In all of the higher animal groups, however, this is not the case; here differentiated cells are present whose sole function is to receive and conduct stimuli and thus to bring about responses in other tissues which, for the most part, are themselves incapable of receiving stimuli directly. In the coelenterates, simple nerve cells are present, but they are not aggregated to form ganglia. In the higher animals, however, the nervous tissue constitutes an elaborate system of nerves and ganglia, the organization of which has already been considered in the earthworm and the frog.

The nervous system, in controlling the responses of an animal to external influences, makes it possible for various groups of tissues to act together as a unit. In other words, it directs and coordinates all vital functions. Without the controlling influence of the nervous system, there could be no bodily activities. It is important to understand how the nervous system brings about activity in other tissues.

It will be recalled that a nerve cell, or *neuron,* consists of a central nucleated portion (the *cell body*) and of a number of extremely fine cytoplasmic extensions, called *nerve fibers,* which conduct impulses (Fig. 20*A*). Each neuron has two kinds of nerve fibers: commonly a number of short, branched *dendrites,* and a single long *axon* which usually is branched only at its tip. The former carry impulses *to* the body of the neuron, the latter carries them *away from* the neuron. A nerve cell, as a whole, can carry impulses only in one direction—*sensory neurons* from a point of stimulation to a nerve center (as the brain or spinal cord), *motor neurons* from a nerve center to a tissue in which a response is to be induced (as a muscle or gland).

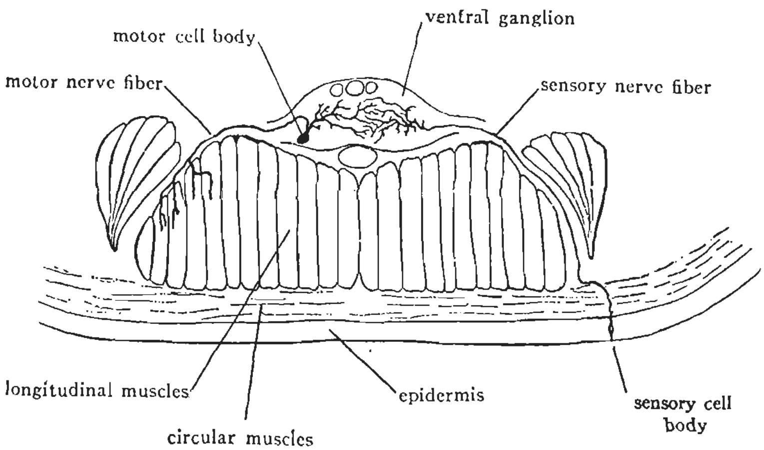


FIG. 123.—Diagrammatic cross-section of the ventral nerve cord and surrounding structures of an earthworm. (*From Parker, in Popular Science Monthly, after Retzius.*)

Ganglia are merely aggregations of neurons, while nerves are bundles of nerve fibers usually enclosed by a sheath of connective tissue. A *sensory nerve* consists of the fibers of many sensory neurons, a *motor nerve* of the fibers of many motor neurons. *Mixed nerves,* on the other hand, are composed of both kinds of fibers, and so are both sensory and motor in function.

A simple illustration of the way in which a response to a stimulus manifests itself may be seen by touching the skin of an earthworm. The mechanism of this reaction may be understood by reference to Fig. 123. Lying in the skin are a number of sensory neurons, the dendrites of which receive stimuli acting upon the surface. The axon of each of these neurons passes inward to one of the ganglia of the central nervous system, where its end comes in contact (although not in organic union) with the dendrites of one of the many motor neurons of which the ganglion is composed. The axons of certain of these motor neurons pass outward to the muscles of the body wall. Stimulation of the skin causes an impulse to be sent over one or more sensory nerve fibers to the central nervous system. There it is transmitted by one or more motor nerve fibers to a group of muscles which are thereby stimulated to contract. This behavior is called *reflex action* because the impulse is reflected from the nerve center somewhat as light is reflected by a mirror. Many of the bodily activities in the higher animals are brought about by reflex actions.

CHAPTER XII

REPRODUCTION AND DEVELOPMENT IN ANIMALS

In connection with plants, certain fundamental facts and principles regarding reproduction in general have been considered which need not be repeated here (see Chap. VIII). In the present chapter our interest will center chiefly on such phases of reproduction and development as are illustrated by animals.

Asexual Reproduction.—We have seen that among unicellular organisms the prevailing method of reproduction is fission—an equal division of the body into two new parts which separate and take up an independent existence. Occasionally, this happens even among some of the lower metazoans, as in *Hydra* and the flatworm *Planaria* (Fig. 124). Spore reproduction, although characteristic of nearly all plants, is very rare among animals, occurring only in certain protozoans (see pp. 25–26 and 258–260). Other methods of asexual reproduction are found in animals, however, particularly among the lower groups of metazoans. For example, attention has already been called to the formation of buds in *Hydra* (see p. 117), lateral outgrowths from the body wall which become detached and give rise to new individuals. This is a method of reproduction comparable to "vegetative multiplication" among plants. Budding is common in the sponges, coelenterates, and

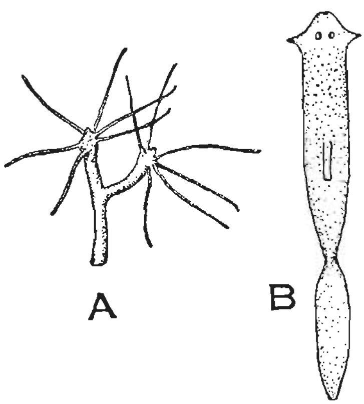


FIG. 124.—Fission in metazoans; *A*, in *Hydra; B*, in *Planaria*. (*From Wieman, "General Zoology," McGraw-Hill Book Company, Inc., A, after Koelitz; B, after Child.*)

flatworms, often giving rise to multicellular colonies, as previously explained (see p. 117). Among the higher animals, asexual reproduction is rare; in fact in the vertebrates it does not occur at all.

Sexual Reproduction.—Nearly all animals reproduce by the sexual method. In fact, in most cases, it is the only way in which new individuals arise, but even where asexual methods have been developed (as in *Hydra*), sexual reproduction is also present. Even many of the protozoans exhibit a form of sexual reproduction, although the rapid increase in number of individuals is brought about chiefly by fission. In *Paramoecium*, for example, under certain circumstances, a behavior known as *conjugation* takes place (Fig. 125). Two individuals come in contact with each other, complex nuclear trans formations occur, and, after an exchange of nuclear material, the two cells separate. Because no new individual is formed, however, strictly speaking, this behavior is not reproduction. The significance of conjugation has been variously interpreted, but is still somewhat uncertain. It is only in a relatively few protozoans that gametes are formed and a permanent union takes place between them.

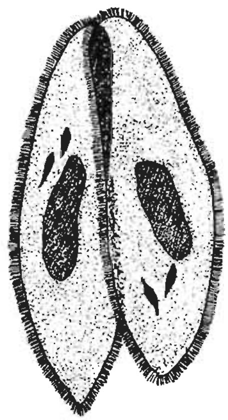


FIG. 125.—Conjugation in *Paramoecium*.

In the growth of a metazoan from the fertilized egg, as we shall soon see, most of its cells become specialized to form muscle, nerve, blood, and other tissues which are primarily concerned with metabolic activities—with the maintenance of the individual of which they are a part. These are called *somatic tissues*, or collectively the *soma*, and are comparable to what we have termed "vegetative tissues" in plants. Of all the cells which arise from the fertilized egg, however, a relatively few remain unspecialized, taking no part in general bodily functions. During the development of the individual, these *germ cells*, as they are called, undergo a period of multiplication within the body, but are incapable of functioning as reproductive cells until the animal reaches maturity. Then they undergo certain complex changes (to be described in the next chapter), and thereby become transformed into gametes.

In the sponges, germ cells are scattered throughout the body, but in all other metazoans they are confined to

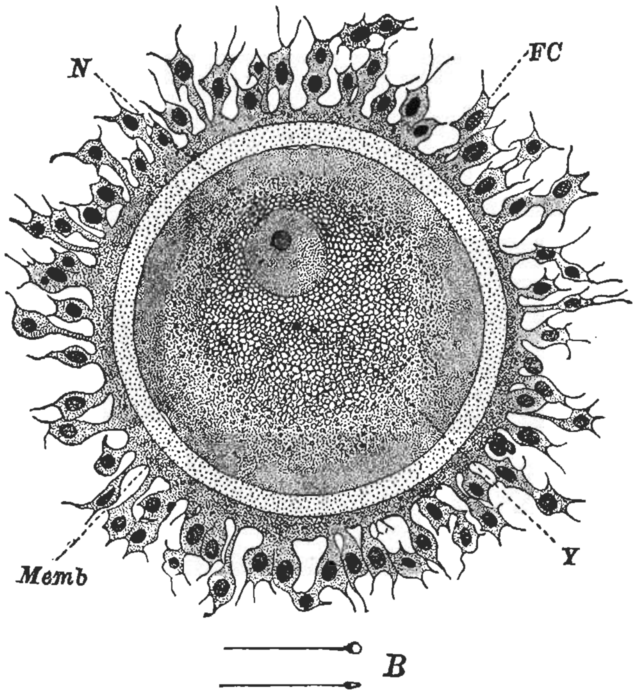


FIG. 126.—A nearly ripe human ovum in the living condition. The ovum is surrounded by follicle cells (*FC*) inside of which is the clear membrane (*Memb*) and within this is the ovum proper containing yolk granules (*Y*) and a nucleus (*N*) imbedded in a clear mass of cytoplasm. × 500; *B*, two human spermatozoa drawn to about the same scale of magnification as the egg. (*From Conklin, "Heredity and Environment," Princeton University Press, after Hertwig; B, after Retzius; by permission.*)

definite sex organs: testes or ovaries. The male gametes of animals, called *sperms* (or *spermatozoa*) are of various forms, but are always very small, and ordinarily consist of little more than a nucleus (Fig. 126*B*). In most cases, they swim actively by means of a flagellum or tail. The female gametes, called *eggs* (or *ova*), are generally spherical in shape, a great deal larger than the sperms but much less numerous, and are nearly always non-motile (Fig. 126). The human egg cell is approximately 0.2 millimeter (1/125 inch) in diameter, but other eggs are much smaller than this and some a great deal larger. In addition to the nucleus, all eggs have a relatively large amount of cytoplasm containing reserve food which constitutes the *yolk*. In some animals the yolk is uniformly distributed throughout the egg, while in others it accumulates at one end. In many cases part of the reserve food is stored in accessory layers which surround the egg. Thus the white portion of a bird's "egg," called *albumen*, is merely accessory food material surrounding the yellow portion, the latter constituting the ovum or real egg enormously enlarged by the accumulation of yolk. The eggs of many animals are surrounded by a special protective envelope or shell, particularly in such forms as reptiles and birds, which lay their eggs on land. Its chief purpose is to prevent evaporation.

Fertilization.—Among animals, as among plants, the essential feature of sexual reproduction is the fusion of a sperm with an egg, a new individual arising from the zygote by repeated cell division. All other features associated with reproduction are incidental; they merely aid in bringing about this gametic union or in providing a means for the new individual to develop. The sperm swims to the egg and penetrates its outer membrane; its nucleus then gradually increases in size as it approaches the egg nucleus, and when the male and female nuclei fuse they may be approximately equal in size (Fig. 127). The egg is now said to be fertilized. Although an egg may be surrounded by millions of sperms, only one normally succeeds in fusing with the egg nucleus. It is important to realize that the fertilized egg or zygote gives rise to all of the cells of the adult individual. This means that every metazoan begins its existence as a single undifferentiated cell. The zygote marks the beginning of the next generation; in fact, it is actually the new individual itself!

In order that the sperms may reach the eggs, there must be a liquid medium through which they can swim. In aquatic animals this is provided by the water in which they live. Most of the groups of invertebrates are aquatic, and, consequently, to them fertilization presents no difficulties. For example, in the starfish, where the sexes are separate, both the sperms and eggs are discharged into the water and there fertilization takes place. Among the vertebrates it is only in the fishes and amphibians that a similar condition exists. The eggs pass down through the oviducts and out of the body before being fertilized, and the sperms are discharged directly into the water, usually over the eggs just after they have been laid, as in most fishes, or as they are leaving the body, as in the frog.

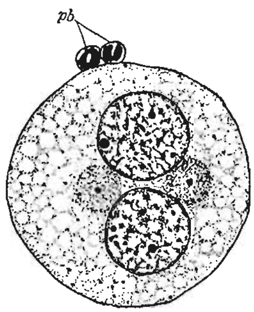


FIG. 127.—Fertilization in one of the roundworms (*Ascaris megalocephala*), the male and female nuclei in contact within the cytoplasm of the egg, × 1,000; *pb*, polar bodies.

In animals which do not live in the water, the means by which the gametes are brought together must necessarily be modified. Here the eggs are fertilized before they are laid. The sperms are introduced into the body of the female and swim to the eggs through fluids which are secreted for the purpose. Internal fertilization occurs in the insects and in a few other invertebrate groups, in a few fishes and amphibians, and in all reptiles, birds, and mammals. In some invertebrates the eggs are fertilized while still in the ovaries, but in the vertebrates fertilization occurs in the oviducts.

Parthenogenesis.—While, in the great majority of animals, an egg will not develop unless a sperm has united with it, in some animals, mainly invertebrates, an unfertilized egg may give rise to a new individual directly. This phenomenon is known as *parthenogenesis*. It occurs, for example, in a group of microscopic aquatic forms called rotifers, in certain small crustaceans, and in such insects as plant lice or aphids, and among ants, bees, and wasps (Fig.

128). Sometimes no males are produced for many generations, and in some cases there are apparently no males at all. In the bees and related insects (Fig. 129) the female lays

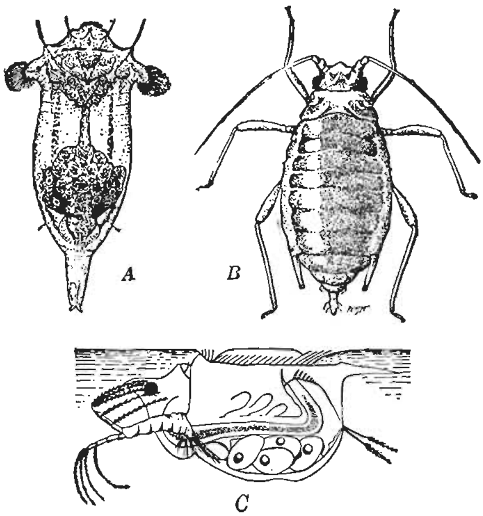
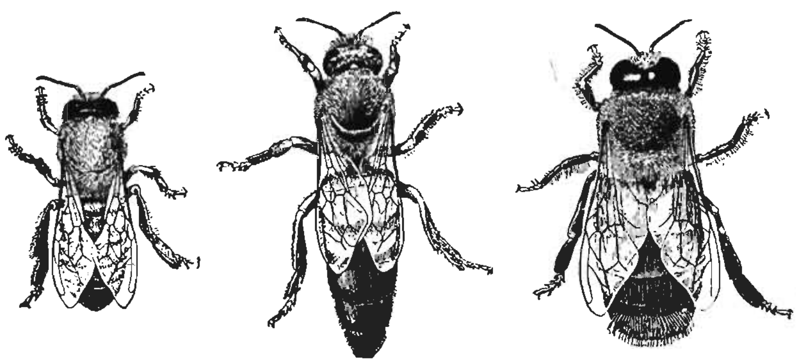


FIG. 128.—Parthenogenetic animals; *A*, a rotifer; *B*, an aphid; *C*, a crustacean (*From Shull, "Heredity," McGraw-Hill Book Company, Inc., A, after Harring; B after Webster; C, after Storch; by permission.*)



Worker Queen Drone

FIG. 129.—Honeybee, × 2. (*From Phillips, U. S. Department of Agriculture Farmer's Bulletin* 447.)

both fertilized and unfertilized eggs, the former always developing into *queens* (fertile females) and *workers* (sterile females), the latter into *drones* (males).

Early Embryonic Stages.—In the development of the embryo from the zygote, we find that the early stages are

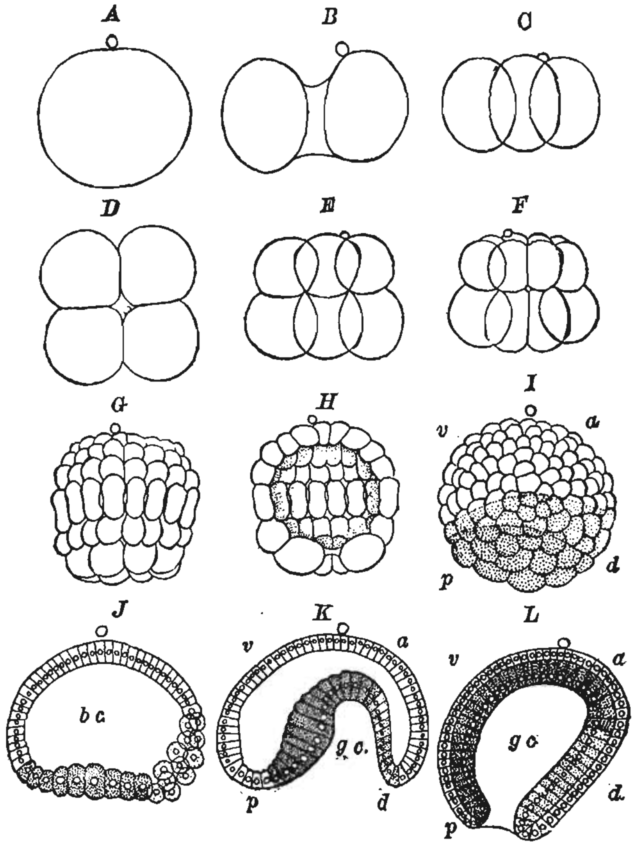


FIG. 130.—Successive stages in cleavage and gastrulation of *Amphioxus; A*, one cell; *B*, two cells; *C* and *D*, four cells; *E*, eight cells; *F*, sixteen cells; *G*, blastula stage of about ninety-six cells; *H*, section through same showing the cleavage cavity (blastocoele); *I*, blastula seen from the left side, showing three zones of cells, *viz.*, an upper clear zone of ectoderm, a middle (faintly shaded) zone of mesoderm, and a lower (deeply shaded) zone of endoderm cells; *J*, section through same showing these three types of cells; *K* and *L*, successive stages in the infolding of the endoderm. *a*, anterior; *p*, posterior; *v*, ventral; *d*, dorsal; *bc*, blastocoele; *gc*, gastrocoele. (*From Conklin, "Heredity and Environment," Princeton University Press, A-H, after Hatschek; by permission.*)

essentially similar in all metazoans, the differences which occur being mostly in details. This development we shall follow in a very general way, using as an illustration the lancelet (*Amphioxus*), a very primitive chordate (Fig. 130). Very shortly after fertilization has taken place, the zygote divides to form two cells which remain together. Each of these then undergoes a division in a plane at right angles to the first one, and four cells are formed. Then each cell divides in the third plane, resulting in the formation of eight cells. These early stages in the development of an individual are called *cleavage stages*. The process of cell division continues until a small spherical mass of cells is built up, and at the same time a central cavity appears which is termed the *cleavage cavity* (or *blastocoele*). The embryo is now said to be in the *blastula* stage, a blastula being merely a hollow sphere consisting of a single layer of cells surrounding a cavity.

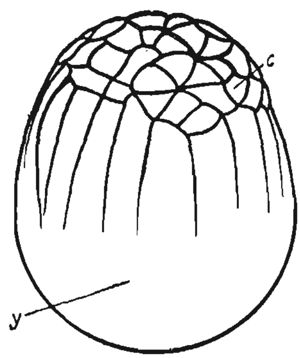


FIG. 131.—Cleavage in the egg of the gar pike (*Lepidosteus*), about 5 hours after fertilization. The yolk-laden half of the egg remains undivided. (*From Shull, LaRue, and Ruthven, "Principles of Animal Biology," McGraw-Hill Book Company, Inc., after Eycleschymer; by permission.*)

The above account applies especially to the development of eggs in which the yolk is evenly distributed. In cases where a large amount of yolk is massed at one end of the egg, the cleavage divisions do not extend the entire length of the embryo, but the portion with the yolk remains undivided (Fig. 131).

Gastrulation.—Following the formation of the blastula, a very important phase of development occurs (Fig. 130). The cells on one side of the embryo, which ordinarily are slightly larger than the others, begin to bulge inward, or invaginate, and this process continues until the lower and upper cells are in contact and the cleavage cavity is obliterated. The embryo is now called a *gastrula*. The new cavity formed by the process of gastrulation is known as the *archenteron* (or *gastrocoele*), while the opening at one end of the embryo is the *blastopore*. The outer layer of cells comprises the *ectoderm*, the inner layer the *endoderm*.

As our study of the hydra has clearly shown, some animals go no farther in their development than the gastrula stage. Both the sponges and coelenterates have only two layers of cells surrounding a single cavity which communicates with the outside by one opening. Of course, many minor modifications in this fundamental plan arise, such as the development of tentacles in the hydra, but these are special features related to the life habits of the animal and which enable it to carry on an independent existence. The most important fact to remember concerning the two lowest groups of metazoans is that they remain permanently in the gastrula stage of development.

In the higher animal groups, the gastrula now elongates somewhat, and further changes take place. The most important of these are concerned with the formation of the mesoderm and coelom.

Mesoderm and Coelom Formation.—In all metazoans, except the sponges and coelenterates, there now arises between the two primary layers of cells a third layer called the *mesoderm*, which may be derived from the ectoderm, endoderm, or both. Another important feature of embryonic development is the differentiation of the archenteron into a coelom and an enteron, the former developing outside of the latter. As has been seen, a coelom is characteristic of all metazoans except the sponges, coelenterates, and flatworms. The methods of mesoderm and coelom formation vary greatly among the different groups of metazoans, but these details are not important. A common method is shown in Fig. 132. Here the mesoderm is seen to arise from the endoderm by the formation of a pair of lateral pouches which becomes cut off, the archenteron thus giving rise to the coelom (surrounded by mesoderm) and the enteron (surrounded by endoderm).

The embryo of the lancelet at this stage of development also shows the way in which the central nervous system of the chordates arises, *viz.*, as a dorsal infolding of the ectoderm, the edges of which unite to form a tube. The notochord is seen to arise as a dorsal outgrowth from the endoderm. This structure, it will be recalled, appears in the embryogeny of all chordates, but is persistent throughout life only in the lowest members of the group (see pp. 144–145).

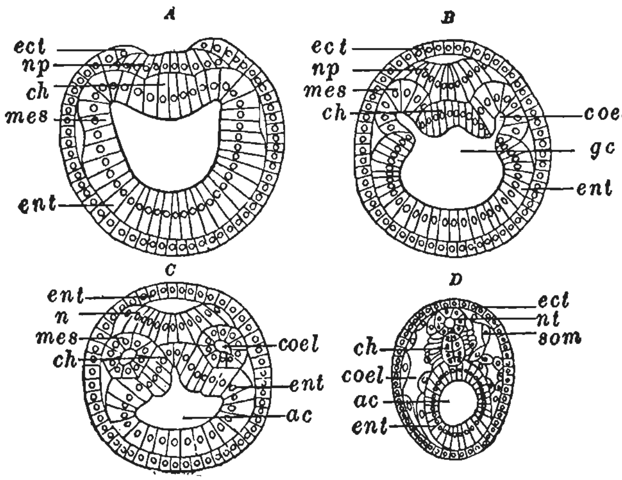


FIG. 132.—Cross-sections of older embryos of *Amphioxus* in successive stages of development, showing the formation of coelom and mesoderm; *ect*, ectoderm; *ent*, endoderm; *mes*, mesoderm; *np*, neural plate, *nt*, neural tube; *ch*, notochord; *gc*, gastrocoele; *coel*, coelom; *ac*, enteron or alimentary canal. (*From Conklin, "Heredity and Environment," Princeton University Press; by permission.*)

Later Development.—The further growth of the embryo is complex and subject to great variation among the higher metazoan groups. Up to this point there is little or no differentiation between the cells of the embryo, no specialized tissues being formed as yet. In the subsequent development, however, each of the three primary cell layers gives rise to certain definite sets of tissues. These are, in part, as follows: The ectoderm gives rise to the outer part of the skin, to certain superficial appendages (such as scales, hair, feathers, nails, etc.), and to the entire nervous system. The endoderm forms the lining of the digestive and respiratory tracts. The mesoderm gives rise to the muscles, connective and supporting tissues, blood vessels, the blood itself, and most of the other tissues of the body. Nearly all of the organs of the adult animal are composed of cells derived from more than one of the primary cell layers of the embryo.

It is a remarkable fact that animals so diverse in their adult stages as an earthworm, starfish, frog, and mammal should begin their development in essentially the same way and follow a similar sequence of stages. Minor variations are many, especially beyond the earliest stages, but the main features of development are constant. It is only in the later course of embryogeny—in the formation of organs—that a great deal of diversity arises.

Oviparity and Viviparity.—In animals with external fertilization, the embryo necessarily develops outside the

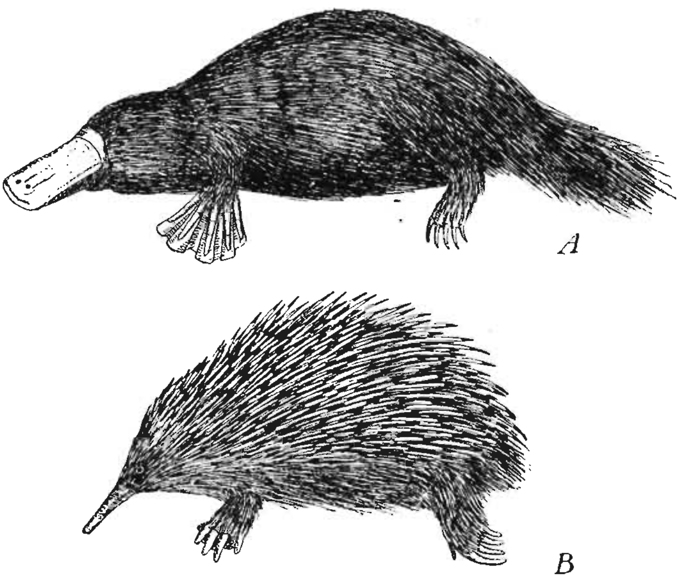


Fig. 133.—Egg-laying mammals; *A*, Duckbill (*Ornithorhynchus*); *B*, Spiny ant eater (*Echidna*).

body. Where fertilization is internal, however, the embryo may develop within the body, as in mammals, or outside, as in birds and most reptiles. In the two latter groups fertilization occurs before the shell is formed, and so when the "egg" is laid, the embryo has already started to develop. The large amount of reserve food present is entirely consumed by the embryo during the course of its development. Animals in which the embryo develops outside the body are said to be *oviparous*, regardless of whether fertilization is external or internal. Except in a very few cases, the invertebrates, fishes, amphibians, and reptiles are oviparous, while the birds are oviparous without exception. Nearly all of the mammals, on the other hand, are *viviparous*, which means that the embryo develops within the body, deriving its nourishment by direct absorption from the maternal tissues. There are only two egg-laying mammals known: the duckbill or platypus (*Ornithorhynchus*) and the spiny anteater (*Echidna*), both natives of Australia (Fig. 133). These forms are the most primitive mammals in existence, for not only are they oviparous, but they have a cloaca, an organ characteristic of amphibians, reptiles, and birds, but absent in all other mammals.

The following table is a convenient summary of the relations discussed above.

Group	Fertilization external or internal	Oviparous or viviparous
Invertebrates	Mostly external	Mostly oviparous
Fishes	Mostly external	Mostly oviparous
Amphibians	Mostly external	Mostly oviparous
Reptiles	Internal in all cases	Mostly oviparous
Birds	Internal in all cases	Oviparous in all cases
Mammals	Internal in all cases	Mostly viviparous

Intrauterine Development.—The nourishment of the mammalian embryo is a matter which deserves further consideration. The general features of the female reproductive system of vertebrates have been illustrated by the frog, and it has been learned that the ripe eggs escape from the pair of ovaries, enter the open ends of the oviducts, and pass downward to the uteri where they are temporarily stored (see pp. 133–134). In mammals the uterus is similarly an enlargement of the oviduct. There may be either two separate uteri (as in most rodents), the uteri may be fused only at their lower ends (as in carnivores and many ungulates), or the fusion may be complete, resulting in a single undivided uterus (as in man and other primates).

Fertilization occurs in the oviduct, the zygote passing down into the uterus where the embryo undergoes its development. At first the embryo uses up the food previously stored in the egg, but soon another source of nourishment becomes necessary. This is obtained from the mother by means of an organic attachment between the embryo and the uterus (Fig. 134). There is formed a

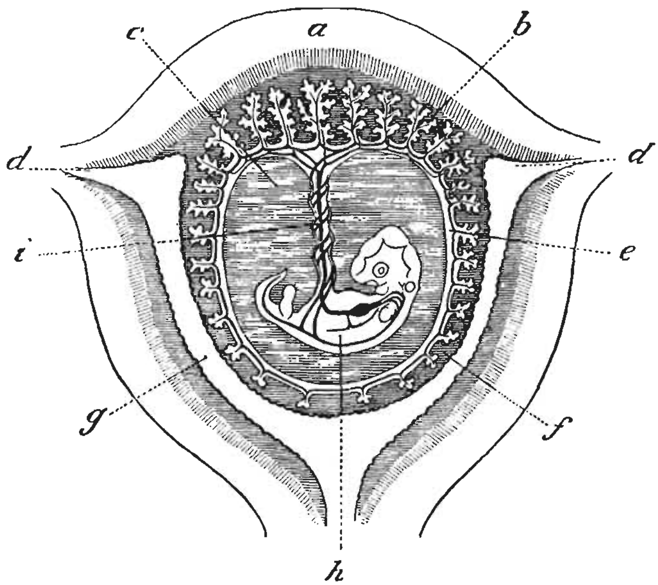


FIG. 134.—Diagrammatic section of human uterus with young embryo; *a*, dorsal wall of uterus; *b*, placenta; *c*, fluid-filled cavity surrounding embryo; *d*, lower ends of oviducts (Fallopian tubes); *e*, embryonic membranes; *f*, uterine tissue; *g*, uterine cavity; *h*, embryo; *i*, umbilical cord with blood vessels. (*From Woodruff, "Foundations of Biology," copyright 1922 by The Macmillan Company; reprinted by permission.*)

disk-shaped organ, called the *placenta*, which consists of both maternal and embryonic tissues. It is firmly attached to the wall of the uterus and connected with the embryo by means of the *umbilical cord*. Food and oxygen are brought to the placenta by the maternal blood vessels, and pass to the embryonic tissues by osmosis. The blood vessels of the embryo extend the length of the umbilical cord and into the placenta. They not only absorb nourishment and oxygen from the maternal circulation, but give back carbon dioxide and other waste products.

The above facts make it clear that the embryo is essentially a parasite in the body of the mother. It should be distinctly understood, however, that the blood vessels of the mother and of the embryo are entirely separate from each other, and consequently no blood passes between them. All the blood cells of the embryo, like all of its other tissues, have been derived directly from the zygote. There is merely an osmotic movement through the placenta of food and oxygen from mother to embryo and of waste products in the opposite direction. There are also no nerve connections and, consequently, there is no way in which the mental state of the mother—her thoughts, desires, or fears—can influence the unborn offspring.

Larval Stages.—Until the individual becomes independent of the mother or of the nourishment contained in the egg, it is an embryo. When it is born or hatched, as the case may be, it may be fairly well developed and thus show a general resemblance to the adult parents, or it may be very immature and very unlike the parents. For example, when a grasshopper's egg hatches, the young individual is unmistakably a little grasshopper, but a butterfly's egg hatches into a worm-like caterpillar, an individual which bears practically no resemblance to the adult insect (Fig. 135). In all cases similar to the latter, the young is called a *larva.* Many other insects pass through a larval stage. In the butterflies and moths the young are called *caterpillars;* in the beetles, *grubs;* and in the flies, bees, wasps, and ants, *maggots.* These insects live for a relatively long time in the larval stage, and usually consume large quantities of food during this period. Then they go into a resting condition, called the *pupa* stage, in which further development takes place. Finally they emerge as full-fledged, active adults.

Among vertebrates it is only the amphibians which exhibit a larval stage in development. A tadpole is really a larva, leading an independent existence as it gradually develops toward the adult condition. Some of the salamanders do not go beyond the larval stage, but remain aquatic throughout life. The transformation of a larva into an adult is known as a *metamorphosis*.

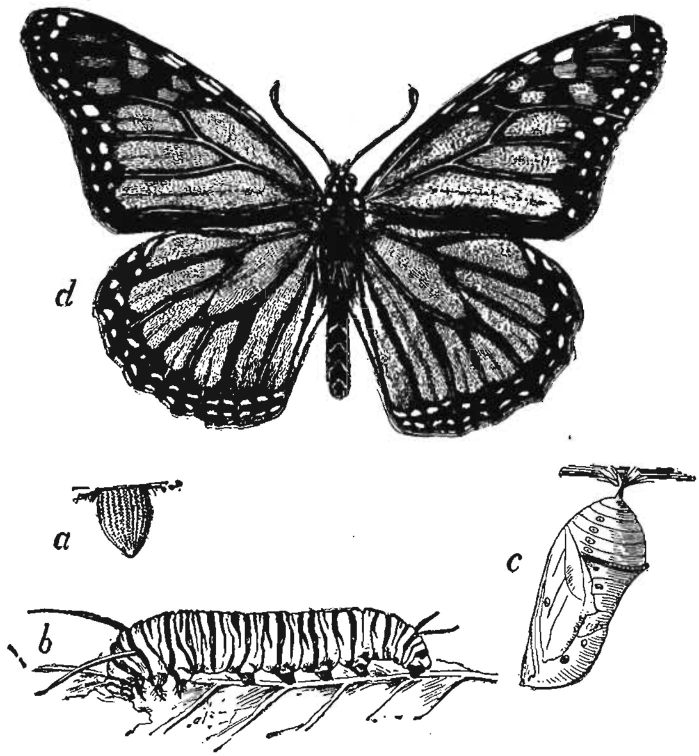


FIG. 135.—Metamorphosis of the monarch butterfly (*Anosia plexippus*); *a*, egg; *b*, larva; *c*, pupa; *d*, adult. (*From Jordan and Kellogg, "Evolution and Animal Life," D. Appleton & Company, New York; by permission.*)

Parental Care.—In most invertebrates and in nearly all vertebrates belonging to the three lower groups—fishes, amphibians, and reptiles—the eggs are laid without any further attention being given them by the parents. When the young are hatched they must shift for themselves. As might be expected, great numbers of eggs and young are eaten by other animals or destroyed by other deleterious external agents. Consequently, in the lower groups, it is necessary that enormous numbers of eggs be produced, because few offspring reach maturity. In most of the birds and mammals, on the other hand, relatively few young are produced, but they are so protected that a much greater proportion survives.

In most birds the eggs are incubated by one or both of the parents, the heat of the body being essential to the growth of the embryo, and, of course, in the mammals the relation of

FIG. 136.—Nest of ruffed grouse.

the mother to the unborn young is much more intimate. The young of most birds and mammals are very helpless at birth, and cannot live without parental care. Thus, in all of our common songbirds the young are born blind, without feathers, and unable to walk or fly. They have to be raised in a nest of elaborate construction, and be fed and protected by the parents. In such birds as gulls, snipe, ducks, grouse, quail, domestic fowls, etc., prenatal development goes much farther and when hatched the young are provided with a covering of down, have eyes, can walk, and need little or no parental care. Some of these birds make no pretense at nest building, merely depositing their eggs on the ground (Fig. 136); others build a very crude nest which serves only to hold the eggs. A few birds do not even incubate their eggs, relying for heat upon some external source.

The young of mammals similarly exhibit various degrees of dependence upon the parents. For example, mice are born in a very helpless condition, while new-born guinea pigs are much more mature and are soon independent of parental care. In all mammals the fact that the young are nourished by the mother's milk brings about a relation between parent and offspring which is absent in the lower groups. In fact, the long period of dependence of the human young upon the mother, both before and after birth, is regarded as having been a very potent factor in the evolution of the higher mental faculties and of social organization.

CHAPTER XIII

PHYSICAL BASIS OF HEREDITY

All of the characteristics of an organism, both structural and functional, arise from the interaction of two influences: *heredity* and *environment*. Their relation to each other, and the relative importance of each in the development of an individual, are problems of great interest, especially in their application to man. For the present, however, we shall confine our attention to the great internal influence—heredity—reserving for subsequent chapters a consideration of the part which external factors play in determining the individual and racial constitution of organisms.

The fact that characters are transmitted through successive generations is self-evident. When a comparison is made between an individual and its parents, in a great many respects a marked similarity may be seen. This resemblance is not accidental, but due to the direct transmission from one generation to the next of a material substance (chromatin) containing the possibilities for directing the development of the individual along certain definite lines. Thus the characters which an organism comes to have are largely predetermined by its ancestry, and the reappearance of parental characters in the progeny is due to an actual organic continuity between successive generations.

While offspring tend to develop characters like those of their parents, there are always a number of differences between them. In general, "like begets like," but likeness is never complete. Every individual is unique, especially with respect to details. Fundamental similarity is the rule among organisms related by descent, but individual variability is everywhere apparent. Some of the differences between parents and their offspring are due to environmental influences, but usually most of them, like most of the resemblances, are due to heredity. Certain hereditary variations may represent new combinations of parental characters, while others may be due to the reappearance of ancestral characters which were latent in the parents. Thus an individual may differ from both of its parents in a given particular, but resemble one or more of its grandparents or even a more remote ancestor. These facts make it clear that differences, as well as resemblances, may be inherited, and that a parent may transmit characters which he himself does not manifest, but, due to his inheritance, possesses in a latent condition.

The biological science of *genetics*, one of the most interesting fields of modern scientific study, deals with the resemblances and differences exhibited by organisms which are related by descent. It is concerned not only with the known facts and principles of heredity, but seeks to arrive at an ultimate understanding, so far as is possible, of all problems concerned with hereditary transmission. Like other fundamental scientific generalizations, the laws of heredity are essentially the same in all living things, and so what is learned from a study of one kind of organism may be applied to others.

Uniparental Inheritance.—Whère reproduction is asexual, or where it is sexual but either self-fertilization or parthenogenesis regularly occurs, it is evident that an individual has only one parent. In such cases there is always practically complete resemblance between the parent and its offspring. For example, if a cutting taken from a grape vine is planted, it will produce exactly the same kind of grapes as if it had been left to grow as part of the original vine. Here the offspring is merely a detached portion of the parent, composed of precisely the same kind of protoplasm, and thus the complete hereditary resemblance between them is explained. The slight amount of variability which does occur among related individuals which are propagated asexually, or by repeated self-fertilization, arises for the most part under the influence of the environment. The above facts make it clear that where inheritance is uniparental, an individual transmits all of its hereditary characters to all of its offspring, and consequently the latter show not only almost perfect resemblance to the parent, but to one another.

Biparental Inheritance.—In all cases where sexual reproduction involving two different individuals occurs, a very different situation prevails from that described above. Here every individual is strictly biparental in origin. It arises as a cell formed by the fusion of two gametes, each coming from a different parent. Even though the egg ordinarily is immensely larger than the sperm, *both parents are equally potent in transmitting* hereditary characters.[1] In biparental inheritance an individual inherits some of its peculiarities from one parent and some from the other, but neither parent transmits all of its hereditary characteristics to any one of its offspring. Consequently, biparental inheritance results in a much greater degree of variability among offspring of the same parents than does uniparental inheritance, for each of the progeny represents a different combination of ancestral characteristics.[2] Thus, from the standpoint of heredity, an individual must be regarded, not as a unit, but as an aggregation of innumerable independently heritable characters which happened to have been brought together when the individual came into existence as a zygote, and which will later become separated and redistributed in various ways to its own offspring.

The Hereditary Bridge.—Since the only material contribution which each parent makes to its offspring is a gamete, it necessarily follows that this single cell carries the parent's entire hereditary contribution. This means that the zygote, formed through the act of fertilization, must

[1] This is because the physical basis of heredity is contained in the nucleus, as will be seen later.

[2] The only exception occurs in the special case of identical twins, but here the two individuals are produced by fission from a single zygote, and so have the same inheritance. Thus their resemblance, amounting to practical identity, is explained (see also p. 190).

contain all of the potentialities for the complete development of the new individual. All of the organism's inherent capacities are present in the zygote, having been brought together by the fusion of the two gametes. It is apparent, therefore, that because the gametes are the sole means of maintaining organic continuity between successive generations, they are the conveyors of the heritage.

It should be kept in mind that an organism's inheritance is the sum of its innate capacities. When it is said that characteristics or traits are inherited, we are speaking figuratively. It is obvious that a child cannot inherit any of its parents' actual peculiarities, as these belong to the parents. What it does inherit is something present in the gametes which *represents* characters. It inherits potentialities—capacities for developing along some predetermined line.

Vegetative or Somatic Mitosis.—The phenomena of hereditary transmission are closely associated with the process of cell division. When a cell gives rise to two new cells, they derive from it not only their living substance, but also their inheritance, that is, their capacity to develop in a definite way. Thus it is necessary to consider briefly, first the mechanism of cell division, and then certain matters closely associated with it.

In all multicellular organisms, growth takes place by the formation of new cells from those already present. In general, growth presents three overlapping phases, as follows: (1) A multiplication of cells occurs by *cell division;* (2) this is followed by a limited amount of *cell enlargement;* (3) finally, *cell differentiation* takes place, a particular kind of tissue being formed. We shall be concerned here only with the first phase of growth. Cell division in plants is confined largely to root tips, buds, and to the cambium of roots and stems. In animals it is most active in embryos, but continues in all parts of the body until the adult stage is reached. Then it is limited principally to groups of unspecialized cells found in most tissues which replenish wornout or injured cells.

Except in a few rare cases, cells divide by a complex process called *mitosis* in which the nucleus is conspicuously involved. It is essentially similar in both plants and animals. Figure 137 shows a series of stages in vegetative

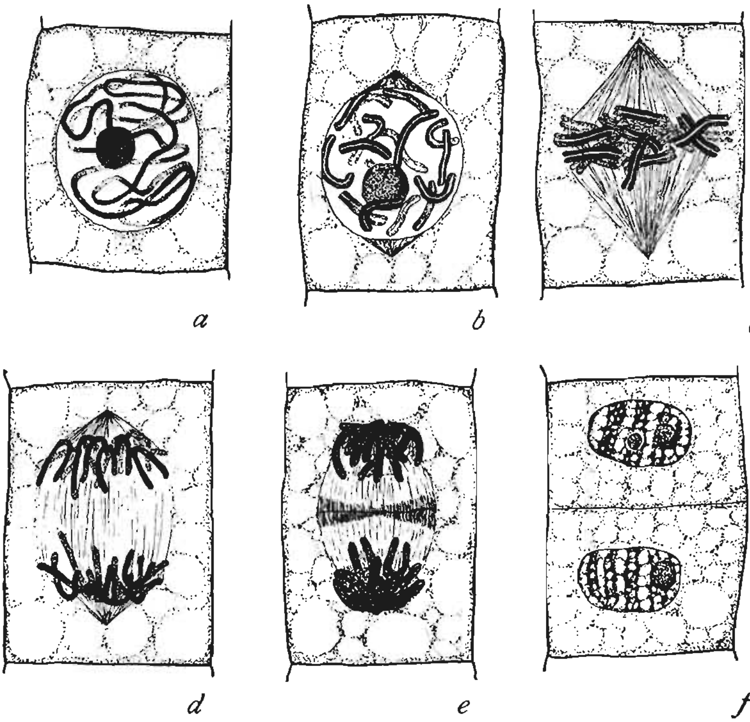


FIG. 137.—Successive stages in cell division as seen in a root tip of onion (*Allium cepa*), × 1,400. (For cells in the resting condition, see Fig. 3); *a*, organization of chromatin into a thread; *b*, formation of chromosomes and appearance of spindle fibers; *c*, bipolar spindle organized and chromosomes arranged at equator, each chromosome being longitudinally split; *d*, separation of daughter chromosomes; *e*, arrival of daughter chromosomes at poles of spindle and beginning of cell-wall formation; *f*, organization of daughter nuclei and completion of cell-wall formation.

mitosis drawn from a root tip; these should be carefully studied in connection with the following account.

When a cell is about to divide, the chromatin of its nucleus condenses to form a long, slender, coiled thread, which, after becoming shorter and thicker, segments transversely into a definite number of rod-like pieces called *chromosomes.*[1] Two groups of delicate fibers now appear in the cytoplasm at opposite poles of the nucleus, each group radiating inward from its own common center. Meanwhile, the nuclear membrane and the nucleolus gradually disappear, and the fibers meet to form a bipolar spindle. At the equator of the spindle the chromosomes become arranged in a plane perpendicular to its long axis.

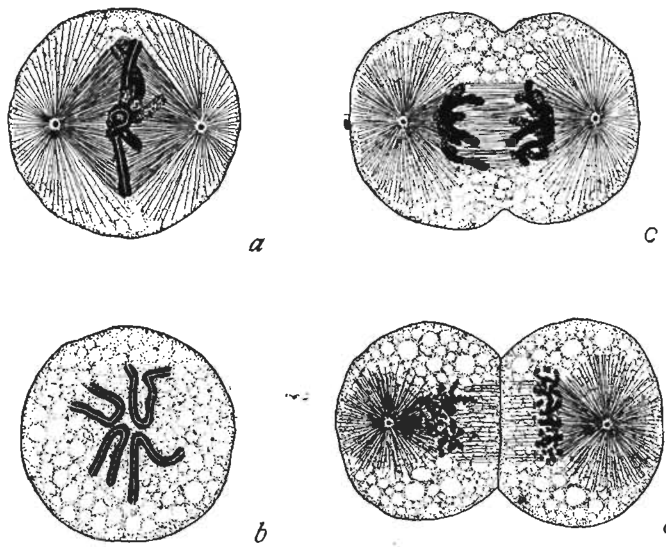


FIG. 138.—Fertilized egg of a roundworm (*Ascaris megalocephala*) undergoing cleavage, × 1,000; *a*, bipolar spindle with split chromosomes arranged at equator (note the conspicuous centrosomes with radiations extending from them); *b*, polar view of same stage, showing four chromosomes, the diploid number; *c*, separation of the two groups of daughter chromosomes and cleavage of the cytoplasm; *d*, completion of cell-division.

By this time each chromosome has become longitudinally split into two equal parts. Some of the spindle fibers are attached to the chromosomes, while others extend from pole to pole. The halves of each split chromosome are now drawn to opposite poles of the spindle, apparently by a shortening of the spindle fibers which are attached to them. Upon reaching the poles, each group of chromosomes becomes organized to form a new nucleus. At the same

[1] In many cases, the chromosomes are distinct from the beginning, no thread being formed.

time, a new cell wall forms on the spindle midway between the two daughter nuclei, thus dividing the cell into two parts.

In animal cells, and in some of the lower plants, there are usually a pair of minute spherical bodies called *centrosomes* which are concerned with the formation of the spindle (Fig. 138). From these bodies fiber-like radiations extend in all directions, some of which form the bipolar spindle. Another conspicuous difference between most plant and animals cells is that in the latter the cytoplasm divides by a simple constriction rather than by the formation of a cell wall.

Mitosis represents an elaborate mechanism for securing an exactly equal distribution of chromatin to each daughter nucleus, and thus for preserving a constant number of chromosomes throughout all the body cells of the organism. With few exceptions, the number of chromosomes is definite and constant for each species of plant and animal, as the following examples show:

Plants	Animals
Garden pea, 14	Hydra, 12
Onion, 16	Domestic fowl, 18
Indian corn, 20	Frog, 26
Lily, 24	Earthworm, 32
Tobacco, 48	Man, 48
Cotton, 56	Horse, 48
Shield fern, 144	Crayfish, 200

Significance of Fertilization.—When two gametes unite, the zygote receives two complete sets of chromosomes, one from the sperm and the other from the egg. Then when the zygote undergoes its first division, each chromosome splits longitudinally, as in an ordinary mitosis, the halves passing to opposite poles of the spindle. As a result, each of the daughter nuclei has a double set of chromosomes, half of which are paternal, half maternal (Figs. 138 and 139). Because this behavior is repeated with each subsequent somatic cell division, the double chromosome number is transmitted to all of the cells of the embryo and eventually to all of the somatic (or vegetative) cells of the adult organism. Thus, each body cell contains a descendant of every chromosome which was present in the zygote; that is, it contains a definite number of *pairs* of chromosomes, one member of each pair being paternal in origin, the other maternal. For this reason, the members of each pair are said to be *homologous.* The body cells, having a double set of chromosomes, are designated as *diploid,* the gametes, with a single set, as *haploid.* It is important to under-

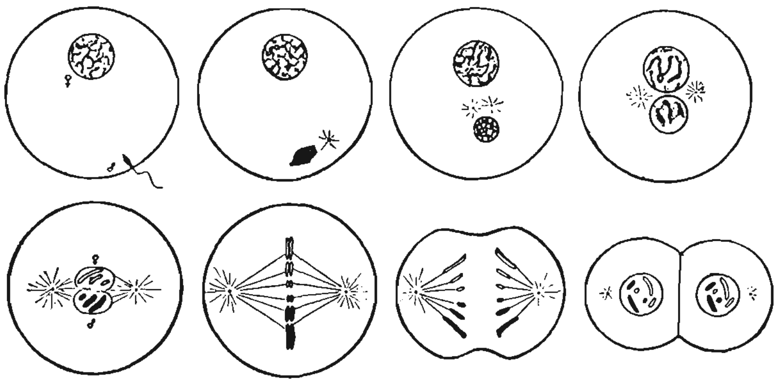


FIG. 139.—Diagram of fertilization and cleavage. Each of the daughter cells arising from the zygote has a double set of chromosomes, one set having been contributed by the sperm, the other by the egg. *(From Sharp, "Introduction to Cytology," McGraw-Hill Book Company, Inc., by permission.)*

stand how this reduction in chromosome number is brought about.

Reduction of Chromosomes.—It has already been stated that sperms and eggs in animals are derived from unspecialized cells, called *germ cells,* and not from differentiated somatic tissues (see pp. 159–160). In some cases, it is possible to identify in a very early stage of embryonic development a primordial germ cell from which all of the germ cells will be derived (Fig. 140). All of the other cells of the embryo become specialized to form somatic tissues and take no part in reproduction. As development proceeds, the germ cells undergo a period of multiplication, dividing by the regular mitotic process. When the animal has reached maturity, some of them ripen, and this ripening process, called *maturation*, in most cases continues throughout the lifetime of the individual.[1]

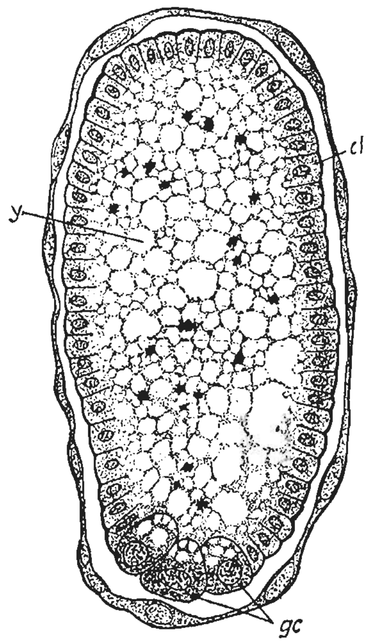


FIG. 140.—An early stage in the development of the embryo of the fly *Miastor*, showing the somatic cells (*cl*) at the periphery and the germ cells (*gc*) at the posterior end, the latter having arisen from a single primordial germ cell. The yolk (*y*) is in the center. (*From Shull, LaRue, and Ruthven, "Principles of Animal Biology," McGraw-Hill Book Company, Inc., after Hegner.*)

Reduction in the number of chromosomes takes place in animals directly in connection with the formation of gametes (Fig. 141). Maturation of the germ cells involves two cell divisions; that is, each unripe germ cell produces four potential gametes. Like all of the somatic cells, the unripe germ cells are diploid. At the time of the first cell division, the chromosomes, after being formed from the chromatin of the resting nucleus, come together in pairs and remain in contact until the bipolar spindle is formed. This unique pairing of the chromosomes, which takes place at no other time in the life history, is called *synapsis*. It is apparent that there are half as many chromosome pairs as there were separate chromosomes in the unripe germ cell. Now, unlike what takes place in an ordinary mitosis, the chromosomes do

[1] In the human male, the germ cells continue to multiply during childhood, but in the female the period of multiplication ends before birth. During childhood the female germ cells increase in size and accumulate reserve food, but otherwise remain dormant. The liberation of ripe eggs from the ovaries, called *ovulation*, normally takes place only between the ages of thirteen and forty-five, and it is supposed that one or two eggs are extruded every 28 days. It is at the time of ovulation that the germ cells undergo maturation.

not split longitudinally, but, instead, the members of each pair merely separate, one going to one pole and one to the other. As a consequence, the two daughter nuclei have half as many chromosomes as the parent cell. Then

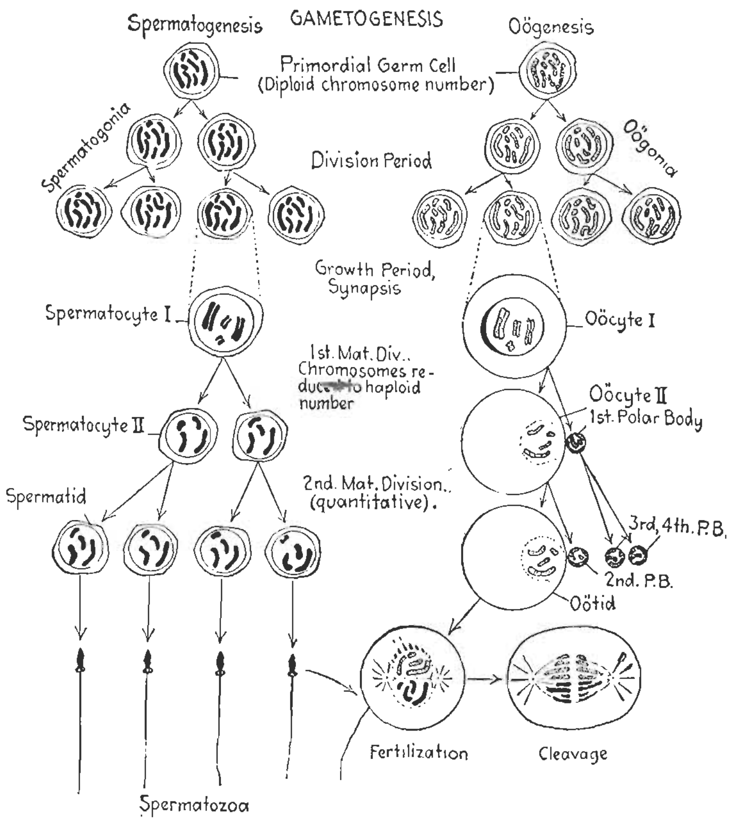


Fig. 141.—Diagram showing the behavior of the chromosomes in the multiplication and maturation of the germ cells, in fertilization, and in cleavage. During the multiplication period, the primordial germ cells, by an indefinite number of cell divisions (only two of which are shown in the diagram), give rise to a large number of unripe germ cells (called *spermatogonia* in the male and *oogonia* in the female), all of which are diploid. (*From Wieman, "General Zoology," McGraw-Hill Book Company, Inc., by permission.*)

follows a second cell division, but this time a regular mitosis occurs, involving a longitudinal splitting of each chromosome, so that four haploid cells are formed. It should be borne in mind that each of these four cells contains descendants of only one member of each pair of chromosomes which were present in the unripe germ cell.

While the essential features of maturation, as outlined above, are the same in both sexes, a slight difference occurs in the result. In the male, each of the four cells derived from the unripe germ cell becomes transformed into a functional sperm. In the female, however, the first division results in two cells which are very unequal in size, and when the larger one divides a second time the same thing occurs. Thus each unripe female germ cell gives rise to one large cell and three very small ones. The large cell, which is the egg, alone is functional, while the three small *polar bodies*, as they are called, soon degenerate. In this way, one cell gets all the yolk which otherwise would be equally divided among four.

Grouping of Chromosomes in Gametes.—Two very important details concerning the process of reduction remain to be considered. (1) At synapsis the pairing of chromosomes is not promiscuous, but involves homologous chromosomes; that is, each pair consists of one paternal and one maternal chromosome. In other words, one which originally came from the sperm of the preceding generation pairs with one contributed by the egg. (2) When separation occurs, it is entirely a matter of chance to which pole either member of a pair of homologous chromosomes passes, since this depends upon the position in which each chromosome happens to lie, with reference to its mate, when they are lined up on the equator of the spindle preparatory to separation. Consequently, there are various possible assortments of paternal and maternal chromosomes in each gamete, but only one member of each pair of homologous chromosomes can be present.

To illustrate, in an animal where the diploid number of chromosomes is six, the paternal chromosomes may be designated as A, B, and C, the maternal ones as a, b, and c (Fig. 142). All of the somatic cells and unripe germ cells contain three kinds of chromosomes and two chromosomes of each kind, one paternal and the other maternal. In synapsis, *A* pairs with *a*, *B* with *b*, and *C* with *c*. Since the gametes can have only one member of each pair of homologous chromosomes, it follows that there can be eight possible kinds of gametes formed in approximately equal numbers. In other words, there are eight different ways in which the three kinds of chromosomes may be grouped: *ABC*, *ABc*, *AbC*, *Abc*, *aBC*, *aBc*, *abC*, and *abc*.

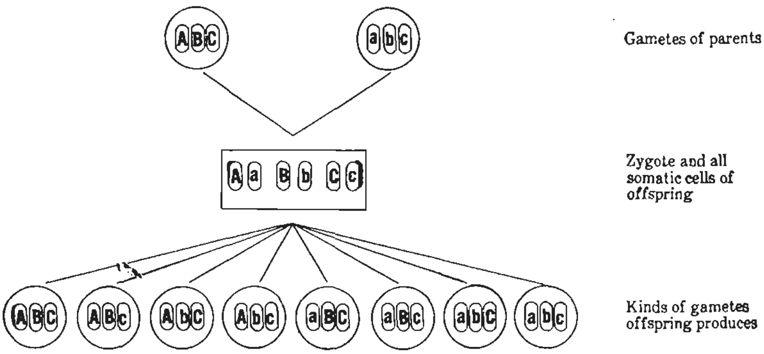


FIG. 142.—Diagram illustrating the distribution of paternal and maternal chromosomes to the gametes formed by the offspring. The number of different kinds of gametes depends upon the number of chromosomes.

That the number of possible kinds of gametes formed depends on the number of chromosomes is shown below:

Pairs of chromosomes in unripe germ cells	2	3	4	5	6
Number of possible kinds of gametes	4	8	16	32	64, etc.

In the case of man, where the number of chromosome pairs is 24, the possible number of different kinds of gametes is 16,777,216. It is evident that the chances of any two gametes carrying the same assortment of chromosomes is exceedingly small.

Significance of Alternating Generations.—Alternation of generations in plants involves more than the production of two kinds of plant bodies in the life history (see pp. 99–100). It introduces definite haploid and diploid individuals, the gametophyte representing the former and the sporophyte the latter. The zygote, formed by the fusion of two gametes, is the first cell to have the diploid number of chromosomes. This number is then transmitted to all of the cells of the sporophyte. When spores are formed, however, the reduction of chromosomes takes place, so that each spore is haploid. When the spore germinates, the haploid number is carried over to all of the cells of the gametophyte, including the gametes. In animals, reduction of chromosomes always occurs directly in connection with the formation of gametes, but in the higher plants (in some of the thallophytes and in all of the three higher groups) it takes place when spores are produced, the spores always being formed in groups of four.

Summary.—Because the number of chromosomes is doubled in fertilization, a reduction must occur before or when gametes are formed in order that the number of chromosomes can remain constant through successive generations of diploid individuals. Assuming that the chromosomes are the bearers of hereditary elements, the association of paternal and maternal chromosomes in fertilization and their subsequent separation at the time of reduction according to the law of chance, explain four things: (1) why inheritance in all organisms which reproduce by sex is biparental (except in cases of self-fertilization and parthenogenesis); (2) why the male and female are equally potent in transmitting their hereditary characters; (3) why the same combination of paternal and maternal chromosomes do not enter into the formation of every gamete which an individual produces; (4) why fertilization effects innumerable new combinations of ancestral characters.

Determination of Sex.—In the fruit fly (*Drosophila melanogaster*), an insect which has been extensively studied by geneticists, each of the body cells has eight chromosomes (Figs. 143 and 144). There are two pairs of large curved chromosomes, one pair of very small ones, and one pair of straight chromosomes about two-thirds as long as the curved ones. A slight visible difference exists between the sexes in that, in the male, the end of one of the straight chromosomes is slightly hooked. This is known as the

y-chromosome, while the straight ones, of which the male has one and the female two, are called x-chromosomes.

Since all of the body cells and unripe germ cells of the female have a pair of x-chromosomes, it follows that, in the formation of gametes, each egg will contain a single

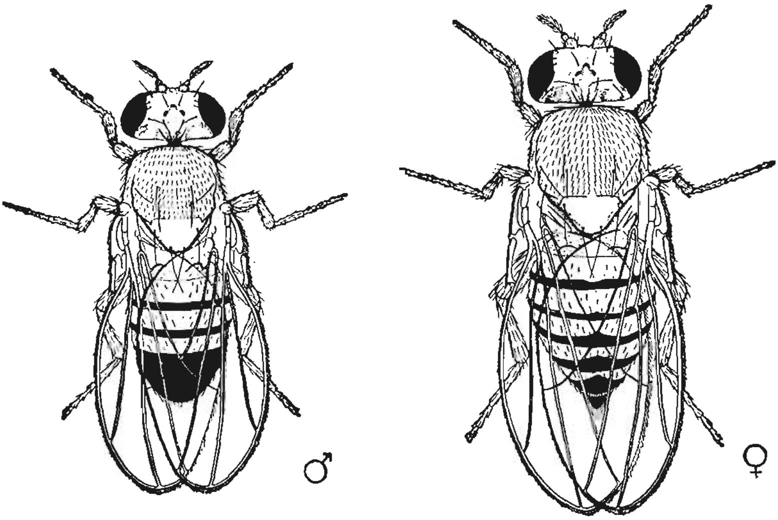


FIG. 143.—Male and female fruit flies (*Drosophila melanogaster*). (*From Morgan, "Physical Basis of Heredity," J. B. Lippincott Company, by permission.*)

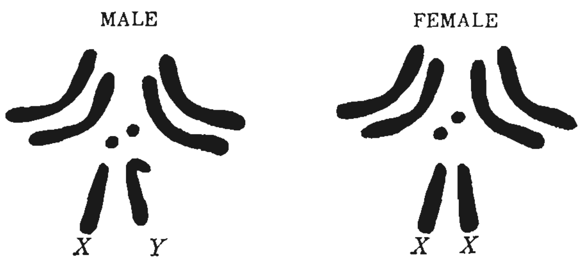


FIG. 144.—Diagram showing the chromosomes which occur in all of the somatic cells of the fruit fly (*Drosophila melanogaster*). In the male an X- and a Y-chromosome correspond to the pair of X-chromosomes of the female. (*After Morgan.*)

x-chromosome. The male, on the other hand, will form two kinds of sperms: half of them will have an x-chromosome and half a y-chromosome. If an egg is fertilized by a sperm of the first type, the result is an xx-zygote; if fertilized by the other kind of sperm an xy-zygote is formed

(Fig. 145). The former develops into a female, the latter into a male. Because the two kinds of sperms are equally numerous, random mating of gametes will produce as many *xx*- as *xy*-zygotes, and thus the number of male and female offspring will tend to be equally numerous.

There are a great many other kinds of animals in which a *y*-chromosome has been identified in the male. In some cases it differs from its mate in size rather than shape, or there may not be any apparent difference at all. Occasionally, the *y*-chromosome is absent, the *x*-chromosome in the body cells of the male then being unpaired. For

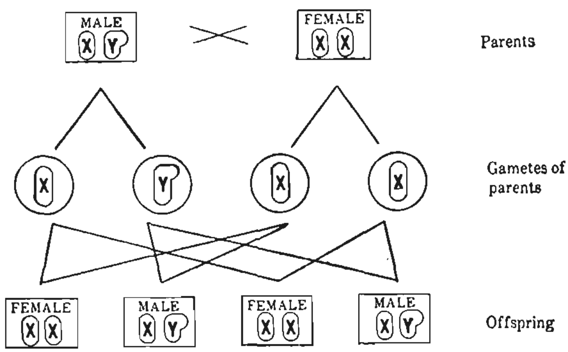


FIG. 145.—Diagram showing the mechanism of sex determination in the fruit fly. The sperms are of two kinds, the eggs all alike. The sex of any one of the offspring depends upon the kind of sperm which entered into the formation of the zygote from which it has developed.

example, in the squash bug (*Anasa tristis*), the female has 22 chromosomes, the male only 21, the missing one being the *y*-chromosome. Consequently, all of the eggs and half of the sperms have 11 (10 plus an *x*-chromosome), the rest of the sperms having only 10. For this reason (and for others), it seems probable that it is not the presence of the *y*-chromosome in the zygote which causes it to develop into a male individual, but the presence of only a single *x*-chromosome.

In the case of man there has been a diversity of opinion in regard to the total number of chromosomes and to the difference between the male and female sets. It now seems certain, however, as a result of very careful recent investigations, that both sexes have 48 as the diploid number, but in the male the *y*-chromosome is very small.

While most cases of sex determination follow the same scheme as that described above, in a few animals the situation is slightly different. For example, in birds and in moths it has been found that it is the female which produces two kinds of gametes, those of the male being all alike. Consequently, here sex is determined by the chromosome equipment of the egg, but the mechanism is exactly the same as where the male is heterogametic.

In only a few plants where male and female individuals are differentiated has a visible chromosome difference been discovered. There is reason to believe, however, that future research will show that the causes underlying sex determination in plants and animals are practically the same.

That the sex of an individual is determined at the time of fertilization is substantiated by the fact that identical twins are always of the same sex. Human twins are of two sorts: those coming from two different zygotes (*fraternal twins*), and those which arise from the splitting of an embryo in an early stage of cleavage (*identical twins*). The former may or may not be of the same sex, and are no more alike in their hereditary characters than ordinary brothers and sisters born at different times. The latter, however, are invariably of the same sex and are alike in regard to all of their other hereditary characters. This is because they have exactly the same chromosome equipment, both individuals having arisen from the same zygote.

CHAPTER XIV

MENDELIAN LAWS OF HEREDITY

The foundation for our present knowledge of heredity was laid by the work of Gregor Mendel (1822–1884, Fig. 146), an Austrian monk. He crossed certain varieties of garden peas, and discovered that their differentiating characters are inherited in accordance with definite mathematical laws. Mendel published his results in 1866,

FIG. 146.—Gregor Mendel, 1822–1884.

but, unfortunately, they were not appreciated by the scientific world until 1900, when they were rediscovered and announced. Other biologists have since found that the laws of heredity which Mendel discovered apply to all other organisms, including man, and are thus of fundamental importance.

Two plants are crossed by taking pollen from one and applying it to the pistils of the other. In most cases, the unripe stamens of the second flower must first be removed so that self-pollination cannot occur. The seeds produced as a result of a cross, when planted, give rise to *hybrids*. A hybrid is simply an organism whose parents represent two distinctly different types of individuals. They may belong to the same species or to different species, but, ordinarily,

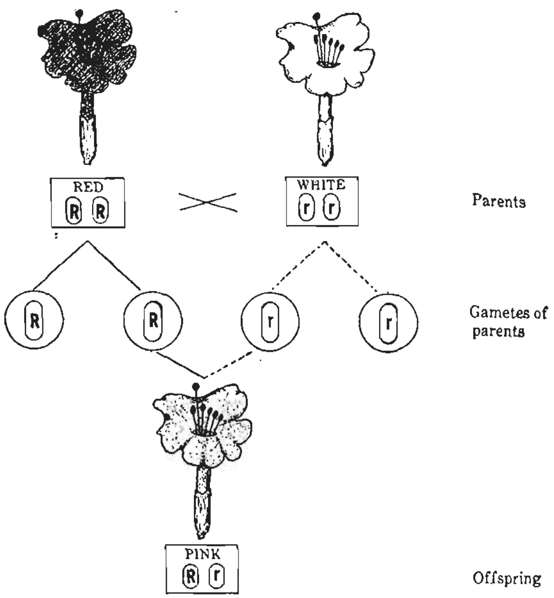


FIG. 147.—Diagram of a cross between a red-flowered and a white-flowered four-o'clock (*Mirabilis*), showing the history of the chromosomes carrying the factors for red (*R*) and for white (*r*) flower color. The hybrids are intermediate between the parents.

individuals which are not rather closely related cannot be crossed; that is, no offspring will result. As an illustration of Mendel's first law, for the sake of simplicity, we shall choose a different kind of plant than the one with which he experimented.

Principle of Segregation.—A four-o'clock (*Mirabilis Jalapa*) having red flowers is crossed with a white-flowered plant. When the seeds are planted they give rise to hybrids with pink flowers (Fig. 147). If the reciprocal cross is made, that is, white with red (pollen being taken from the former instead of the latter), the result is exactly the same. In either case, the hybrid plants are intermediate between the parents. When these hybrids are allowed to pollinate themselves, however, the resulting seeds give rise to three kinds of individuals in the ratio of 1:2:1; that is, approximately 25 per cent of the plants will have red flowers, 50 per cent pink, and 25 per cent white (Fig. 148).

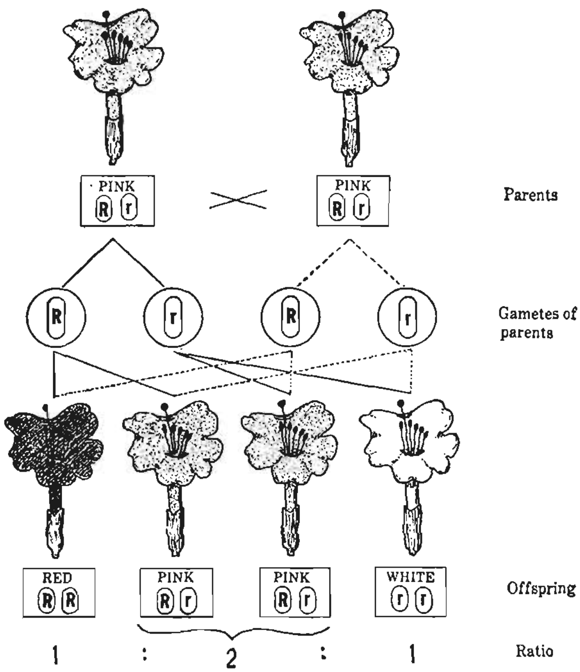


FIG. 148.—The principle of segregation. Diagram illustrating the results of interbreeding pink-flowered four-o'clocks. The 1:2:1 ratio arises from the fact that the hybrid parents produce two kinds of gametes.

The red-flowered plants derived from the pink parents "breed true," that is, when self-pollinated they produce only plants with red flowers. Similarly the white-flowered plants give rise only to white-flowered progeny. The pink-flowered individuals, however, always produce offspring in the ratio of 1 red: 2 pink: 1 white. Thus pink-flowered four-o'clocks are always hybrids, and 50 per cent of their offspring are likewise hybrids.

A similar case among animals is seen in Andalusian poultry. There are three kinds of Andalusian fowls: black, white, and speckled (called "blue"). Blacks crossed with whites, or *vice versa*, always give rise to blue offspring, but when blue fowls are interbred, the result is 1 black: 2 blue: 1 white, on the average. Blue Andalusians are hybrids exactly comparable in their behavior to pink-flowered four-o'clocks.

Hereditary Elements.—The explanation of Mendel's principle of segregation is seen in the behavior of the chromosomes during fertilization and reduction (Fig. 147). Hereditary characters are represented in all of the cells of an organism by invisible units or elements called *factors* (or *genes*). For instance, all of the gametes produced by a red four-o'clock carry a factor for red flower color on one of their chromosomes. This factor may be designated as *R*. When an egg and a sperm unite, each carrying an *R* factor, the zygote receives two *R* factors and all of the vegetative cells derived from it the same. Hence the plant, designated *RR*, will have red flowers. Similarly, all of the gametes of the white four-o'clock have a factor for white flower color (or lack the red factor, which amounts to the same thing), and so the plant is represented by the formula *rr*.

When a red four-o'clock is crossed with a white one, the zygote receives from one gamete a chromosome bearing an *R* factor, from the other a homologous chromosome having an *r* factor (Fig. 147). Thus the pink hybrid is designated *Rr* because all of its vegetative cells contain one factor for red (*R*) and one for white (*r*) flower color. Because homologous chromosomes always separate at reduction, the members of the pair of alternative factors must also separate and go to different cells. As a result, there are two different kinds of gametes (both eggs and sperms) formed by the hybrid in approximately equal numbers: half of them have only the *R* factor, half only the *r*. In other words, since a gamete can have only one member of each pair of homologous chromosomes, it can carry a factor for only one member of each pair of factors. This is the essential feature of

Mendel's first principle. "The units contributed by each parent separate in the germ-cells of the offspring without having had any influence on each other" (Morgan).

In regard to any given character, if both members of a pair of factors are the same, as in the red (*RR*) and white (*rr*) four-o'clocks, the individual is said to be *homozygous* for the character in question. But if the two factors in each body cell are different; that is, if they are contrasted or alternative in their relation to each other, as in the pink (*Rr*) four-o'clock, the individual is termed *heterozygous*.

Factor Combinations.—Pink-flowered four-o'clocks produce two kinds of sperms and two kinds of eggs, as stated above. When two pink plants are crossed, or self-pollination occurs, the gametes pair according to the law of chance; that is, there is a random mating of two kinds of sperms (*R* and *r*) with two kinds of eggs (*R* and *r*) (Fig. 148). This results in four possible combinations (*R* with *R*, *R* with *r*, *r* with *R*, and *r* with *r*) which occur in the same frequency; one is likely to occur as often as any other. Of these four possible gametic unions, two (*R* with *r* and *r* with *R*) give rise to the same kind of zygote (*Rr*), and thus the 1:2:1 ratio is explained. A careful study of Fig. 148 should make these points clear.

The situation just described is comparable to the simultaneous tossing of two coins. Referring to the two sides of the coin as head (*H*) and tail (*h*), out of 100 trials we would get approximately 25*HH*, 50*Hh*, and 25*hh*, because these combinations are governed entirely by the law of probability. It is evident that the 1:2:1 ratio is more closely approximated the greater the number of trials.

Back-crosses.—With red, white, and pink four-o'clocks, six different matings are possible, as follows:

Red (*RR*) × red (*RR*) → 100 per cent red (*RR*)
White (*rr*) × white (*rr*) → 100 per cent white (*rr*)
Red (*RR*) × white (*rr*) → 100 per cent pink (*Rr*)
Pink (*Rr*) × pink (*Rr*) → 25 per cent red (*RR*), 50 per cent pink (*Rr*), 25 per cent white (*rr*)
Pink (*Rr*) × red (*RR*) → 50 per cent red (*RR*), 50 per cent pink (*Rr*)
Pink (*Rr*) × white (*rr*) → 50 per cent pink (*Rr*), 50 per cent white (*rr*)

All of the above crosses have been considered except the last two, namely, those involving a pure (homozygous) and a hybrid (heterozygous) individual. These are called *back-crosses.* The gametes of the pure individual are all alike, but those of the hybrid are of two different kinds. Thus there are only two kinds of zygotes which can possibly be formed, and these must occur in the same frequency.

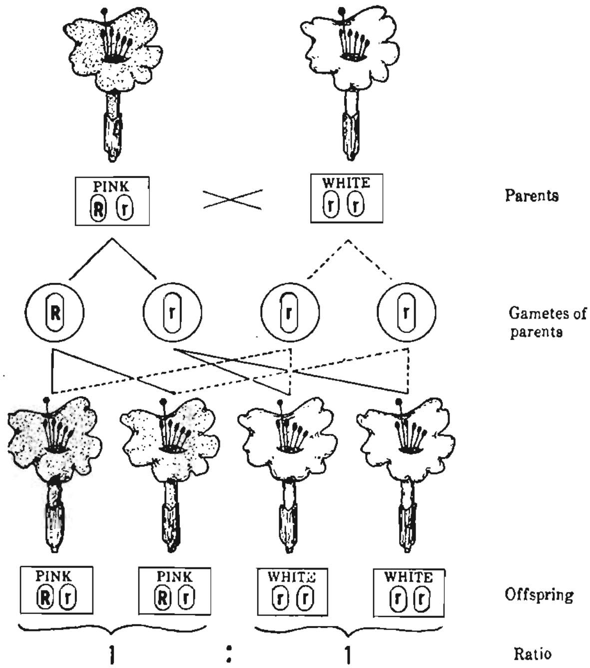


FIG. 149.—The back-cross. Diagram illustrating the results of crossing a pink-flowered with a white-flowered four-o'clock. Only one of the parents produces two kinds of gametes, thus resulting in a 1:1 ratio among the progeny.

That half of the offspring resemble one parent and half the other can be easily understood by reference to Fig. 149.

Dominant and Recessive Characters.—We are now ready to consider one of Mendel's own experiments with garden peas. If tall peas are crossed with dwarf peas, or *vice versa,* the resulting hybrids are all tall, not intermediate, but no shorter than the tall parent (Fig. 150). While factors for both characters are present in all of the plants

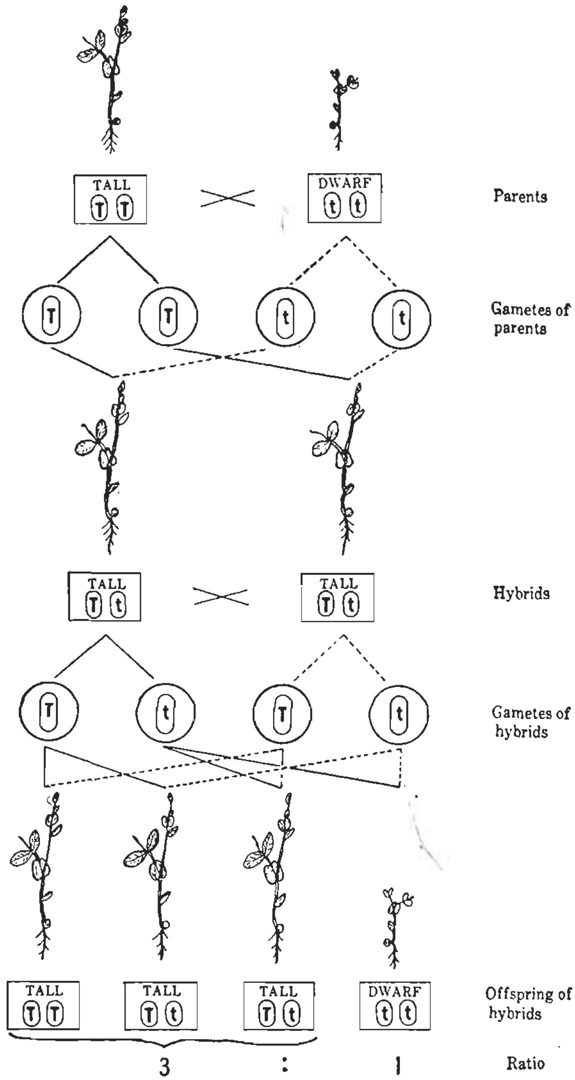


FIG. 150.—Dominant and recessive characters. Diagram of a cross between a tall and a dwarf pea, showing the history of the chromosomes carrying the factors for tallness (T) and for dwarfness (t). Because the hybrids are similar to the dominant parent, a 3:1 ratio results when they are interbred.

of the hybrid generation, one manifests itself to the total suppression of the other. In other words, one factor for tallness produces the same effect as though two factors were present. Mendel designated tallness the *dominant* character and dwarfness the *recessive*. Now when the tall hybrids are interbred (or allowed to self-pollinate), among the resulting progeny there are approximately three tall plants to every dwarf. Because the hybrids are visibly indistinguishable from the dominant parent, however, this 3:1 ratio is really only a modification of the 1:2:1 ratio, as Fig. 150 clearly shows.

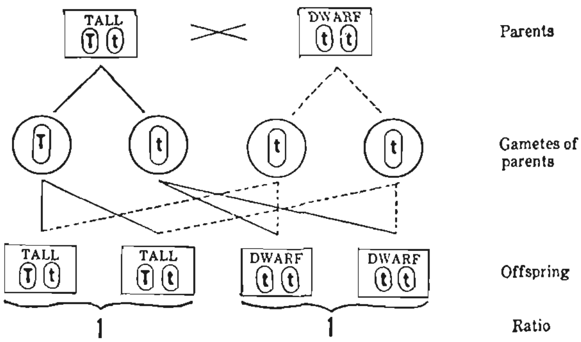


FIG. 151.—The back-cross where dominance occurs. Because the parent showing the dominant character is heterozygous, half of the offspring are recessives.

Thus, there are two kinds of tall individuals: pure (homozygous) tall (*TT*), and hybrid (heterozygous) tall (*Tt*), while the dwarfs (*tt*) necessarily are always pure. Although the pure and hybrid tall plants are similiar to each other on the basis of outward appearance, they do not have the same breeding possibilities. Where dominance occurs, it is always possible to tell whether an organism is homozygous or heterozygous for a given character by back-crossing it to an individual showing the contrasted recessive character. If homozygous, all of the offspring will exhibit the dominant character, but if heterozygous, only half of them will (Fig. 151).

Mendel experimented with other characters in peas, and found that purple flowers are dominant over white, yellow seeds over green, smooth seeds over wrinkled, etc. The phenomenon of dominance applies to the characters studied by Mendel and to many characters in other organisms, but probably does not apply to most hereditary characters. The principle of segregation, however, is fundamental and always holds true. The following list contains a few characters exhibiting dominance chosen from many which are known. It also shows how widely applicable are the laws of heredity discovered by Mendel:

Organism	Dominant character	Recessive character
Indian corn	Starchy endosperm	Sweet endosperm
	Black endosperm	White endosperm
	Yellow endosperm	White endosperm
Tomato	Red fruit	Yellow fruit
	Two-chambered fruit	Many-chambered fruit
Garden pea	Tall vine	Dwarf vine
	Colored flowers	White flowers
	Green pods	Yellow pods
	Yellow seeds	Green seeds
	Smooth seeds	Wrinkled seeds
Summer squash	White fruit	Yellow fruit
	Disk fruit-shape	Sphere fruit-shape
Fruit fly	Red eyes	White eyes
	Gray body	Black body
	Long wings	Vestigial wings
	Bar eye	Normal eye
Guinea pig	Rough coat	Smooth coat
	Black coat	White coat
	Short hair	Long hair
Domestic fowl	Pea comb	Single comb
	Rose comb	Single comb
	Feathered legs	Smooth legs
Sheep	White coat	Black coat
Cattle	Polled	Horned
	Black coat	Yellow coat

Principle of Free Assortment.—The cases of inheritance which thus far have been considered are comparatively simple, for in all of them the parents differ in regard to just one pair of contrasted characters. When crossed, they give rise to *monohybrids*. Mendel also crossed peas differing with respect to two pairs of contrasted characters, thus obtaining *dihybrids*, and as a result he discovered a second important principle. If a pea having yellow smooth seeds (*YYSS*) is crossed with one having green wrinkled seeds (*yyss*), all of the hybrids will have yellow smooth seeds (*YySs*) because both of these characters are dominant (Fig. 152). When these hybrids are interbred, however, four different kinds of individuals appear in approximately

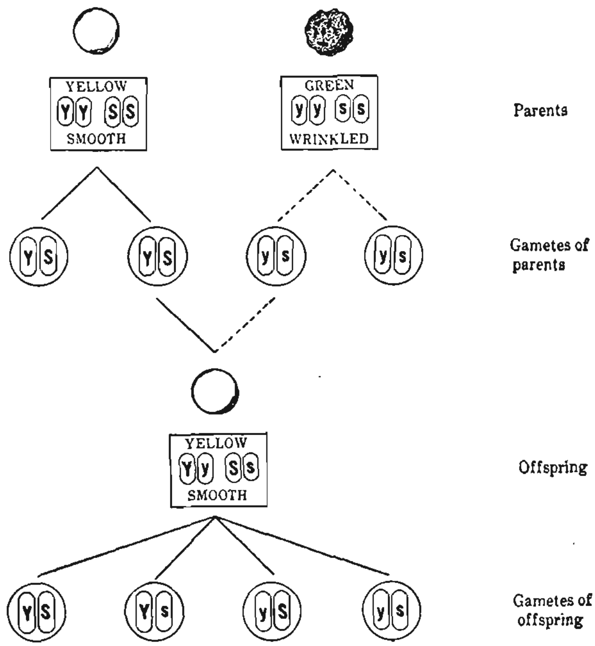


FIG. 152.—Principle of free assortment. Diagram of a cross between a yellow smooth and a green wrinkled pea. The two pairs of contrasted characters are represented by factors borne on two pairs of homologous chromosomes. The hybrid produces four different kinds of gametes.

the following proportions: 9 yellow smooth: 3 yellow wrinkled: 3 green smooth: 1 green wrinkled (Fig. 153). The fact that two of these combinations are new shows that the four characters are inherited independently of one another.

In order to understand how this ratio arises, each pair of characters must be considered separately. It is evident that the ratio of yellow peas to green ones must be 3:1 and of smooth peas to wrinkled ones the same. Therefore the number of peas which are both smooth and wrinkled is determined by multiplying the number of yellow peas by the number of smooth ones (3 × 3). Similarly, the number of yellow wrinkled is 3 × 1, of green smooth 3 × 1, and of green wrinkled 1 × 1.

By referring to Fig. 152, it can be seen that the factors *Y* (for yellow seeds) and *y* (for green seeds) are associated with one pair of homologous chromosomes in all of the vegeta-

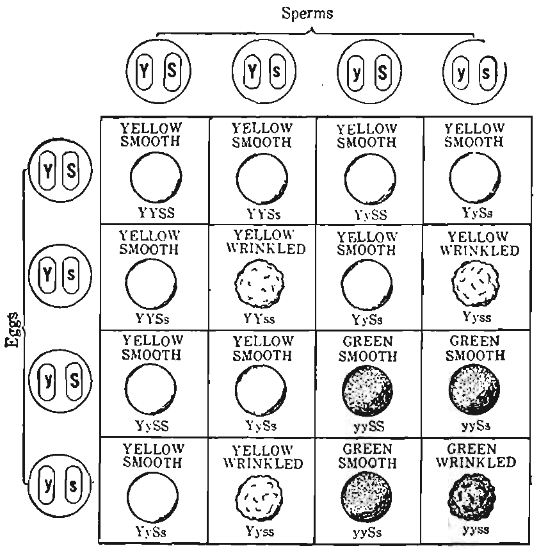


FIG. 153.—The dihybrid ratio. Diagram showing the 16 gametic unions resulting from random mating of four kinds of sperms with four kinds of eggs, giving rise to the phenotype ratio of 9:3:3:1.

tive cells of the hybrids, while the factors *S* (for smooth seeds) and *s* (for wrinkled seeds) are associated with another pair. Since, at the time of reduction, paternal and maternal chromosomes are distributed to the gametes independently of one another, there must also be *free assortment* of factors carried on different chromosome pairs. Consequently, the dihybrid peas produce four different kinds of gametes in approximately equal numbers, and each carries a different assortment of factors, as follows: *YS*, *Ys*, *yS*, and *ys*. When two dihybrids are crossed, random mating of gametes results in 16 possible unions, which, on the basis of outward appearance, fall into four classes (Fig. 153). While each class includes individuals which look alike, all do not have the same breeding possibilities. Thus there are four kinds of yellow smooth individuals, two kinds of yellow wrinkled, two kinds of green smooth, but just one green wrinkled. Individuals with the same hereditary formula are said to belong to the same *genotype*, while those which look alike, regardless of whether they have the same hereditary formula, belong to the same *phenotype*. Thus, from the dihybrid cross there are nine distinct genotypes, but only four phenotypes. These are given below. It should be noted that only 4 individuals out of the 16 are homozygous for both characters and, consequently, these alone will breed true.

Number of individuals	Genotype	Number of individuals	Phenotype
1	*YYSS*	9	Yellow smooth
2	*YYSs*		
2	*YySS*		
4	*YySs*		
2	*Yyss*	3	Yellow wrinkled
1	*YYss*		
2	*yySs*	3	Green smooth
1	*yySS*		
1	*yyss*	1	Green wrinkled
Total 16	9	16	4

The principle of free assortment may be illustrated among animals by an example chosen from the heredity of guinea pigs. These animals, like many other domesticated forms, may have either colored or white fur. White animals are called *albinos*. If a black guinea pig derived from a pure stock is mated with an albino, all of the offspring will be black, as colored fur is dominant to white. If the parents are alike in other respects, the simple monohybrid ratio of 3: 1 arises when the hybrids are interbred; but if the parents differ in another way, such as in regard to smoothness of coat, the offspring, when interbred, exhibit the dihybrid ratio. A rough or rosetted coat is

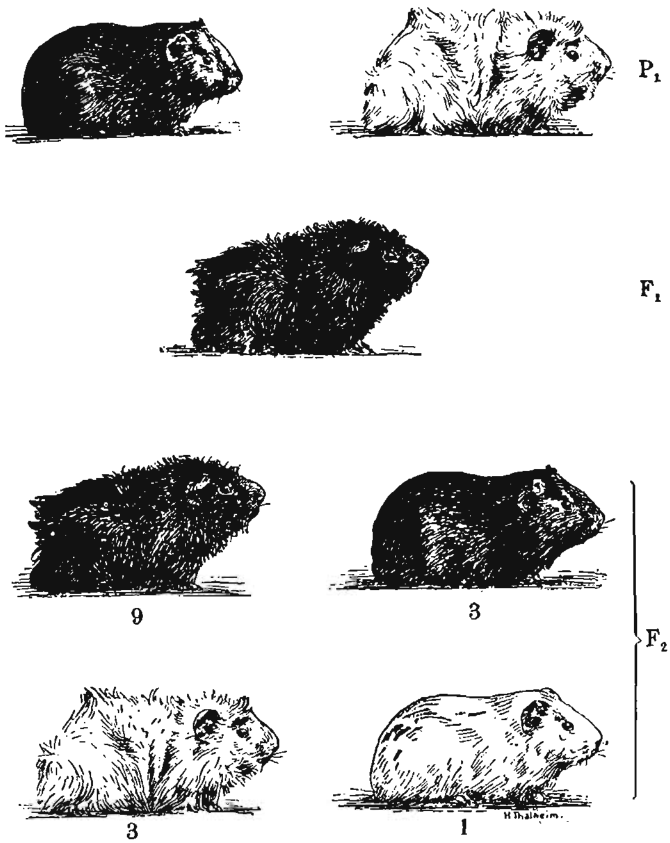


FIG. 154.—Results of crossing a smooth black with a rough white guinea pig. The hybrids (F_1) are rough black, and when interbred produce offspring in the ratio of 9 rough black: 3 smooth black: 3 rough white: 1 smooth white. (*From Baur, "Einführung in die experimentelle Vererbungslehre," Gebrüder Borntraeger, Berlin, after Castle; by permission.*)

dominant to the ordinary smooth coat. Thus, when a smooth black guinea pig (*rrBB*) is crossed with a rough albino (*RRbb*), the hybrid offspring will be rough black (*RrBb*), as each parent contributes one dominant and one recessive character. When these are interbred, four types appear among the progeny, approximately in the ratio of 9 rough black: 3 smooth black: 3 rough albino: 1 smooth albino (Fig. 154). The relations of these to one another are precisely the same as those of the four classes of peas shown in Fig. 153.

When there are three different pairs of contrasted characters, all showing dominance, and their factors are borne on three different sets of chromosomes, the resulting *trihybrid* produces eight different kinds of gametes. When two trihybrids are crossed, there are 64 different gametic unions possible, giving rise to the phenotype ratio of 27:9:9:9:3:3:3:1. In the case of 10 pairs of differentiating characters, the number of possible combinations is 1,048,-576. This gives some idea of the complexity of the hereditary mechanism. Furthermore, when it is realized that most individuals are heterozygous for many characters, we can appreciate why there is so much diversity among individuals of the same species, even among those as closely related as brother and sister.

Linkage.—Free assortment occurs where different sets of factors are associated with different chromosome pairs.

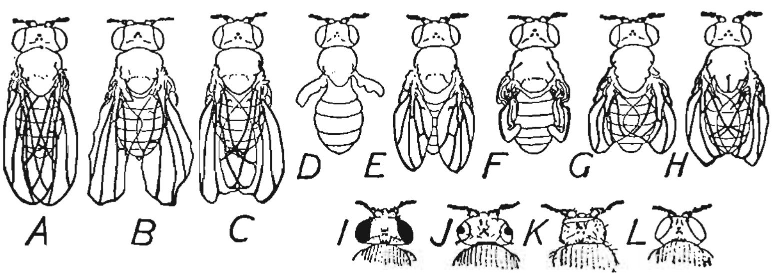


FIG. 155.—Some of the heritable variations which have arisen in the fruit fly (*Drosophila melanogaster*); *A*, normal wing; *B*, beaded wing; *C*, notch wing; *D*, vestigial wing; *E*, miniature wing; *F*, club wing; *G*, rudimentary wing; *H*, truncate wing; *I*, normal red eye; *J*, bar eye; *K*, eyeless; *L*, white eye. (*From Shull, LaRue, and Ruthven, after Morgan, et al.*)

There is a great deal of evidence, however, indicating that each chromosome bears not one, but many factors. This condition is called *linkage*. For example, in the fruit fly about 400 different characters have been studied, and yet the animal has only four pairs of chromosomes (Figs. 144 and 155). Where two factors are linked, that is, borne on

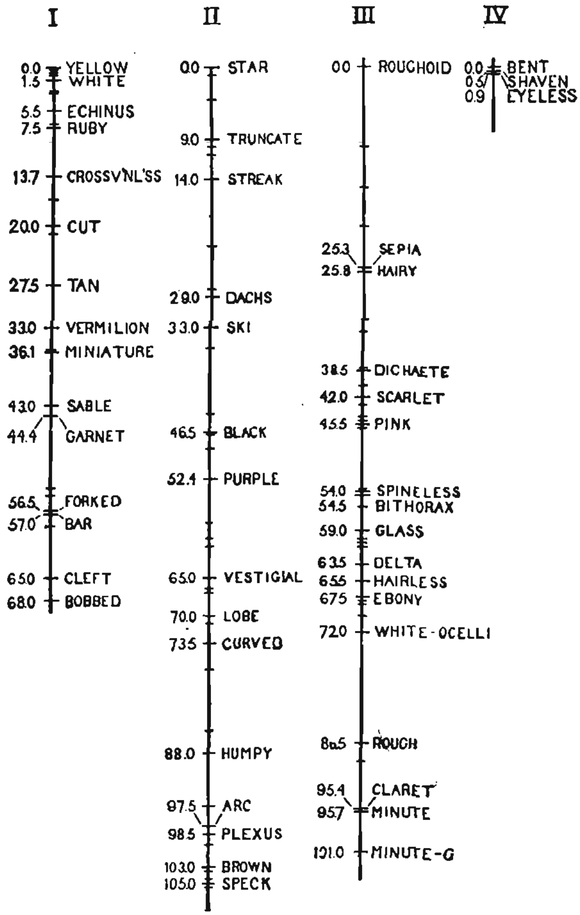


FIG. 156.—Chromosome map of *Drosophila melanogaster*, showing the location of some of the factors which have been studied. These fall into four groups, I, II, III, and IV, corresponding to the four pairs of chromosomes. The names indicate the characters in the fly with which these factors are associated; the numbers represent the distance of the locus of each factor from one end of the chromosome. (*From Morgan, "Evolution and Genetics," Princeton University Press, by permission.*)

the same chromosome, there is no free assortment, and so the monohybrid ratio results. Thus, in peas, if the factors yellow and smooth were borne on one chromosome, and green and wrinkled on another, under ordinary conditions[1] there could be no new combinations of characters, such as yellow wrinkled and green smooth. All yellow peas would be smooth and all green ones wrinkled.

Thus linked characters tend to be inherited together because their factors are carried by the same pair of chromosomes. It has been found, that in the fruit fly, all of the factors which have been studied fall into four groups corresponding to the four pairs of chromosomes (Fig. 156). While the factors in different groups show independent assortment, those in the same group show linkage. Moreover, there is considerable evidence indicating that the factors on each chromosome are arranged in a linear series. In fact, in the fruit fly it has even been possible to determine through hereditary behavior the relative position of the factors on each chromosome with reference to one another, as indicated in Fig. 156. This has been one of the outstanding accomplishments of the science of genetics.

Sex-linked Inheritance.—In many animals there are hereditary characters which are transmitted in a unique way. This is due to the fact that their factors are carried by the *x*-chromosomes. Such characters are termed *sex linked*. The inheritance of white eye color in the fruit fly is a well-known example.

When a male fruit fly with white eyes is mated with a red-eyed female, all of the offspring are red eyed, showing that red is the dominant character. When these individuals are interbred, however, all of the female progeny have red eyes, while half of the male are red eyed and half white eyed (Fig. 157). The typical monohybrid ratio of 3:1 appears, but invariably the white-eyed individuals are males. These results are easily understood if it is assumed that the factor for red eye color is carried by the *x*-chromosomes, and that the *y*-chromosome does not carry any factors.

[1] Due to a peculiarity in the behavior of the chromosomes at the time of reduction, called "crossing over," linked factors often become separated from one another.

When the reciprocal cross is made, that is, a red-eyed male mated with a white-eyed female, all of the sons have white eyes and all of the daughters red eyes (Fig. 158).

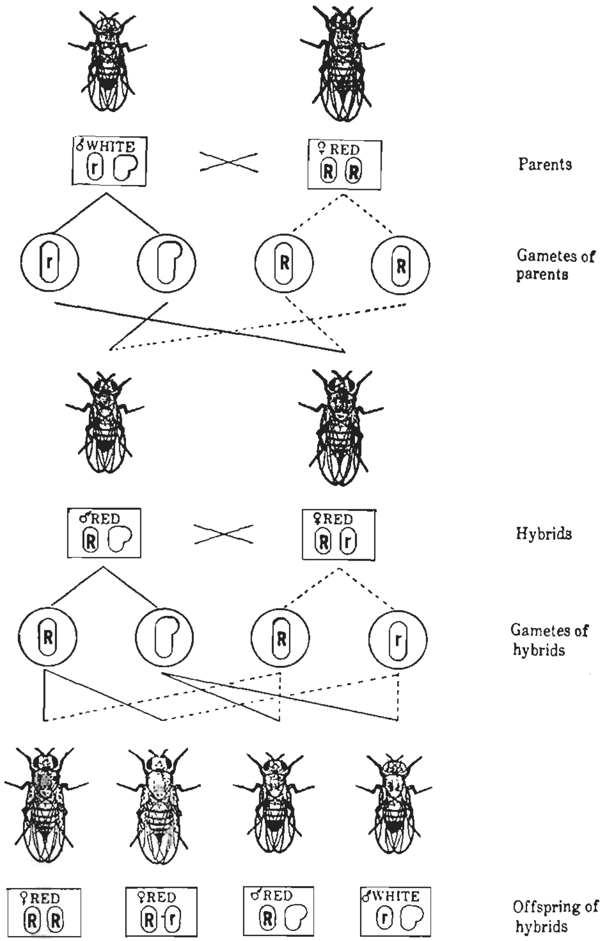


FIG. 157.—Diagram of a cross between a white-eyed male and a red-eyed female fruit fly, illustrating sex-linked inheritance. The factors for eye color are associated with the x-chromosomes. (*Adapted from Morgan.*)

But when these hybrids are interbred, their offspring fall into the following classes: 1 red-eyed female: 1 white-eyed female: 1 red-eyed male: 1 white-eyed male.

The type of sex linkage described above occurs in many other insects, in certain fishes and amphibians, in sheep, cats, man, and probably in most mammals. In butterflies

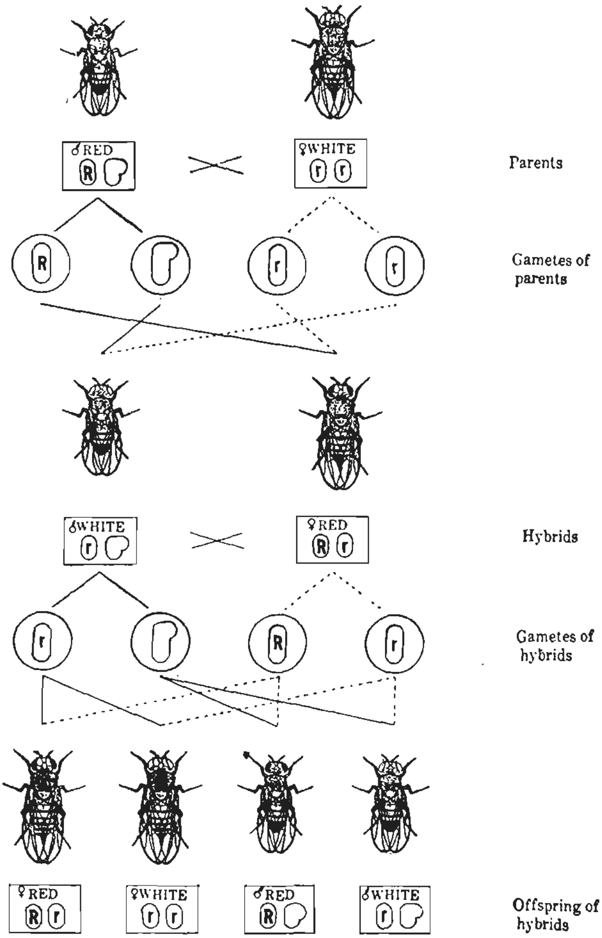


FIG. 158.—A red-eyed male crossed with a white-eyed female fruit fly, the reciprocal of the cross shown in Fig. 157. (*Adapted from Morgan.*)

and moths, in birds, and in some fishes, the inheritance of sex-linked characters is exactly the reverse, because here the male has two x-chromosomes, the female only one (see p. 190).

Color blindness in man is a sex-linked character which follows the same scheme of inheritance as white eye color in the fruit fly. Color blindness is recessive to its contrasted

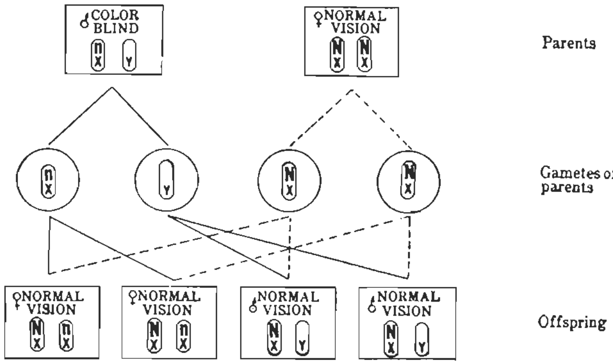


FIG. 159.—Diagram of the inheritance of human color blindness through the male. The offspring are all phenotypically normal, but the daughters are heterozygous for the defect.

character, normal vision. A color-blind man, mated to a normal woman, transmits a factor for the defect to all of his daughters, but to none of his sons (Fig. 159). Since the

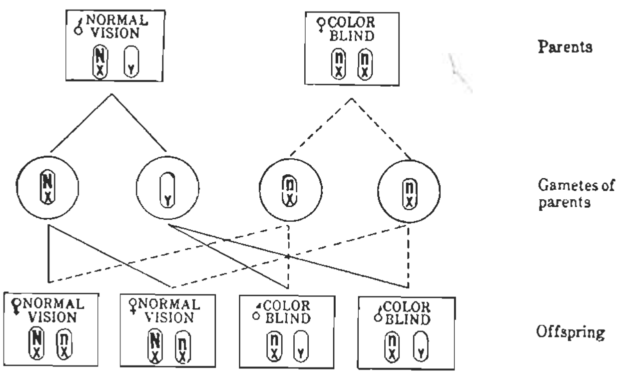


FIG. 160.—Diagram of the inheritance of human color blindness through the female. A color-blind woman has color-blind sons and normal daughters, but the latter are heterozygous for the defect.

character is recessive, none of the daughters are themselves color blind, but are merely heterozygous, having but one factor for the defect. Such women are called "carriers." A color-blind woman, on the other hand, mated to a normal man, transmits the defect to all of her sons (Fig. 160). Because the factor for color blindness is carred by the x-chromosome (the y-chromosome being not involved at all), males are either normal or actually color-blind, while females may be either normal, color blind, or heterozygous for the character. Color blindness in women is very rare, because it depends upon the mating of a color-blind man to a woman who is either herself color blind (homozygous) or a carrier for the defect (heterozygous), and this seldom happens.

CHAPTER XV

APPLICATION OF HEREDITARY PRINCIPLES

With the rediscovery of Mendel's laws in 1900, a great impetus was given to the study of heredity, and, as a result, a large mass of facts has been accumulating ever since. The mechanism of hereditary transmission has been studied in a great many organisms, and it has been found that the fundamental features of Mendelism are practically universal in their application. It should be understood, however, that heredity is a much more complex matter than our elementary consideration of it has indicated. For example, many characters are determined by several or many factors which interact with one another to produce a given result, while in other cases one factor may control the development of several characters. Another complication arises from the fact that the mode of expression of characters is often subject to environmental influences. Consequently, in an elementary course it is not possible to present more than a very general background of information pertaining to heredity, as has been done, or to touch upon its application to human interests except in a very superficial way.

PLANT AND ANIMAL BREEDING

The improvement of plants and animals must have started soon after primitive man began to raise crops and to bring wild animals under domestication. But although the art of breeding has been practiced from time immemorial, it has been on a scientific basis only since our modern knowledge of genetics has developed. Plant and animal breeding is an extensive subject which can be discussed here only in its barest outline, giving attention chiefly to the methods which modern scientific breeders use in developing improved races.

Variation.—Common observation demonstrates that all kinds of organisms show considerable diversity among themselves; in fact, no two individuals of any species are exactly alike in all respects. It is by reason of this fact of universal variability that it is possible for plants and animals to be improved under man's guidance. The differences between individuals are called *variations.* While it may seem that all variations are capable of being transmitted from parent to offspring, such is not the case, and consequently the existence of both heritable and non-heritable variations is recognized. To the latter class belong most differences which arise through the direct action of environmental influences and through use and disuse. While such induced changes may be profound, there is practically no evidence that they are transmitted to subsequent generations (see pp. 310–314). On the other hand, variations which are inherent—which are determined by the germinal constitution of the organism—are of course transmissible. It is only heritable variations which are important to the breeder, as they alone make racial improvement possible. Of the great host of characters in cultivated plants and domesticated animals which are determined largely by heredity, the following may be mentioned: vigor and rate of growth, yield, size and shape of parts, hardiness, color of flowers, quality of fruits, disease resistance, drought resistance, milk production in cattle, and egg production in poultry.

The multitudinous races of plants and animals which serve human needs have been developed by selection, hybridization, or a combination of the two. There are two methods of selection in common use: *mass culture* and *pedigree culture.*

Mass Culture.—This is a method of selection used only with plants. It is the oldest method of plant breeding, and, while it has been more or less replaced by other methods, it is still of considerable value. Mass culture involves breeding from a selected group of individuals, a group which varies in some desirable direction, such as greater yield, larger fruits, brighter flowers, etc. Seed is collected from these superior individuals and sowed *en masse*. The selection process is continued with each generation until an improved race of plants is developed. Mass culture has been widely used in the breeding of corn and cotton, and also of many other crop plants. While mass culture has certain advantages, its limitations should be kept in mind. These are as follows:

1. In most cases it is necessary to continue the process of selection indefinitely; otherwise the improved strain deteriorates.

2. Mass culture cannot produce new characters, but merely improves such characters as already exist.

3. It does not isolate the best individuals, but merely raises the average quality of a large group.

4. Selection is made entirely on the basis of outward appearance, which, in heterozygous individuals, is often deceptive, as has been seen.

5. The selected individuals, in many cases, owe their superior qualities to environmental factors, and such variations have no permanent value.

6. Mass culture is a slow method, the progress made in each generation being slight.

Pedigree Culture.—This method of breeding has long been applied to animals, but only rather recently to plants. It involves the selection of single plants, each of which is made the basis of a separate race. Seeds from each selected individual are planted in an isolated plot in order to prevent intercrossing. An exact record, or pedigree, is kept of the progeny of each selected individual, and after several generations the best strain is preserved and made the basis of an improved variety, the others being discarded. Thus selection is made on the basis of hereditary behavior, not merely on outward appearance.

The pedigree method of breeding results in a much greater degree of uniformity among the members of the improved race than where mass culture has been used. In fact in many cases the offspring of the originally selected individual show so little variability that further selection is unnecessary. All that is required is to prevent the plants of the improved race from crossing with inferior stock. The new variety will breed true if the plant which was originally isolated is homozygous for the superior characteristic or quality which it is desired to preserve; otherwise not all of the progeny will be superior.

Pedigree culture is valuable as a means of preserving *mutants* or "sports." This term is applied to individuals strikingly different from the others—individuals which appear spontaneously. In nearly all cases they breed true for their peculiarities if isolated. Examples of mutants are plants bearing seedless fruits (which must be propagated vegetatively), double flowers, purple leaves, etc., and animals without tails, without horns, with loss of pigment (albinos), etc. Many new varieties of plants and animals have arisen as "sports."

Pedigree culture is best adapted to plants which are normally self-pollinated, and has been used very successfully with such plants as wheat, oats, peas, beans, tobacco, potatoes, etc. With corn and certain other cross-pollinated plants the isolation of individuals and the development of homozygous strains result in a marked loss of vigor, and hence the pedigree method is not applicable to such cases.

It is apparent that in animal breeding two individuals must necessarily be selected as the basis for an improved strain, and both must have the superior character. Knowledge of the hereditary constitution of the selected individuals is available in their recorded pedigree. While it is not always advisable to mate the offspring of a single pair of parents, much inbreeding is necessary as a means of preserving a particular set of characters. Consequently, all members of an improved stock are usually more or less closely related.

The older method of breeding was to judge an animal entirely on the basis of appearance or performance; the newer method is to consider its relatives as well. Its appearance may or may not be an index of its breeding possibilities. Thus the value of an animal for breeding purposes depends on its pedigree.

Hybridization.—The method of hybridization is used extensively in both plant and animal breeding. A hybrid has been defined as an organism whose parents represent two distinctly different types of individuals. While, as a rule, only closely related organisms can be crossed, many hybrids have been produced by crossing individuals belonging to distinct species or even to different genera. In some cases, however, the progeny resulting from a wide cross are sterile, the best-known example being the mule, produced by mating a jackass with a mare.

The chief value of hybridization is that it brings together characters to form combinations which did not occur previously. Because a desirable combination depends upon chance, usually a great many crosses of the same kind have to be made. Hybridization is particularly useful as a method of plant breeding where vegetative multiplication is possible, as then the hybrid can be propagated without using seeds. The advantage is obvious, for without sex reproduction there can be no segregation of factors. Hence the characters of the hybrid can be preserved indefinitely. Where sex reproduction is necessary, as in many plants and in all domesticated animals, the situation is far more difficult. Because segregation occurs when the hybrids are interbred, the members of the next generation are exceedingly diverse and represent all kinds of new character combinations. If some of these represent what is desired, they may be isolated and raised under pedigree culture, selection being continued until a pure-breeding race is obtained.

Another value of hybridization is to increase vigor. Many hybrids are more vigorous than either of the parents. Hybrid vigor may express itself in more rapid growth, in larger parts, in greater resistance to adverse conditions, or in other ways. For example, Burbank's "royal walnut," a cross between the California walnut (*Juglans californica*) and the black walnut of New England (*Juglans nigra*), grows twice as rapidly as either parent and greatly exceeds them in height. In corn, hybrids may yield as much as

50 per cent more grain than the average yield of their parents. Among animals, hybridization results in greater vigor in hogs, cattle, horses, sheep, dogs, and probably many others.

EUGENICS

The science of *eugenics* was founded by Francis Galton (1822–1911), and was defined by him as "the study of agencies under social control that may improve or impair the racial qualities of future generations, either physically or mentally." It is an attempt to apply to man the same principles of scientific breeding which have been so effectively used in the improvement of plants and animals. In other words, eugenics is an effort to control human evolution by selective mating. Most of the agencies concerned with the improvement of man—education, religion, medicine, philanthropy, etc.—deal primarily with environmental factors; they seek to improve the surroundings. While these influences are indispensable, it should be realized that they affect only the individual, not the race. Man cannot be improved racially by improving the environment any more than a farmer can create prize winners from scrub stock by giving them the best of food and care.

Heredity and Environment.—The relative importance of heredity and environment in the development of an individual has long been a matter of controversy. Until recent years it has been rather generally assumed that environmental influences are of the greater importance, and many people still have this opinion. That all men are born equal and that the nature of the surroundings determines the characteristics an individual comes to have are old ideas.

Modern biology teaches that the more powerful influence in determining the constitution of an organism is heredity, but that environment has an important part to play in the final expression of adult characteristics and qualities. Our innate capacities and tendencies are fixed by heredity. The environment merely determines how they shall develop, that is, what we shall do with our natural gifts.

Thus, for the most part, the environment is a guiding influence, not a creative one. Capacities for improvement are inherited, but improvement itself depends upon the presence of favorable circumstances. Environment merely gives an inherent tendency an opportunity to develop along lines predetermined by heredity. One may inherit exceptional musical ability, but, in the absence of an opportunity for sound training, it may never express itself. On the other hand, no amount of training can create a musician from a person with no natural aptitude in this direction.

The study of twins furnishes strong evidence as to the greater importance of heredity in development. As Galton first showed, and others have later substantiated, when identical twins (see p. 190) are separated in early life and each is brought up under a different set of surroundings, their resemblances in both mind and body persist. On the other hand, when fraternal twins, which always have a different set of hereditary characters, are brought up under exactly the same set of environmental influences, the dissimilarity between them does not diminish but usually increases as time goes on.

Hereditary Characters in Man.—The study of human heredity presents a number of difficulties, and the results are less certain than those obtained with the lower animals. There are several reasons for this. (1) Man is more complex, especially mentally, than any of the lower animals, and subject to a much greater set of environmental influences. (2) Experimental breeding is not possible, and consequently we must rely for information upon family records and other vital statistics. (3) Such data are often incomplete and unreliable, and even at best show only average conditions. (4) Every individual represents a complex mixture of many hereditary lines. (5) The production of relatively few offspring makes it difficult to obtain ratios indicating the chances involved, and to determine what all the hereditary possibilities may be in any given mating.

While many human characters are known to be heritable, much uncertainty exists regarding their mode of transmission, and those concerning which we have the greatest amount of information are mostly abnormal or defective characters. A brief list is given below of some of the hereditary characters in man:

DOMINANT	RECESSIVE[1]
Dark hair	Blonde hair
Brown eyes[2]	Blue eyes
Hereditary cataract	Normal eyes
Normal pigmentation	Albinism
Brachydactyly (short digits)	Normal digits
Polydactyly (extra digits)	Normal digits
Syndactyly (fused digits)	Normal digits
Normal	Hereditary feeble-mindedness
Normal	Hereditary epilepsy
Normal	Hereditary insanity
Normal	Congenital deaf-mutism
Normal	Left-handedness
Normal	Haemophilia (profuse bleeding)[3]
Normal	Color blindness[3]
Normal	Night blindness[3]

[1] In a few of the cases listed here it is a slight overstatement to say that one of the characters is recessive. The case is not quite so simple.

[2] Including green, hazel, and all other shades but pure blue.

[3] Sex-linked (see pp. 206–210).

The following characters are blending in their inheritance, and in most cases arise from the action of several independently inheritable factors: general body size, stature, weight, skin color, hair form (degree of curliness), shape of head, facial features, etc.

A great many characters are known to be largely determined by heredity, but the mode of their inheritance is uncertain. Some of these are: general mental ability, memory, temperment, musical ability, artistic ability, literary ability, mechanical ability, baldness, tendency to produce twins, and longevity.

Aims of Eugenics.—Eugenics has two definite aims or purposes: (1) to eliminate undesirable qualities from the race by preventing the breeding of defectives; (2) to increase the proportion of superior strains in the general population by encouraging matings between highly endowed individuals. In both of these ways the average quality of the race may be kept from deteriorating. The urgent need of eugenics is apparent when it is realized that the present rate of reproduction among the mentally superior individuals is unusually low, among the mentally inferior, unusually high. The highest birth rate exists among the classes having the least value to society. It is the principal object of eugenics to discover the causes underlying this deplorable situation and to seek means of remedying it.

Elimination of Defectives.—By defectives is meant not only the feeble-minded and insane, but criminals, paupers, tramps, beggars, and all persons who are a burden to society. While many of these are confined to prisons, asylums, almshouses, and similar institutions, a great many defectives are at large, free to propagate their kind. For example, it has been estimated that there are between 300,000 and 500,000 feeble-minded persons in the United States of which perhaps only one-tenth are confined in institutions. Although most of these individuals are not a direct menace to society themselves, as a class they are reproducing at a higher rate than normal persons.

While many defectives may be the victims of a poor environment and owe their unfortunate condition largely to this fact, there is no question but that most defectives are mentally deficient and simply lack the capacity for improvement. Feeble-mindedness results from a failure of the mind to continue its normal development, the intelligence of the individual remaining child-like. While some cases of feeble-mindedness may be caused by accident or disease, at least 60 per cent of them are due to an inherited tendency, and cannot be corrected. The condition is a complex one, probably representing a combination of several defects. For the most part, it seems to be inherited as a simple Mendelian recessive. There is also ample evidence that many forms of insanity are inherited. While insanity seems to be a recessive character, the exact mode of its transmission is not understood. This is due to the unreliability of the data, to the fact that the condition may be greatly modified by the environment, and because the term is used to cover a great variety of disordered nervous conditions.

Because most human defects, both physical and mental, seem to be recessive, they may become latent in many strains without their presence being suspected. Consequently two normal individuals, both heterozygous for the same defect, may produce some abnormal children. For this reason, intermarriage among families having hereditary defects is to be condemned. Defectives tend to intermarry, however, because they are largely avoided by normal persons.

The tendency to commit crimes is closely associated with feeble-mindedness, many criminals being mentally defective. The same is true of paupers, drunkards, prostitutes, etc. Mental tests performed on juvenile criminals in state "reformatories" have shown 50 to 90 per cent to be feeble-minded.

As a means of eliminating defective members of society, a number of plans have been suggested, but many of these are not practical. The tendency has always been to protect and care for the unfit, to give them every opportunity to improve, and except in extreme cases to grant them the same "personal rights" as normal individuals. The result has been a constant multiplication in numbers. An attempt has been made to meet the situation by legislation, but laws cannot be made effective except in a limited number of cases. Our present immigration laws keep defectives from entering the country, but are inadequate because many immigrants who appear to be normal carry latent hereditary defects, that is, are heterozygous. It is evident that if defectives are prevented from leaving offspring, the inferior strains will eventually die out. Laws preventing the marriage of defectives, however, have no effect, as the percentage of illegitimate births among the socially worthless is very high. Laws compelling the segregation of the sexes in institutions are effective if enforced, but the most satisfactory plan is sterilization. In the male this is accomplished by a very simple operation (*vasectomy*) involving no risk to health, but in the female a similar operation is attended with as much inconvenience and danger as any other abdominal operation. In neither case, however, is there any interference with normal instincts or functions, except that reproduction is made impossible. Although sterilization is the only certain way of preventing the breeding of defectives, there are few sterilization laws in operation, chiefly due to the fact that public sentiment is not yet sufficiently enlightened to the necessity of enacting and enforcing them.

Increase of Superiors.—That superior mental ability runs in families was first proved by Galton, and is accepted today as a fact. Not only is general intellectual capacity inherited, but also special aptitudes for music, art, literature, etc. While we recognize the fact that these and many other mental qualities are inherited, we know little concerning the manner of their transmission.

It has been pointed out that the birth rate among the intellectual classes is lower than among the population as a whole, so low in fact, that they are not maintaining themselves. No class can persist indefinitely unless there is an average of 3.7 children per family, and the superior stocks do not average two. For example, it has been shown that only half of the graduates of women's colleges marry as compared with over 90 per cent of all women, while but three-fourths of the graduates of men's colleges marry. The graduates of coeducational institutions average only 5 to 9 per cent higher.

The low birth rate of superiors is largely due to economic factors, not to inherent infertility. Late marriage is unquestionably an important cause; this arises chiefly from the necessity of obtaining an education. The high cost of maintaining modern standards of living is also a vital factor in reducing the number of children, while luxury and selfishness must be added as a third factor, as many people have no desire for children.

CHAPTER XVI

ADAPTATION

In making a detailed study of any plant or animal, one is impressed with the striking correlation which exists between the structure of its various organs and the functions they perform. As has been seen, structural differentiation has come about through a specialization of different parts of the body for particular kinds of work. A root, for example, owes its distinctive features to the fact that it anchors the plant in the soil, absorbs water therefrom, and carries it to the shoot system. The form and structure of a leaf, on the other hand, is very unlike that of a root chiefly because its functions are different, the leaf being primarily fitted to do the work of photosynthesis and to regulate transpiration. The same correlation between structure and function is also everywhere apparent in the animal body. The structure of the heart has significance only when we understand its mode of action, and the same is true of the stomach, an eye, a limb, or any other part of the body.

Not only is every organ, by reason of its structure, fitted to perform certain definite functions, but a marked three-fold relation exists between structure, function, and environment. One of the most obvious facts in nature is that organisms are suited to their surroundings—to the great complex of external conditions which we call the environment. An organism is related not only to light, air, water, temperature, etc., but to other organisms as well. The former set of factors constitutes the *inorganic environment*, the latter, the *organic environment*. The branch of biology which deals with the life relations of organisms, that is, with their relations to the conditions under which they live, is called *ecology*. The marvellous adjustment exhibited by all organisms between structure, function, and environment is what is ordinarily implied by the term *adaptation*. It is the fitness of organisms to the conditions under which they live.

The variations seen among organisms living under different sets of external conditions are largely correlated with the conditions themselves. Any set of conditions capable of supporting life constitutes a *habitat*, and in any given habitat only such plants and animals can live as are fitted by nature to meet the particular conditions which characterize it. Ponds, rivers, sea shores, meadows, swamps, deserts, prairies, forests—each has its own distinctive fauna and flora. This is because organisms which occur in the same habitat have similar life requirements, and these are largely fulfilled by the nature of the local conditions. Thus, the plants and animals living in an alpine habitat are very different from lowland forms, chiefly because the environmental conditions in the two cases are dissimilar. For the same reason, tidepool animals are not found in the deep sea, or the plants of a moist meadow upon the desert. The most important factors governing the distribution of plants into various kinds of habitats are chiefly those arising from differences in soil and climate. In animals the nature and abundance of particular kinds of food is perhaps of major importance, although physical factors also play a prominent role.

The term "adaptation" is applied not only to the fact of fitness, but to adaptive characters themselves. Some characters, especially the trivial ones which often serve to distinguish closely related species from each other, have no obvious adaptive significance, but most of the basic features of plants and animals show a relation to the environment. In general, the appearance of characters in an organism is dependent upon the presence of a particular set of hereditary factors in the chromatin of all of its body cells and while the final expression of many characters may be influenced by certain environmental factors, for the most part the surroundings themselves do not cause an organism to develop adaptive features. These arise, like most other characters, through the great internal influence— heredity. Thus, nearly all adaptations are racial, that is, inborn into the organism.

RACIAL ADAPTATIONS

We are now ready to consider a few conspicuous examples of racial adaptations—cases where an intimate relation between structure, function, and environment has been largely determined by the organism's ancestry. Since every individual has been called a "bundle of racial adaptations," many more examples will be suggested by the few which are given.

Desert Plants.—Plants which live in deserts exist under a set of very severe conditions: intense light, high tempera-

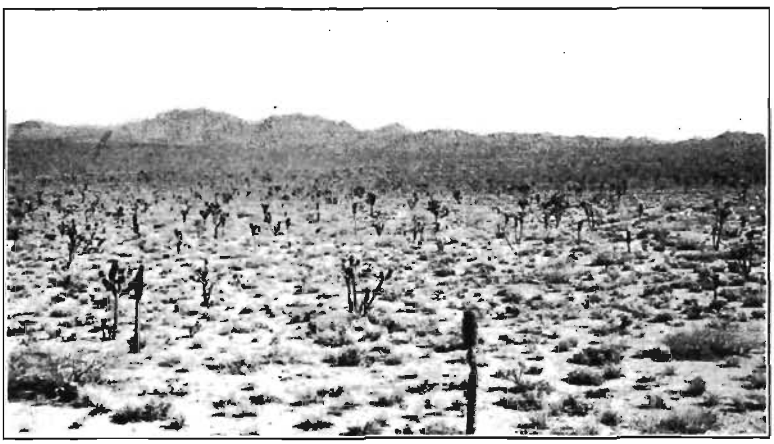


FIG. 161.—Desert vegetation. (*Photograph by Miss Caroline P. Canby.*)

tures, very dry air, and dry soil. Only such plants can live there as are structurally adapted to endure these rigorous conditions (Fig. 161). It is evident that the greatest problem of the desert environment is the conservation of water, and this is solved by desert plants, both by increasing absorption and retarding transpiration. Various structural adaptations bring about the same results in different cases, as the following examples show:

Many desert plants have a very deep root system which enables them to absorb water from a great depth. Others have a shallow root system but a very extensive one. In most desert plants the leaves are small (Figs. 162 and 164), often being developed as mere scales or spines. Reduction of

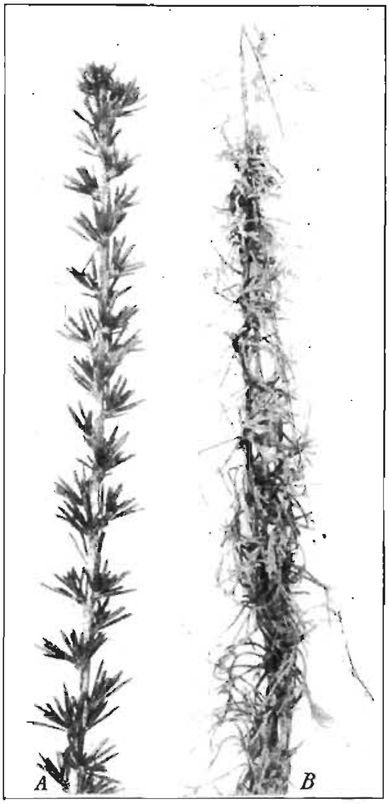


FIG. 162.—Two small-leaved shrubs common on the dry foothills of southern California, × 5/6; *A*, Chamiso (*Adenostoma*); *B*, Sagebrush (*Artemisia*).

leaf surface effectively lessens transpiration, but because photosynthesis is hindered at the same time, generally where the leaves are reduced, the stems are green and often enlarged, as in the cacti. Another adaptation seen in many desert plants is the development of water-storage tissue, either in the leaves or stems. In the aloe and agave the leaves are thick and fleshy—in the cacti, the stems (Figs. 163 and 164). Many desert plants have hard stiff leaves due to the presence of a thick cuticle which acts as a check against transpiration. In such cases the stomata are usually sunken below the level of the leaf surface and often confined to pits (Fig. 165). The presence of a thick covering of hairs, characteristic of many desert plants, is also thought to be related to the conservation of water. Hairs are outgrowths from the epidermal cells.

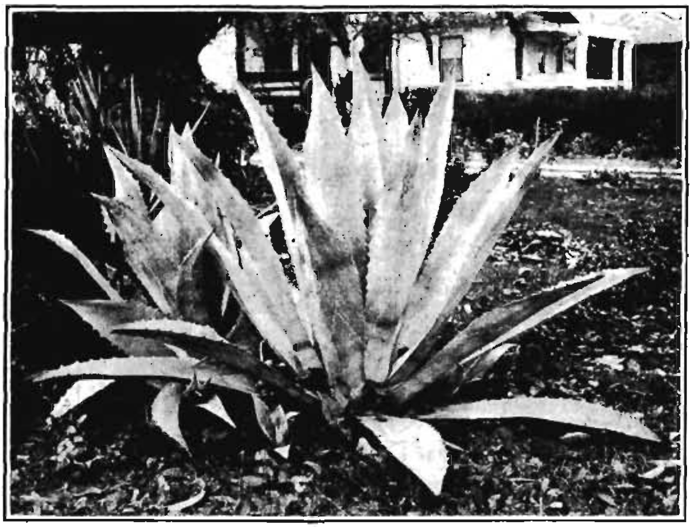


FIG. 163.—A thick-leaved desert plant (*Agave americana*), the fleshy leaves serving as reservoirs for the accumulation of water.

Desert plants are peculiar because they live under a set of extraordinary conditions. They are structurally adjusted to meet these conditions, and for the most part their distinctive features are racial, not acquired. Thus when most plants of dry regions are grown under ordinary garden conditions, they retain their desert characteristics.

Seed Dispersal.—The seeds of many plants are adapted to be disseminated by some particular agency, the two most important ones being wind and animals. Trees such as the elm, ash, maple, and catalpa have winged seeds[1] adapted to dispersal by the wind (Fig. 166). In falling to the ground the wing presents a flat surface to the air, in some cases causing the seed to spin around; thus its descent is retarded. A strong wind would carry such a seed some little distance from the parent plant. The dandelion,

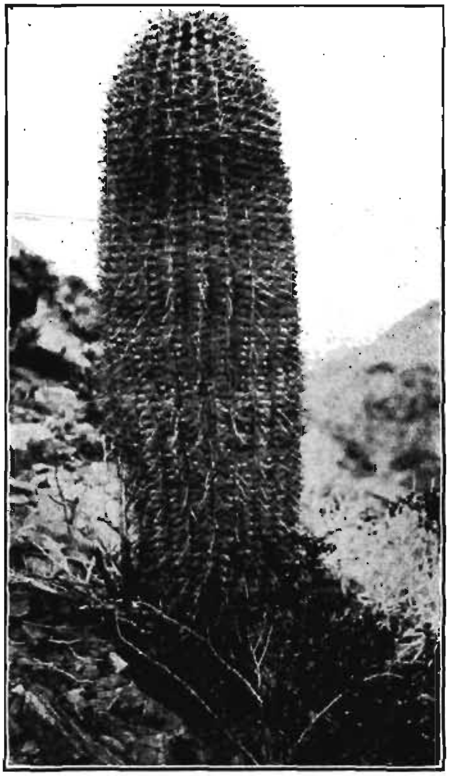


FIG. 164.—A barrel cactus (*Echinocactus cylindraceus*). The thickened, green, longitudinally fluted stem stores water and carries on photosynthesis, the leaves being reduced to spines. (*Photograph by Miss Caroline P. Canby.*)

thistle, milkweed, cottonwood, and many other plants have downy seeds; a tuft of cotton or down which acts as a parachute keeps them suspended in the air for a long time. Such seeds are often carried great distances by the wind. The seeds of the various kinds of "tumble-

[1] In some of these and the following examples, the "seeds" are really small dry one-seeded fruits, but this distinction is of no significance here.

weeds," such as the Russian thistle, are dispersed by the wind in another way. These plants grow on open plains. By an incurving of the branches the plant gradually assumes a spherical form. When the seeds are ripe the entire plant breaks off at the ground and is blown about by the wind, dropping its seeds as it moves along.

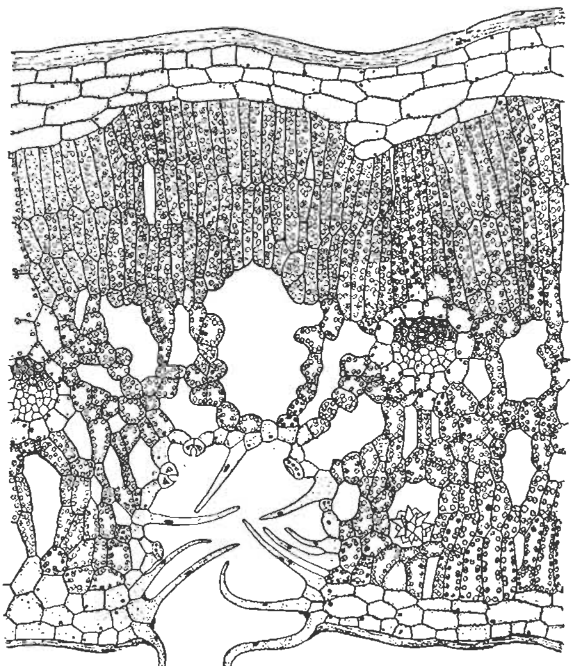


FIG. 165.—Cross-section of a leaf of oleander (*Nerium*), a plant adapted to live in dry air, × 200. Note the thick cuticle, the several layers of epidermal cells, upper and lower palisade tissue, and stomata in pits protected by epidermal hairs.

Animals carry seeds in several different ways. The barbed appendages of the cocklebur, burdock, and various kinds of "stick-tights" serve as a means of attachment to the bodies of animals (Fig. 167). Many marsh plants owe their wide distribution to the fact that their seeds are carried in the mud which clings to the feet of wading birds. Fleshy fruits, particularly brightly colored ones and those attractively flavored, are eaten in great numbers by various kinds of birds and mammals. Often the seeds are voided

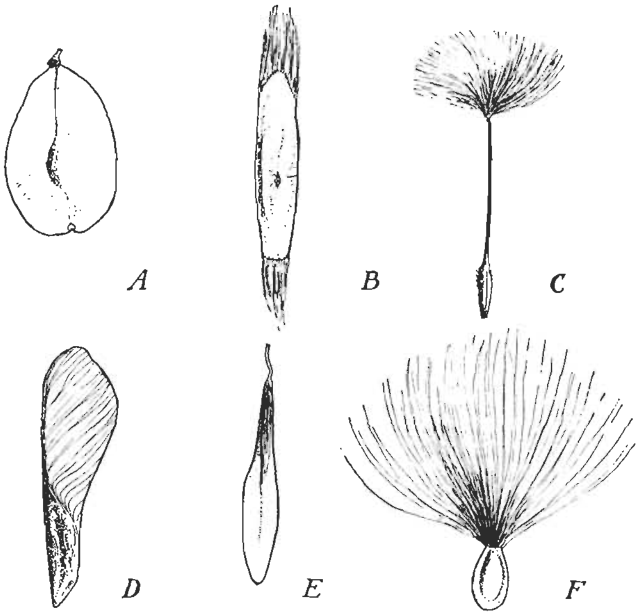


FIG. 166. Seed dispersal by wind; *A*, winged fruit of elm; *B*, winged seed of catalpa; *C*, downy fruit of dandelion; *D*, winged fruit of box elder; *E*, winged fruit of ash; *F*, downy seed of milkweed. (*C*, × 2; others, × 1.)

without being swallowed, but in many cases when swallowed they pass through the body unaffected by the digestive fluids.

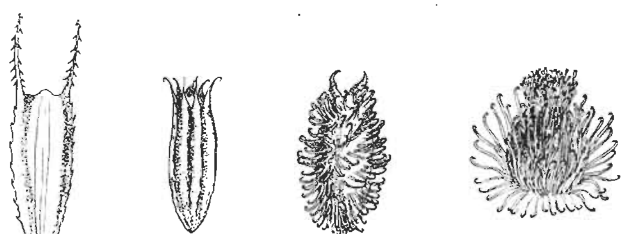


FIG. 167.—Seed dispersal by animals; *A*, beggar ticks; *B*, horehound; *C*, cocklebur; *D*, burdock. (*A* and *B*, × 2; *C* and *D*, × 1.)

Insect Pollination.—Flowers are either self-pollinated or cross-pollinated, depending upon whether each flower pollinates itself or whether pollen from one flower is transferred to the pistil of another. Cross-pollination is brought about chiefly by wind or by insects. Self-pollinated flowers and those cross-pollinated by the wind are usually inconspicuous, while most flowers cross-pollinated by insects have brightly colored parts or an attractive fragrance. Insects visit flowers chiefly to get nectar from them, the act of pollination being purely an incidental matter. Nectar is a sweet liquid secreted inside the flower, either at the base of the petals (Fig. 78), or in a special sac or spur (Fig. 168).

FIG. 168.—Flower of nasturtium (*Tropaeolum*) cut through the middle to show the spur (s) and the nectary (n), × 1.

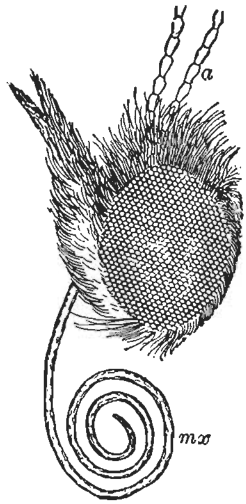


FIG. 169. Side view of head of butterfly, with part of antennae (a) removed, showing proboscis (mx). (*From Sanderson and Jackson, "Elementary Entomology," Ginn and Company, by permission.*)

Insects gather nectar as food, either for themselves or for the larvae. In getting nectar from a flower, some part of the insect's body comes in contact with the stamens and is covered with pollen. This is then carried to the next flower where some is rubbed off on the stigma. In this way cross-pollination is accomplished. It should be understood that there is nothing intentional in this operation; the insect unavoidably carries pollen as it goes from flower to flower in search of food.

Butterflies and moths obtain nectar for their own use, as the caterpillars are not fed by the adults. The mouth apparatus of a butterfly consists of a very long tube called a *proboscis,* which under ordinary circumstances is coiled under the head like a watch spring (Fig. 169). Flowers which are adapted to be pollinated by butterflies or moths, such as the tobacco, petunia, honeysuckle, pink, etc. have a tubular or funnel-shaped corolla at the bottom of which nectar collects (Fig. 170). The stamens are situated at the mouth of the corolla. Such flowers are largely

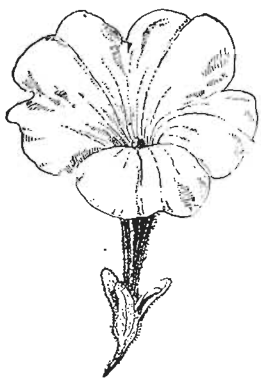


FIG. 170.—Flower of *Petunia,* a type adapted to pollination by moths. The five petals are united to form a tubular corolla, at the bottom of which nectar collects.

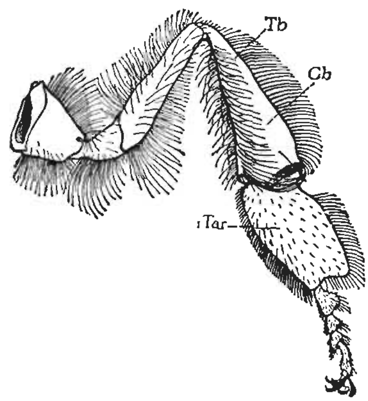


FIG. 171.—Left hind leg of honeybee (worker), showing pollen basket (*Cb*) on outer surface of tibia (*Tb*). (*From Snodgrass, "Anatomy of the Honeybee," McGraw-Hill Book Company, Inc., by permission.*)

dependent upon butterflies or moths for their pollination, as these insects are particularly adapted to reach the nectar.

Bees gather both nectar and pollen which they feed to the larvae. In many bees a portion of the hind legs serves as a "pollen basket" (Fig. 171) by means of which pollen is carried to the hive. While this pollen is lost to the plant, that which adheres to other parts of the body may be rubbed off on the stigmas of other flowers. In the snapdragon, violet, sweet pea, and sage we have flowers especially adapted for pollination by bees (Fig. 172). Although these flowers are not related—belonging to different families, in fact—they have a highly specialized corolla somewhat similarly modified. Normally the flower is more or less closed; that is, the parts of the corolla fit together in such a way that the stamens and pistil are hidden. This makes the essential organs inaccessible to such insects as ants, which often steal pollen but are practically of no value as pollinators. In all of the flowers mentioned above there is a sort of lower lip or platform upon which a bee may alight, the weight of its body causing the corolla to open.

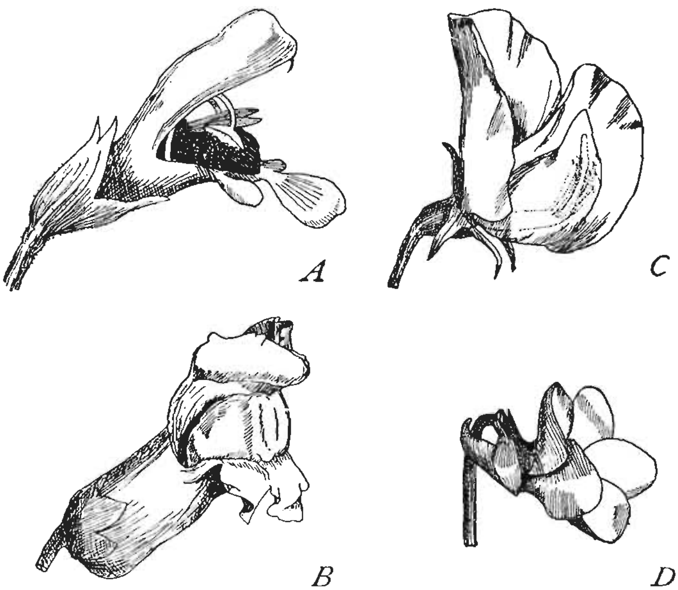


FIG. 172.—Flowers pollinated by bees; *A*, common sage, showing bee entering corolla; *B*, snapdragon; *C*, sweet pea; *D*, violet. In *C* the right lateral petal has been removed. (*A*, *redrawn after Lubbock*.)

The pistil is so situated that as the bee enters the flower it comes in immediate contact with the stigma, thus rubbing off some of the pollen brought from another flower. It then encounters the stamens, usually located below the pistil, and thereby acquires a new lot of pollen. Finally it gathers the nectar and departs.

Protective Resemblance.—In a great many animals the color or form of the body harmonizes with the surroundings, thus rendering it inconspicuous and affording concealment from enemies. A great many examples could be given, but a few will suffice to point out the general situation (Fig.

Fig. 173.—Protective resemblance among insects: *a*, katydid; *b*, walking-stick insect on a twig; *c*, larva of geometrid moth resting extended from a twig. (*a, from Sedgwick, "A Student's Textbook of Zoology," after Riley, by kind permission of the publishers, George Allen & Unwin, Ltd., London: The Macmillan Company, New York; b, c, from Jordan and Kellogg, "Evolution and Animal Life," D. Appleton & Company, New York; by permission.*)

173). The green body of the katydid with its veined wings blends with the foliage upon which it feeds. The walking-stick insect with its slender elongated body and legs shows a striking resemblance to a branched twig, and thus is very difficult to see. The measuring worms, which are caterpillars of certain moths, are greatly like twigs in form and color, and when disturbed some of them assume a rigid position at an acute angle from the stem. The dead-leaf butterfly (*Kallima*) of India is one of the most amazing

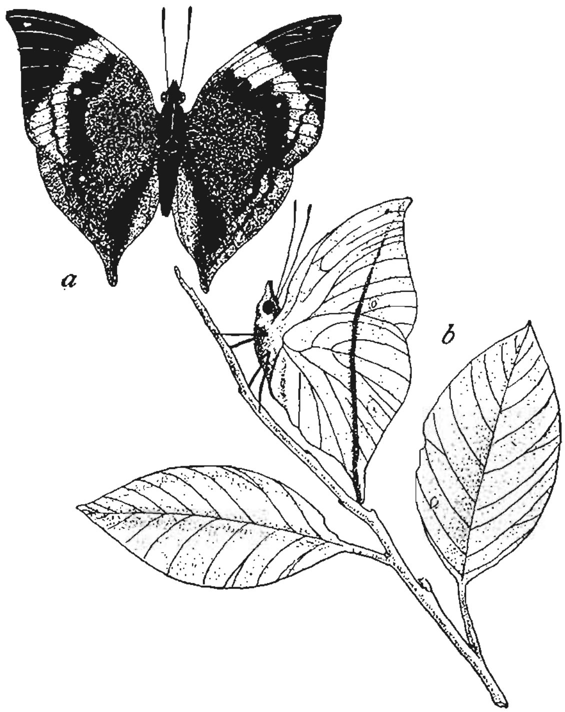


FIG. 174.—The dead-leaf butterfly (*Kallima*) of India, × ½; *a*, with wings extended; *b*, at rest on a leafy twig.

instances of protective resemblance known. When its wings are folded, it exhibits almost perfect similarity to a dead leaf, in regard to the shape, color, veining, petiole, and even the worm holes (Fig. 174).

The color change of the chameleon and certain other lizards from brown to green, or *vice versa*, to harmonize with the background is well known. A protective coloration of mammals in the wild state is very common. Prairie and desert forms tend to be brown or gray, as the wolf, camel, and lion. Arctic animals are usually white, at least during the winter, the polar bear, Arctic fox, and weasel being good examples. Forest-dwelling types, such as the zebra, tiger, and leopard tend to be spotted, striped, or mottled. Some of these forms are colored not so much for protection as to render them inconspicuous to animals upon which they feed, while in others, as in many similar cases, the protective value of their coloration has been greatly overrated.

Feet and Bills of Birds.—One of the most striking illustrations of adaptations in animals is seen in the modification

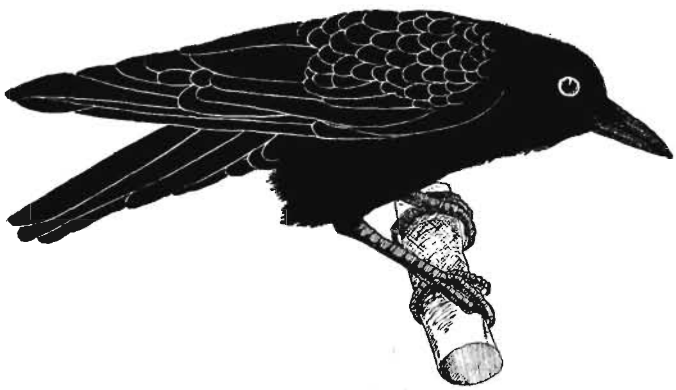


FIG. 175.—Crow (*Corvus brachyrhynchos*), a generalized bird. × ⅙.

of the feet and bills of birds for the performance of diverse functions. A generalized bird, an excellent example of which is the crow (Fig. 175), uses its bill for many different purposes. It can capture insects, pick fruit, dig corn, crack nuts, kill smaller birds, and break open eggs. As a consequence of this varied diet, the bill of the crow is in no way modified. Similarly its feet are generalized, being used for walking, scratching, perching, wading, walking on snow, etc. The more restricted a bird's diet and the more specialized its method of getting food, the greater is the amount of structural modification which it exhibits. A few examples will be given.

Scratching birds, such as chickens, turkeys, quail, grouse, etc. (Fig. 176) have short legs and straight, stout, short toes. They feed mostly on seeds, in consequence of which their bills are short, stout, and curved. Spending most of their time on the ground, scratching birds in general are poor fliers.

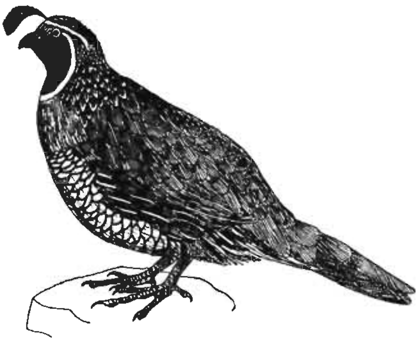


FIG. 176.—California quail (*Lophortyx californica*), a scratching bird, × 1/8.

FIG. 177.—Pigeon hawk (*Falco columbarius*), a bird of prey, × 1/3.

Hawks, eagles, and other *birds of prey* (Fig. 177) have powerful feet provided with sharp curved claws adapted to seize and carry living prey, and strong hooked beaks for tearing flesh.

Insect-eating birds are of several different types, some being more highly specialized than others. The woodpeckers (Fig. 178) dig into tree trunks for grubs and beetles. Their

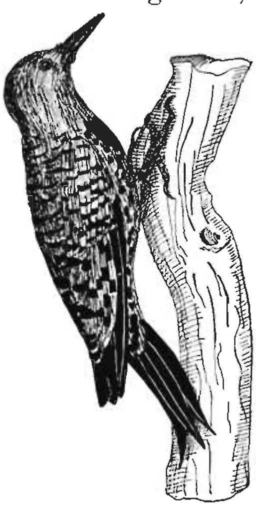


FIG. 178.—Red-shafted flicker (*Colaptes cafer collaris*), a woodpecker, × 1/6.

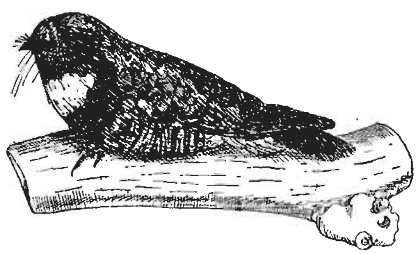


FIG. 179.—Poor-will (*Phalaenoptilus nuttallii*), a night-flying insectivorous bird, × 1/3.

bills are straight, strong, and chisel-like, the tongue sharp-pointed and barbed. The feet are sharp clawed and the tail feathers stiff, the latter acting as a brace against the tree. The nighthawks and whip-poor-wills (Fig. 179) are night feeders which capture insects on the wing. They have long narrow wings and very poorly developed feet. The latter are too weak to be used in walking or even to support the body, but are used merely for clinging, the body resting lengthwise on a limb or on the ground. These birds have very small bills surrounded by bristles. They fly through the air with the mouth widely open, swallowing such insects as happen to be in the way.

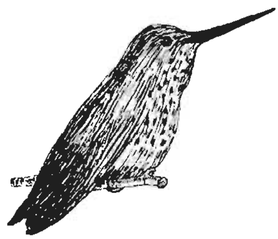


FIG. 180.—Humming bird (*Calypte ana*), a nectar feeder, × ½.

The humming birds are *nectar feeders*, their long slender bills being well fitted for probing into flowers (Fig. 180). They are the smallest of birds, their rapidly moving wings holding the body poised in front of the flower without coming to rest.

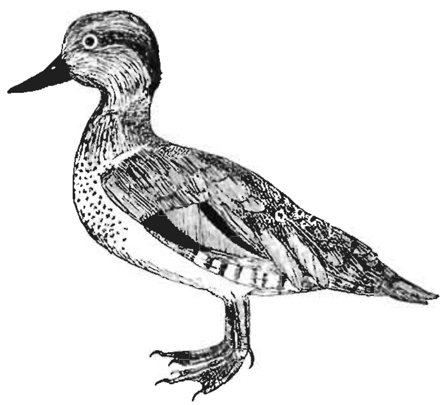


FIG. 181.—Green-winged teal (*Nettion carolinense*), a swimming bird of the duck type, × ⅕.

Swimming birds have lobed or webbed feet, short legs, and are usually awkward on land (Fig. 181). Their bills are modified in accordance with their feeding habits, being pouched in the pelicans, strong and hooked in the gulls, broad and flat in the ducks and geese, etc. Grebes

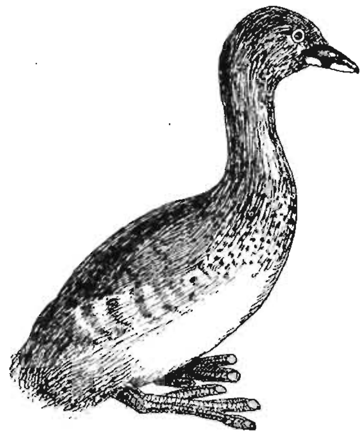


Fig. 182.—Pied-billed grebe (*Podilymbus podiceps*), a diving bird, × 1/5.

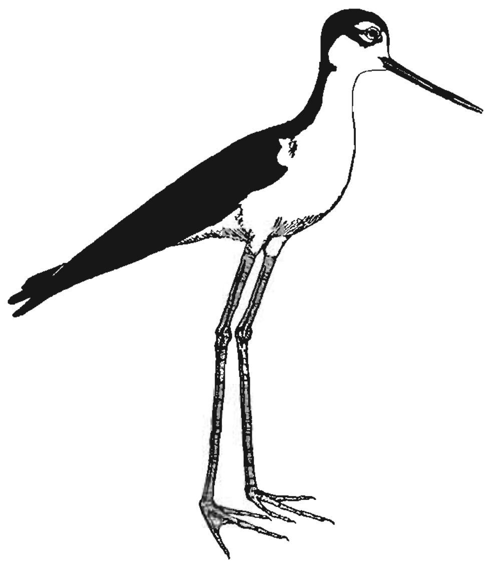


Fig. 183.—Black-necked stilt (*Himantopus mexicanus*), a wading bird, × 1/5.

and loons are *diving birds*, swimming under water both to capture fishes and to avoid their enemies (Fig. 182). The toes are webbed or lobed and the feet placed far back on the body, so that on land an erect position is assumed. The sharp-pointed beak is well fitted for grasping fishes.

Wading birds are characterized by long slender legs (Fig. 183). The toes are either very long and thin, or shorter and more or less webbed, in either case preventing the bird from sinking into the mud. Because the legs lift the body above the water, the neck and bill are elongated to permit feeding in the water or in the mud on the bottom. The cranes and herons have long, stout, sharp-pointed beaks for spearing fish, while in the stilts, snipes, sandpipers, and plovers the bill is long but slender and more or less soft at the tip, being used to probe for small worms, mollusks, crustaceans, etc., along shore or in shallow water.

Adaptation in Mammals.—In mammals, as in all other animal groups, a striking correlation between structure and life habits is seen. While structural modification may

FIG. 184.—A shrew (*Sorex ornatus*), a relatively unspecialized mammal, × $\frac{3}{4}$.

affect any part of the body, it is particularly evident in teeth and limbs. The most generalized mammals are mostly ground dwellers, having relatively short pentadactyl limbs, and walking with the entire foot resting flat upon the ground (*plantigrade*). Among the most primitive of placental mammals are the shrews—small, mostly terrestrial forms with pointed heads, small eyes, and a general mouse-like appearance (Fig. 184). Shrews live chiefly on insects, their teeth being small, sharp-pointed, and but slightly differentiated.

In typical mammals there are four distinct kinds of teeth: *incisors, canines, premolars,* and *molars*. These can be studied to good advantage in man or in any of the monkeys, where all four types are present in a relatively unspecialized condition (Fig. 185). In the *rodents*, an herbivorous group including the rats, mice, guinea pigs, squirrels, rabbits,

FIG. 185.—Skull of spider monkey (*Ateles*), a mammal whose teeth are relatively unspecialized, × ½. The number of teeth is the same as in man, except that here there are three pairs of premolars in each jaw instead of two pairs.

FIG. 186.—Skull of beaver (*Castor canadensis*), a rodent, × ½. The two pairs of incisors, adapted for gnawing, are very large and chisel-like, canines are absent, while the premolars and molars are flat-crowned and adapted for grinding.

beavers, gophers, etc., the teeth are adapted for gnawing. There are no canines, but the incisors are very conspicuous and chisel-like; the back teeth are mostly flat crowned and used for grinding (Fig. 186). Most of the *carnivores* have teeth adapted for tearing and cutting flesh. To this group belong the wolves, foxes, cats, bears, raccoons, skunks, badgers, etc. The incisors are small and of little use,

FIG. 187.—Skull of timber wolf (*Canis occidentalis*), a carnivore, × 1/4. The teeth are adapted for cutting and tearing flesh. Note the two pairs of conspicuous canines and the pointed, ridged character of the premolars and molars.

the canines are large and pointed, while commonly the premolars and molars are sharply ridged (Fig. 187). The dentition of the *ungulates*, or hoofed mammals, in most

FIG. 188.—Skull of horse (*Equus caballus*), an ungulate, × 1/4. The incisors are adapted for cropping, the premolars and molars for grinding. Small canine teeth are present in the male, but absent in the female.

cases is highly specialized for an herbivorous diet. Here belong the cattle, sheep, goats, deer, hogs, horses, elephants, etc. While in most ungulates all four kinds of teeth are present, the canines are usually small and of little value. The incisors, which are used for cropping grass or herbage, are generally large and chisel-like, while the molars and premolars are broad and flat and provided with a complex surface for grinding (Fig. 188). One order of mammals, the *edentates*, is characterized by an imperfect development or absence of teeth. To this group belong the sloths, armadillos, and some of the anteaters. A total absence of teeth is also characteristic of some of the whales.

A number of mammals excavate burrows and live in them, especially many of the rodents, but in most cases they spend much of their time at the surface. The moles, however, live entirely underground, and consequently are

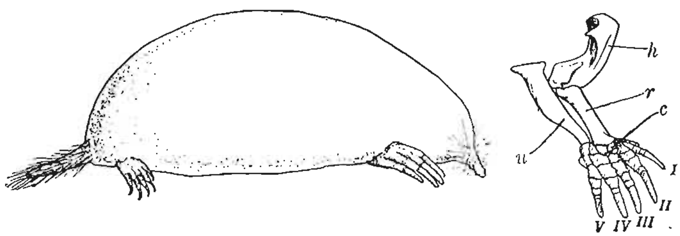


FIG. 189.—A mole (*Scapanus latimanus*), × ½, and bones of right fore limb; *h*, humerus; *r*, radius; *u*, ulna; *c*, carpus; *I* to *V*, digits.

very highly specialized for a subterranean existence (Fig. 189). The spindle-shaped body with its pointed snout, short neck, narrow shoulders, and short tail is obviously adaptive. The extremely short limbs are modified for digging, the hands and feet being provided with long strong claws. External ears are absent and the eyes are rudimentary. Moles are *insectivores*, belonging to the same order as the shrews and hedgehogs. Their teeth are simple.

In mammals which are adapted to run rapidly over the ground, the body is relatively light and the limbs long and slender. The carnivores have limbs provided with four or five clawed digits, and in most cases elongation of the arms and legs has been brought about by an elevation of the wrist and heel above the ground (Fig. 190*B*), so that they walk on their toes (*digitigrade*). In most ungulates, on the other hand, the digits have been reduced to either three, two, or one, the others being functionless or entirely absent. Ungulates typically walk on the tips of their toes (*unguligrade*), the hoof corresponding to the nail or claw of other mammals (Fig. 190*C*).

The monkeys represent a type of mammal adapted to living in trees. Together with man they form a group of their own, the *primates*. Both the fore and hind limbs are

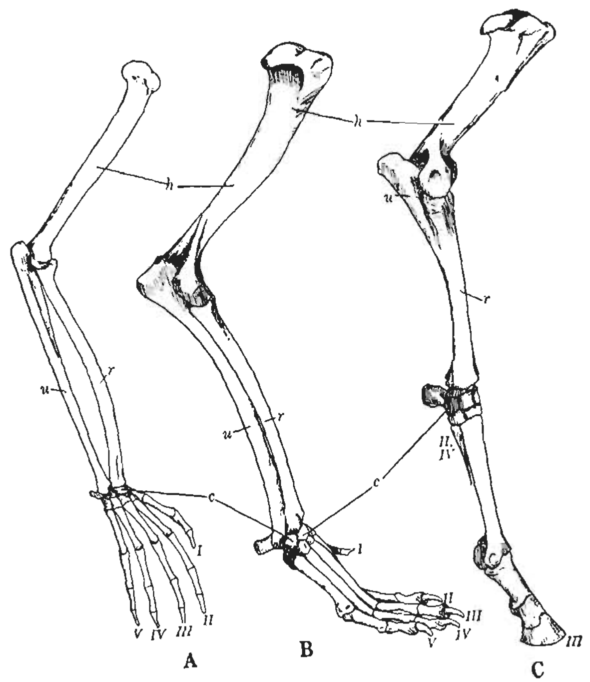


FIG. 190.—Right fore limbs of rhesus monkey (*A*), wolf (*B*), and horse (*C*). Labeling as in Fig. 189.

modified for grasping branches, the first digit being opposable to the others (Fig. 190*A*). The tail is long, and in the New World forms, is prehensile, thus being of great utility to the animal as it swings from one branch to another.

The seals (Fig. 191) are aquatic mammals belonging to the carnivore group. They are not so highly specialized as the whales, porpoises, and dolphins, which constitute an independent order, the *cetaceans*. The elongated,

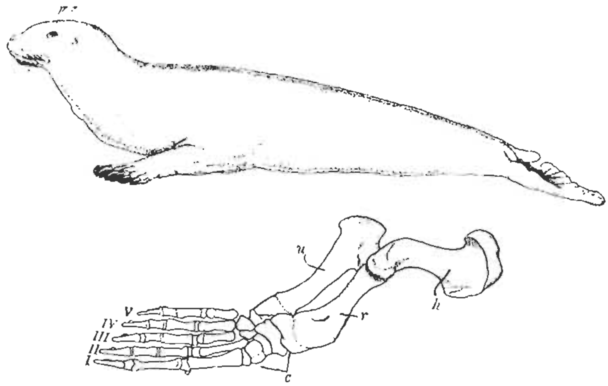


FIG. 191.—Harbor seal (*Phoca vitulina*), × 1/12, and bones of right fore limb Labeling as in Fig. 189.

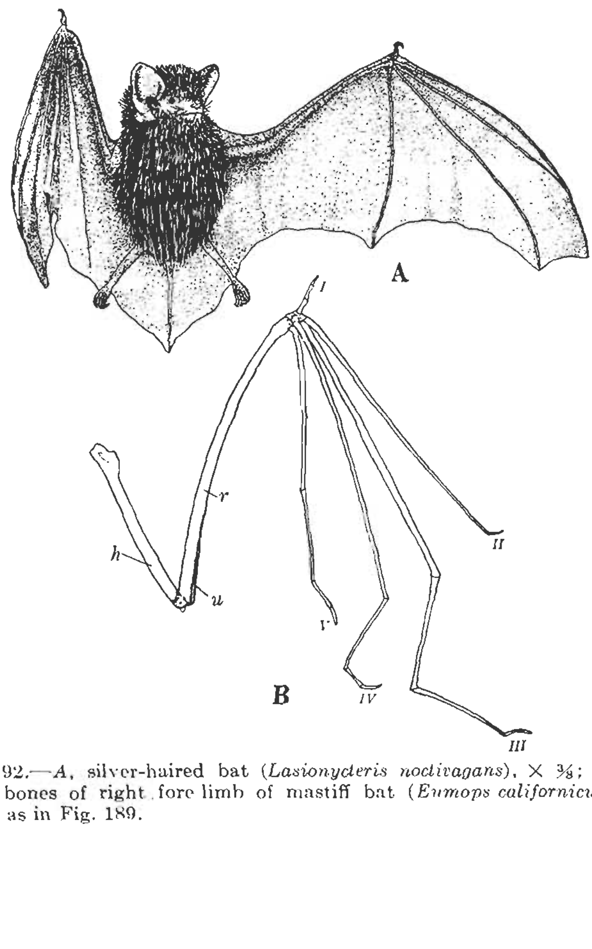


FIG. 192.—*A*, silver-haired bat (*Lasionycteris noctivagans*), × 3/8; *B*, dorsal view of bones of right fore limb of mastiff bat (*Eumops californicus*), × 1/2. Labeling as in Fig. 189.

short-necked, somewhat fish-like body of the seal with its smooth fur is obviously adapted to progression through the water. The limbs are paddle-like, the upper portion being short, but the hands and feet are elongated and provided with completely webbed digits. The sea lions and walruses can use their hind limbs in walking, but the seals cannot, thus being more highly adapted to aquatic life.

While some mammals, such as the flying squirrels, are adapted for gliding through the air for short distances, the only mammals which really fly are the bats (Fig. 192), and to serve this function their bodies are highly modified. The forearm and four of the digits are greatly elongated; these support a thin fold of skin which reaches to the body and to the hind limbs forming a wing. The thumb is much shorter than the other digits and is clawed. Bats have great difficulty in moving on the ground. When at rest they hang head downward from a support by means of their clawed feet, or with head up, suspending themselves by their wing-claws. As in birds, the bones are light and the pectoral muscles highly developed.

INDIVIDUAL ADAPTATIONS

Although the structure of organisms and the way in which their parts function are determined mainly by heredity, the environment, in providing an opportunity for inherent tendencies to express themselves, constantly exerts a modifying influence. It is apparent that in every habitat conditions constantly fluctuate, and that all organisms, by virtue of the power of irritability, respond to these slight changes, mostly in ways advantageous to themselves. When abnormal changes occur, however, as when an organism is removed from its natural environment and placed under a new set of conditions, it also may be able to adjust itself, especially if the change is made very gradually.

Adaptive Response.—It is important to distinguish between the state of being adapted and the process of becoming adapted. An organism *is adapted* to the normal conditions of its particular habitat chiefly by reason of its hereditary constitution, and so most adaptive characters are racial. To a limited extent, however, it may react favorably to new conditions which arise; in other words, it may *become adapted* to a new environment. This is known as the power of adaptive response. The reaction to the changed conditions may be functional, structural, or both. Adaptive characters which thus arise as a direct response

FIG. 193.—Two pots of bean seedlings exactly of the same age; *a*, plants grown in the light; *b*, plants grown in total darkness. In *b* the stems are white and the leaves pale yellow. Both sets of seedlings were given the same amount of water and kept at the same temperature.

to external influences are spoken of as *acquired* (or *individual*) *adaptations*. A few examples will be given.

Everyone knows that the growth of a plant is greatly influenced by temperature, light, moisture, the character of the soil, diseases, injuries, etc. When a plant is grown in darkness it fails to develop chlorophyll, its leaves remain small, and the stem becomes very long and weak (Fig. 193). While there may be no adaptive significance to this behavior there are many responses in plants where adaptation is clearly indicated. For example, when grown in the shade, many kinds of plants have larger leaves than when grown in bright sunlight, and thus a greater amount of green tissue is exposed for carrying on photosynthesis. Many plants develop much more extensive root systems in dry soil than in moist soil, thus enabling sufficient water to be absorbed. The cuticle on many leaves becomes thicker when they are grown under dry conditions, and this results in diminished transpiration.

Animals are influenced by temperature, moisture, the character and amount of food, exercise, diseases, injuries, etc., and many of the changes thus brought about are adaptive. A familiar example is the tanning of the human skin through continuous exposure to bright sunlight. The formation of brown pigment (which in the negro is racial) tends to prevent further burning and consequent injury to the underlying tissues. The development of callosities on the skin through friction is also an adaptive response, as is the enlargement of muscles by persistent exercise. Recovery from a disease often brings about a condition of immunity to further attacks, and a tolerance for certain poisons, such as caffeine or nicotine, may be gradually acquired.

An important limitation regarding the power of adaptive response which should be kept in mind, is that only minor adjustments are possible. The basic features of organisms are incapable of modification. By a manipulation of the environment we cannot increase individual human stature, change eye color, increase potential intellectual ability, or alter any of the other characters which are determined largely by heredity. In the vast majority of cases the amount of modification which may be effected through a radical change in external influences is slight and always limited. The striking cases ordinarily mentioned are exceptional, some organisms being much more plastic than others, and hence more susceptible to modification.

Explanation of Adaptation.—In speaking of the power of adaptive response, it is often said that an organism "adapts itself" to this or that condition of the environment. This and all similar phrases implying conscious effort or purpose should be avoided, as their meaning is entirely metaphorical even in the case of intelligent animals. Some reactions are advantageous, while others are not, but in neither case can desire on the part of the organism produce a modification in structure or function. For example, some plants produce substances as waste products of metabolic activity which may happen to be bitter, poisonous, or otherwise unattractive to certain animals, and such plants may be avoided for this reason. But to say that they produce substances "to protect themselves" from being eaten by animals is entirely misleading in that it implies foresight on the part of the plant.

If adaptation is not purposive, how has it come about? Like many other biological problems, this is a question which has never been satisfactorily answered. Most individual adaptations are in the nature of direct responses to external conditions, but we cannot explain why an organism reacts to a given stimulus in a characteristic way. Regarding the origin of racial adaptations, it is certain that they have arisen by a process of evolution, but as to how they have evolved there is much uncertainty. Two plausible theories have been suggested: one called *the inheritance of acquired characters*, the other, *natural selection*. These are discussed in their proper setting in Chap. XX.

CHAPTER XVII

SAPROPHYTISM, PARASITISM, AND SYMBIOSIS

It has been pointed out in the last chapter that organisms are related in their life habits not only to the physical factors of their environment, but to other organisms as well. Each kind of living thing has reciprocal relations with other kinds—none can live unto itself. The limitless ways in which organisms are associated and interact with each other constitutes such a vast subject, however, that here we can give attention only to a few of its many aspects. The phenomena of saprophytism, parasitism, and symbiosis are of particular interest to the student of elementary biology because they illustrate some of the more striking ways in which organisms are adapted to the living environment.

SAPROPHYTISM

Saprophytes are plants without chlorophyll which absorb their food directly from dead organic matter. Their supply of carbon comes not from the carbon dioxide of the air, as does that of green plants, but from organic compounds occurring in dead plants and animals or in the waste products of living organisms. In the course of obtaining food for themselves, saprophytes gradually break down these complex food substances into simpler products, and thus are the direct cause of decay. It is important to realize that the decomposition of all dead organic matter takes place entirely through the agency of living organisms, and that they thereby obtain material and energy necessary to their own metabolism. The breaking down of carbohydrates is called *fermentation*, of protein material, *putrefaction*, but these processes are essentially similar.

Decay of Organic Matter.—The decomposition of dead organic matter represents a complicated series of changes, there usually being a large number of intermediate products formed. Ordinarily, there is a succession of various kinds of decay-producing organisms, chiefly bacteria, each carrying the process a little farther, until finally only a few relatively simple substances are left. All of these organisms gain their subsistence from the great amount of potential

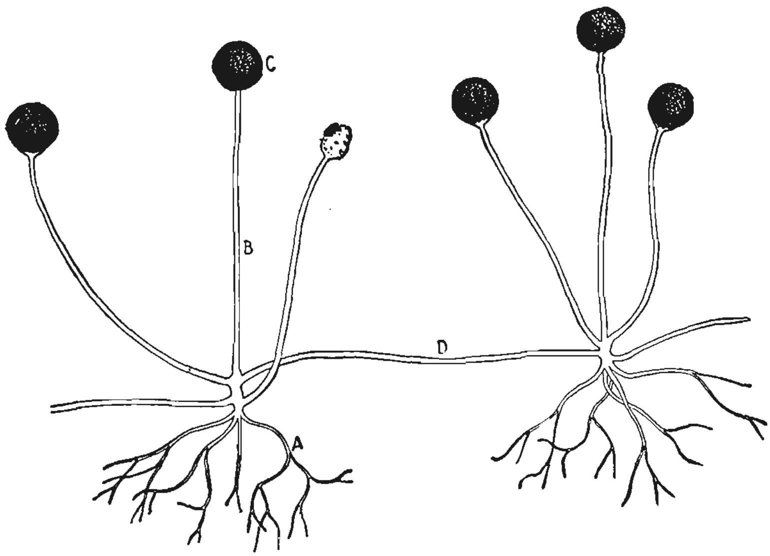


FIG. 194.—Mycelium of bread mold (*Rhizopus nigricans*) giving rise to sporangia. (See also Figs. 25 and 68C.) (*From Sinnott; "Botany Principles and Problems," McGraw-Hill Book Company, Inc., by permission.*)

energy contained in the dead material, but none except the last ones exhaust it. The ultimate products of decomposition are chiefly water (H_2O), carbon dioxide (CO_2), ammonia (NH_3), methane (CH_4), hydrogen sulphide (H_2S), free hydrogen, and free nitrogen. The water and carbon dioxide may be directly used again by green plants in the synthesis of new organic compounds, but the other substances can be utilized only after being acted upon by certain other bacteria which oxidize them in order to obtain a source of energy for themselves. For example, ammonia is converted to nitrites and then to nitrates by the *nitrifying bacteria* (of which there are two types, one carrying on the first change, the other the second).[1]

FIG. 195.—Two saprophytic seed plants found in rich, moist woods. On the left, Indian pipe (*Monotropa uniflora*); on the right, pinesap (*M. hypopitys*). (*Photograph supplied by McFarland Publicity Service.*)

Besides the bacteria of decay, there are many other kinds of saprophytic fungi, such as yeasts, molds, and most of the mushrooms and other fleshy types. These forms

[1] Other kinds of bacteria oxidize methane, hydrogen sulphide, and free hydrogen, forming substances directly utilizable by green plants, while still others, the *nitrogen-fixing bacteria*, have the power of forming nitrates directly from free nitrogen (see pp. 262–264 and 289).

live on humus, rotting logs, dead animals, etc. The yeasts are unicellular, but most of the other fungi have a delicate, white, thread-like body called a *mycelium* (Figs. 25 and 194). The fleshy "mushroom" (Fig. 27) is really only a spore-producing structure, the vegetative body of the plant being a mycelium which grows in the soil or in decaying wood. Among the higher plants there are only a relatively few saprophytes, one of the best known being the Indian pipe (*Monotropa uniflora,* Fig. 195). The whole plant is white or reddish, and is entirely without chlorophyll. The unbranched stem, often reaching a height of 30 centimeters (1 foot), bears a few rudimentary leaves and a single terminal flower. The Indian pipe grows in moist, rich woods, absorbing its nourishment from the partially decayed organic matter contained in the soil.

Cycle of Elements.—By virtue of their ability to construct food from inorganic substances, green plants provide a source of material and energy for themselves, for animals, and for dependent plants. It will be recalled that green plants obtain the entire supply of carbon, hydrogen, and oxygen which they use in food manufacture from the carbon dioxide of the air and the water of the soil, and that these elements enter into the formation of all of the organic substances in plants and animals. All of the other elements which become part of the plant body, however, such as nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, iron, etc., are absorbed as salts dissolved in the soil water (Fig. 196).

It should be understood that the chemical elements of which the various components of protoplasm and its derivatives are constructed, are only temporarily associated in an organism. During life, waste products resulting from the breaking down of protoplasm in respiration are constantly given off, while after death, destructive processes continue under the influence of other organisms. A plant may be eaten by an animal and some of its substance become temporarily transformed into animal protoplasm, but eventually all organic matter constructed by green plants is decomposed into its constituent elements. It is apparent that saprophytes, in effecting this decomposition, ultimately return elements to the inorganic world. Without them dead plants and animals would rapidly accumulate, and the various elements essential for life would be "locked up" and hence be unavailable for green plants. Soon the carbon dioxide of the air and the mineral salts of the soil would be greatly diminished

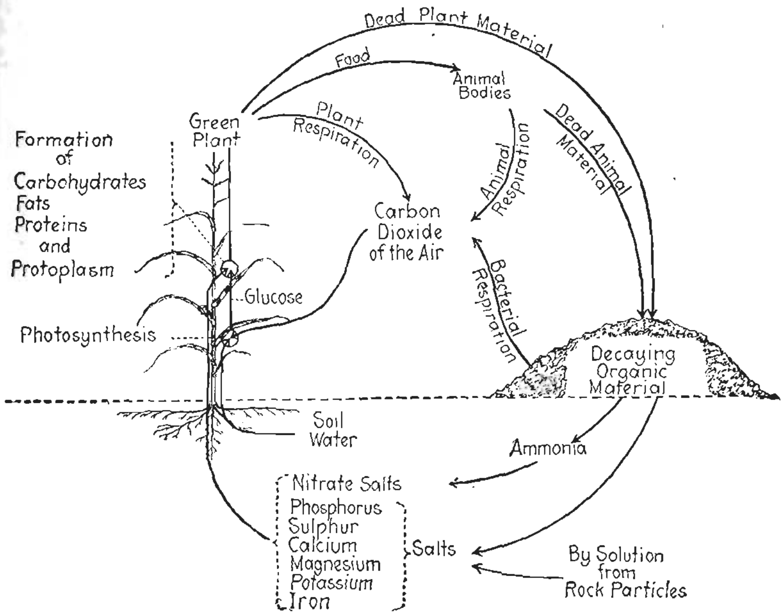


FIG. 196.—Diagram representing the circulation of elements through the air, soil, and bodies of organisms. (*From Sinnott, "Botany; Principles and Problems," McGraw-Hill Book Company, Inc., by permission.*)

in quantity, and eventually life would cease. Thus saprophytes play a much more important role in the economy of nature than is commonly realized.

Because all of the products resulting from the breaking down of protoplasm and its derivatives, both during life and afterward, are either immediately available for use again by green plants, or are ultimately rendered so, and because green plants supply all of the food which other organisms utilize, there exists in nature a continual circulation of elements in its complete form, from the inorganic world through green plants to animals, to saprophytes, and then back to the inorganic world. A careful study of Fig. 196 will make this situation clear.

PARASITISM

So far as plants are concerned, there is no sharp line of distinction between saprophytism and parasitism. All dependent plants absorb organic substances from an external source, and it makes little difference whether the source is living or dead. In fact, many fungi may live either as saprophytes or as parasites, that is, are *faculatative*, in contrast to the *obligate* forms which can live only one way or the other. Similarly, parasitism among animals is not a clearly defined phenomenon. All animals eat either dead or living organisms (or their products), and so have the same relation to their food supply as do dependent plants. We do not, however, consider the relation between a predatory animal and its victim, or an herbivorous animal and the vegetation upon which it feeds, as cases of parasitism.

Parasitism, as applied to both plants and animals, has a rather limited meaning, being used to describe cases where one kind of organism lives attached to another, either inside or outside its body, obtaining its nourishment at the other's expense. The two organisms involved in this type of association are known respectively as *parasite* and *host*. Not only does the parasite receive all of the benefits of the association, but the host is always more or less injured. If injured sufficiently to cause some marked disturbance in its normal functions, the host is said to be *diseased*. It should be understood that the disease is merely a response on the part of an organism to the presence of a parasite living upon it. A disease manifests itself by *symptoms*, which are abnormalities in function or structure.

Parasitic Plants.—Among plants by far the greatest number of parasites, as of saprophytes, is found among

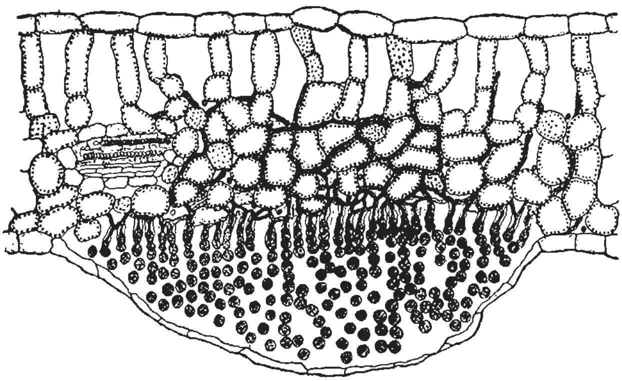


FIG. 197.—Cross-section of a radish leaf infected with a parasitic fungus (*Albugo candida*). × 100. The mycelium forces its way between the mesophyll cells and produces spores beneath the epidermis, thus forming a blister on the surface of the leaf which finally ruptures and liberates the spores into the air.

FIG. 198.—Galls produced on cherry twigs by the "black-knot" fungus (*Plowrightia morbosa*). The gall consists of mycelium and hypertrophied host tissue.

the bacteria and other fungi, all of which lack chlorophyll and are consequently dependent upon some external source of food. Nearly all of the true fungi which are parasitic confine their attacks to other plants, but parasitic bacteria live on both plants and animals. Among the many plant diseases caused by true fungi, the following may be mentioned: grape downy mildew, potato blight, brown rot of stone fruits, corn smut, and wheat rust. In some cases the mycelium lives on the surface of the host, sending short branches into the epidermal cells (Fig. 26), but in most parasitic fungi the mycelium is internal, merely producing spores at the surface (Fig. 197). Some forms cause an hypertrophy of the host tissue, resulting in the formation of tumors or galls (Fig. 198).

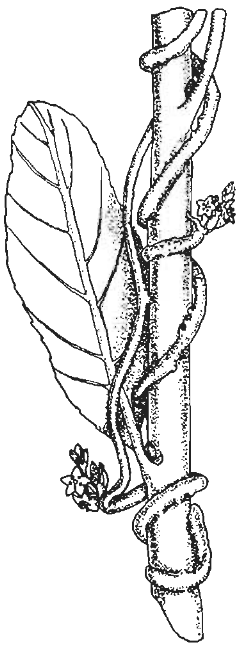


FIG. 199.—Dodder (*Cuscuta*), a seed-plant parasite, twining about a poplar stem, × 1. Short, sucker-like processes are sent into the host, and through them nourishment is absorbed.

Of the bacterial diseases of plants, the following are wide-spread: pear blight, cabbage rot, cucurbit wilt (attacking melons, squashes, and cucumbers), and crown gall. Most of the diseases of man and of the higher animals are caused by bacteria, the following being well-known examples: typhoid fever, tuberculosis, diphtheria, cholera, pneumonia and tetanus.

Only a few parasites are found among the higher plants, two conspicuous examples being the dodder (*Cuscuta*) and the mistletoes. The dodder is related to the morning glory; it attacks various woody and herbaceous seed plants (Fig. 199). The yellow or orange-colored, practically leafless stem twines about the host and sends short sucker-like processes into it which penetrate the vascular system, absorbing both food and water therefrom. The parasite has no connection with the soil, and, lacking chlorophyll, is unable to carry on photosynthesis.

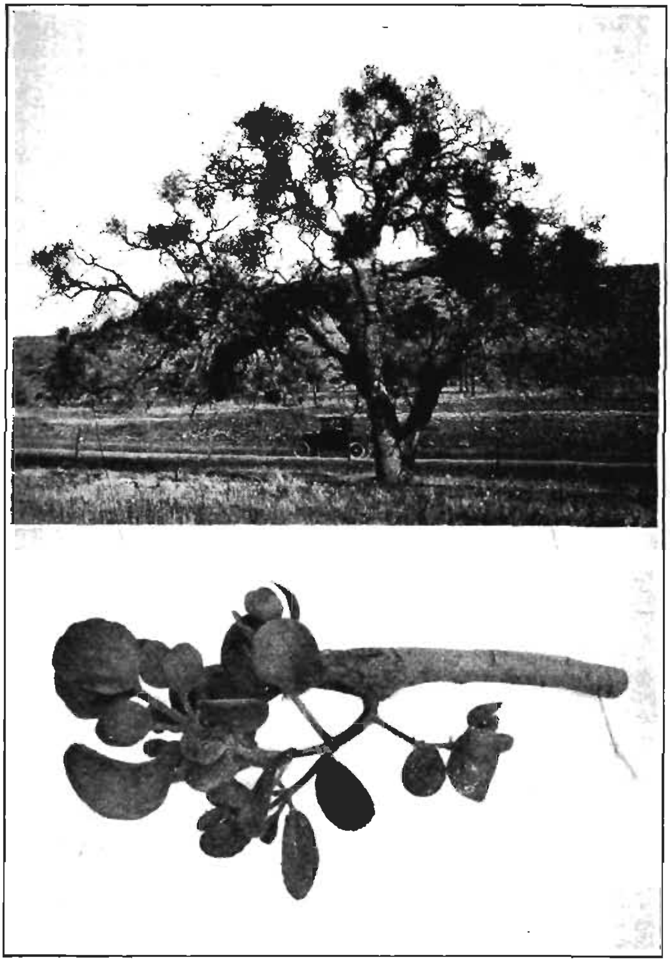


Fig. 200.—A mistletoe (*Phoradendron villosum*) growing on an oak tree, and (below) a closer view of another species (*P. flavescens macrophylla*) growing on a poplar stem, × ⅓.

Mistletoes live on various kinds of trees, and, like the dodder, send suckers into the vascular tissues of the host (Fig. 200). While some kinds of mistletoes are entirely parasitic, others are only partially so. The latter have green leaves and are able to make at least part of their own food. Having no connection with the soil, however, all mistletoes obtain their entire supply of water and mineral salts from the host. The seeds of mistletoes are sticky and are distributed by becoming attached to the feet of birds.

Parasitic Animals.—Animal parasites are found among many different groups, such as protozoans, flatworms, roundworms, annelids, crustaceans, insects, arachnids, mollusks, and vertebrates, but are very rare among the last two. Animal parasites may be external, such as fleas, lice, leeches, ticks, etc., or internal, such as many protozoan parasites, worms of various kinds, etc. They may be parasitic during only part of their life, or permanently so. Some can live on a variety of hosts; others can live only on one kind of host or a succession of several specific hosts. Correlated with their easy life, many animal parasites are sluggish and structurally degenerate, having lost their organs of sense, food-getting, locomotion, etc. The two examples given below are of specialized parasites, both requiring two different hosts to complete their life cycles.

Malarial Parasite.—One of the greatest discoveries of modern medicine is that organisms which cause certain human diseases are carried by insects, and this fact has been known in connection with the transmission of malarial fever only since 1898. The parasite which causes malaria in man is a minute protozoan which goes through a rather complicated life cycle (Fig. 201). The only mode of infection is through the bite of a mosquito. As it enters the human body, the organism consists of a minute, slender, pointed cell which invades and feeds upon one of the red blood corpuscles. As a result, the organism gradually increases in size, coming to resemble a small amoeba. After destroying the contents of the corpuscle, it produces a number of small spores which escape, each entering another corpuscle and repeating the processes of growth and reproduction. When the spores escape, poisons are liberated into the blood stream. These represent waste products resulting from the destruction of the corpuscle as well

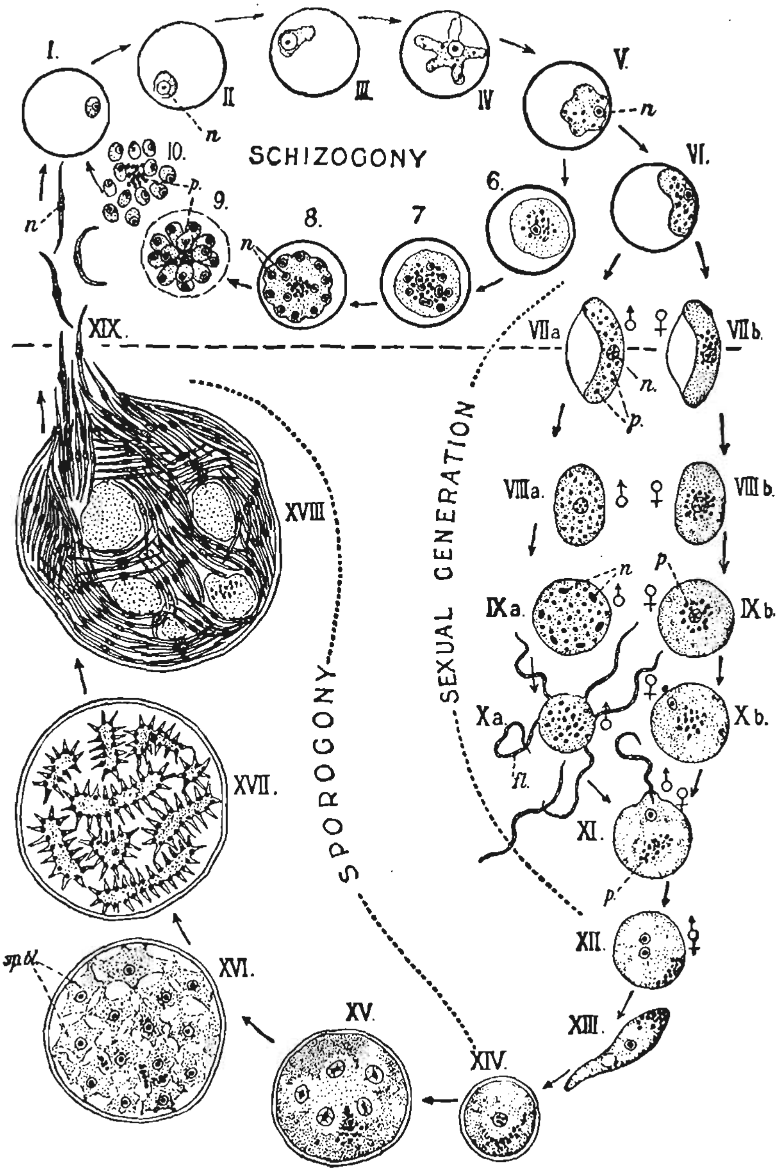


FIG. 201.—Diagram illustrating the life history of the malarial parasite (*Plasmodium malariae*). The stages above the line occur in the human body, those below in the body of the mosquito. I to V and 6 to 10 show parasite entering human red blood corpuscle, growing, and producing spores. During the sexual phase of the life history, sperms and eggs are differentiated and unite to form a zygote (XII). This encysts in the wall of the mosquito's stomach and undergoes changes which result in the formation of a large number of slender pointed cells (XVIII) which make their way to the salivary glands and are then ready to be injected into a human being. (*From Minchin, in Lankester's "Treatise on Zoology," A. & C. Black, Ltd., by permission.*)

as those arising from the parasite itself. It is the liberation of this poisonous material which causes the chill and fever characteristic of the disease. In some forms of malaria these symptoms occur at regular intervals.

If a malarial patient is bitten by a mosquito of a certain kind (an *Anopheles* mosquito), a number of malarial organisms enter the body of the insect with the blood which it sucks. There they undergo a series of complex changes, finally resulting in the production of a great many spores of another kind. When the infected insect bites another human being, some of these spores are injected into the blood stream, and the individual contracts the disease. It is evident that the only way in which a man can contract malarial fever is through the bite of a mosquito which itself carries the parasite by having bitten either a malarial patient, or a person who has recovered from the disease but still carries some of the parasites in his blood. It has long been realized that the most effective way of controlling malaria is to destroy the mosquitoes which transmit the parasites from one human being to another.

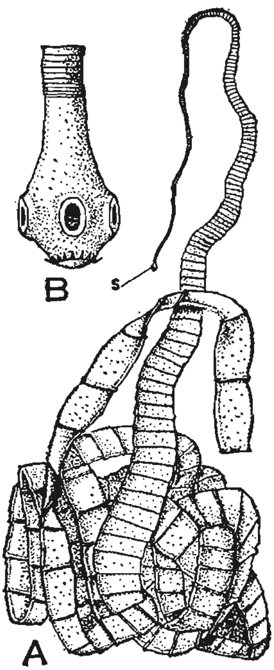


FIG. 202.—The pork tapeworm (*Taenia solium*); *A*, entire worm; *B*, the "head" (*s*) enlarged. (*From Wieman, "General Zoology," McGraw-Hill Book Company, Inc., after Leuckart-Nitsche wall chart, by permission.*)

Tapeworms.—Tapeworms are parasites which live in the digestive tract of the higher animals, there being several species which commonly infect man. The body of a human tapeworm is composed of a minute head-like organ and a number of flat posterior segments which become larger and larger throughout its length (Fig. 202). The head is attached to the intestinal wall and gives rise to the posterior segments by a process of budding. Thus the "worm" is really not a single animal composed of a number of metameres, as its general appearance would seem to indicate, but a colony of multicellular individuals. A single specimen of beef tapeworm may consist of several thousand segments and may reach a length of 6 to 9 meters (20 to 30 feet) or more.[1] Tapeworms have no digestive system; they absorb food through their body wall after it has been digested by the host.

The segments pass out of the human body through the the digestive tract. Each contains thousands of small embryos, as the tapeworm is hermaphroditic and self-fertilizing. Some of these embryos may then be swallowed by the alternate host, which may be a hog, a cow, or some other animal, depending on the species of tapeworm. After entering the body of the other host, the parasite bores into the muscles, undergoes further development, and finally passes into a resting stage. In this form it enters the body of man when infected meat is eaten. The eating of raw or insufficiently cooked pork, beef, or fish is generally responsible for the presence of tapeworms in the human body.

SYMBIOSIS

Symbiosis is an association in which two different kinds of organisms live together in such a way that one does not materially injure the other, or if one is injured it receives some compensating benefit from its association with the other. There are many different degrees of mutual dependence, and consequently a number of kinds of symbiosis are often recognized, but here we shall be interested merely in a few well-known examples chosen to illustrate the general situation.

Ants and Aphids.—The relation which exists between these animals is a sort of slavery, and is a real case of symbiosis because both members of the association are benefited. Aphids, or plant lice, are small oval green bugs which suck the juices of plants (Fig. 128*B*). They are often

[1] The pork tapeworm, another species, is smaller, rarely exceeding 3 meters (10 feet) in length.

seen on young tender shoots, but some kinds attack roots. Aphids secrete a sweet substance from their bodies called "honeydew," of which ants are very fond. Wherever aphids are found ants may be seen running back and forth between the aphids and the ant nests, gathering the sweet secretion and carrying it to the larvae. The ants defend the aphids against attack and take care of them in other ways. Some kinds of ants take the aphids to their own nests during the winter and feed them in order to secure a constant supply of honeydew. For this reason aphids are often called "ants' cattle."

FIG. 203.—The root system of a young bean plant (*Phaseolus*), showing numerous tubercles in which nitrogen-fixing bacteria live, × ½.

Nitrogen-fixing Bacteria.—As we have seen, nitrates are formed in the soil both by the action of the nitrifying bacteria upon ammonia, and by the nitrogen-fixing forms which convert free nitrogen to nitrates (see pp. 250–251).

While some of the latter are saprophytic upon organic matter in the soil, others enter into a peculiar relation with certain seed plants, particularly legumes, such as clover, alfalfa, beans, peas, lupines, etc. The bacteria invade the roots of the legume and live as parasites upon carbohydrates in the root tissues. As a result of their presence, the roots undergo local enlargement, forming tubercles or nodules

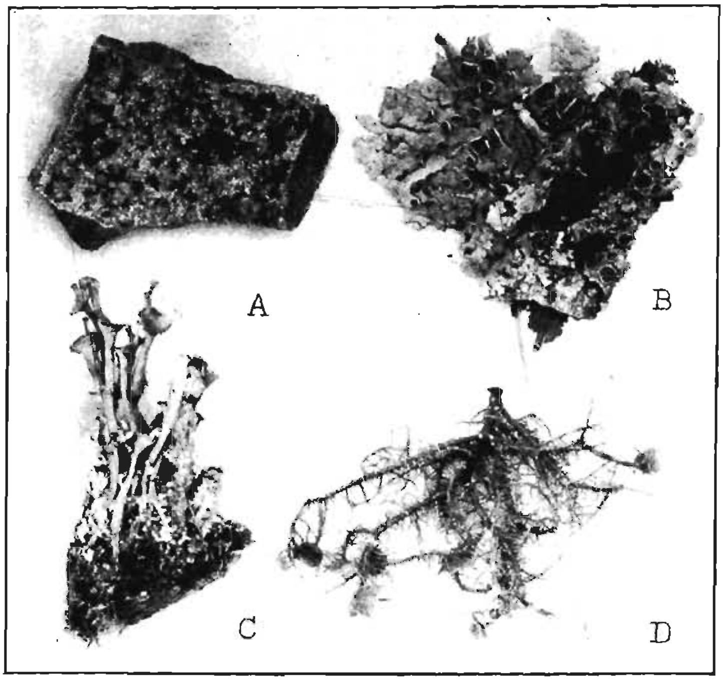


FIG. 204.—Group of common lichens, × 1. *A*, a crustose form (*Placodium*) growing on rock; *B*, a foliose type (*Parmelia*) growing on bark; *C*, a lichen (*Cladonia*) which grows erect upon the ground; *D*, a branching form (*Usnea*) which hangs from the limbs of trees.

(Fig. 203). These bacteria (like the saprophytic forms mentioned above which live free in the soil) are unique in being able to absorb free nitrogen from the air and to "fix it," that is, to form nitrogenous compounds within their own cells. After this process has gone on for a while, the legume digests some of the bacteria and thus obtains a supply of protein food. When the legume dies, however, there is always a considerable amount of nitrates added to the soil, and these are then available for other green plants. Thus as a means of restoring nitrates to impoverished soils, the cultivation of legumes is an important agricultural practice. That legumes have come to depend upon nitrogen-fixing bacteria for their supply of nitrogen

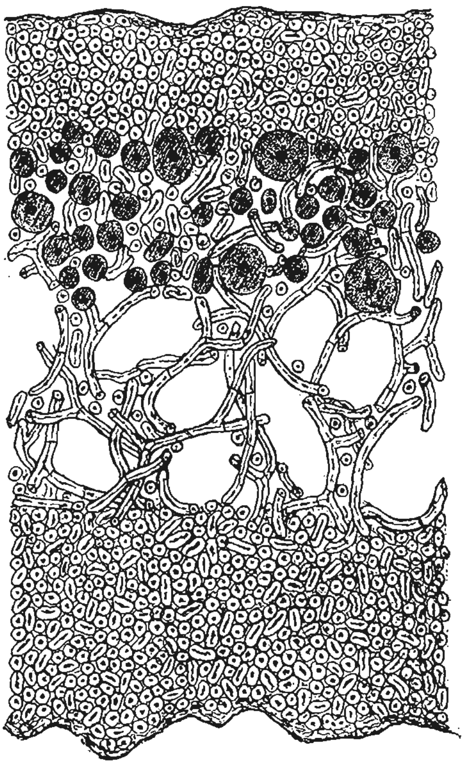


FIG. 205.—Cross-section of a lichen body (*Physcia*), showing cells of the alga (above) surrounded by a mass of interlacing fungous filaments. × 500.

is shown by the fact that when cultivated in sterilized soil growth is very feeble, even when nitrate salts are supplied in abundance. For obvious reasons the relation between the nitrogen-fixing bacteria and the legume is often called *reciprocal parasitism.*

Lichens.—Lichens are small plants of various form commonly seen growing on rocks, tree trunks, dead wood, and on the ground (Fig. 204). Their usual color is gray or grayish green, but some are more conspicuous. A lichen is not a single plant, as its appearance suggests, but an alga and a fungus living together in symbiotic relationship. This is clearly indicated by a cross-section through the lichen body (Fig. 205). The greater part of the lichen is composed of a dense mass of tangled fungous filaments, among which are the cells of the alga. The fungus lives upon the alga as a parasite, but does not kill it. In fact, the alga seems to be but slightly injured, merely giving up some of the food which it makes. At the same time, however, the alga is benefited in that the fungous body readily absorbs and holds moisture. The alga supplies the fungus with food, while the fungus gives moisture to the alga. This reciprocal relation enables lichens to grow in dry, exposed situations where neither the alga nor the fungus would be able to live alone. Thus the association between the two lichen components is one of mutual advantage.

CHAPTER XVIII

THE FACTS OF EVOLUTION

The scientific study of organisms, in all of its many aspects, has produced convincing evidence as to the reality of evolution—the process whereby modern forms of life have been derived from earlier, simpler forms through the operation of natural laws. The multitudinous species of plants and animals now inhabiting the earth owe their present condition of structural organization to this process of gradual change; they are the modified descendants of preexisting species. The earliest forms of life were very simple, and from them have gradually evolved forms more and more complex. Thus all organisms are related to one another by descent—all have had a common origin. This means that life, represented by an unbroken succession of individuals, has been continuous from the beginning. While evolutionary development, for the most part, has been progressive, in some cases it has been retrogressive, leading to a reduction or loss of parts or to other degenerative changes, but in either case, evolution is a process of racial modification.

All of the physical sciences prove that everywhere in the universe dynamic conditions prevail. Instability is characteristic of all matter. The entire universe is in motion and is undergoing constant transformation—heavenly bodies, the earth itself, molecules. Permanency in nature is purely a relative term. The physical sciences also demonstrate that the universe is ruled by natural laws, and that these operate in the production of changes. The process of change which takes place in the physical world constitutes what is known as *inorganic evolution*. It is a principle fundamental to the sciences of astronomy, geology, physics, and chemistry. *Organic evolution* is merely the same process in living things.

In previous chapters it has been shown that perpetual change is characteristic of individual organisms—that growth and metabolism are but expressions of a ceaseless series of transformations. We know that organic diversity accompanies the production of new organisms, and that, to a certain extent, environmental influences can produce structural modification. We shall now study the history of life, shall see that changes always have gone on, and that the present complex conditions of organic nature represent the culmination of a long series of events. It should be emphasized that the process of evolution is continual and has proceeded with extreme slowness over an inconceivably vast extent of time.

Geology teaches that at first the earth was lifeless—that primal conditions were not favorable for the existence of organisms. Life appeared in a very simple form and has been evolving ever since. It should be understood that, because of the present limitations of our knowledge, the study of evolution is concerned only with the development of life. We do not know how life first arose, and we have absolutely no evidence regarding the nature of the first living forms. Discussions of evolution must take the origin of life for granted, and proceed to explain how it has developed.

Importance of Evolution.—The doctrine of descent with modification is a fundamental axiom of biology. As a scientific principle it is as well established as the law of gravitation. The evolutionary interpretation of nature is accepted today by all scientists of recognized standing, and has been since the middle of the last century. It is universally accepted because it offers the only rational explanation of a great mass of facts which otherwise would be utterly meaningless. There is no controversy whatsoever among biologists that organisms have evolved, although, as will be seen in a subsequent chapter, there is considerable difference of opinion as to how they have evolved.

The establishment of the fact of evolution as a fundamental principle of biology probably has had a more profound influence on human thought than has any other scientific generalization. At the present time it dominates all branches of learning, even those having no relation to science. We recognize, for example, an evolution of languages, customs, warfare, government, religious thought, etc. Briefly stated, the establishment of the principle of organic evolution has revolutionized man's conception of the universe and of himself.

Popular Misconceptions.—A great deal of confusion exists in the popular mind concerning evolution, and as a result many false ideas regarding it have become current. One of the most prevalent is that evolution is the subject of a creed—something which one accepts on faith. It has been pointed out that the principle of evolution, supported by an overwhelming mass of scientific evidence, is a logical explanation of the facts of nature. It is not a theory, although there are many theories relating to how it operates. One does or does not "accept" evolution in the same sense as any other scientific generalization based on demonstrable facts. Moreover, it should be realized that any reluctance one might have in admitting the occurrence of evolution, or of any other natural process, in no way detracts from its reality.

Another misconception is that knowledge of evolution is antagonistic to religion. This is based on a failure to differentiate between the functions of science and the functions of religion. Millikan[1] says:

> The purpose of science is to develop, without prejudice or preconception of any kind, a knowledge of the facts, the laws, and the processes of nature. The even more important task of religion, on the other hand, is to develop the consciences, the ideals, and the aspirations of mankind.

There can be no real conflict because each properly occupies a different sphere; each appeals to different aspects of human thought. It is only when one takes upon itself the functions of the other that difficulties arise.

[1] Part of a joint statement recently issued and signed by a group of 31 leading religious leaders and scientists.

Science does not deny the existence of a creator; it merely shows that the method of creation is evolution. To say that the world has developed in accordance with natural laws does not deny the existence of an unknown guiding influence, call it what we may.

It is popularly supposed that evolution means direct descent of man from the gorilla, the chimpanzee, or from some other existing species of ape or monkey. This misconception is based on a failure to understand how the process of evolution has operated. Except in rare instances one form of life cannot be regarded as ancestral to another which is contemporaneous with it.[1] While all of the existing evidence indicates that both man and the apes have evolved from a lower type of life, it also indicates that each has developed independently along a divergent line from some extinct, generalized common ancestor unlike either living form. Thus the relationship between man and the modern apes is not *lineal*, but strictly *collateral*.

Nature of the Evidence.—The principle of organic evolution is an explanation of demonstrable facts drawn from all fields of biological science. These facts cannot be explained on any other basis than that of descent with modification; according to any other interpretation they are rendered wholly unintelligible. Not only do numerous facts of biology support this explanation, but none have ever been discovered which refute it or warrant any alternative explanation. Thus the doctrine of organic evolution stands as a great scientific generalization, and is accepted today as such. The evidence upon which the principle rests comprises "the facts of evolution." Some of the more striking classes of these facts we are now ready to consider.

Classification.—We have already seen that all members of the plant and animal kingdoms fall naturally into a number of distinct groups which can be arranged in an

[1] Only a relatively few cases are known where an ancient type of organism has persisted in a comparatively unchanged condition into the present, living contemporaneously with its modified descendants. Nearly all of the countless species of plants and animals of the past are utterly extinct.

ascending series (see Chaps. V and X). The basis upon which these groups is constructed is fundamental structural resemblance. The major groups are called *phyla,* the more important of which we have already considered. A phylum may be divided into several *subphyla*, but more commonly directly into *classes*. Thus the vertebrates are a division of the phylum Chordata and consist of five main classes: fishes, amphibians, reptiles, birds, and mammals. Each class consists of smaller groups called *orders*. The carnivores, rodents, ungulates, bats, primates, etc., each constitute an order of mammals. An order is composed of still smaller groups called *families*. The carnivores, for example, include the dog family, the cat family, the bear family, etc. A family, in turn, is an assemblage of related *genera* (singular, genus). Thus the dog family includes the dog genus (*Canis*), the fox genus (*Vulpes*), and other dog-like forms. Finally each genus includes one or more *species*.[1] The dog genus includes not only the common domestic dog (*Canis familiaris*), but the European wolf (*Canis lupus*), the gray or timber wolf of North America (*Canis occidentalis*), the prairie wolf or coyote (*Canis latrans*), the jackal (*Canis aureus*), etc. It should be noted that the *scientific name* of an organism is the name of its genus combined with the name of its species. The position of the dog in the animal kingdom is indicated below.

Phylum Chordata (the chordates)
 Subphylum Vertebrata (the vertebrates)
  Class Mammalia (the mammals)
   Order Carnivora (the carnivores)
    Family Canidae (the dog family)
     Genus *Canis* } The common dog
      Species *familiaris* }

A comparative study of the members of any group shows that their bodies, despite many superficial differences, are built according to the same general plan. Structural resemblance means relationship, and relationship denotes descent from a common ancestry. The members of each

[1] In some species still smaller divisions, called *varieties*, are recognized.

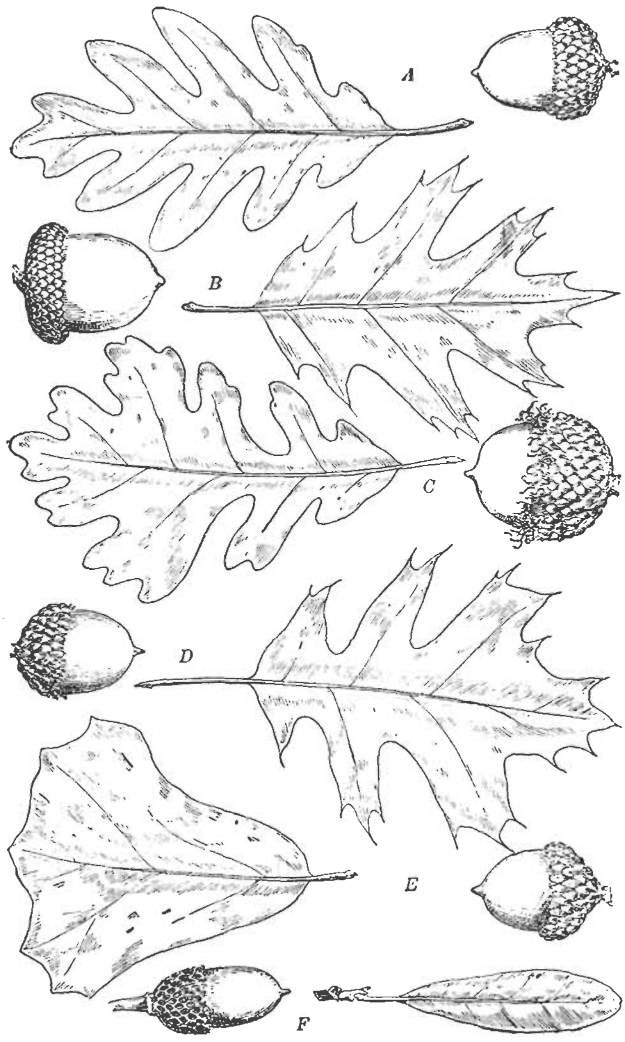


FIG. 206.—The basis of classification. A group of leaves and acorns illustrating some of the differences between six species of oak (*Quercus*); *A*, white oak (*Q. alba*); *B*, red oak (*Q. rubra*); *C*, bur oak (*Q. macrocarpa*); *D*, black oak (*Q. velutina*); *E*, blackjack oak (*Q. marylandica*); *F*, live oak (*Q. virginiana*). (*From Bergen and Caldwell, "Practical Botany," Ginn and Company, after Hough, by permission.*)

group have common structural features because they have had a common evolutionary origin, the differences between them having arisen through each having subsequently followed a divergent line of development. The greater the degree of basic resemblance between any two organisms, the closer is their relationship, and consequently the less remote the common ancestor from which each has sprung (Fig. 206).

The relationship of the various groups of organisms to each other may be represented in the form of a tree. Existing groups are at the ends of twigs, some lower on the tree, some higher. The branches represent divergent lines of descent, and all can be traced to a common trunk. Thus the mere fact that organisms can be classified on the basis of structural similarity and show various degrees of likeness indicates that evolution has taken place.

Vestigial Structures.—Most plants and animals possess some parts which perform no useful function and which are present in a more or less degenerate condition. These are called *vestigial structures*. Their presence can be adequately explained only by assuming that they were more fully developed and functional in the organism's ancestors. A few examples will be given.

The flowers of the common asparagus are of two kinds: one having perfect stamens and a rudimentary pistil, the other with rudimentary stamens and a perfect pistil (Fig. 207). The only reasonable interpretation which can be placed on this fact is that the ancestors of the asparagus had flowers with both the stamens and the pistil functional in all of them. The asparagus also has rudimentary leaves in the form of small scales which are entirely functionless. Obviously, an adaptation to compensate for the reduced condition of the leaves and to provide for photosynthesis is the fact that the stems are green and highly branched, the branches being very fine (Fig. 208).

The garden slug is a mollusk closely related to the snails; in fact it is really a snail with a greatly reduced shell. Snails possess a spiral shell into which the soft body can be withdrawn (Fig. 209). The shell is lined with a thin fold of skin called the *mantle*. In the slug the mantle consists of a small oval muscular patch on the animal's back; the

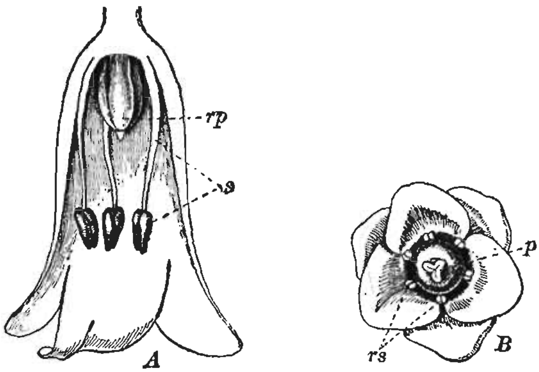


FIG. 207.—Flowers of garden asparagus; *A*, staminate flower, with perfect stamens (*s*) and rudimentary pistil (*rp*); *B*, pistillate flower, with fully developed pistil (*p*) and rudimentary stamens (*rs*). (*From Bergen and Caldwell, "Practical Botany," Ginn and Company, after H. Mueller; by permission.*)

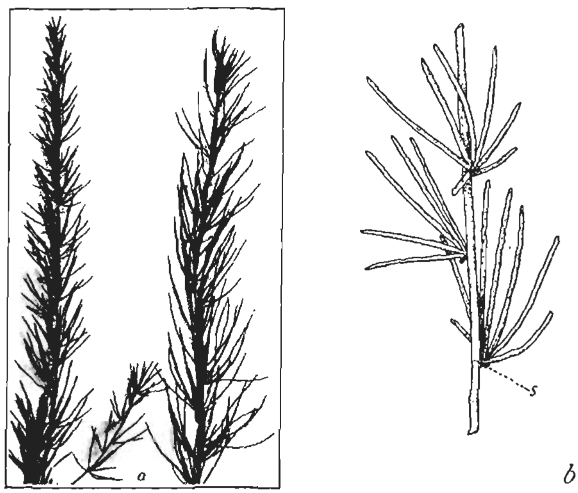


FIG. 208.—Shoots of garden asparagus; *a*, photograph, × ½; *b*, drawing showing that the leaves borne on the main stem are reduced to minute scales (*s*), × 2. In the axil of each scale a cluster of green leafless branches arises.

shell, of a thin, flat plate imbedded in the mantle. The presence of this useless shell testifies that the slug has been derived from snail-like ancestors.

The snakes and lizards belong to the same group of reptiles, as they have many structural features in common.

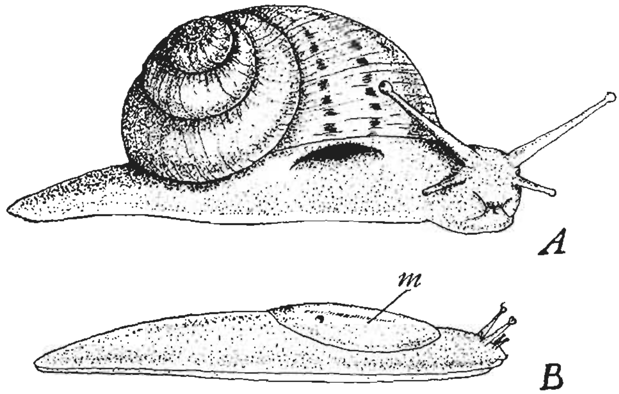


FIG. 209.—*A*, a snail (*Helix*), a mollusk with a well-developed shell, × 1. *B* a slug (*Ariolimax*), a closely related form, having a vestigial shell covered by the mantle (*m*), × 1.

It is part of their plan of organization to have four limbs, but correlated with the special mode of locomotion assumed

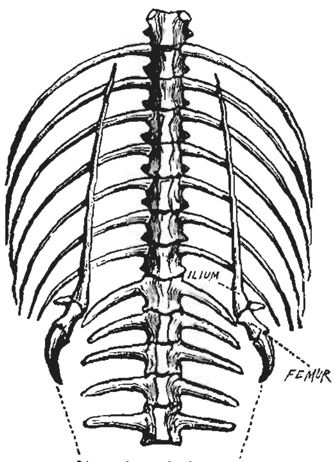


FIG. 210.—Vestigial pelvic girdle and hind limbs of the python, × ¼. (*From Romanes, "Darwin and After Darwin," Open Court Publishing Co., by permission.*)

by the snakes, limbs are absent. That they have been derived from limbed ancestors, however, is indicated by the presence of vestigial hind limbs in certain existing species of snakes (Fig. 210).

In many of the lower vertebrates there is present a third eyelid (the *nictitating membrane*) consisting of a thin translucent membrane which may be drawn diagonally across the eyeball. In *man* this structure is represented by a remnant called the *semilunar fold* (or *plica semilunaris*), situated at the inner corner of the eye (Fig. 211). The

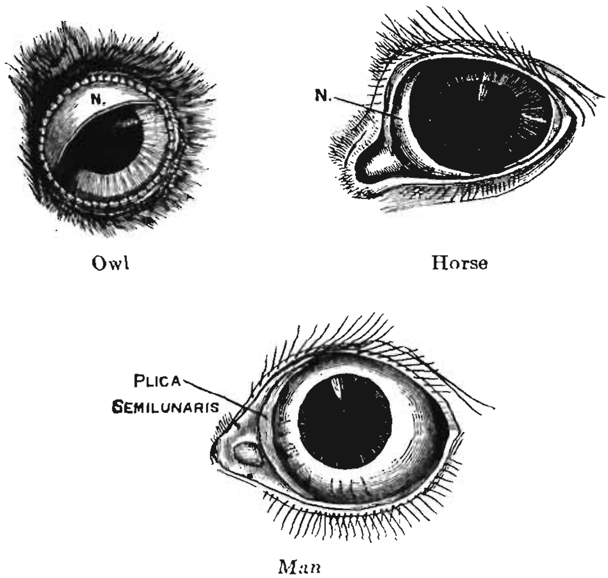
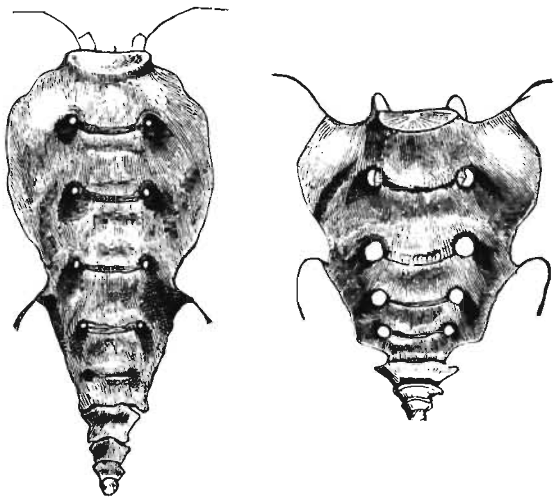


FIG. 211.—The nictitating membrane (N) in the owl and horse compared with its rudiment in man. (*From Romanes, "Darwin and After Darwin," Open Court Publishing Co., by permission.*)

power of moving the ears so as to more effectively catch sound is well developed among such mammals as the dog and horse. In man this power has become lost, but that it was once present is evidenced by the occurrence of feebly developed ear muscles lying close against the head. There are present, at the lower end of the spinal column a short row of *coccygeal bones*, representing a rudimentary tail which is well developed during a portion of early embryonic life (Fig. 212).

The examples cited above of vestigial structures are only a few selected from thousands which have been described, over a hundred from man alone. They all testify to the reality of evolution.



Gorilla Man

FIG. 212.—Sacrum of gorilla compared with that of man, showing the rudimentary tail bones of each. (*From Romanes, "Darwin and After Darwin," Open Court Publishing Co., by permission.*)

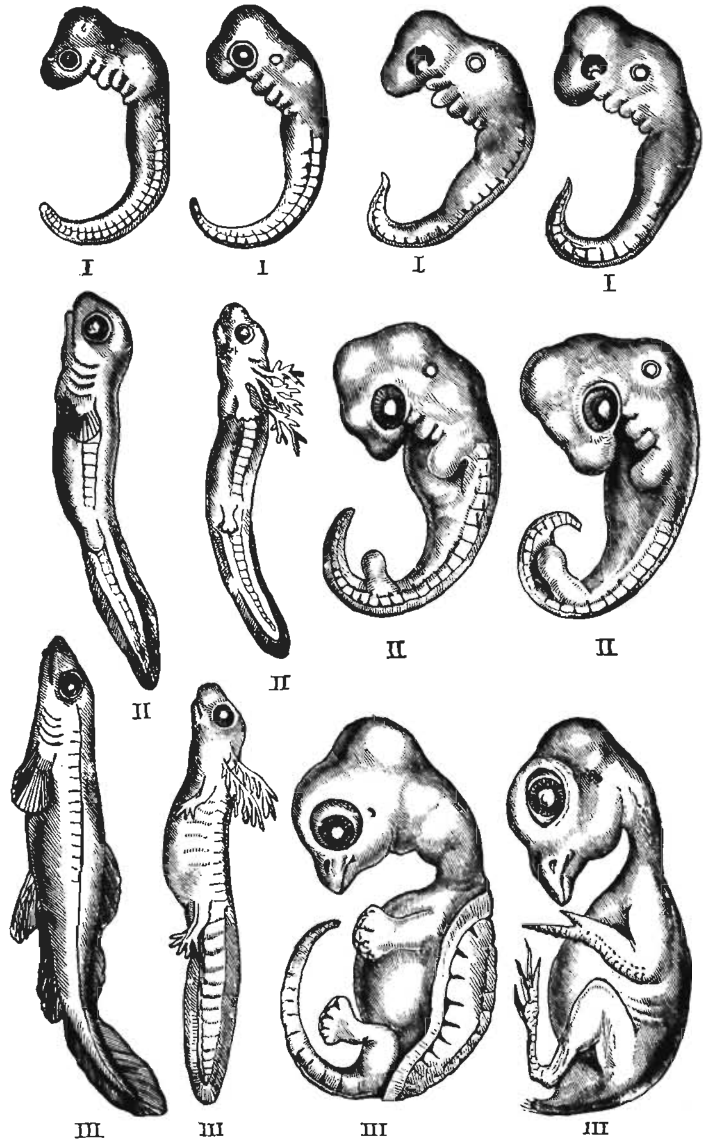
Embryology.—Attention has been called repeatedly to the fact that every organism which reproduces by the sexual method begins its existence as a single cell—the zygote. It is apparent that this cell represents an individual in the simplest possible condition of structural organization, a condition in which unicellular organisms remain permanently, but multicellular organisms only temporarily. Thus it is a self-evident fact that, like other metazoans, every human being is unicellular at the beginning of its existence.

The series of early embryonic stages involved in the processes of cleavage and gastrulation are essentially alike in practically all multicellular animals (see pp. 165–166). We have seen that some of the lower animals proceed only a short way in their development, some remaining in the blastula stage, others in the gastrula stage. The coelenterates, it will be recalled, are permanent gastrulas, having neither mesoderm nor a coelom. The members of the next group, the flatworms, have mesoderm but no coelom, while all of the higher groups have both features.

In a general way, the sequence of its embryonic stages is indicative of the development through which an animal has gone in the course of its evolution. Embryonic development is a brief and condensed repetition of a series of ancestral stages through which the race has passed. Or, as often stated, *ontogeny* (the development of the individual) recapitulates *phylogeny* (the development of the race). This is a statement of the *recapitulation theory*. It should not be taken to mean that the parallelism between individual and racial development is perfect, for it is always only approximate.

The recapitulation theory is well illustrated among insects. We have seen that the annelids and arthropods have many structural features in common, and thus are closely related. The life history of any member of one of the higher groups of insects substantiates this interpretation. The larval stage of a butterfly, bee, fly, or beetle is distinctly worm-like, not only in general appearance, but in a number of more fundamental respects (Fig. 135). This strongly indicates that the insects have evolved from worm-like ancestors.

While the earliest stages in embryonic development are essentially similar in all metazoans, it is only among members of the same group that resemblances persist during later development, but these are always striking. For example, in Figs. 213 and 214, where embryos representing each of the five great vertebrate groups are shown, relationship is apparent by their general structural similarity, indicating descent from a common ancestry. The figures also show that members of each of the five vertebrate classes begin to manifest conspicuous differences much earlier in development than members of the same class.



Fish Salamander Tortoise Chick

FIG. 213.—A series of embryos at three comparable and progressive stages of development, representing each of the main classes of vertebrates below the mammals. (*From Romanes, "Darwin and After Darwin," Open Court Publishing Co., after Haeckel, by permission.*)

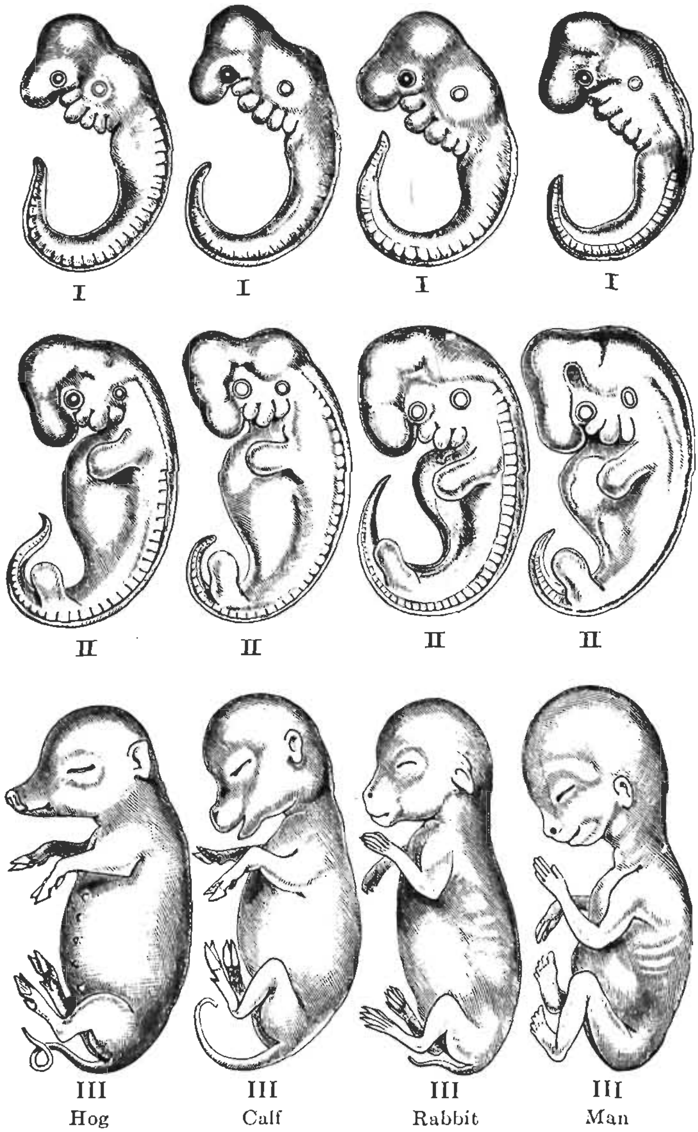


FIG. 214.—A series of embryos similar to those shown in Fig. 213, representing four different divisions of the class Mammalia. (*From Romanes, "Darwin and After Darwin," Open Court Publishing Co., after Haeckel, by permission.*)

Embryology teaches that many structures which are permanent in the lower members of a group appear only in embryonic stages in the case of the higher members, and then either later disappear completely, persist as vestiges, or become modified to form other structures. For example, during a certain period of prenatal development, the human embryo has a tail as well developed as that of any of the other vertebrates (Fig. 214). Likewise, in common with all vertebrates it has gill slits. The latter become functional only in the fishes and amphibians, as has been seen, but their appearance in all vertebrates is indicative of descent from aquatic ancestors. In fact, it can mean nothing else.

Intergrading Species.—Before evolution had become an established principle of biology, it was supposed that every species of plant and animal has always existed in its present state, and each was thought to be entirely distinct from all others. It was soon found, however, that while many species seem to be distinct, some show such a great range of variation that it is very difficult to determine their limits. In other words, some genera exhibit "intergrading species." Typical members of one species may be very different from typical members of another, but often individuals may be found which are intermediate between the two, individuals which show some of the characters of both species. This is true of the asters, roses, hawthorns, willows, oaks, and many other plants. In the animal kingdom, intergrading species are especially common among insects, fishes, birds, and mammals. In all such cases the limits of each species are more or less arbitrarily defined, and taxonomists differ greatly as to where the lines of demarcation are to be drawn. If all species were fixed and incapable of modification, it would be difficult to account for the occurrence of intermediate forms, but, on the basis of the principle of evolution, genera exhibiting intergrading species are merely those in an active condition of evolution at the present time.

Cultivation and Domestication.—Everyone is in agreement that all cultivated plants and domesticated animals

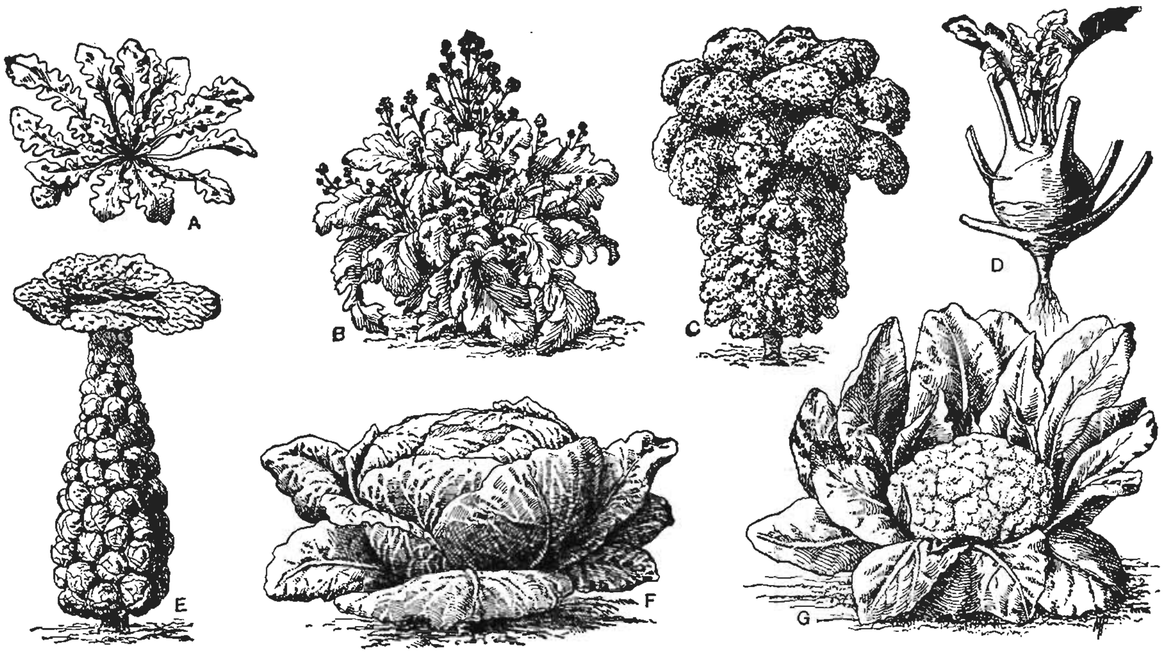


Fig. 215.—Horticultural plants which have arisen from the wild cabbage; *A*, wild cliff-cabbage (*Brassica oleracea*), the probable ancestor of the group; *B*, broccoli; *C*, kale; *D*, kohlrabi; *E*, Brussels sprouts; *F*, cabbage; *G*, cauliflower. (*From Gager, "Fundamentals of Botany," P. Blakiston's Son & Co., by permission.*)

are the modified descendants of wild species. Many have been under man's influence since prehistoric times, for such a long period, in fact, that their origin is lost in obscurity. In many instances such profound changes have taken place that it is impossible even to recognize the wild ancestral form. Where such recognition is possible, however, striking facts are often revealed. For example, the wild cabbage still grows in Europe, but bears little superficial resemblance to its cultivated descendants (Fig. 215). From this single species man has developed not only all of the different kinds of cabbages, but cauliflower, kale, kohlrabi, Brussels sprouts, collards, etc. When one considers all of the different kinds of pigeons, poultry, cattle, dogs, horses, etc., it is difficult to realize that each group has evolved from one or several original wild species. If species were incapable of modification, such striking changes as these would not have been possible in such a comparatively short time.

CHAPTER XIX

THE LIFE OF THE PAST

Paleontology is the study of fossils—the remains of organisms of the past found imbedded in the earth. The "testimony of the rocks" represents evidence of a very direct sort, demonstrating the reality of evolution in a striking way. Paleontology also indicates the *course* of evolution, giving us much information concerning the origin and development of whole groups of organisms. Before considering the history of life as revealed by the fossil record, however, it will be necessary to understand how the relative age of the various layers of rock forming the earth's surface is determined.

Division of Geologic Time.—Geology teaches that the surface of the earth is constantly undergoing transformation as a result of the action of various natural forces upon it. One set of changes are those involved in the processes of erosion and deposition. The disintegration of rock by weathering and its subsequent transportation, chiefly by running water, tends to result in a gradual wearing down of highlands and a filling in of depressions. It has been estimated that, at the present time, the North American continent is being degraded, on the average, at the rate of 1 foot in 9,000 to 10,000 years. The eroded material, carried to lower levels, is deposited as sand, clay, gravel, etc. Later these sediments may become solidified to form such kinds of rocks as sandstone, shale, and conglomerate.

The processes of erosion and deposition which are going on today in all parts of the world have always been in operation. As a result of continued degradation and slow sinking of the earth's surface, vast portions of what are now dry land have been covered by large bodies of water (Fig. 216). During these periods of subsidence, sedimentary rocks have been formed. Subsequently these areas have been lifted into the air and once more exposed to the various agents of erosion. Because sediments accumulate and vertical movements of the earth's surface take place very slowly, enormous stretches of time have elapsed between and during successive periods of deposition.

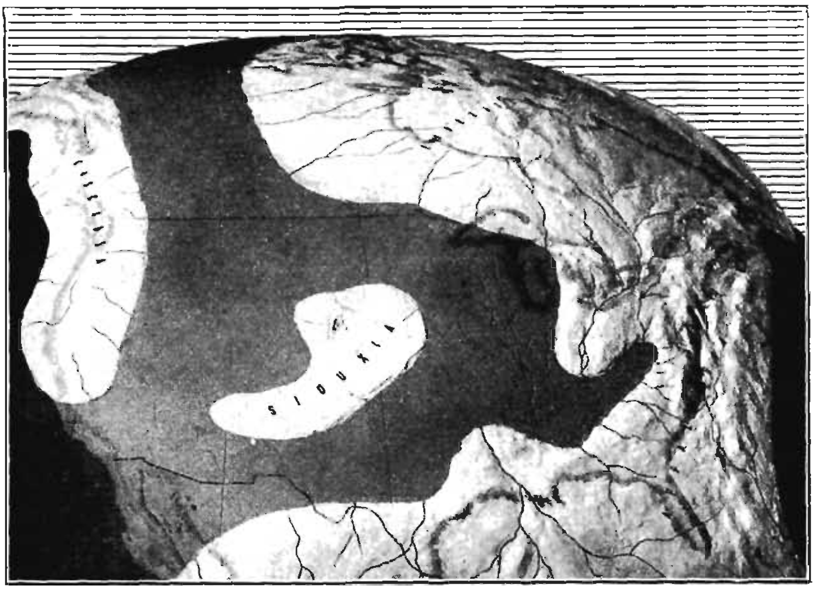


FIG. 216.—North America in Cambrian times. Theoretic restoration of the North American continent (white), continental seas (gray), and oceans (dark gray) in Upper Cambrian time, during which there occurred the earliest known great invasion of land by the oceans. The lands were probably all low and the climate warm. *(From Osborn, "Origin and Evolution of Life," Charles Scribner's Sons; by permission. Photograph of globe model in the American Museum by Chester A. Reeds and George Robertson, after Schuchert.)*

It is evident that the various strata of sedimentary rocks comprising the earth's surface have been laid down in chronological order, the youngest rocks lying above the older ones. By studying the series of stratified rocks in different parts of the world, geologists have been able to reconstruct the history of the earth in a very definite way. Geologic time is divided into five great *eras*, and each era into a number of *periods:* these are given in the following table:

TABLE OF GEOLOGIC TIME[1]
(Modified from Osborn)

Eras	Periods	Dominant animal life
Cenozoic, 3,000,000 years	Recent Pleistocene Pliocene Miocene Oligocene Eocene	Age of mammals
Mesozoic, 9,000,000 years	Cretaceous Comanchean Jurassic Triassic	Age of reptiles
Paleozoic, 18,000,000 years	Permian Pennsylvanian Mississippian	Age of amphibians
	Devonian Silurian	Age of fishes
	Ordovician Cambrian	Age of higher invertebrates
Proterozoic, 12,000,000 years	Keweenawan Animikian Huronian Algomian Sudburian	Age of primitive invertebrates
Archeozoic, 18,000,000 years	Laurentian Grenville	Age of unicellular life

[1] The time estimates are extremely conservative; they indicate the relative duration of each era.

Kinds of Fossils.—In general, fossils occur in three different forms. (1) *Actual organic remains* are simply dead organisms or their parts which have been preserved from decomposition by some special means, and which consequently have undergone little change. Examples are mammoths found frozen in arctic tundras, insects in amber, animals in asphalt lakes and peat bogs, etc. (Fig. 217). Fossils of this sort are the most favorable for study, but unfortunately are very rare. (2) *Petrifactions* are fossils in which the organic matter has been replaced, particle by particle, by mineral matter. It is chiefly hard parts which have been preserved in this way, such as wood, teeth, bones, shells, etc. (Fig. 218). Petrifactions show not only external form, but sometimes internal structure as well.

FIG. 217.—Actual organic remains. Group of bones of the imperial mammoth in an asphalt pit at Rancho La Brea, Los Angeles, Calif. (*Courtesy of Los Angeles Museum of History, Science, and Art.*)

Thus sections often can be made of petrified material and studied with the microscope. (3) *Natural molds and casts* represent the most common kind of fossils (Fig. 219). If the dead body of an organism falls into soft mud or sand, the impression may be preserved after all of the organic matter has been destroyed. If the sediment then hardens to form rock, a natural mold results. This cavity may later become filled with mineral matter to form a cast. It is apparent that molds and casts tell a great deal about the size, shape, and other external features of organisms, but give no information concerning their internal structure.

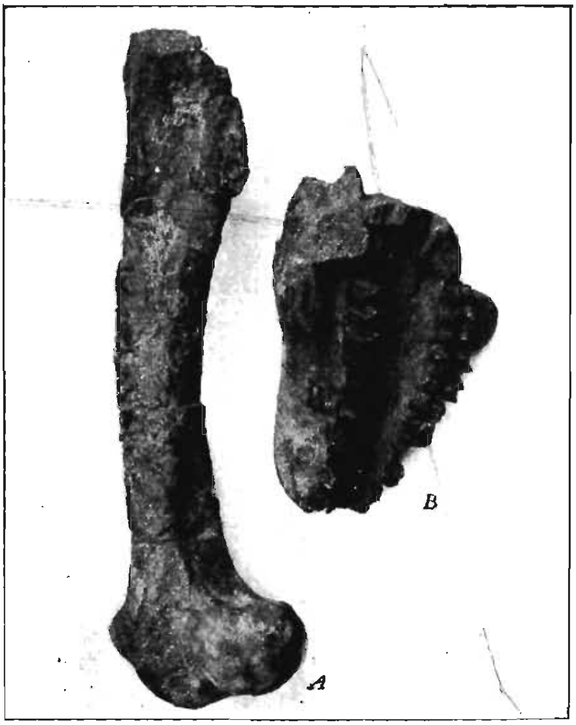


FIG. 218.—Petrifactions; *A*, thigh bone of a Miocene horse (*Merychippus* (?)); *B*, portion of the skull of an oreodont of Oligocene age, one of a group of extinct hoofed mammals peculiar to North America. In both cases the original bone has been replaced by mineral matter.

Early Development of Life.—The Archeozoic era is the portion of geologic history when the oldest known rocks were formed. While largely igneous in origin, many of the Archean rocks consist of metamorphosed sediments. Life is thought to have arisen during the latter part of this vast era. There is no direct evidence concerning the character of the first forms of life. Being probably of a simple and perishable nature, the earliest organisms were

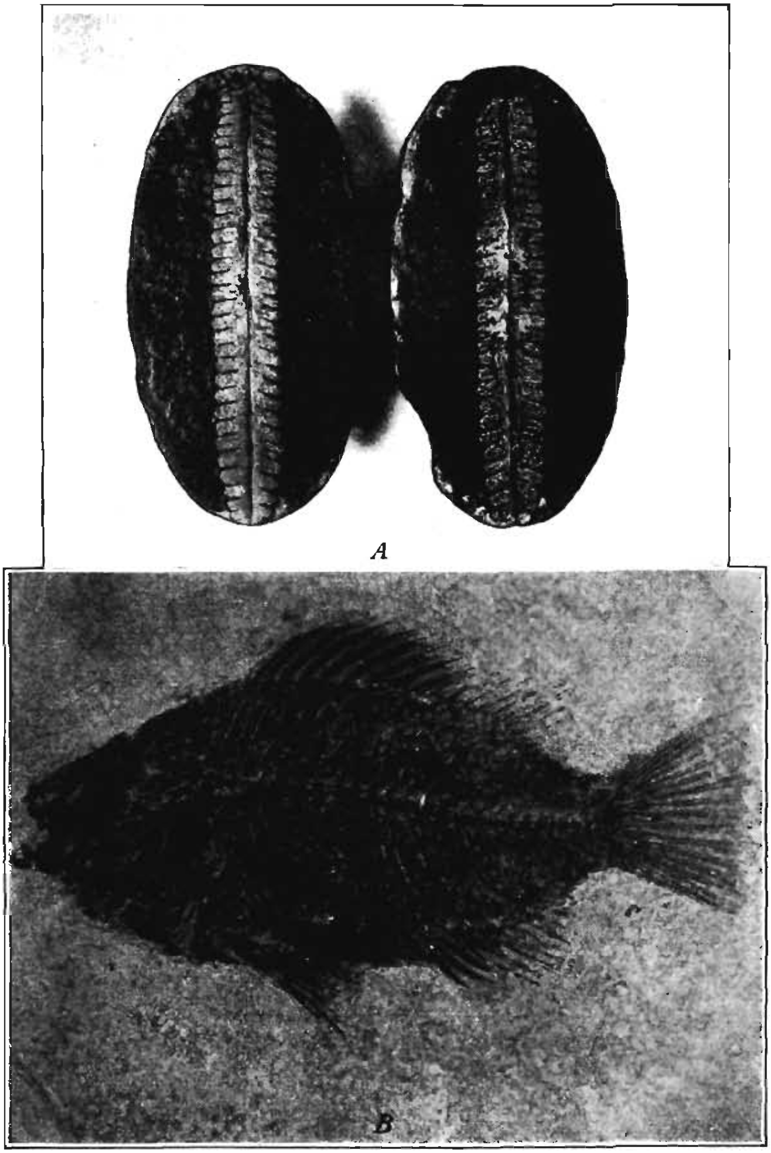


Fig. 219.—Impressions in rock of a fern leaf (*A*) and a Miocene fish (*B*), × ⅚.

not amenable to preservation, and, because of subsequent alteration of the Archeozoic rocks through tremendous pressure and great heat, any direct fossil evidence which might have accumulated has been obliterated. The early existence of life is indicated, however, by the enormous accumulations of limestone and graphite in the Archeozoic formations and of iron as well in the Proterozoic, as organisms are often known to be concerned with the formation of these substances.

There are three reasons for thinking that bacteria or bacteria-like organisms may have been the first forms of life to have existed on the earth: (1) Because bacteria are the chief agents in effecting decomposition of all dead organic matter, a world devoid of bacteria is inconceivable. (2) Bacteria are the simplest organisms in existence. (3) While most bacteria are saprophytic or parasitic, and so could not exist in the absence of other forms of life, some can make foods directly from water and carbon dioxide (or carbonates) without the aid of chlorophyll and light. Instead of utilizing solar energy, they obtain energy from the oxidation of various inorganic compounds (see pp. 250-251).

A later stage in the development of life may have been the appearance of simple algae—green plants able to carry on photosynthesis and thus to utilize solar energy. Simple unicellular animals probably evolved at an early period, but obviously must have followed the appearance of plants. The evolution of the first simple multicellular organisms must have occurred during pre-Cambrian time, for during the Proterozoic, primitive multicellular animals of many types developed, although there is little fossil evidence as to their nature. Proterozoic fossils are scarce; a few protozoans and sponges, and worm burrows indicating the presence of annelids, comprise about the only animal remains which have been found, but there is abundant evidence of the existence of lime-secreting algae.

Life of the Early Paleozoic.—With the beginning of the Paleozoic era a great development of life had been reached, but it was entirely marine. Cambrian fossils are very abundant and diverse, but are entirely of marine invertebrates. No trace has ever been found of land animals or of vertebrates. The most highly developed animals of the time were trilobites (Fig. 220), a kind of extinct arthropod. During the Ordovician period the first fishes appeared, but they were very primitive forms known as ostracoderms (Fig. 221), and were not common. Like the modern lampreys and hagfishes (cyclostomes), they were

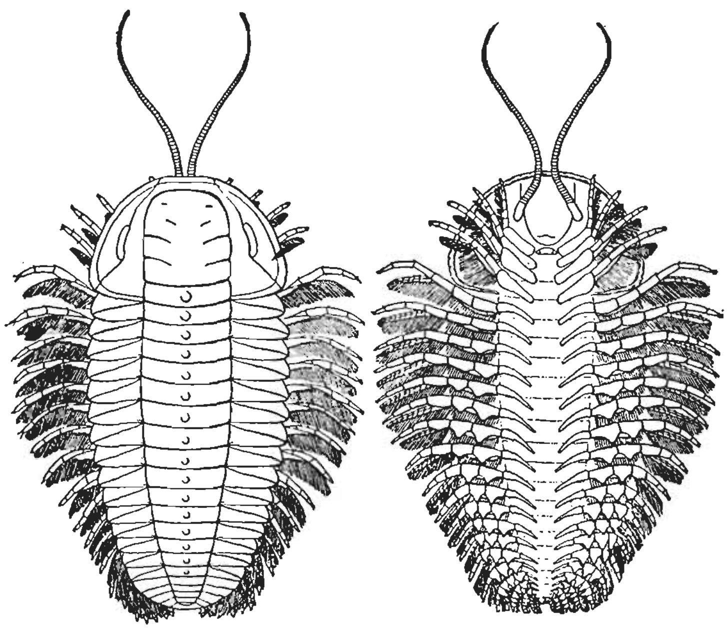


FIG. 220.—An Ordovician trilobite (*Triarthrus becki*), restored, × 2. 1, dorsal view; 2, ventral view. (*From Beecher.*)

without true jaws and paired fins. Little is known of the plant life of the early Paleozoic, but algae must have been very abundant to have supported such a luxuriant marine fauna. There is no record of the existence of land plants, but it seems likely that during the Cambrian period primitive non-woody plants were evolving which may have been like our modern bryophytes. It is thought that pteridophytes were in existence during the Ordovician because of their abundance during subsequent periods.

Life of the Middle Paleozoic.—During the Silurian period fishes became abundant. They were largely of simple types, most of them being ostracoderms. This curious group became extinct during the Devonian, but so many

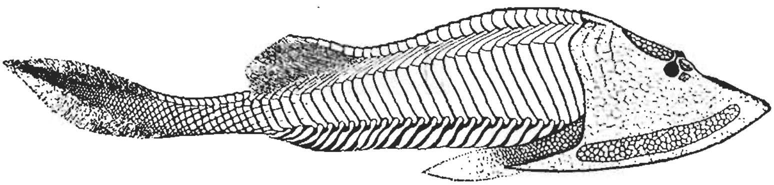


FIG. 221.—Restoration of *Cephalaspis*, a Devonian ostracoderm, side view. These forms, representing the oldest known vertebrates, appeared in the Ordovician, lived through the Silurian, and became extinct at the close of the Devonian. (*From Patten, "Evolution of the Vertebrates and their Kin," P. Blakiston's Son & Co., by permission.*)

new forms of fishes arose during the middle Paleozoic that they became the dominant animal group. Devonian fishes included sharks and other primitive types (Fig. 222), but there were no representatives of the bony fishes, the

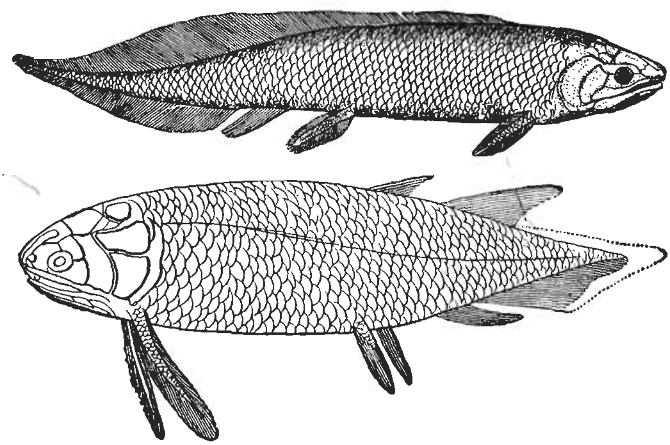


FIG. 222.—Devonian fishes. (*From Linville and Kelly, "A Textbook in General Zoology," Ginn and Company; by permission.*)

great modern group which includes over 95 per cent of all living species. The first land vertebrates probably arose during the Devonian, but they were very rare. In fact, the only evidence indicating their existence at this time consists of a single three-toed footprint found in an upper Devonian shale deposit in Pennsylvania. Another notable feature of the middle Paleozoic was the appearance of air-breathing arthropods—scorpions and myriapods—in the Silurian. Plant remains from the Silurian are fragmentary, but from the Devonian are fairly abundant. The dominant land forms were pteridophytes—forms related to our modern equisetums and lycopods, large tree ferns, and many herbaceous types. The first gymnosperm fossils are from the Devonian deposits. They consist of fern-like plants with seeds, leaving no doubt as to the close relationship between ferns and seed plants.

Life of the Late Paleozoic.—The oldest amphibian remains are known from the Mississippian deposits.

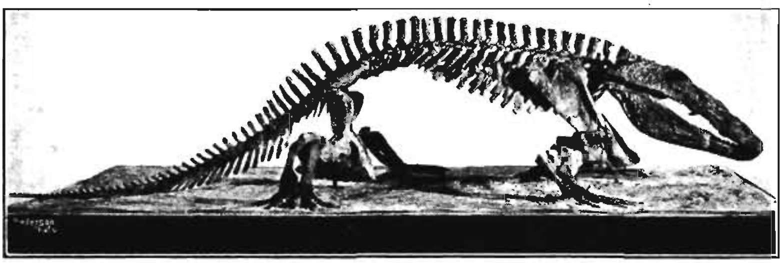


FIG. 223.—Skeleton of *Eryops*, an amphibian from the Permian of Texas. Length about 10 ft. Photograph of specimen mounted in the American Museum of Natural History, New York. (*Courtesy of American Museum.*)

Amphibians were not abundant during this period, however, and were mostly of small simple types somewhat resembling modern salamanders. During the Pennsylvanian and Permian periods the amphibians became the dominant animal group, at the same time reaching the highest point in their development (Fig. 223). For this reason, the late Paleozoic periods are known as the "age of amphibians." In the upper Pennsylvanian and Permian deposits, primitive reptiles have been found, but they are so closely similar to amphibians that in many cases it is difficult to recognize them as reptiles.

A warm climate prevailed during the Pennsylvanian which favored a most unusually luxuriant development of land vegetation consisting of both pteridophytes and gymnosperms (Fig. 224). It was during this period that

Fig. 224.—Restoration of a late Paleozoic landscape; 1, a tree fern; 2, *Calamites*, a giant relative of modern equisetums; 3, 4, *Lepidodendron* and *Sigillaria*, giant relatives of modern lycopods; 5, *Cordaites*, a primitive gymnosperm. (*From Bergen and Davis, "Principles of Botany," Ginn and Company, after Potonié; by permission.*)

the most extensive coal deposits were formed. Coal represents accumulated plant remains subsequently metamorphosed by geologic agencies.

Life of the Mesozoic.—The Mesozoic era was the "golden age of reptiles," as it was at that time that they

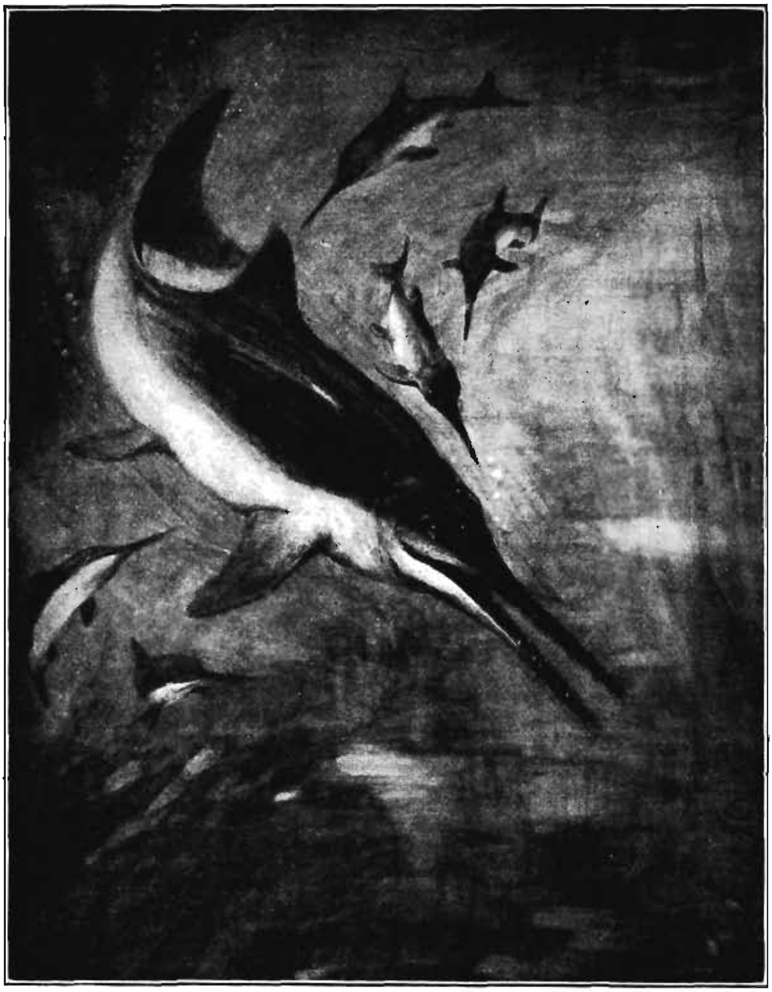


Fig. 225.—*Ichthyosaurus*, a highly specialized aquatic reptile from the Jurassic of Germany. Restoration by Charles R. Knight. The ichthyosaurs were viviparous; the figure represents a mother with brood of young. (*Courtesy of American Museum of Natural History, New York.*)

reached their greatest display as a group, dominating all others. With the close of the Paleozoic the amphibians declined greatly in numbers, only a relatively few types

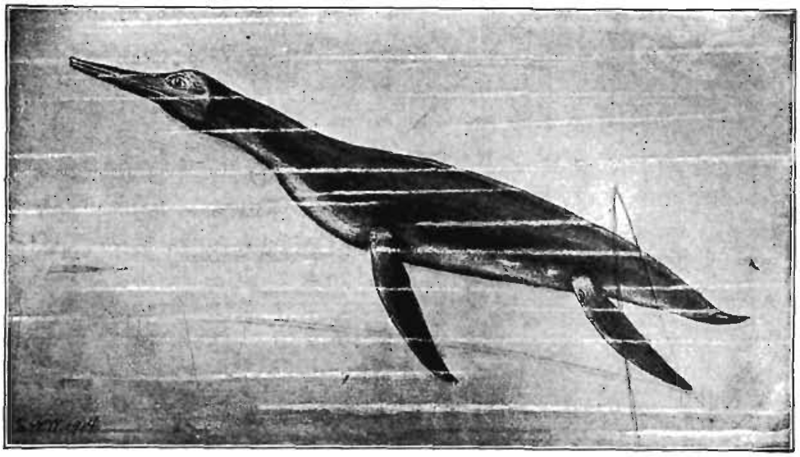


FIG. 226.—Restoration of *Trinacromerium*, a Cretaceous plesiosaur. Length about 10 ft. (*From Williston, "Water Reptiles of the Past and Present," University of Chicago Press; by permission.*)

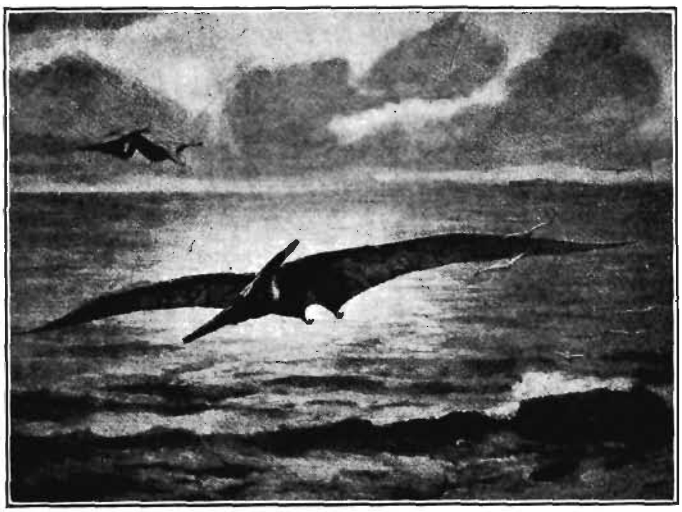


FIG. 227.—Restoration of *Pteranodon*, a Cretaceous pterosaur with a wing spread of nearly 20 ft., probably the largest flying creature which has ever lived. Restoration by Lucas and Langley. (*Courtesy of American Museum of Natural History, New York.*)

remaining. Concurrently, the reptiles began their ascendancy. From a few simple types there arose many highly specialized and diverse groups: dinosaurs, crocodiles, lizards, turtles, pterosaurs, ichthyosaurs, plesiosaurs, and others. During the Mesozoic the reptiles dominated the

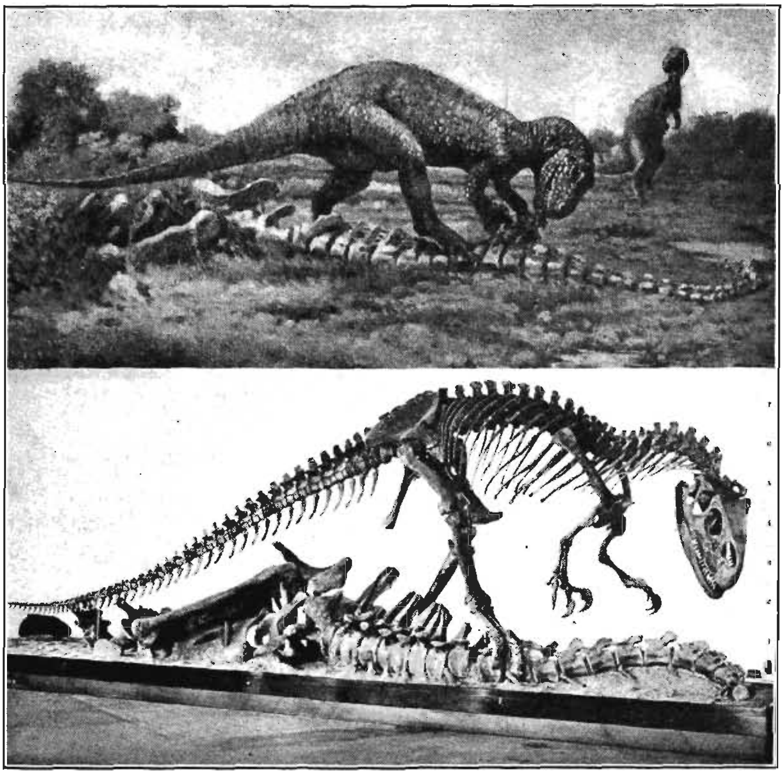


FIG. 228.—Skeleton of the bipedal carnivorous dinosaur *Allosaurus*, mounted in the American Museum of Natural History, New York, and restoration of same by Charles R. Knight. The creature is shown preying upon one of the contemporary giant herbivorous dinosaurs. Length of specimen approximately 34 ft. *Allosaurus* lived in North America during late Jurassic and Comanchean times. (*Courtesy of American Museum.*)

sea, the air, and the land. The ichthyosaurs and plesiosaurs were lung-breathing, aquatic reptiles descended from terrestrial ancestors. The latter were long-necked, lizard-like forms, while the former were fish-like and more highly specialized for marine life (Figs. 225 and 226). The pterosaurs were flying forms, and in many ways were the most extraordinary of all reptiles (Fig. 227). The most abundant and characteristic land forms were the dinosaurs. These remarkable creatures were of various types, some

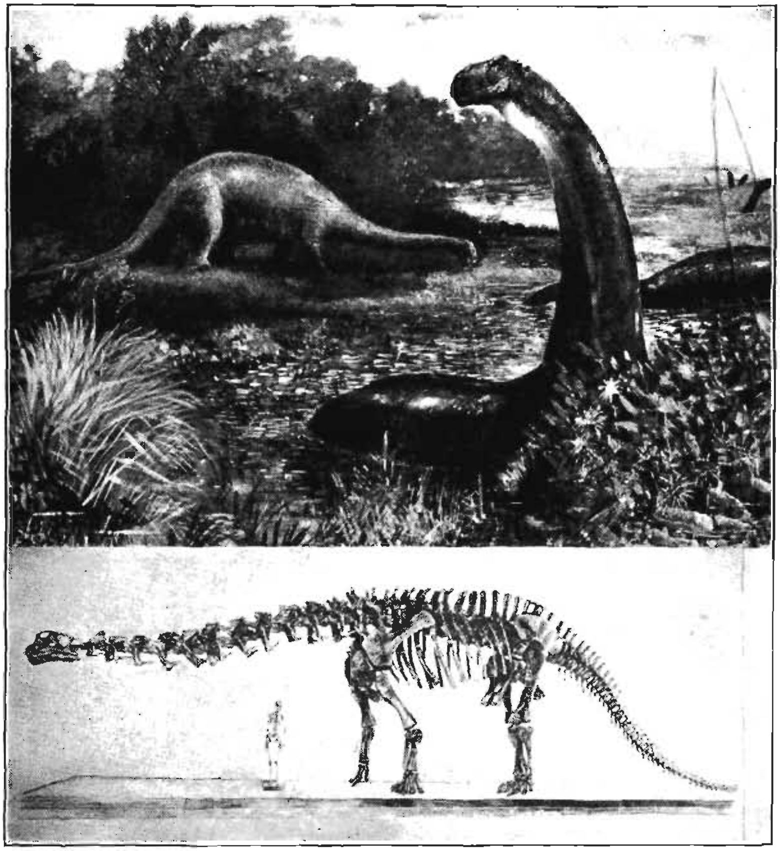


FIG. 229.—*Brontosaurus*, a gigantic, quadripedal, herbivorous dinosaur from the Comanchean of Wyoming. Length about 66 ft., and estimated weight, 37 tons. Mounted skeleton in the American Museum of Natural History, New York; restoration by Charles R. Knight. This form inhabited swampy meadows and flood plains. (*Courtesy of American Museum.*)

carnivorous, others herbivorous; some used all four limbs in walking, others only the hind limbs (Figs. 228 to 230). Many of the Triassic dinosaurs were small and relatively unspecialized, but during the Jurassic they reached a higher and more diversified development, at the same time becoming the most numerous and most powerful group of land animals. The dinosaurs reached their climax during the Comanchean period, there then being the greatest variety and the largest ones which ever existed. Most of these gigantic types did not live into the next period, however, but during the Cretaceous the dinosaurs became very highly specialized in other ways, some developing protective structures of various kinds, such as a thick hide, plates, spines, horns, etc. (Fig. 230).

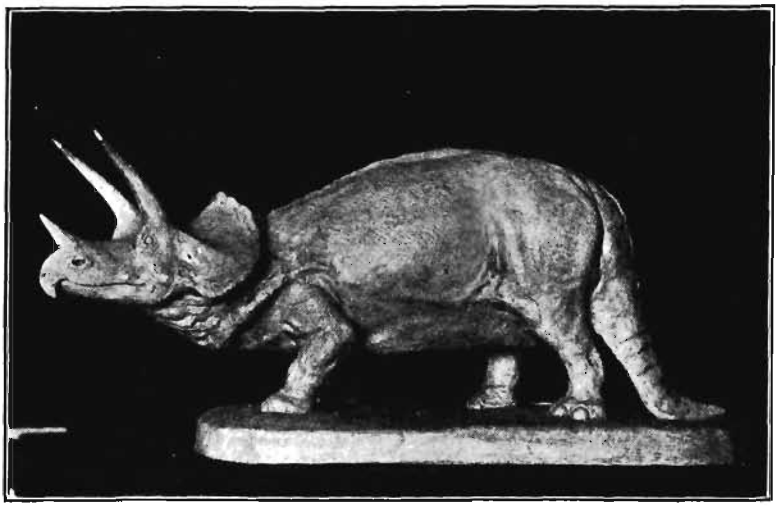


FIG. 230.—Model of *Triceratops*, a horned dinosaur from the upper Cretaceous of western North America. Length 20 to 25 ft. (*Courtesy of American Museum of Natural History, New York.*)

A notable feature of the Mesozoic was the appearance of birds and mammals. The first true mammalian fossils are known from the Triassic deposits, and consist of small reptile-like, egg-laying forms very primitive in a number of ways. The first birds are known from the Jurassic (Fig. 231). They did not evolve from pterosaurs, as the structure of their wings clearly shows, but from some more remote reptilian stock. Jurassic birds were intermediate in structure between reptiles and modern birds, having teeth, a long vertebrated tail, and wings provided with three free claws. Birds and mammals were rare during the Mesozoic and made little evolutionary progress, probably because of the dominance of the reptiles. A

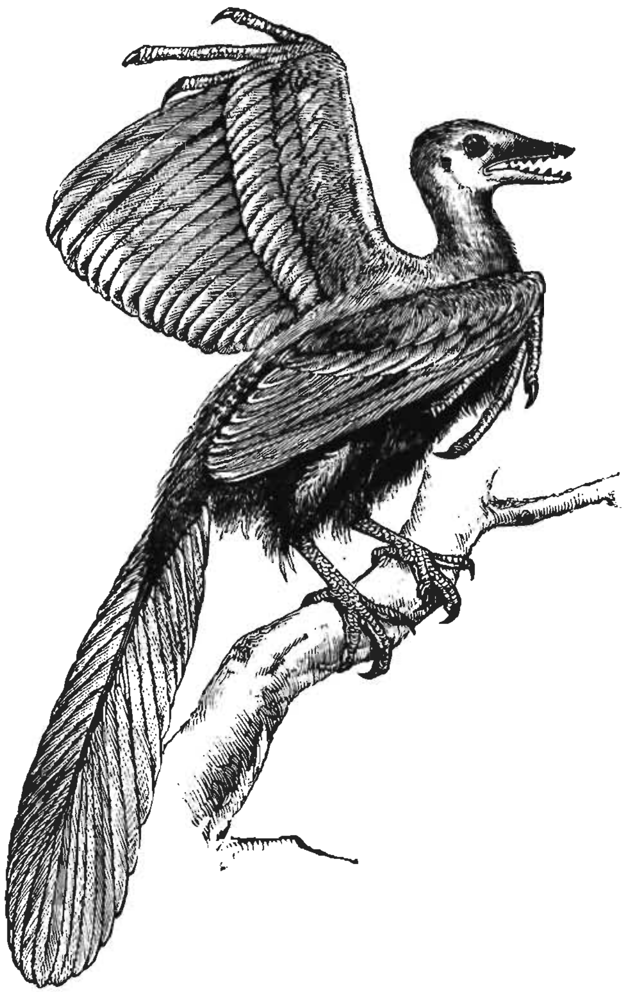


FIG. 231.—Restoration of *Archaeopterix*, a primitive Jurassic bird showing many reptilian features. × ⅛. (*From Romanes, "Darwin and After Darwin," Open Court Publishing Co., by permission.*)

special feature of the Triassic was the appearance of the bony fishes; by the Cretaceous they had become the dominant aquatic animal group, as they are today.

The plant life of the early Mesozoic was dominated by gymnosperms, but these were of more advanced types than lived during the Paleozoic, while many of the older forms were entirely extinct. The first angiosperm remains are known from the late Comanchean. During the Cretaceous the angiosperms evolved with great rapidity and spread over the entire world, gradually replacing the older gymnosperm types as the dominant group of plants.

Life of the Cenozoic.—The Cenozoic marks the rise and culmination of the mammals. With the close of the Mesozoic, the great reptiles became extinct for reasons which can only be surmised. The mammalian ascendancy began early in the Eocene, true placental forms appearing although at first small in size, simple in structure, and with small brains. Their early evolution was so rapid, however, that before the end of the Eocene nearly all of the modern orders were represented. The mammals reached their climax during the Miocene, both in numbers and kinds, and have been a steadily declining group ever since. The vegetation of the Cenozoic consisted chiefly of angiosperms, and was distinctly modern in general aspect.

No account of paleontology would be complete without a brief consideration of the evolution of the horse and of the elephant. The fossil history of both is well known and furnishes a striking example of the trend of evolution along two divergent lines.

Evolution of the Horse.—Modern horses and those of the Pleistocene belong to the genus *Equus*, a highly specialized branch of primitive ungulate stock. Specialization has progressed along two general lines: for rapid running over hard ground, and for grazing. The structure of the horse has been modified in accordance with these functions. Thus the legs are very long and slender, and can bend only in one plane. The bones of the upper arm (radius and ulna) are fused together. The wrist and heel do not touch the ground, the foot consisting of but a single, enlarged, functional toe which corresponds to the middle

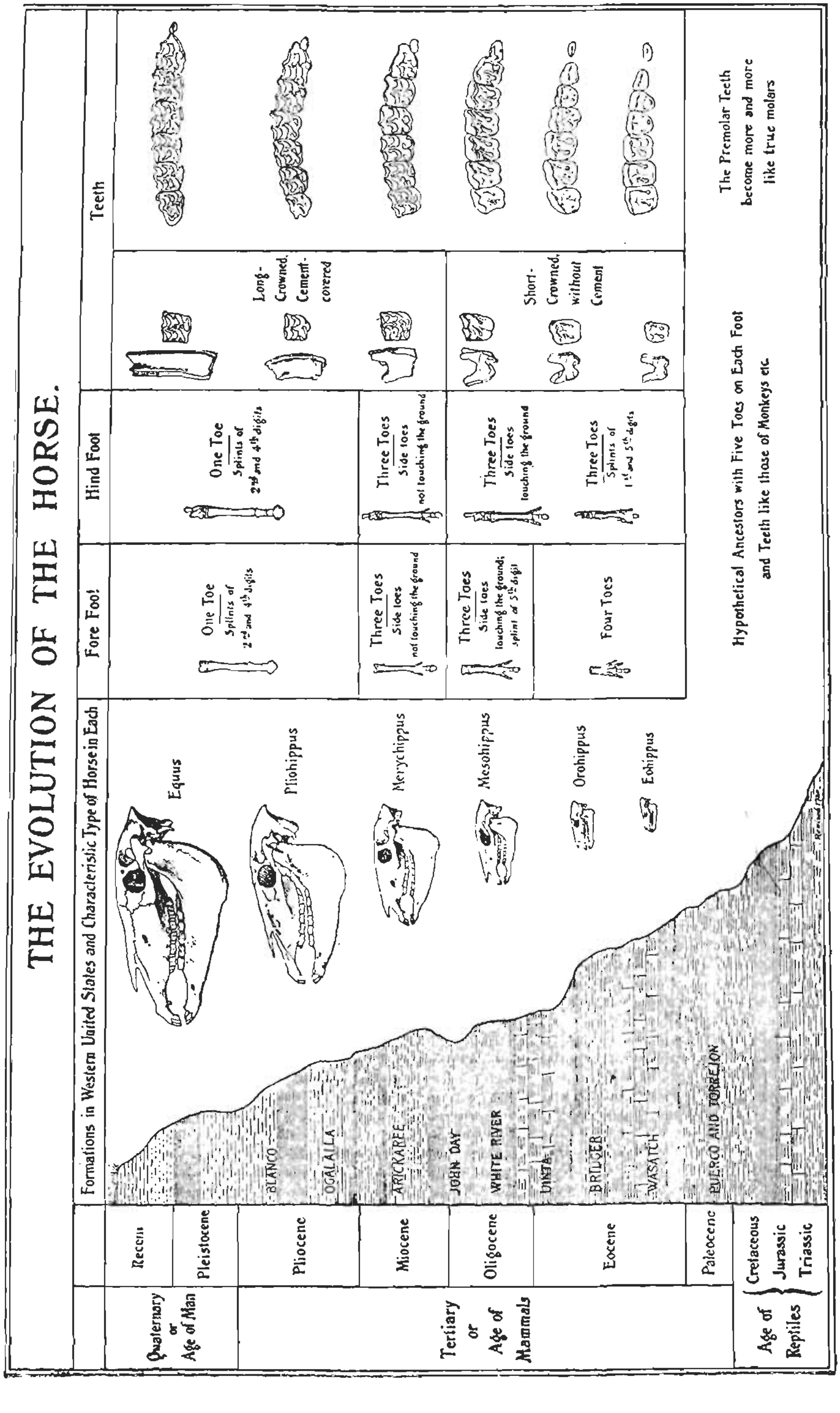


FIG. 232.—Diagram showing the evolution of the horse. (*From Matthew, in Quarterly Review of Biology*, 1926; *by permission*.)

digit of a pentadactyl limb, and two "splint bones" representing the remnants of the second and fourth digits (Fig. 190*C*). The horse walks upon the tip of the toe, this being provided with a large hoof. Modern horses are about 15 decimeters (5 feet) or more in height.

The greatly elongated skull not only is adapted for reaching the ground in grazing, but provides room for the development of the grinding teeth. For the same reason, the jaws are very high and large. The neck is long, thus permitting the head to reach the ground without bending the knees. The teeth of the horse are adapted for cropping and chewing grass (Figs. 188 and 233). The cropping teeth (incisors) are very large and strong, while the grinding teeth (premolars and molars) are broad and flat. The latter have a very complex masticating surface and continue for a long time to grow in height as they are worn down.

The evolution of the horse has been traced through a number of successive stages, some of which we shall now consider (Fig. 232).

The most primitive genus of horses is *Eohippus,* a form which lived in North America during early Eocene times (Fig. 233). During the same period a very similar form (*Hyracotherium*) lived in Europe. *Eohippus* was a slender animal about 3 decimeters (1 foot) in height, or about the size of a fox. Its head, neck, and limbs were relatively short. Its grinding teeth were simple, the masticating surfaces having a very primitive pattern. The fore limbs of *Eohippus* bore four functional toes, the hind limbs three. There was no trace of the first digit on the fore feet, but on the hind feet vestiges both of the first and fifth digits were present. Thus there can be no doubt that *Eohippus* was the descendant of a five-toed ancestor.

Mesohippus was a North American horse which lived during the Oligocene period. It was about 4.5 to 6 decimeters (18 to 24 inches) tall, or about the size of a sheep. Its head, neck, and limbs were longer than those of its progenitor, but the skull was relatively short and unspe-

FIG. 233.—Skull of modern horse (*Equus*) and model of Eocene horse (*Eohippus*) photographed to same scale. (*Courtesy of American Museum of Natural History, New York.*)

cialized. Each foot was provided with three functional toes, the middle one being the longest. The fore limbs bore a rudiment of the fifth digit. The teeth of *Mesohippus* were low-crowned, but more complex than those of *Eohippus*.

Merychippus lived in North America during the Miocene. It was considerably larger than its forerunners, being 9 to 12 decimeters (3 to 4 feet) in height. Its skull was more elongated and its lower jaw heavier. All of the feet were three toed, but the middle toe was relatively larger than that of *Mesohippus*, while the two lateral toes did not touch the ground. The grinding teeth were relatively high crowned, their surfaces somewhat complex, but were incapable of continued growth. *Merychippus* is thought to have been the first horse to have turned from a browsing to a grazing habit.

Pliohippus was a late Pliocene form, not much larger than *Merychippus*, but advanced in other ways. The two lateral toes were reduced to splint bones, while the teeth were more highly crowned and had complex grinding surfaces. *Pliohippus* gave rise to *Equus*, which spread from North America to South America, Asia, and Europe, but for some unknown reason became extinct on the American continents during the Pleistocene.

Evolution of the Elephant.—The genus *Elephas* includes two modern species of elephants and the extinct mammoths. During the Pleistocene the genus was widely distributed over Europe, Asia, and North America, but living elephants occur only in Asia and Africa. The characteristics of the elephants will be briefly outlined.

With the exception of the whales, elephants are the largest living mammals. The Indian species attains a maximum height of about 30 decimeters (10 feet), while the largest African elephants are said to be nearly 40 decimeters (13 feet) tall. Some of the mammoths of the Pleistocene were as large or slightly larger than the modern African elephant (Fig. 234). The limbs are large and pillar-like, an obvious adaptation for supporting the enormous weight of the body. The feet are five toed, each toe being hoofed. In most long-legged mammals the neck is elongated to permit the head to reach the ground, but in the elephants the massive head makes this arrangement impossible. Accordingly the trunk takes the place of a long neck. The trunk is a prolongation of the nose and upper lip; it is used chiefly in conveying food to the mouth.

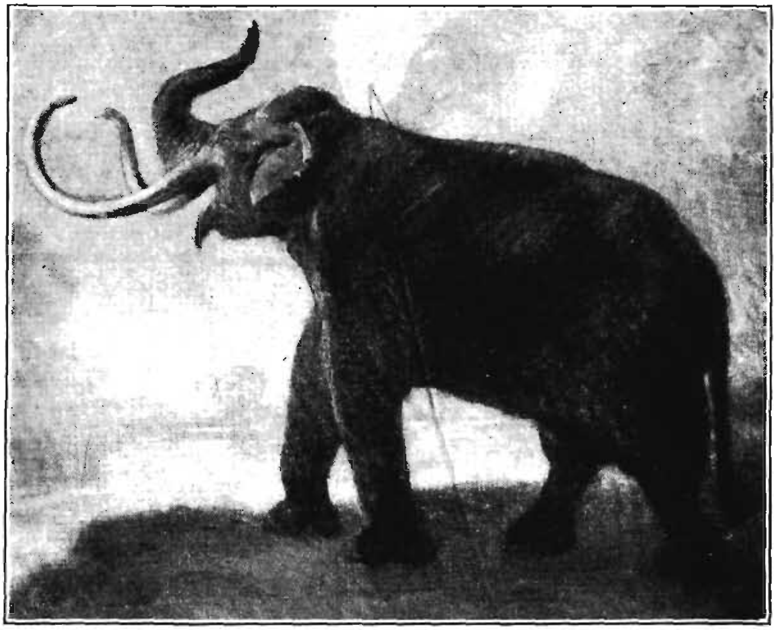


Fig. 234.—Restoration of imperial mammoth (*Elephas imperator*) by Charles R. Knight. (*Courtesy of American Museum of Natural History, New York.*)

The skull of the elephant is very high, being entirely out of proportion to its length. The tusks are highly modified incisor teeth which reach an extreme length of 30 decimeters (10 feet) in the African elephant. In some of the mammoths the tusks were 50 decimeters (16 feet) long. Aside from the tusks, the only teeth which the elephant has are molars, and of these it never has more than four complete or eight partially worn ones at a time. As the grinding teeth are worn down they move forward in the jaw, and are replaced by new ones appearing behind. The chewing surface is very complex, having in the African elephant up

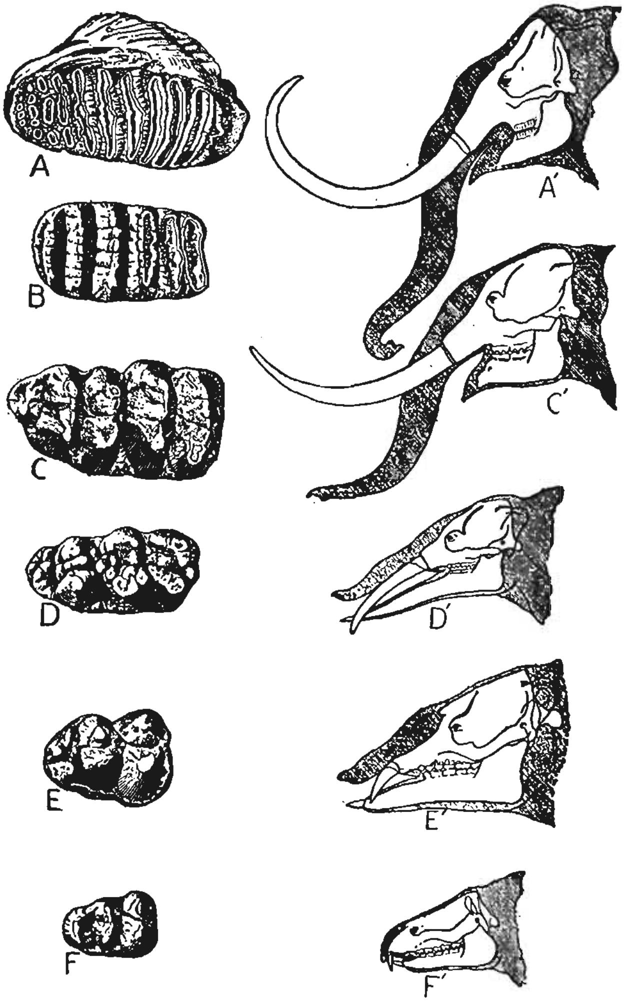


FIG. 235.—Evolution of the head and molar teeth of elephants; *A*, *A'*, *Elephas*, Pleistocene; *B*, *Stegodon*, Pliocene; *C*, *C'*, *Mastodon*, Pliocene; *D*, *D'*, *Trilophodon*, Miocene; *E*, *E'*, *Paleomastodon*, Oligocene; *F*, *F'*, *Moeritherium*, Eocene. (*From Lull, "Organic Evolution," copyright* 1918 *by The Macmillan Company. Reprinted by permission.*)

to 10 or 11 transverse ridges, but in the Indian elephant and the extinct Siberian mammoth up to 27.

There has been found in the upper Eocene and lower Oligocene deposits of Egypt a mammal called *Moeritherium*, generally recognized as the progenitor of the modern elephants (Fig. 235). It was about 10 decimeters (3½ feet) in height. It did not look like an elephant except in having a high skull, short tusks in both jaws, and grinding teeth with two or three transverse ridges. There was no trunk, but the upper lip may have been prehensile. The neck was long enough to have enabled the animal to reach the ground.

A form called *Paleomastodon* has been found in the lower Oligocene formations of Egypt and India. It was larger than *Moeritherium*, had a higher skull, a relatively shorter neck, and longer tusks, but the lower tusks were much shorter than the upper ones. The molar teeth were larger than in the earlier form, and the three transverse ridges were more conspicuous. The upper lip was slightly elongated, and probably reached to the tip of the tusks.

Trilophodon lived during the Miocene period in Europe, Africa, and North America. It was a large animal—almost as tall as the modern Indian elephant. It made an advance over *Paleomastodon* in having longer tusks and more complex grinding teeth. The latter were large and reduced in number, as in modern elephants, but there were still only three transverse ridges. *Trilophodon* was peculiar in that its lower jaw was greatly elongated and provided with a pair of tusks. As compared with modern species, the trunk was short, but probably reached as far as did the tusks.

Mastodon, of which several species are known, lived during the Pliocene and Pleistocene in North America, Europe, and Asia. The mastodons were larger than the earlier forms, being about the size of the modern Indian elephant, but they were stockier in build (Fig. 236). A pair of tusks was present only in the upper jaw, and were 27 decimeters (9 feet) or slightly more in length. The lower jaw was greatly shortened and the teeth reduced in number, there being never more than eight molars present at any time. The transverse ridges did not exceed five or six.

Conclusions.—The evidence from paleontology justifies several general conclusions with reference to the course of evolution. These may be briefly stated as follows: (1) Throughout geologic history there has been an ascending succession of plant and animal groups corresponding to the sequence of rock formations in which their fossils are imbedded. Thus each succeeding geologic period marks a progressive advance in life. (2) The general trend of evolu-

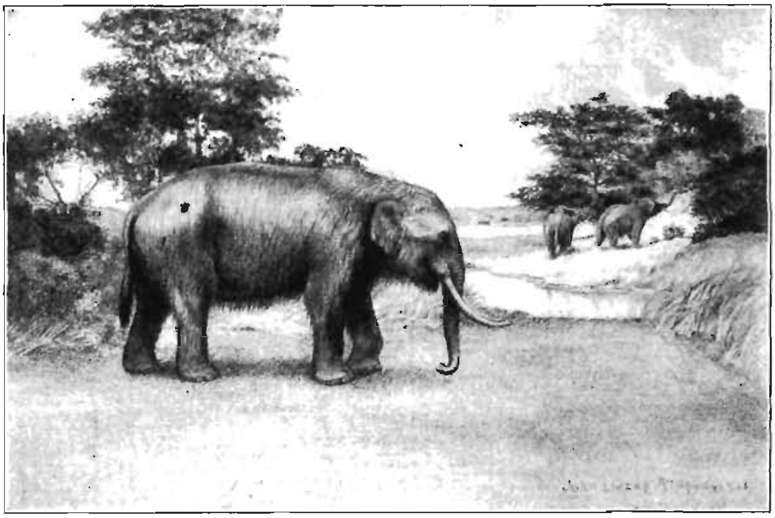


FIG. 236.—Restoration of American mastodon (*Mastodon americanus*) by John L. Ridgway. (*Courtesy of Los Angeles Museum of History, Science, and Art.*)

tion has been toward greater structural specialization as an adaptation to particular conditions of living. (3) Higher groups have sprung from generalized members of lower groups, not from highly specialized ones. (4) Forms highly modified for living under a particular set of external conditions cannot again become generalized, but can change only in the direction of greater specialization. With a radical change in environment they are unable to survive or to give rise to modified progeny, and thus become extinct.

CHAPTER XX

THE CAUSES OF EVOLUTION

Some of the classes of evidence upon which the principle of evolution rests have been examined and it has been seen that all of the facts presented in the last two chapters can be explained only on the basis of descent with modification. Biologists are unanimous in their conviction that evolution is a natural process. They are not in agreement, however, as to how the process operates—as to the causes underlying organic changes. This is because the method by which evolution has come about is imperfectly understood, and, consequently, a diversity of opinion exists as to what are the most important factors involved. A number of causative theories have been advanced, but none is entirely satisfactory. It is one thing to prove that evolution has taken place, but another thing to explain how it has taken place, and so we must bear in mind that, while proposed explanations may be discarded, the fact of evolution will always remain.

Theories of evolution are usually associated with modern times, but it should be realized that crude conceptions regarding the derivation of higher organisms from lower ones have existed from the time of the early Greek philosophers. It has only been since the beginning of the nineteenth century, however, that evolution has been the subject of scientific study. The older evolutionary conceptions were speculative, but our modern theories of causation are based on careful observation and experimentation.

We shall consider only the most important theories of evolution, and take them up in the order in which they have been advanced.

INHERITANCE OF ACQUIRED CHARACTERS

That organisms can be modified through the action of external influences is a matter of general observation, and it has long been assumed that such induced changes are transmitted to subsequent generations. The greatest exponent of this idea as a cause of evolution was the French naturalist, Jean Baptiste de Lamarck (1744–1829, Fig. 237), whose theory was announced in 1801. An *acquired character*

FIG. 237.—Jean Baptiste de Lamarck, 1744–1829.

is a modification which arises as a direct response to an external stimulus, such as a change in environment or function. It is not part of the organism's inheritance, but something imposed upon it by the surroundings. Lamarck's theory is based on the idea that acquired characters are inherited—that individual adaptations become racial—that inheritance is modified by environment.

Direct Action of Environment.—Lamarck thought that modification arises somewhat differently in the case of plants and lower animals on the one hand, and higher animals on the other, although in both cases the causal agent is a change in environment. In the former the environment acts directly, in the latter indirectly. Examples of structural changes induced by the environment have been given (see pp. 245–247). Lamarck assumed that the effects produced by a change in external conditions become cumulative through succeeding generations; he thought that racial characters have developed by the inheritance of direct responses. According to this theory,

Fig. 238.—Monterey cypress (*Cupressus macrocarpa*), a tree native to the central California coast in the vicinity of Monterey Bay. Exposed to the sea winds, the crown becomes very broad and flat, and the branches, often grotesquely bent and gnarled, tend to grow horizontally away from the wind. (*Photograph by Mrs. L. S. Slevin, Carmel, Calif.*)

the peculiar features of desert plants, for example, have resulted from the direct action of the desert conditions upon them, the changes induced in each generation being transmitted to subsequent generations.

While cases of individual adaptations are often striking, it must be realized that the power of adaptive response is limited. Only minor adjustments are possible. Even in the most plastic organisms, the basic features are so firmly fixed by heredity that little or no alteration can take place. Many widely distributed organisms live under a great variety of conditions—most of our common weeds, for example—and yet in most cases members of the same species exhibit relatively slight differences among themselves. On the other hand, members of the same species living under a uniform set of conditions often exhibit considerable variation.

Another important point should be kept in mind. When organisms are placed in a new environment, as a rule the changes induced are not permanent, for when put back in the old environment the "acquired characters" become lost. Thus when seeds or cuttings taken from lowland plants are grown in alpine regions, the progeny often become highly modified. In fact they are said to become "transformed" into alpine species. When taken back to the lowland, however, even after many generations of exposure to alpine conditions, they return to their original state. Trees growing along sea coasts are often highly modified by wind action (Fig. 238), but when seeds from these trees are planted under normal conditions, no effect of the former environment is seen.

Use and Disuse.—Among the higher animals Lamarck thought that structural modification arises chiefly through changes in function, basing his belief on the fact that organs are strengthened through use and weakened through disuse. He thought that the environment does not act directly, but indirectly, a change in external conditions causing an animal to experience new needs. These call for new habits and modes of life in accordance with which certain organs are used to a greater extent, others to a lesser extent. The former then tend to develop, the latter to atrophy. Lamarck believed that

> . . . everything which has been acquired, impressed upon, or changed in the organization of individuals during the course of their life, is preserved by generation [heredity] and transmitted to the new individuals which have descended from those which have undergone those changes.

It is in this feature of Lamarck's theory that the greatest weakness lies.

Lamarck explained the development of a great many structures as a result of the inherited effects of use, for example, the webbed feet of ducks and geese, the long legs of wading birds, the tentacles of snails, the horns and hoofs of mammals, and the long neck of the giraffe. As a result of disuse he explained the limbless condition of snakes, the degenerate eyes of the mole, the absence of teeth in certain vertebrates, etc.

The idea of the inheritance of acquired characters was first strongly opposed in 1883 by the German zoologist, August Weismann, whose views have largely influenced modern opinion. He claimed that, to be inherited, characters must arise in the germ cells, as these are the sole means of transmission between parent and offspring. Because probably in all metazoans except the very lowest, germ cells are set apart early in development from undifferentiated embryonic cells, to cause a change in the next generation, influences which may later modify the soma must also affect the germ cells (see p. 313). There is no known mechanism, however, whereby modifications may be transferred from somatic tissues to gametes. This means that any induced change undergone by the soma has no racial effect because somatic cells do not become part of the next generation.

While it is true that the theory of the direct transmission of somatic modifications does explain the development of a great many structures, both progressive and retrogressive, many of these cases can be explained on some other basis. A more fundamental objection, however, is that the theory is unsupported by experimental work. Changes in organisms can be produced by use and disuse, mutilation, disease, or directly by the environment, but even after the causal agent has been operative for a great many generations, the induced effect disappears as soon as the cause is removed. In a few cases, however, there seems to be a permanent effect through "parallel induction." This means a simultaneous modification of the germ cells by the same influence which affects the soma, but without any transfer from the latter to the former.

In conclusion, it may be said that, although Lamarck's theory seems plausible and is supported by a few modern biologists, it is rejected by most because it rests upon an extremely unlikely assumption which is not supported by experimental work.

NATURAL SELECTION

The greatest name associated with the principle of organic evolution is that of Charles Darwin (1809–1882, Fig. 239). Darwin did two things: (1) He accumulated an over-

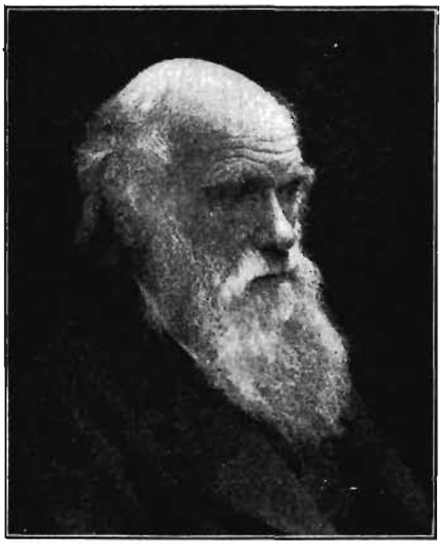


FIG. 239.—Charles Darwin, 1809–1882. *(From University Magazine. Photograph by Leonard Darwin.)*

whelming mass of evidence in support of organic evolution, and thus proved its reality; (2) he proposed a theory, that of *natural selection,* to explain how evolution has taken place. His conclusions were published in 1859 in "The Origin of Species," a book which has had a more profound influence on human thought than any scientific work ever written. It was this book which resulted in the establishment of the principle of evolution as a fundamental scientific generalization.

Darwin's theory is based on several well-established facts, and is merely a logical inference drawn from them.

Overproduction.—In 1798, Malthus published an essay in which he showed that human populations tend to increase in a geometrical ratio—a rate greatly in excess of their means of sustenance. Darwin became impressed with this fact, and saw that it applies to all living things. If an annual plant produces only 10 seeds, and if this rate continues in each generation and all of the progeny live, at the end of 10 years there will be one billion descendants of the original plant. Of course, most plants produce many more than 10 seeds a year—some tens or even hundreds of thousands. Similarly, the number of young produced by some animals is enormous. For example, a single sturgeon may lay two million eggs a year, a cod six million, an oyster sixty million. While these cases are extreme, it is perfectly true that the normal rate of reproduction in most species is of such magnitude that, if all of the individuals produced were to live, in only a few generations the earth would not be large enough to hold them.

Competition.—Because of the limitations of available space and food, a great many more individuals are brought into existence than can possibly live to maturity. Consequently there follows a severe competition, called by Darwin "the struggle for existence," which acts as a check to the high rate of increase. In other words, organisms compete for an opportunity to live. Competition must not be regarded as necessarily a struggle to kill—an active combat—for it may be entirely passive. It may involve a struggle for room, for food and other necessities of life, or merely a struggle against adverse physical conditions of the environment. Most animals are destroyed while in a very young stage of development, many while still within the egg. This is why oviparous species must produce so many more offspring than viviparous ones. The seeds of most plants, falling into situations unfavorable for growth, do not even get a chance to sprout, while most of the seedlings which do develop never reach maturity because of competition with other plants for light, moisture, and other vital necessities.

Competition results in an *equilibrium of species.* It is a well-known fact that, where natural conditions remain undisturbed, approximately the same number of individuals of the same kind may be found in any given region from year to year. This means that even with an enormously high rate of increase, competition is so severe that only enough individuals survive to replace the parents. Each species has established an equilibrium under its own set of environmental conditions, and this remains constant so long as disturbing factors do not arise. When man disturbs the balance of nature by killing off certain species, or by introducing foreign species to compete with the native ones, very serious consequences usually follow.

Variation.—The fact of variation—the tendency of individuals belonging to the same species to be different—is of the utmost importance, for without variation there could be no evolution. No two individuals are exactly alike, although it often requires critical examination and a thorough acquaintance with the organism to detect differences. Darwin did not clearly distinguish between heritable and non-heritable variations, but merely took the fact of variation for granted, and assumed that practically all organic differences are heritable.

Survival of the Fittest.—Darwin's theory of species formation is a logical inference based on the facts which have been presented. Infinitely more individuals come into existence than can possibly live, and this leads to a severe competition in which only a few survive. Because all members of any given species are highly variable, some may be better adapted to their environment than others. These individuals have an advantage over the rest, and consequently are the ones to survive and to transmit their favorable variations to their offspring. Thus the best-adapted individuals are "selected" to survive and to leave progeny, while all of the others perish. Continuing generation after generation, this selection process is assumed to result in a gradual but steady modification of the characters of the species in the direction of better fitness to the environment.

This idea of "the preservation of the favored races in the struggle for life" was called by Herbert Spencer the *survival of the fittest.* Darwin called the process *natural selection,* because it was suggested to him after making an intensive study of the method used by man in the development of his numerous races of cultivated plants and domesticated animals, namely, the selection of certain individuals as the basis for the next generation and the elimination of the others, the selected individuals being those showing variations in some desired direction. This process Darwin called "artificial selection" (see Chap. XV).

Under a constant set of environmental conditions, evolution by natural selection is gradual, but when conditions change, new standards of selection are instituted and evolution is more rapid. Thus, in a region undergoing a slight but persistent change in climate over a long period of time, organisms adapted to the old conditions would not be able to survive under the new ones. Only those individuals varying in the direction of greater fitness would leave offspring, and thus in time many new forms would come into existence and many old ones disappear.

LIMITATIONS OF NATURAL SELECTION

Granting that a selective process does occur in nature, and that the fittest survive, there has been considerable question raised as to how far natural selection is adequate to explain the formation of new species. The fact that it has certain weaknesses was realized by Darwin himself; in fact, he did not consider natural selection the exclusive factor in evolution, but merely the chief factor. We shall consider here some of the most serious limitations of natural selection as a complete explanation of the origin of species.

Non-adaptive Characters.—Natural selection has been used to account for many striking cases of adaptation between organisms and their environment(see Chap. XVI), and perhaps it is the most satisfactory explanation yet *proposed of the origin of adaptive characters. It should* be realized, however, that not all characters are useful, nor do they appear ever to have been useful in the organism's ancestry. Most species are distinguished from one another on the basis of slight, trivial, non-adaptive characters which apparently have no direct *survival value*, that is, they do not seem to give the organism any advantage in the struggle for existence. Any complete theory of evolution must account for all characters, not just adaptive ones.

Overspecialization.—On the basis of natural selection, it is difficult to understand cases of overspecialization—where structures have been developed far beyond their point of greatest utility. In many organisms, both living and extinct, evolution has gone so far that the individual is really handicapped in the struggle for existence. The extinct Irish elk, for example, which lived during the Pleistocene, had horns so large that they must have seriously interfered with its movements. The enormous curved tusks of the mammoths were similarly too highly specialized to have served their original function. Many paleontologists believe that overspecialization has been a most important factor in causing the extinction of species.

Origin of Variations.—It has long been realized that, although natural selection may be effective in modifying characters which are already present, it cannot produce new ones. As commonly stated, the theory may explain the survival of the fittest, but it cannot explain the arrival of the fittest. We have seen, however, that natural selection is not concerned with the origin of variations; it takes the existence of heritable variations for granted, merely explaining how they are preserved and modified.

Incipient Stages.—Not only is natural selection limited in its operation to characters already present, but it cannot act upon structures until they have developed sufficiently to have become useful. Otherwise it would give the organism no advantage in the struggle for existence.

Many characters have no survival value until fully formed; in an undeveloped condition they are useless.

Heritability of Variations.—While Darwin assumed that practically all variations are heritable, it has been found that many are not. With respect to their origin two kinds of variations are now recognized: *germinal* and *somatic*. The former are determined by heredity, the latter by the environment. Because somatic variations are not heritable, selection based on them does not bring about a permanent change in the race, and hence has no evolutionary value. Thus selection, to be effective, must be limited to germinal variations.

Cumulative Effect of Selection.– Even when limited to germinal variations, selection is able to bring about only a very definite amount of change. Among a mixed population, selection in any given direction tends to create pure strains relatively uniform for the characters involved, but gradually selection becomes ineffective in producing further change. In other words, selection cannot proceed beyond the natural range of variability. For example, tall parents tend to produce tall offspring, and while a tall race will result from the continued mating of tall individuals, the tallest offspring will be no more extreme than those which occur among the general population. Selection may raise the general average but cannot transcend the limits of variability which already exist; it merely tends to isolate pure strains from a mixed population.

MUTATION

The mutation theory was announced in 1901 by Hugo de Vries, a Dutch botanist. It was based largely on a study of an American species of evening pr mrose, known as *Oenothera lamarckiana*, which had been introduced into Holland and was growing wild in the vicinity of Amsterdam (Fig. 240). De Vries observed that, while most of the plants in the field were typical in every way, a few were strikingly different, different enough, in fact, to constitute new species.

He then took seeds from typical *lamarckiana* plants, sowed them in his botanical garden, and found that among the progeny there were always a relatively few new individuals each characterized by some striking peculiarity, such as

FIG. 240.—Lamarck's evening primrose (*Oenothera lamarckiana*, left) and one of its mutants (*Oe. gigas*, right), flower stalks and rosettes. (*From de Vries, "Mutationstheorie," 1st ed., Von Veit & Co., and "Gruppenweise Artbildung," Gebrüder Borntraeger. Reproduced by permission.*)

smooth leaves, short styles, red veins, dwarf habit, tall habit, etc. These new individuals, of which de Vries found altogether about 12 different types, he called *mutants*. Further breeding revealed the fact that these mutants, for the most part, came true to type, and thus their differences were constant. As a result of these studies, de Vries proposed the *mutation theory*—that new species appear suddenly, are distinct from the beginning, and are constant.

Continuous and Discontinuous Variations.—The outstanding difference between the theories of natural selection and mutation lies in the kind of variations which each emphasizes. Darwin considered that new species are formed by the gradual accumulation, through many generations, of numerous small intergrading variations under the influence of natural selection. De Vries, on the contrary, thought that new species arise suddenly and are distinct from the beginning. The variations which Darwin emphasized are called *continuous variations* or *fluctuations* because they vary about a standard, forming a graded series from one extreme to the other, as where a group of men are arranged in a line according to height. The variations which de Vries considered of prime importance are called *discontinuous variations* or *mutations* because they are not connected with each other by intergrades. Mutants have frequently arisen in plants and animals under domestication (see p. 214); in fact, de Vries thinks that most of our new varieties have originated in this way.

Relation to Natural Selection.—The mutationists give natural selection a role in species formation, but not one as prominent as that ascribed to it by Darwin. They consider that new species come into existence by the spontaneous appearance of mutants, but through the struggle for existence, natural selection determines whether or not these new forms will survive. If better adapted to the environment than the parent species, they persist, but if not so well adapted, they are eliminated. In fact, most mutants are not as fit as the species from which they have arisen, and under natural conditions would not survive.

It should be understood that the factors responsible for the appearance of new characters are largely unknown. While it seems certain that mutations arise from internal causes operating on the germ cells, it is not known why they arise. That the environment has nothing to do with the matter seems very probable, but is not certain. Thus the theory of mutation is not an explanation, but merely a statement of fact, and is supplementary to the theory of natural selection.

Objections.—Two important objections have been raised against the mutation theory. (1) An objection which at once occurred to de Vries and has been more or less urged ever since, is the possibility that *Oenothera lamarckiana* is a hybrid or at least an impure species—that the "mutants" are merely segregates arising from the "splitting" of a hybrid. De Vries observed that mutants appear in about 1.5 per cent of the progeny of *lamarckiana* plants, and while this ratio does not offer ready explanation according to Mendelian principles, nevertheless the possibility of the hybrid nature of this species exists. (2) While the evening primrose studied by de Vries is unquestionably giving rise to new types, and while it has been found that a number of other plants and animals are behaving similarly, such cases are comparatively rare. Although a great many species have been studied, it must be admitted that most of them are not in a "mutating" condition. Thus, if mutation is not a general phenomenon, it can have but slight significance as a means of species formation.

CONCLUSIONS

The various theories which have been presented in an attempt to explain how the process of evolution operates represent a difference of opinion as to what are the most important factors involved. We have seen that no one theory is entirely adequate—each has its strong and weak points. Thus the method by which evolutionary changes have come about is still imperfectly understood. It seems certain, however, that several or many cooperating factors are involved, and that the problem of explaining the causes underlying racial changes in structure is of much greater complexity than the early students of evolution thought it to be. Although much progress is being made toward a solution of this great central problem of biology, a complete answer will not be forthcoming until a great deal more knowledge of plants and animals has accumulated.

Of the various evolutionary factors, some are primary or causative, while others are secondary or directive. To the former category belong variation and heredity, to the latter the environment and natural selection.

Causative Factors.—Since it is obvious that there could be no evolution without variation, a knowledge of the causes of variation and their manner of hereditary transmission is fundamental to any complete explanation of evolution. For this reason much modern research is being directed along these two lines. While we have learned to differentiate between somatic and germinal variations and to recognize that it is probably only the latter which are of evolutionary value, our knowledge of the causes operative in the production of germinal variations is very meagre. It seems rather certain, however, that they arise independently of the environment. The pioneer work of Mendel initiated an intensive study of the mechanism of hereditary transmission, and has focused attention upon the chromosomes of the germ cells as the probable place where heritable variations originate.

Whether variations are continuous or discontinuous is of little consequence, for each kind may be either germinal or somatic. The important thing is to recognize that variations may be due to any one of three causes: (1) differences in environment or functioning; (2) recombination of hereditary characters or reappearance (segregation) of latent ones; (3) mutation. Somatic variations arise from the first cause, germinal variations from the other two. On the basis of outward appearance it is usually impossible to determine to which one of these three causes any given variation may be due; they can be distinguished only by breeding.

Mutations are heritable variations which are not due to segregation or recombination of factors. They apparently arise spontaneously in the germ cells from unknown causes. Mutations may be either large or small. The former, often involving several characters at once, are frequently due to the addition or loss of chromosomes in the germ cells arising from irregularities in their distribution at the time of reduction. Mutations of this sort, which are comparatively rare, are thought by some to give rise to new species directly. This is the method of evolution emphasized by de Vries. Small mutations, which are very common,[1] arise mostly as sudden changes involving individual factors, and it is this type of variations which form the raw material for natural selection to work upon. It is they which are gradually accumulated and built into new species according to the Darwinian conception.

Directive Factors.—We have seen that the general trend of evolution is toward greater fitness to the conditions of existence and that one of the great problems of biology is to explain adaptation. The history of life, as revealed by the fossil record, plainly teaches that there has been a marked correlation between changes in physical surroundings and the appearance of new types of organisms. While this means that the environment is an important evolutionary factor, it does not imply that it is a direct one, as Lamarck and other early evolutionists assumed.

Both the theories of Lamarck and of Darwin deal with the development of adaptive characters, but the latter is generally considered to be by far the more adequate. According to the theory of natural selection, in general, individuals which survive in the struggle for existence are those best adapted to their environment. Thus the environment determines survival but not fitness, the latter resulting from spontaneous variability arising from primary causes. This means that the environment determines the course of evolution, but not directly.

Selection is not a causative factor because it cannot originate variations; it merely preserves and accumulates such as already exist, provided that they have survival value. In other words, natural selection determines which

[1] For example, most of the heritable variations exhibited by the fruit fly (*Drosophila*) are of this type (Fig. 155).

individuals, among a population exhibiting infinite diversity, shall be preserved. It is generally considered to be the most important directive factor yet discovered.

So far as the application of the selection principle to the racial improvement of man is concerned, it is certainly true, as Conklin says, that

> . . . the past evolution of the human race has been guided by the elimination of the unfit, whether physical, intellectual, or social, and the future progress of the race must depend upon this same process.

CHAPTER XXI

THE EVOLUTION OF MAN

It has long been realized that the human body is constructed on the same general plan as that of other mammals, that it comes into existence, grows, and is nourished in the same way, and that it is subject to the same natural laws which apply to other organisms. Therefore whatever causes have played a part in the evolution of other animals have also been operative in the derivation of the human species from a more primitive ancestor.

For the same reason that the dog is classified with the carnivores and the horse with the ungulates, man must be placed in the primate group—that order of mammals which includes the lemurs, monkeys, and apes. The primates include six well-defined families: the lemurs (Lemuridae), the marmosets (Hapalidae), South American monkeys (Cebidae), Old World monkeys (Cercopithecidae), the anthropoid apes (Simiidae), and mankind (Hominidae). The lemurs comprise the lowest group, the anthropoid apes the group most closely related to man. In fact, the structural resemblances between the two highest families are much greater than between the anthropoid apes and the lower primates (Fig. 241).

All of the races of modern man are considered to belong to the same species—*Homo sapiens*—but three main varieties are commonly recognized: the Ethiopian, Mongolian,[1] and Caucasian.

The Anthropoid Apes.—The four anthropoid apes, the gibbon, orang-outang, chimpanzee, and gorilla, are distinguished from the other primates by several important characters: (1) All are tailless; (2) the number of teeth

[1] While the American Indian is sometimes separated as a fourth variety, it is usually included under the Mongolian.

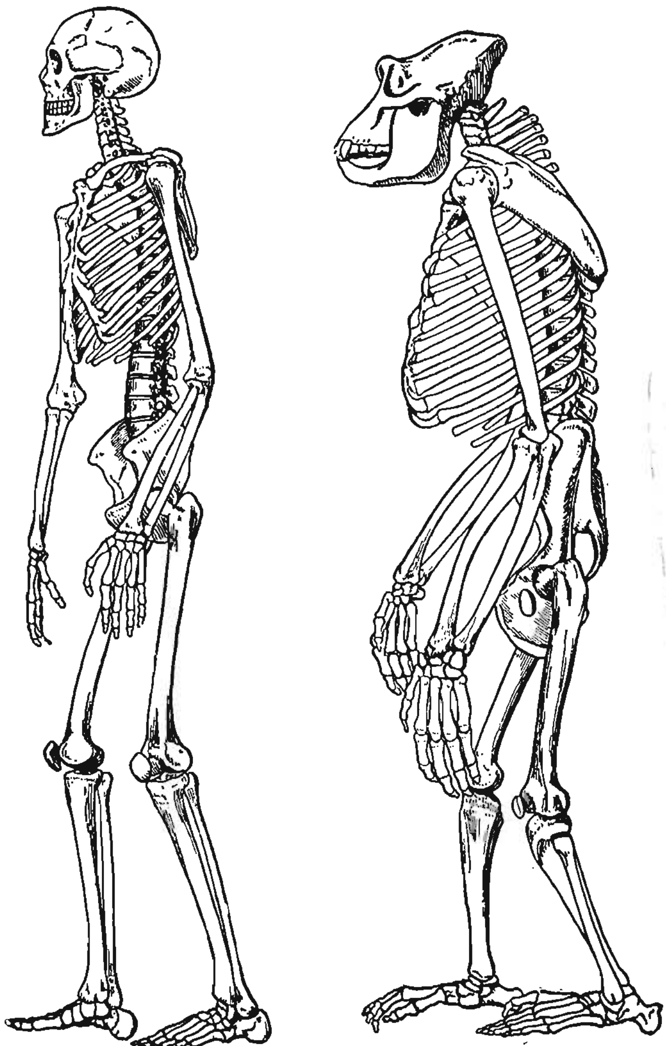


FIG. 241.—Skeletons of man and gorilla. The general fundamental similarity is striking, the differences being mostly in details. Among these, note the size and shape of the cranium, of the teeth, and of the lower jaw; the relative length of the arms and legs; the curvature of the spine; the position of the great toe. (*From Lull, "Organic Evolution," copyright, 1918, by the Macmillan Company. Reprinted by permission.*)

is the same as in man, both in the temporary and permanent sets; (3) the arms are much longer than the legs; (4) when on the ground they can walk more or less erect on the hind limbs; (5) the thumb is short, but the great toe is well developed and opposable; (6) all are much more intelligent

FIG. 242.—The gibbon, the most primitive of the anthropoids in regard to certain characters of the skull and teeth, but with limbs highly specialized for arboreal life. When on the ground it walks erect. (*Courtesy of the New York Zoological Society.*)

than the lower primates, the brain being more highly developed.

The gibbon and orang-outang are found in southern Asia, the chimpanzee and gorilla in Africa (Figs. 242 to 245). The gibbon is the smallest of the anthropoids, rarely exceeding 9 decimeters (3 feet) in height, while the gorilla is the largest and most powerful, attaining a maximum height of about 17 decimeters ($5\frac{1}{2}$ feet) and a weight of about 500 pounds. The gibbon is the only form which habitually walks erect when on the ground, but the others can do so by touching the knuckles to the ground in order to maintain their balance. The skull of the gibbon is smooth on the top and does not have bony arches over the eyes, but in the

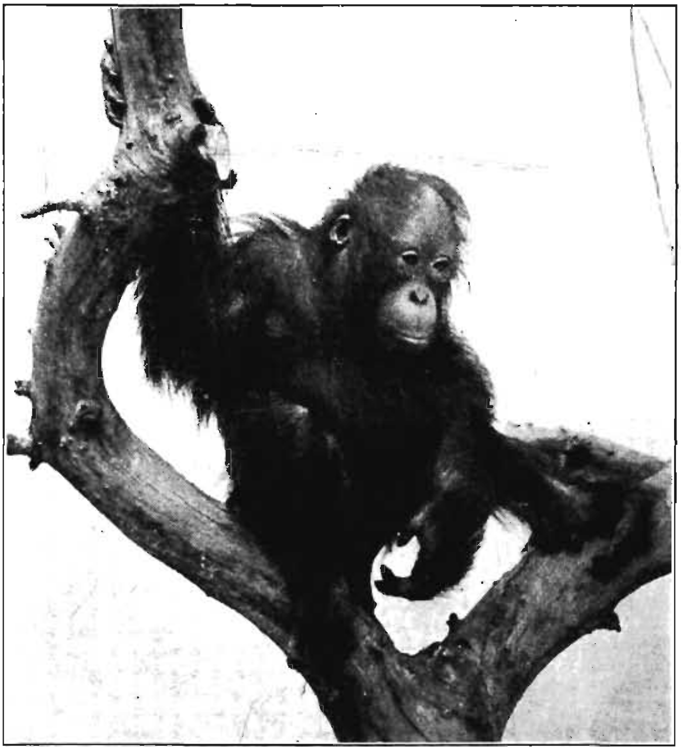


FIG. 243.—The orang-outang, a brown-haired anthropoid native of Borneo and Sumatra. The skull is higher and more rounded and the face much longer than in the gibbon. (*Courtesy of the New York Zoological Society.*)

other anthropoids the skull bears a median crest and the eye arches are prominent (Fig. 246). In the chimpanzee and gorilla the canine teeth are conspicuous, in the latter being developed as short tusks.

Distinctive Features of Man.—Man is distinguished from the anthropoid apes and other primates chiefly by the following characters: (1) The brain, especially the cerebrum, is notably larger and more complex; (2) the face is short and nearly vertical; (3) the lower jaw bears a distinct chin; (4) all of the teeth are reduced in size, the canines not being larger than the others; (5) the spinal

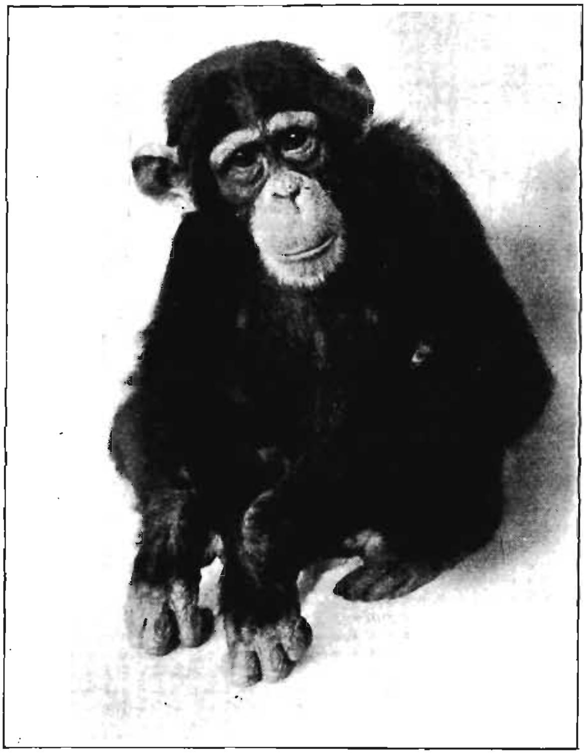


FIG. 244.—The chimpanzee. Note the protruding jaw and very prominent eye arches. The arms are longer than the legs, but relatively shorter than those of the gibbon and orang-outang. (*Courtesy of the New York Zoological Society.*)

column, adapted to erect posture, has four distinct curves; (6) the arms are not as long as the legs; (7) the thumb is freely opposable, but the great toe is not; (8) the power of articulate speech is fully developed.

The differences between man and the other primates are chiefly associated with the assumption of the erect posture and the development of the brain. With the gradual abandonment of arboreal life and the growing ability to walk erect with ease, it became possible for the precursors of man to make freer use of the hands, a most important factor in early human evolution. For example,

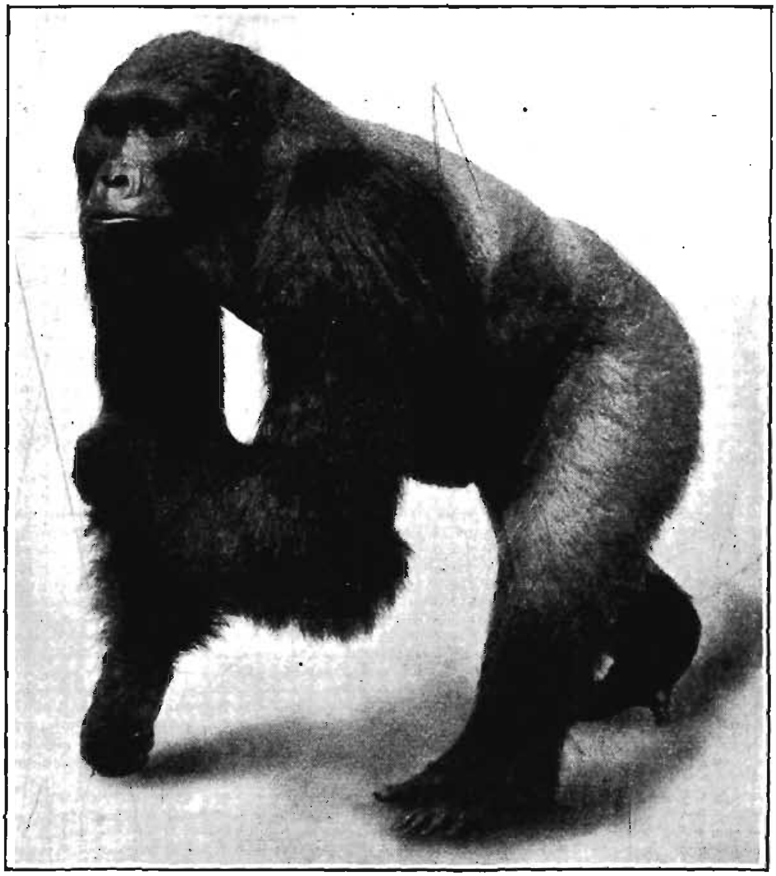


FIG. 245.—Mounted specimen of male gorilla, the largest of the anthropoid apes, and in many ways the most highly specialized. (*Courtesy of the Field Museum of Natural History, Chicago.*)

the early employment of tools and weapons, correlated with increasing mental powers, marked the beginning of man's supremacy over the other animals. Related to the development of the erect posture were such structural changes as the broadening of the pelvis, straightening of the spine, shortening of the arms, modified position of the head on the spinal column, etc. Associated with the development of the brain was the growing power of articulate speech, at first feebly manifested, but gradually enabling primitive man to communicate by means of language.

History of the Primates.—It will be recalled that the mammals began their ascendancy at the beginning of the Cenozoic era, and soon gave rise to many diverse groups.

FIG. 246.—Skull of chimpanzee, × ⅓. Note the very retreating forehead, the prominent eye arches, the flat nose and protruding jaw, the large canine teeth, and the absence of a chin.

According to prevalent scientific opinion, the carnivores and primates had a common origin, most likely in a primitive stock of insectivores. The primates seem to have arisen as a distinct branch of mammals during the early Eocene, as the oldest fossils come from Eocene rocks. During the following period the anthropoid ape line became differentiated from the other primates, a gibbon-like form (*Propliopithecus*) having been found in the Oligocene deposits of northern Egypt. This form may have been the common ancestor of the modern apes and man (Fig. 247). From the Miocene and Pliocene formations of Europe and Asia there have been obtained several fossil anthropoids, some of which are regarded as ancestral to modern anthropoids, but not to man.

It was probably during the Miocene or early Pliocene, however, that the anthropoid ape line gave rise to the

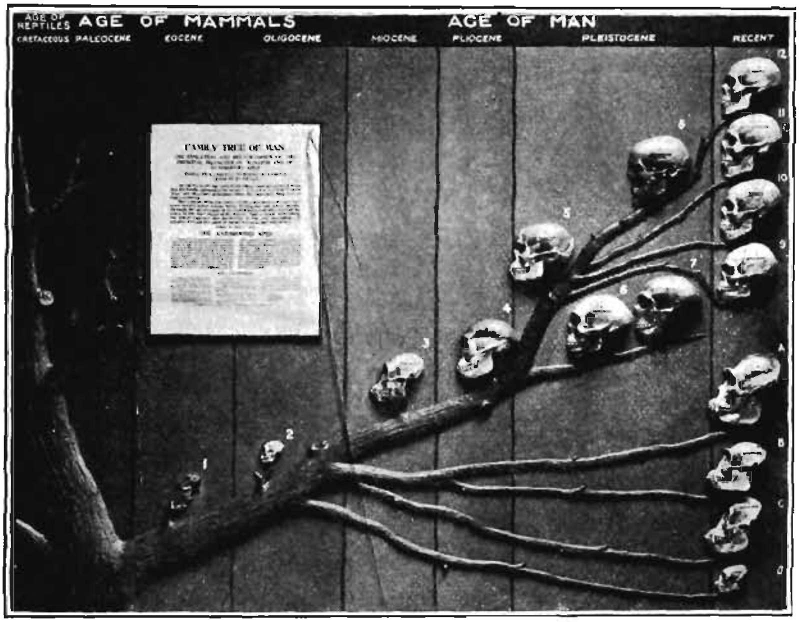


FIG. 247.—Family tree of man, showing the evolution and relationships of the principle branches of mankind and of the anthropoid apes; 1, Primitive primate (*Notharctus*) from the Eocene of Wyoming; 2, Prototypal anthropoid (*Propliopithecus*) of Oligocene age, from Egypt; 3, Primitive anthropoid (*Dryopithecus*) from the Miocene of India; 4, Ape man (*Pithecanthropus*) of Java; 5, Piltdown man (*Eoanthropus*); 6, Heidelberg man (*Homo heidelbergensis*); 7, Neandertal man (*Homo neandertalensis*); 8, Crô-Magnon man (*Homo sapiens*); 9, Australian black man, one of the most primitive of existing human races; 10, Hotentot, representing the Negro group of races; 11, Chinese, representing the Mongolian races; 12, American, representing the Caucasian group; *A*, gorilla; *B*, chimpanzee; *C*, orang-outang; *D*, gibbon. (*Courtesy of Professor William K. Gregory and the American Museum of Natural History.*)

precursors of man. Increasing aridity, especially in central Asia—to which evidence points as the place of origin of the human stock—caused a gradual disappearance of forests, and it has been suggested that this may have been the impelling cause of the origin of man, his immediate ancestors being forced to abandon arboreal existence and to seek a new mode of living. It was during the Pleistocene that man began to rise in supremacy over the other mammals. This period was characterized by the development of enormous continental glaciers which appeared at intervals as a consequence of great climatic changes. At least four distinct invasions of the ice occurred, sepa-

Fig. 248.—*Pithecanthropus erectus*, the ape man of Java, as restored by Prof. J. H. McGregor, Columbia University. Antiquity estimated at 500,000 years or more. (*Courtesy of Professor McGregor.*)

rated by intervening warm periods, and so the Pleistocene is divided into four glacial and three interglacial stages.

We are now ready to consider briefly what is known regarding the earliest races of mankind. Our knowledge is based upon fossils which have been found, for the most part, in river valley deposits or in caves. While we shall consider these races in the order of their age, it should not be assumed that they form a single evolutionary series. In fact, it is generally agreed that they probably represent several divergent lines of descent (Fig. 247).

The Java Ape-man.—In 1891 there was discovered in a river deposit in central Java, associated with the bones

FIG. 249. Side and top views of the skull cap of *Pithecanthropus erectus*, × 1/3. Note its narrowness, especially in the frontal region, the heavy eye arches, and the retreating forehead. (*From Osborn, "Men of the Old Stone Age," Charles Scribner's Sons, after Du Bois; by permission.*)

of extinct mammals, the remains of a creature which has been called *Pithecanthropus erectus* (Figs. 248 and 249). These remains consist of a skull cap (roof of the skull), two upper molar teeth, and a femur (thigh bone). The age of the deposit in which they were found is considered to be either late Pliocene or early Pleistocene, and conservatively estimated at 500,000 years. Some authorities think that

Pithecanthropus lived during the first interglacial stage of the Pleistocene.

The skull cap is very long in proportion to its breadth, and narrow in the frontal region, in this respect resembling

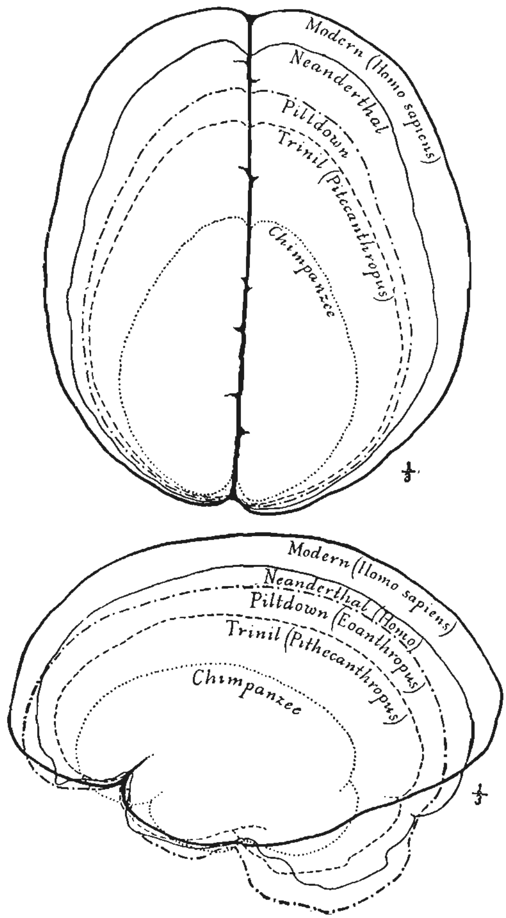


FIG. 250.—Diagram showing the top and side views of the outline of the *Pithecanthropus* brain as compared with that of the chimpanzee and the higher human types of the Piltdown, Neandertal, and modern races. (*From Osborn, "Men of the Old Stone Age," Charles Scribner's Sons; by permission.*)

that of the chimpanzee. The brain capacity has been estimated at 855 cubic centimeters, that of the gorilla being 600 cubic centimeters and of the lowest members of the human race (the native Australians) about 1,300 cubic centimeters (Fig. 250). The average brain capacity of the white race is about 1,500 cubic centimeters and the maximum about 2,000 cubic centimeters. *Pithecanthropus* had a very low, retreating forehead and prominent eye arches, the latter being almost as conspicuous as those of the chimpanzee. Judging from the slope of the forehead, it is probable that the jaw was very protruding. The teeth are intermediate in structure between those of modern man and the apes. If the femur belonged to the same individual, as seems probable, the creature was about 17 decimeters (5 feet, 7 inches) tall and walked erect.

The Heidelberg Man.—The Heidelberg man (*Homo heidelbergensis*) lived in Europe probably during the

FIG. 251.—The Heidelberg jaw, about × 2/3. (*From Osborn, "Men of the Old Stone Age," Charles Scribner's Sons, after Schoetensack; by permission.*)

second interglacial period. It is known only from a single lower jaw (Figs. 251 and 252) discovered in 1907 in southern Germany near Heidelberg. The jaw was found in a river deposit about 80 feet below the surface of the ground. Its age has been estimated at 300,000 to 375,000 years. From the same formation have been obtained the bones of many extinct mammals.

The Heidelberg jaw is very large and heavy, and lacks the projecting point which forms the human chin. In fact, were it not for the teeth, which are all distinctly human (although somewhat primitive in form), the jaw would have been regarded as that of an ancient anthropoid ape.

The Piltdown Man.—This individual (called *Eoanthropus dawsoni*) was first known from a single broken skull and jawbone found in 1911–1912 at Piltdown, Sussex, England. It is thought to have lived during the third interglacial period, possibly 100,000 to 150,000 years ago, although some

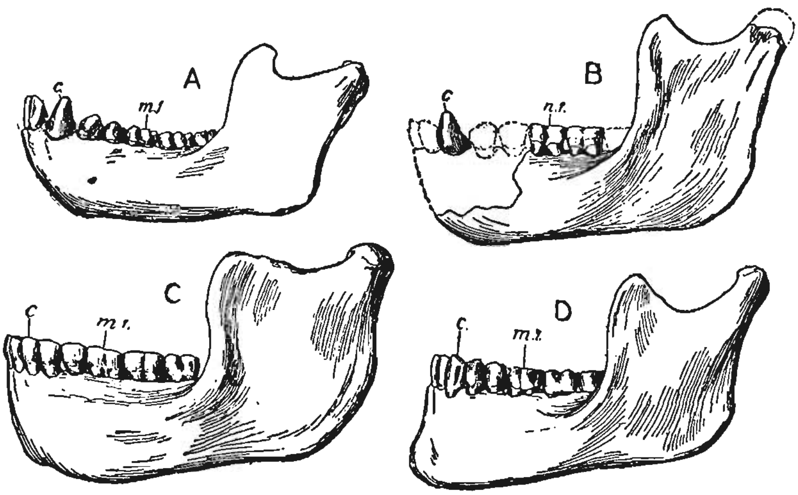


FIG. 252.—Side view of jaws of chimpanzee (*A*), Piltdown man (*B*), Heidelberg man (*C*), and modern man (*D*). (*From Woodward, "Guide to the Fossil Remains of Man," British Museum, by permission.*)

ascribe to it a greater age. The remains were found in association with the bones of extinct mammals and with some very primitive flint implements.

The skull of the Piltdown man is unusually thick, being 11 to 12 millimeters, while that of modern Europeans is 5 to 6 millimeters thick on the average, and of the native Australian 6 to 8 millimeters. The forehead is high and prominent, and is without conspicuous eye arches (Fig. 253). The primitive character of the Piltdown man is revealed particularly in the character of the jaw and teeth. The former is without a chin and almost identical with that of a young chimpanzee (Fig. 252). The teeth are human, but the canines are very conspicuous. Some authorities have considered the skull to belong to a primitive human, but the jaw to an extinct ape, their association being accidental. A few years after the original discovery, however, a portion of another skull and a tooth similar to that present in the first jaw were found in the same region, so that there remains

FIG. 253.—The Piltdown man of Sussex, England, as restored by Prof. J. H. McGregor. Antiquity variously estimated at 100,000 to 300,000 years. (*Courtesy of Professor McGregor.*)

little doubt but that the skull and jaw belong to the same individual.

The Neandertal Man.—The Neandertal race (*Homo neandertalensis*) is known from a number of specimens found mostly in caves in about 20 different localities in Europe. The first specimen was discovered in 1856 in the

Neander Valley, near Düsseldorf, Germany. The Neandertal race lived during the third interglacial and fourth glacial stages and is thought to have occupied Europe at least 50,000 years. They were a low-statured people, the males rarely exceeding 16.5 decimeters (5 feet, 5 inches)

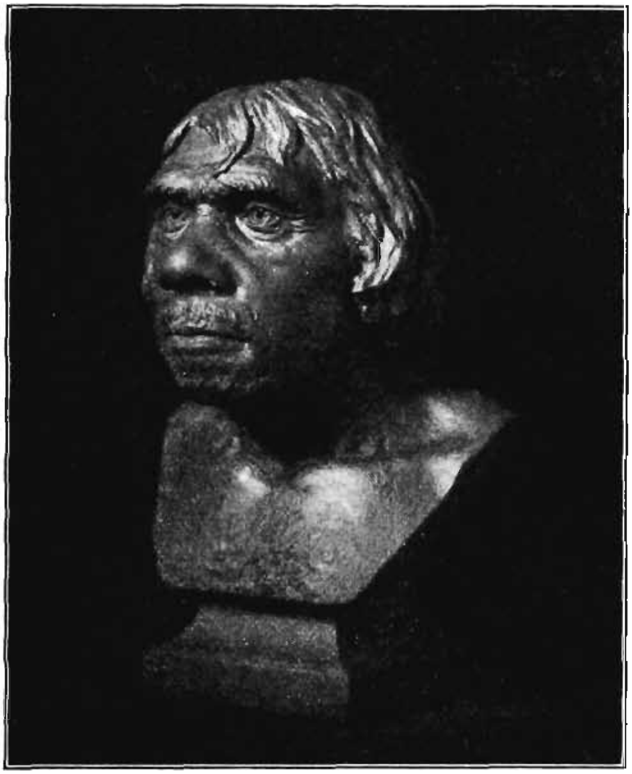


FIG. 254.—Head of the Neandertal man, modelled by Prof. J. H. McGregor. This primitive race inhabited Europe 25,000 to 75,000 years ago. (*Courtesy of Professor McGregor.*)

in height. The limbs were short and thick, the shoulders broad and rounded, and the head protruding slightly forward. The habit of walking erect was not fully established; this was indicated by the curvature of the backbone, the slightly bent knees, the rounded shoulders, and the position of the head.

The skull was thick, long, and narrow, and had a retreating forehead (Figs. 254 and 255). The eye arches were thick and very prominent. The lower jaw and the teeth were primitive, the former being less powerful than that of the Heidelberg man, but yet relatively thick and heavy. The chin was slightly developed in some individuals, but in most cases not. The teeth were more primitive than in modern races, but the canines were not as conspicuous as in the Piltdown man. The average cranial capacity of

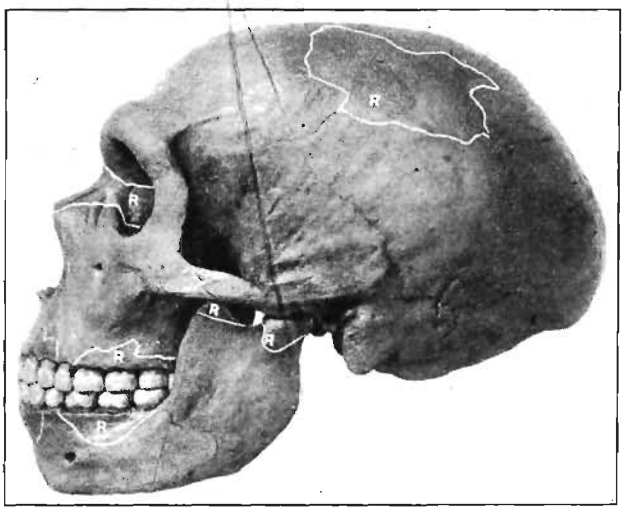


FIG. 255.—Photograph of a cast of a Neandertal skull found at La Chapelle-aux-Saints, Corrèze, France, in 1908, with the missing parts (*R*) restored by Prof. J. H. McGregor, × ⅓. Note the low forehead, the heavy eye arches, and the primitive jaw. (*Courtesy of Professor McGregor.*)

the Neandertals was about 1,500 cubic centimeters, the same as that of modern Caucasians, but the proportions of the brain were different, the frontal portion being relatively smaller and the convolutions simpler.

The Neandertals were a cave-dwelling race. They made use of primitive flint tools and weapons, and hunted such animals as wild horses, cattle, and reindeer. Whether they became entirely extinct or partly evolved into the lower races of modern man is an unsettled question, but at any rate they were succeeded by a vastly superior type of people who came from Asia approximately 25,000 years ago, at the beginning of postglacial time.

The Crô-Magnon Man.—This race (belonging to *Homo sapiens*) had undergone its early evolution in Asia, but migrated into Europe and gradually replaced the Neander-

Fig. 256.—Head of the Crô-Magnon type of *Homo sapiens*, a race inhabiting southwestern Europe about 25,000 years ago. Restoration by Prof. J. H. McGregor. (*Courtesy of Professor McGregor.*)

tals. A number of entire skeletons have been found in various parts of Europe, chiefly in caves. The Crô-Magnons were physically one of the most splendid races of man which have ever existed, the males averaging slightly over 18 decimeters (6 feet) in height. Intellectually also, they were vastly superior to the Neandertals. The skull was large but narrow, and had a broad short face with high cheek bones (Fig. 256). The brain was larger on the average than that of the modern white race, the cranial capacity in some cases being as much as 1,800 cubic centimeters. The forehead was high and the eye arches small or absent. The lower jaw was heavy but provided with a conspicuous chin.

The Crô-Magnons were an artistic people, ornamenting the walls of their caves with drawings and even with colored paintings. They are thought to have persisted in Europe for at least 10,000 years, but finally declined and became supplanted by four or five new races which probably came in from Asia. Elements of these new races are found among modern Europeans. Although the Crô-Magnons were largely replaced, they were probably absorbed to some extent by the races which succeeded them.

Since the time of the Crô-Magnons, human progress has been almost entirely intellectual and social. Lull says:

> Man's physical evolution has virtually ceased, but in so far as any change is being effected, it is largely retrogressive. Such changes are: reduction of hair and teeth, and of hand skill; and dulling of the senses of sight, smell, and hearing upon which active creatures depend so largely for safety. That sort of charity which fosters the physically, mentally, and morally feeble, and is thus contrary to the law of natural selection, must also in the long run have an adverse effect upon the race.

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