THE BOOK WAS DRENCHED

The Human Organism and the World of Life

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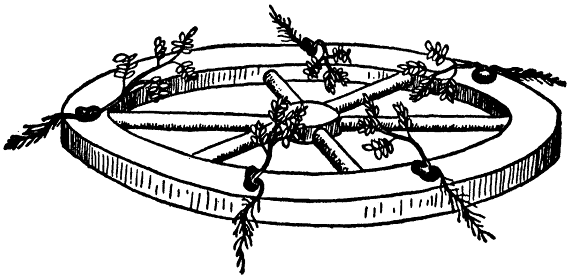

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A Survey in Biological Science

by

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The Human Organism and the World of Life

A-W

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PART III

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Preface

Almost a decade ago, as a part of a general plan of curricular reorganization, there was instituted at Colgate University a survey course in biological sciences which was made a part of the work of every Colgate freshman. Its aim was to give every student a broad view of scientific knowledge concerning the processes of life; and in furtherance of that aim it was planned that it should include a survey of the mental activities occurring in organisms as well as the processes that have more traditionally been included within the realm of biological science. This book is the outcome of our experience in teaching this course. In its present form it is the result of much experimentation, throughout which one question has remained uppermost in our minds: How can this course and this book be made to yield the utmost possible value to the freshman student?

Our most important discovery has been that the student is primarily interested in the life process as it displays itself in his own species, and we have come to the conclusion that this is not only a natural but a thoroughly wholesome prejudice on his part. For human life, one's own life and that of one's companions, is surely the aspect of the biological process that is of most profound importance to every man and woman; and if one is to spend only a brief period in the study of biological science, one will certainly put in his time to best advantage in securing as good an understanding as possible of the ways of life among his own kind.

This centering of attention upon the human organism does not necessarily make for a narrowness of outlook. In the first place, the picture of human life cannot be complete unless it includes within it a portrayal of the relationship between the species *Homo sapiens* and the whole organic world. Secondly, the activity of protoplasmic systems is much the same throughout the two biological kingdoms, and a comprehension of the workings of one organism provides the key to the understanding of all. Hence, our account shifts back and forth from detailed description of human processes to less detailed comparison with the structure and function of plants and animals. Our experience indicates that this approach does make the study of biological science meaningful and interesting to the freshman student and that he finds that it satisfies his own felt needs and desires for knowledge in this field.

Early in our work with the course, we discovered that one of the major difficulties our students experienced was the mastery of biological terminology. To prevent this purely mechanical difficulty from standing between the student and the acquisition of an understanding of the facts and principles which we are primarily interested in conveying to him, we have eliminated as much strange vocabulary as possible and have introduced a rather complete glossary of new terms at the end of each chapter. It is not intended that these glossaries be used for reference purposes. Rather, they are to be employed in the study of each chapter, so that the student can make certain that he has mastered the new terminology before he passes along to sections where the words may be used without explanation of their meaning. In short, these glossaries are intended to serve much the same function as the vocabulary lists attached to each lesson in an elementary course in foreign languages.

While the authors did not confine their work entirely to specific chapters, the chief responsibility for the preparation of Chapters II, V, VI, VII, and XI was in the hands of Dr. Hylander, and for Chapters XII, XIV, XV, XVI, and XVII in the hands of Dr. Stebbins. Dr. Young is chiefly responsible for the preparation of all other chapters as well as for the general editing of the entire book.

In closing, we wish to express our appreciation to all those who have helped us in the preparation of this book with friendly counsel and criticism. Especially, we wish to thank Dr. W. M. Chester, Dr. F. S. Keller, Dr. James Stauffer, Dr. Raymond J. Myers, Dr. Oran Stanley, and Dr. G. H. Estabrooks, our colleagues at Colgate; Dr. Jackson W. Thro, of Hamilton, N. Y.; Dr. H. D. Stebbins, of Brookline, Mass.; Dr. Edgar Anderson, Dr. R. H. Wetmore, Dr. J. H. Welsh, all of Harvard University; and Dr. Ernest B. Babcock, Dr. Richard Goldschmidt, and Dr. Alden Muller, all of the University of California.

Colgate University
April 18, 1938

Clarence W. Young

The Human Organism and the World of Life

INTRODUCTION

All living things, whether plant or animal, whether large or microscopically small, are known as *organisms.* A man is an organism; a stalk of corn is an organism; the "germs" that cause smallpox, which happen to be so small that they cannot be seen with the most powerful microscopes, are organisms.

All organisms have certain traits in common which more or less distinguish them from objects that are not alive. Organisms expend energy and wear their bodies away in the course of their activities, yet they replenish their stocks of energy and replace their wasted structure, either by consuming or by manufacturing food. In addition, organisms grow, they reproduce, and they respond to changes in their environment. Self-maintenance, growth, reproduction, and response may be termed *universal organismic activities,* since they characterize all living things, while non-living things display them to only a slight extent if at all.

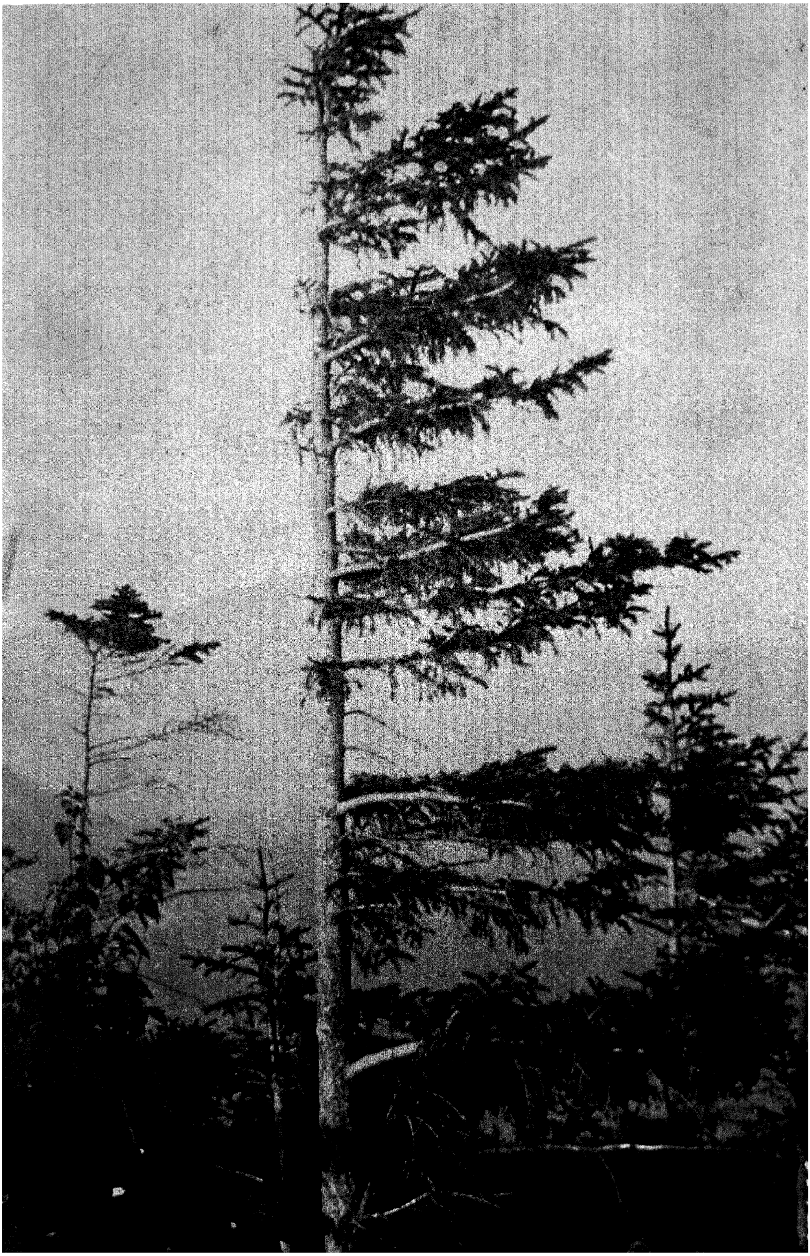
The relationships between organisms are so close that it is possible to look upon the entire world of life as a single great system of activity. Life is unified in two ways. In the first place, organisms are dependent upon one another for the chemical substances which are essential to their existence, and each type of organism plays a part in maintaining the entire world of life as a going concern. In the second place, all organisms are related to one another through a long line of evolutionary descent. A billion years ago or more, the first organisms appeared upon the earth. All the evidence indicates that they were simpler than even the humblest of the organisms with which we may become acquainted by viewing them through the most powerful microscopes. Through the long aeons that have passed since that time, the descendants of those organisms have developed through evolution to become the myriad of living forms both great and small which populate the earth today.

The theme of this book is the rôle of the human organism in the world of life. We shall see how all the great life activities are carried on by the members of the human race and compare the way in which man maintains himself, grows, reproduces, and responds to his environment with the manner in which these functions are carried on in plants and animals. We shall trace the line of descent from the first inconceivably primitive living things down to the human species of today.

Finally, we shall consider how man's capacity for speech, which enables him to build up a body of knowledge and aspiration that can be handed down to his descendants from generation to generation, makes of him an entirely unique sort of organism, possessing capacities far above those of any other form of life, and facing problems with which no other organisms can be even remotely concerned.

PART I

MAINTENANCE AND SURVIVAL



A streamlined tree. (See page 512.)

CHAPTER I

THE SUBSTANCE AND STRUCTURE OF THE HUMAN BODY

The Living Substance.—There is nothing in the world more wonderful than the body of a living organism. It is a structure in which occur all the intricate and remarkable activities which constitute the miracle of living. All the achievements of mankind have depended upon the conformation and structure of the human body, and all the life processes of plants and animals—which appear the more marvelous to us the better we become acquainted with them—are made possible only by the manner in which their bodies are constructed. In this chapter we shall deal with the fundamental principles of bodily organization in the human being.

In the first place, the body is composed in large part of a certain unique substance which forms the most essential part of all living organisms, from the tiniest bacterium to the tallest tree, but which is found nowhere else in nature. It is, like time in the old proverb, the very "stuff that life is made of." It is called *protoplasm*.

Not all the body is composed of protoplasm. The blood, for example, is not protoplasm; neither are those solider substances which give support and protection, such as the mineral part of the bones, the hair, and the outer layer of skin. In fact, protoplasm is usually so completely enmeshed in non-living supporting and protecting structures that it is very difficult to isolate it in such fashion as to make the study of it possible. An extremely minute bit, however—a single cell—can be viewed under the microscope; and it is possible to pick and tear at it with a very fine glass needle, known as a microdissection needle, and thus get a conception of what this living substance is like.

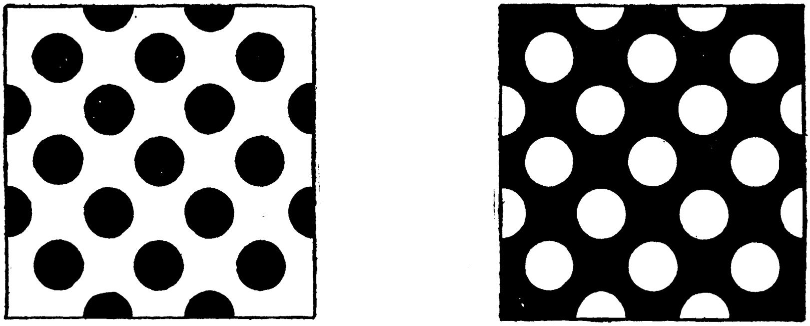
Under high magnification, it is a rather transparent grayish stuff, something like uncooked white of egg, except that it frequently appears to be full of small granules or bubbles. Often it is seen to flow restlessly round and round upon itself. It resembles a globule of oil in that it does not mix with the water that usually surrounds it, but forms a sharp boundary line between itself and its environment.

While watching the tiny mass of protoplasm under the microscope, one can carefully push the microdissection needle a little way into it and then pull it out. A small bit of the living substance sticks to the needle, stretches out, and, when it finally breaks loose, moves back into the cell. In this way one discovers that protoplasm resembles egg white in still other respects; it is sticky and elastic. The needle also reveals that most of it is quite liquid, about the consistency of a light oil, while certain parts may be as solid as a soft jelly. There is a tendency for protoplasm to fluctuate between the jelly-like and the oil-like state.

The activity of this slimy, transparent, viscid, elastic, restless material underlies all the activities of life. The growth of a tree, the flying of a bird, the thinking of man—protoplasmic activity is fundamental to them all. To explain how protoplasm is capable of carrying on these activities would be equivalent to explaining life itself. No scientist has ever been able to do it. But a large number of its properties may be attributed to the fact that it is a highly complex *colloidal system.*

A colloidal system exists where extremely fine particles of one substance are held in suspension in another substance. For example, gold may be broken up into particles so small that they will not settle to the bottom in a jar of water but will remain suspended throughout the jar. The particles are so minute that they cannot be seen even under the highest-powered microscope, yet they are considerably larger than the particles of a substance that is in true solution in water. Ordinary smoke is another example of matter in the colloidal state. In this case, tiny solid particles of ash are held in suspension in the air. There are, in addition, many everyday examples of colloidal substances which are derived from the bodies of living organisms, such as milk, butter, gelatin, agar-agar, various jellies and glues. Although it is not alive, the white of egg, which resembles protoplasm so closely, is also a colloidal system, made up of the same substances that compose protoplasm.

Protoplasm itself is simply a special form of colloid in which small particles of certain substances, known as *proteins,* are suspended in water. These proteins are the most complex chemical compounds known. By this we mean that their molecules contain a larger number of atoms than any other molecules yet discovered. As nearly everyone has learned, the infinitesimally small particles, known as molecules, which are the unit particles of any substance, are themselves composed of still smaller particles, the atoms of the chemical elements. For example, two atoms of the element hydrogen, combined with one atom of oxygen, constitute a molecule of water. Now the protein molecules are made up of the atoms of hydrogen, oxygen, carbon, nitrogen, and a few other elements.



A *B*

FIG. 1.—Diagram of a colloidal system. *A,* continuous phase (white) a liquid (sol). *B,* continuous phase (black) a solid (gel).

But, unlike water molecules, which are composed of only three atoms, protein molecules may contain thousands of them. These may be held together in an almost infinite number of arrangements, so that there are millions of different kinds of proteins which, in suspension in water, produce millions of different kinds of protoplasm. Indeed, the great range of differences between organisms is based to a large extent on the differences in the proteins they contain. We are human beings, instead of being plants or animals of some other sort, partly at least because the protoplasm of which we are composed contains the proteins which are typical of human beings. And if we are afflicted with hay fever, it is because "foreign" proteins from the pollen of plants have entered our systems and started warfare against our own "native" proteins.

Protoplasm, then, is a colloidal system composed largely of water and of the complex and infinitely varied proteins. In addition, there are small quantities of mineral salts and of certain fat-like substances which are essential to the formation of true protoplasm.

But why is protoplasm alive?

Without going into the details of colloidal mechanics, we may say that matter in the colloidal state is capable of carrying on activities that are impossible in any other condition. Many colloids are capable of changing from a liquid to a jelly-like condition and back again. Among non-living colloids, gelatin and a mayonnaise salad dressing may be taken as familiar examples. The former quickly becomes liquid when warmed, and solidifies again when cooled, while the latter changes easily from the solid to the liquid state and back again upon addition and removal of a little water. Many biologists believe that protoplasm can be compared directly in its structure to a combination of these two colloids. There is no doubt, moreover, that many of the activities which we consider to be the very essence of life, and peculiar to living things—such activities as the movement of microscopic animals as well as muscular contraction and nerve action in our own bodies—are brought about by means of these reversible changes from liquid to jelly and back.

Furthermore, non-living as well as living colloids can, on account of the great chemical activity which is possible when matter is in this state, build themselves up from simpler substances, thus adding to their bulk. In other words, they can grow. For instance, if we put a drop of one chemical, a copper salt, into a solution of another, potassium ferrocyanide, a thin membrane of a colloid is formed between these two substances, and this membrane will grow for a long time by building itself up from the chemicals on either side of it. It grows much as does a living membrane, except that the process is chemically much simpler and will not continue indefinitely.

Yet it should be emphasized that non-living colloids display only the simplest beginnings of those activities which constitute the fundamental features of life. Protoplasm in action is vastly different from non-living matter in action. Science is not yet capable of pointing out completely the reasons for that difference, but two ways in which protoplasm is unlike other colloids may here be mentioned.

First, it is exceedingly complex. Protoplasm is not a simple suspension of one substance within another. Under certain circumstances, for example, it is thought that globules of fatty substances may have droplets of water suspended within them, while the suspended water droplets may hold protein particles in suspension within themselves. In other regions of the cell, or under other conditions, the situation may be almost reversed. For to add to all its complexity, protoplasm is never the same thing one instant that it was the instant before. It is hardly accurate to speak of it as *the* living substance. It is rather a mixture of many substances each in a continual state of flux, each continually transforming itself from one thing into another, breaking down, building up, physically restless and chemically unstable.

Secondly, protoplasm is *organized* into small, individual, self-perpetuating systems known as *cells*. This is probably its outstanding characteristic, which sets it apart from ordinary, non-living colloidal systems, since cell organization enables the activities of protoplasm to go on in the orderly, controlled fashion that is essential if living things are to accomplish the acts necessary to keep them alive. The cell is the unit of life, and it is also the unit of structure in the human body.

What a Cell Is Like.—The body is composed entirely of these organized bits of protoplasm called cells, and of the non-living substances that they have built around themselves. They are so small that they cannot be seen by the naked eye, and high-powered microscopes are required to study them adequately. There are many kinds, of the most diverse shapes and sizes, but all have certain characteristics in common. Fig. 2 is a diagram of a very simple cell. It is not intended to be a representation of any actual structure, since no cell in the human body is as lacking in specialization as this one. The diagram merely serves to point out the parts that are characteristic of cells in general.

The nucleus is a more or less spherical body located toward the center of the cell. In living cells it is often difficult to make out, but in sections that have been stained by treating them with certain dyes, the nuclei of the cells are readily seen because they absorb dyes different from those absorbed by the cytoplasm. This nucleus is a sort of "central office" for the cell, since it exercises a directing influence over the cell's most vital activities, especially those which have to do with the building up of structure, and if it is removed, the cell wears itself away without being able to reconstruct itself in the way that a normal cell continually does.

The cytoplasm, which is simply the protoplasm outside the nucleus, is the region in which the everyday work of the cell is carried on. It is in the cytoplasm that the special structures which distinguish one cell from another and which determine the special functions of any cell are to be found. These special structures

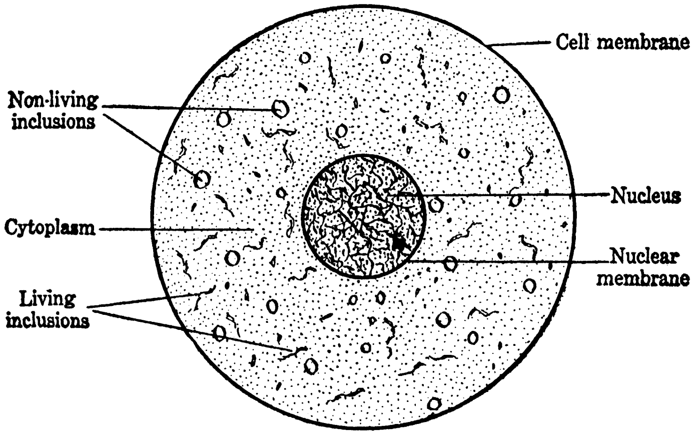


FIG. 2.—Diagram of a cell.

are of two kinds: those which are living parts of the cytoplasm and which perform some special vital function, and those which are not actively engaged in carrying on life processes.

The most important of the latter structures are stored particles of food material. Chemically speaking, there are two major groups of substances which the cell stores, the *carbohydrates* and the *fats.* The carbohydrates are composed of carbon atoms combined with hydrogen and oxygen in the same ratio as that in which they appear in water, namely, two atoms of hydrogen to one of oxygen; hence the name "carbohydrate," which means "carbon with water." The simplest carbohydrates are the *single sugars,* which are responsible for the sweetness in honey and most fruits. Their molecules usually are composed of six atoms of carbon, twelve of hydrogen, and six of oxygen (chemical formula, $C_6H_{12}O_6$). Somewhat more complex are the *double sugars*, of which ordinary table sugar is an example. Their formula is $C_{12}H_{22}O_{11}$. Still more complex are the *starches*, whose molecules may contain hundreds of atoms, but always in the ratio of six carbon to ten hydrogen to five oxygen. It is a relatively easy matter for one carbohydrate to be changed into another. Sugar molecules combine readily to form the larger starch molecules, and the latter can be split up to form sugar molecules. Starch is the form in which carbohydrates are stored, since the small molecules of sugar pass out of the cells too readily to be stored therein. Hence, when a cell has more sugar in it than it can immediately use, the sugar is transformed into minute bits of solid starch which remain in the cytoplasm until they are needed. Cells may use carbohydrates in two ways. First, they may undergo chemical changes, usually combination with oxygen, to furnish energy for the cell's activities, just as coal and gasoline combine with oxygen when they are burned to furnish energy for the running of machines. Second, at least in plants, they may be combined with nitrogen to build up the proteins of the cell structure. Animal cells cannot perform the synthesis of proteins from carbohydrates, and hence must obtain their proteins by devouring the bodies of other organisms.

Fats, like carbohydrates, are composed chiefly of carbon, hydrogen, and oxygen; but they have less oxygen than the latter in proportion to their hydrogen and carbon. They may also be used as fuels to be combined with oxygen for the release of energy, or they may be chemically modified to furnish the fat-like elements of the protoplasmic structure.

It is impossible for a cell to remain alive and not be active; or, to put it another way, activity, as well as cell structure, is an essential condition of life; and if that activity stops for even a brief period, the cell dies and cannot be revived. But all activity requires energy, and hence it is very important for a cell to have stored food substances to provide this energy. If these are lacking, however, the cell can meet the emergency by oxidizing the materials of the protoplasmic structure. Hence, proteins as well as carbohydrates and fats can be utilized as fuel. These three energy-yielding substances are spoken of together as *organic foods*. Water and mineral salts are called *inorganic foods* because they are found in nature apart from life, whereas the organic foods are formed naturally only in the bodies of organisms.[1]

To return to our discussion of the structures in the cytoplasm of cells, another frequent type of non-living structure is the *water vacuole*, a small droplet of water, usually surrounded entirely by cytoplasm, and containing various substances—notably salts, organic foods, and waste products—in solution or suspension. While they are found in the cells of animals, water vacuoles are especially

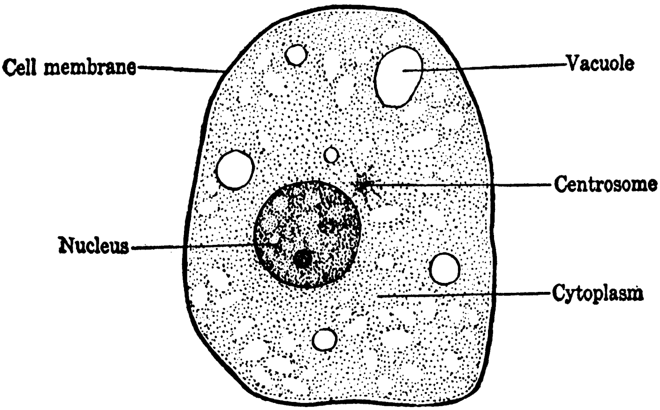


FIG. 3.—Typical animal cell.

characteristic of plant cells. Fig. 4 shows a plant cell with a large water vacuole and certain living cytoplasmic structures, known as *chloroplasts*, whose function will be described in detail in the next chapter.

Another important group of cell structures are the boundary *membranes* which are formed on the surfaces between two different kinds of protoplasm. A somewhat similar membrane is built up between water and oil wherever they come together, and such membranes act as barriers to mixture between two different kinds of substances. Hence, these membranes serve the function of setting apart the various protoplasmic and non-protoplasmic

[1] Chemists classify any substance that has carbon in it as an organic substance, since the carbon atom is so essential to life that all such substances are likely to have been derived ultimately from the bodies of living organisms. Carbon dioxide (CO_2), however, a gas which is present in small quantities in the air and which is the source from which organisms get their carbon, is often classified as inorganic.

structures one from another and keeping substances in the environment from entering the cell, unless they can be formed into a part of the protoplasm. Important among them are the ***nuclear membrane***, which separates the nucleus from the cytoplasm, and the *vacuolar membranes*, which act as boundaries between the water vacuoles and the protoplasm which surrounds them. Most important is the *cell membrane*, which covers the entire surface of the protoplasm, being located just inside the cell wall. All these membranes are part of the protoplasm and are alive, and they are capable of the continuous physical and chemical changes characteristic of protoplasm. It is at the membranes that the fat-like substances of the protoplasm are found in highest concentration.

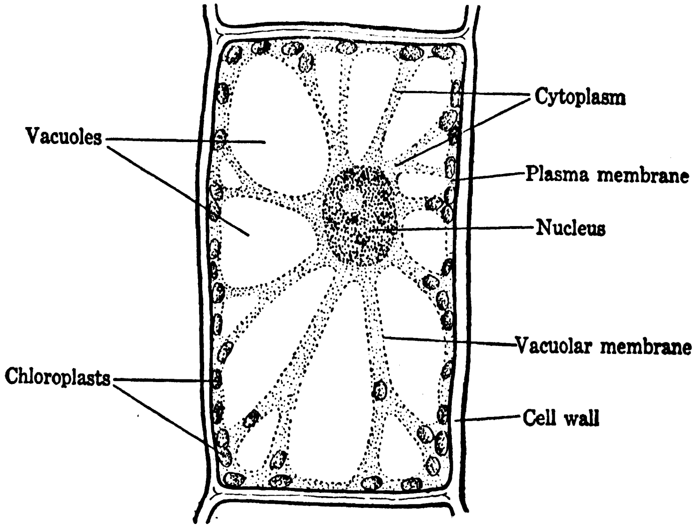


FIG. 4.—Typical plant cell.

Built around this cell is a thick *wall* of non-living substance. Such cell walls, along with other non-living parts of the plant or animal body, such as the mineral matter of the bones, are manufactured through the activity of cell protoplasm, and laid down outside the cell. Walls are particularly characteristic of plant cells, where they are composed chiefly of a highly complex carbohydrate, called *cellulose*. In animal cells, walls are largely protein in composition.

Tissues.—The number of cells in the body of an organism varies enormously. There are thousands of different kinds of plants and animals whose bodies are composed of but a single cell, while it is said that the human body contains something like a million billion of them. In unicellular organisms—plants and animals that are composed of a single cell—it is obvious that one cell must perform every function that is necessary to the life of an organism. But even in our own bodies, cells are, as certain writers have put it, "lesser lives within our life." Each cell is, in a sense, an independent unit which carries on in itself all the essential activities of living. Each takes in food that has been brought to it by the blood stream, uses part of that food to build up or repair its own structure, and burns part of it to furnish energy for its activities. The waste products, or "ashes," from the burning are given off or excreted into the blood. Indeed, certain cells can be completely removed from the body and, if they are put in the proper sort of solution and kept at the right temperature, go right on living; their protoplasm continues its restless movements, and the cells themselves may wander about and even divide to form new cells.

But although each cell leads a life of its own, yet each must play a part in the life of the whole organism. Each has a special task to perform. In this respect, cells have often been compared to workers in a factory, where one group of men perform one operation, other groups other operations, and all of these operations are required to complete the product which is being manufactured. The work of maintaining the organism is done in a similar manner. Muscle cells specialize in moving the body about; bone and cartilage cells build up supporting structures for it; skin cells furnish a protective covering, while gland cells specialize in manufacturing liquids and pouring them forth at appropriate moments.

There is one way, however, in which the specialization among the cells in the body differs from that among the workers in a factory. Cells differ not only in what they do, but also in the way in which they are constructed, in their shape, size and texture. In other words, *structure* is specialized as well as *function*. In a shoe factory the workers who cut the leather do not differ greatly in appearance from those who sew or nail it together. They are all human beings, with the characteristic bodily structure of human beings. But muscle cells, skin cells, and nerve cells, while they all possess nuclei and cytoplasm, show great differences in structure. On the other hand, cells that perform the same function closely resemble one another in structure.

A group or mass of cells that are similar to one another in structure and function is known as a *tissue*. Many tissues have a considerable amount of non-living material between the cells which is also a part of the tissue. A good example is bone tissue in which the cells are scattered throughout the hard substance which forms the greater part of the tissue. The liquid part of the blood is also an intercellular substance. There are many kinds of tissues in the human body, but for purposes of summary they may be grouped into four classes:

1. *Epithelial Tissues.*—These form the linings or coverings of the body. The skin, the hair, the fingernails, and the membranes which line the mouth, stomach, intestines and other internal organs belong to this group. Glandular tissue is a specialized form of epithelial tissue.

2. *Connective and Supporting Tissues.*—The bones, cartilage, and tendons belong to this group, and, in addition, there is a meshwork of connective tissue which extends practically throughout the body and which serves to give firmness to the organs and to hold them in position. The blood is also classified as a connective tissue.

3. *Muscular Tissues.*

4. *Nervous Tissues.*

Of these four groups, the muscular and nervous tissues are the more highly specialized. Their cells are very complex and only faintly resemble the simple, generalized cell that has just been described. On this account, the description of nerve and muscle cells will be reserved for later chapters.

How Cells Are Studied.—Some kinds of cells can be rather clearly made out under the microscope in their living state. One-celled organisms can be found in almost any drop of water taken from a marshy pool or other place where there is decaying vegetable material. It is easy to see them through the microscope and to watch their activities. But the cells of the human body are packed together so closely that special methods must be used to make them visible at all. Since it is practically impossible to study them while they are alive, the histologist, that is, the specialist who studies tissues, proceeds in the following manner:

First he cuts from the dead body a small piece of the tissue which he plans to study. He treats it with a preservative which hardens all the protoplasmic colloids which have not already been hardened by the processes of death. He places the small bit of tissue in a machine, known as a *microtome*, which cuts it into extremely thin slices in much the way that bacon is sliced by machinery in the butcher shop. The slices of tissue are then mounted on glass slides and treated with dyes which stain the nuclei, cell walls, and other special structures so that they stand out clearly from the cytoplasmic groundwork. The thin sections of tissue thus prepared may be slipped under the microscope; and, with the light shining up through them from beneath the platform on which the slide is placed, the structure of the individual cells can readily be made out.

To give the reader some notion of what the various kinds of cells in the body look like, we present here a few drawings made from tissues prepared in the above manner.

Epithelial Cells.—Fig. 5 A shows a group of cells from the skin of a frog that appear hardly more complex than the simple generalized cell previously described. They fit tightly together, and a cross section of them would show that they are quite thin and flat.

Fig. 5 B, C and D shows cross sections of certain more highly specialized epithelial cells from the lining of the windpipe. The "fringe" seen at the top in Fig. 5 B is made up of minute, hair-like threads of protoplasm known as *cilia.* They extend from the surface cells out into the windpipe, and they keep up a continual waving motion which sweeps dust and germs up through the windpipe and out of the lungs. Between the ciliated cells are the grayish, sac-shaped goblet cells. They manufacture a mucous liquid which, every now and then, they pour out into the windpipe, thus preventing its drying out on account of the continual passage of air through it. The goblet cells, therefore, constitute a very simple form of glandular tissue.

Connective Tissue Cells.—Connective tissues are made up of cells which form around themselves thick layers of tough non-living substances which serve to give strength and firmness to the body. Fig. 6 A shows a section of cartilage, such as that found in the end of the nose, in which the cells, usually placed in pairs opposite one another, are embedded in a fibrous substance which they themselves have manufactured.

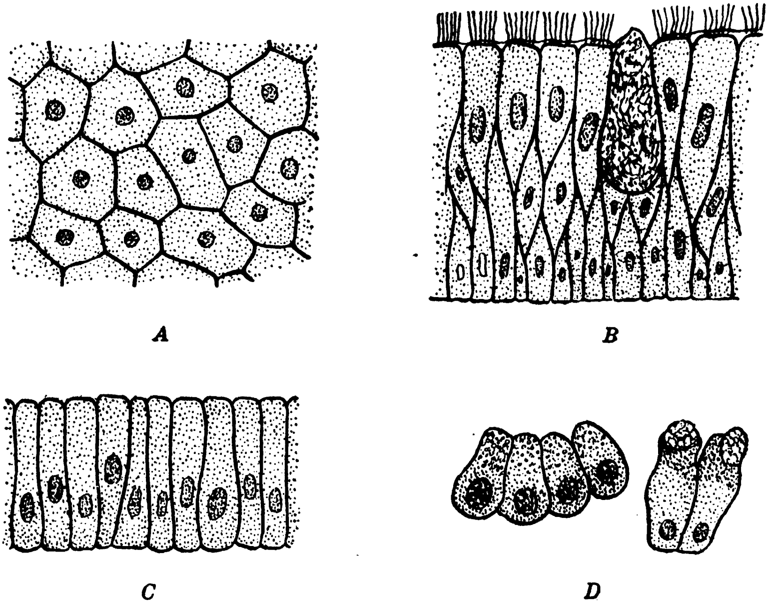


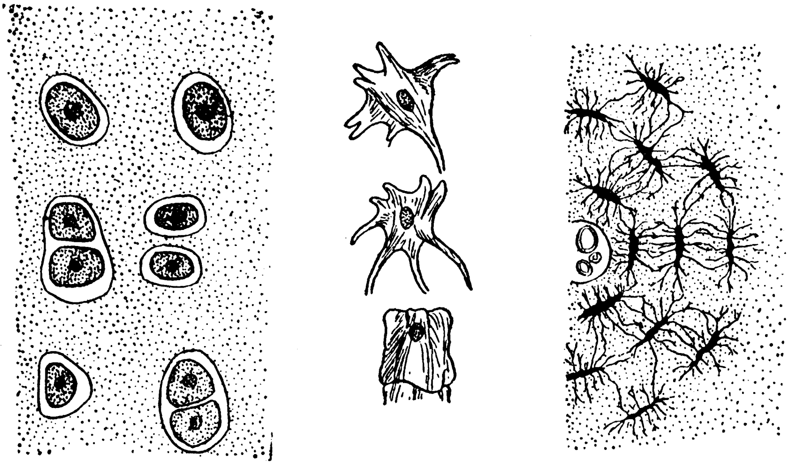
FIG. 5.—Epithelial tissues. *A,* frog epithelium; *B,* lining of windpipe; *C,* lining of stomach; *D,* glandular. (*C* and *D* redrawn from Guyer's *Animal Biology.*)

In Fig. 6 B, young connective tissue cells are shown. At the time they were prepared for microscopic demonstration, they were busy building up the structure of a bone.

Fig. 6 C shows some cells that perform the duty of depositing the mineral matter in our bones. They are embedded in little openings within the bone structure. Tiny canals run from these openings to the blood vessels that make their way through the bone, and food materials pass through these canals to the cells.

Organs and Systems.—Cells are the smallest living units of structure and function. The various tissues combine, however, to form much larger units, namely, *organs* and *systems.*

An *organ* is a part of the body, usually composed of several tissues, which possesses a certain degree of structural independence and which carries on a specific function or group of functions. The heart is the organ which has the function of pumping blood through the blood vessels; the kidneys perform the task of filtering certain groups of impurities out of the blood; the stomach is responsible for a part of the digestive process; the lungs bring oxygen to the blood and take carbon dioxide away; the hand is the organ for grasping and manipulating; the brain is the organ which



A *B* *C*

FIG. 6.—Connective tissues. *A,* cartilage; *B,* connective; *C,* bone.

governs or integrates the responses we make to our environment; while the liver carries on so many functions that it is, in effect, four or five organs in one.

A *system* is a group of organs that are joined one to another and act as a unit in performing some major bodily function. The following are the more important systems found in the human body:

1. The *digestive system* is composed of the mouth, the esophagus (the tube leading from the mouth to the stomach), the stomach, the intestines, and certain glands which empty digestive secretions into those organs. Its function is to prepare the food we eat so that it may enter the blood and be carried to the cells of the body.

2. The *respiratory system* includes the mouth and nose, windpipe, bronchial tubes, lungs, and the muscles which expand and contract the chest. It brings oxygen to the blood and takes carbon dioxide away.

3. The *circulatory system* includes the heart, blood vessels, and lymphatic vessels. Its function is to carry substances to and from the tissues.

4. The *reproductive system* is composed of the various male or female reproductive organs.

5. The *urinary system* includes the kidneys, the bladder, and the tubes or ducts which carry the urine from the kidneys to the bladder and from the bladder to the exterior.

6. The *nervous system* is made up of the brain, the spinal cord, and the nerve trunks.

Both the structure and the function of these systems will be dealt with more fully in succeeding chapters.

Chapter Summary

The bodies of human beings, and of plants and animals as well, are composed of two kinds of material: the living substance, protoplasm, and the non-living substances which the protoplasm has built up around itself.

Protoplasm is transparent, but usually contains structures appearing like small granules and bubbles. It is viscid, sticky, and elastic, and it does not mix with water. It resembles the uncooked white of egg. It is a colloidal system composed of a suspension of proteins in water, together with small amounts of mineral salts and fat-like substances.

The proteins are chemically the most complex substances known, being made up of thousands of atoms of hydrogen, oxygen, carbon, nitrogen and a few other elements. There are millions of different proteins, producing millions of different kinds of protoplasm, and one of the basic causes for the wide range of difference among organisms is the difference in the proteins of which they are composed.

Non-living colloids are capable of carrying on in a primitive way many of the activities characteristic of living things. Nevertheless, the activities of an organism are so intricate and marvelous that they greatly transcend the very crude lifelike activities of non-living colloidal systems. This tremendous difference between living and non-living activity may be partially explained by the great complexity of protoplasmic colloids and especially by the fact that protoplasm is *organized* into structures known as cells.

Cells are microscopic in size. They are units of bodily structure. Although they differ greatly among themselves, all cells possess a nucleus, which is a small rounded body in the center of the protoplasm, and a cytoplasm, which is the protoplasm outside the nucleus. The nucleus exercises a directing influence over the activities of the cell, and the cytoplasm is the region in which those activities are carried on. Within the cytoplasm are two kinds of special structures, those which are living parts of the protoplasm and which perform special vital functions, and certain non-living inclusions. Among the latter may be particles of stored food belonging to two chemical groups, the carbohydrates and fats. Both groups are composed of carbon, hydrogen, and oxygen; and they are capable of combining with more oxygen to yield energy for the activities of life. The carbohydrates are of three types: single sugars and double sugars, whose molecules are small and soluble in water, and starches, whose molecules are large. It is the latter which are stored in the cells in the form of solid granules. Another type of non-living structure is the water vacuole.

Living protoplasmic membranes bound the nucleus, the cytoplasmic inclusions, and the protoplasmic part of the cell. They separate the various kinds of protoplasm within the cell from one another and also set the protoplasm off from the non-living substances, both those within the cell and those in the surrounding environment. Most cells possess thick walls of non-living substance surrounding the protoplasm. In plants, these walls are composed of a complex carbohydrate known as cellulose. In animals they are usually of a protein nature.

The cells of the body are specialized in both structure and function. A group of similar cells is known as a tissue. There are many kinds of tissues in the body, but they can be grouped under four main headings: (1) epithelial tissue, (2) connective and supporting tissue, (3) muscular tissue, (4) nervous tissue.

A part of the body that possesses a certain degree of structural independence and that carries on a special function or group of functions is called an organ. Most organs are composed of several kinds of tissue. Organs are frequently found in special combinations called systems.

A system may be defined as a group of organs which are joined to one another and which act as a unit in performing one of the major bodily functions. The chief systems of the body are the digestive, respiratory, circulatory, reproductive, urinary and nervous systems.

The entire plan of structure of the body may be briefly summed up as follows: The living substance, protoplasm, organizes itself into microscopic structures, known as cells. A group of cells of a given kind constitutes a tissue. Tissues combine to form organs. Organs combine to form systems. And the tissues, organs, and systems, combined as they are, constitute the total organism.

QUESTIONS

1. Describe protoplasm. What are some of the characteristics of protoplasm which help to account for the fact that it is alive?
2. What is a cell? What are the structures which characterize cells? What non-living organic food substances are stored in the cells?
3. Discuss the specialization of structure among the cells of the body.
4. What is a tissue? What are the four general groups of bodily tissues?
5. What is an organ? Give examples.
6. What is a system? Give examples.

GLOSSARY

carbohydrate (car-bō-hī′drāt) Name given to a group of organic food substances which combine with oxygen to yield energy. Carbohydrates are composed of carbon, hydrogen, and oxygen, always having two molecules of hydrogen to one of oxygen. There are three kinds of carbohydrates that ordinarily serve as foods: *single sugars* and *double sugars,* which have small, soluble molecules, and *starches,* which have large, insoluble molecules.

cell The unit of living structure and function. It is composed of a highly organized system of protoplasmic colloids, plus the cell wall of non-living material which the protoplast builds around itself and various non-living inclusions.

cellulose (cel′ŭ-lōs) A carbohydrate substance which forms the walls of plant cells.

colloidal system (kō-loi′dal) A condition of matter in which minute particles of one substance are held in suspension in another substance.

cytoplasm (sī'tō-plaz'm) That portion of the cell protoplasm that is outside the nucleus.

epithelial (ep-i-thē'li-al) Pertaining to the covering or lining tissues of the body.

fat Name given to a group of organic food substances which combine with oxygen to yield energy. Fats are composed of carbon, hydrogen, and oxygen, but there is a lower proportion of oxygen than in carbohydrates.

nucleus (nū'klē-us) A rounded mass of protoplasm found usually near the center of the cell. It governs the growth and repair of the cell.

organ A part of the body that possesses a certain degree of structural independence and that carries on a special function or group of functions. (Be careful not to confuse the terms *organ* and *organism.*)

organic compounds. Chemical compounds containing carbon. They are derived, directly or indirectly, from the tissues of organisms, living or dead.

organism Any living individual, whether plant or animal.

protein (prō'te-in) Name given to a group of very complex chemical compounds that, together with water, constitute the chief structural elements of protoplasm.

protoplasm (prō'tō-plaz'm) The living substance.

system A group of organs which are joined to one another and which act as a unit in performing one of the major bodily functions.

tissue A group of cells that are alike in structure and function.

water vacuole (vak'ū-ōl) A droplet of water contained within the protoplasm of a cell.

CHAPTER II

METABOLISM

What Is Metabolism?—In the previous chapter we have seen that all organisms—whether plant, animal, or human—have in common a substance and a structural organization unknown elsewhere in the physical world. Yet these are as characteristic of dead organisms as of living ones. Life is dynamic, not static. It is far easier to define it in comparison with non-living matter in terms of what it *does* rather than what it *is*. Thus, to understand the phenomenon of life, we must think in terms of energy as well as matter.

Just as protoplasm is the unique type of matter characteristic of living things, so is *metabolism* the unique system of energy changes associated with life. Living organisms are the scene of an unceasing series of chemical and physical changes which collectively manifest themselves in all the varied activities which we designate as life.

Protoplasm, when alive, is in a continual flux, forever taking in materials, transforming them, giving off wastes. It is like a whirlpool in a river which maintains its apparent identity even though at any two successive moments the individual water molecules which constitute it are different. There is a continual flow of energy into and out of protoplasm—which is only a special form of matter capable of capturing, transforming and utilizing energy in certain ways peculiar to the living world. It is this capture and transformation of energy which is known as *metabolism*—the sum total of all the chemical and physical changes whereby protoplasm builds itself up, secures the potential energy to be expended in the ceaseless activities of life, and eventually consumes itself.

There are two aspects to the process of metabolism. The first, which involves the securing of food and the building up of protoplasm, is the constructive aspect termed *anabolism.* The second is the destructive, or *katabolic,* aspect of metabolism. It involves the oxidation of stored foods, the wearing away and oxidation of the protoplasm itself, and the excretion—that is, the giving off or elimination—of waste products resulting from the other katabolic activities. Katabolism, if unbalanced by anabolism, causes a cell to waste away and die; it is the preponderant process during the old age of organisms. In youth anabolic activities predominate, resulting in growth rather than wastage of protoplasmic structures. But katabolism is as essential as anabolism, for while the latter results in the storage of energy in the cell in the form of food, the katabolic activity of oxidation is essential for the release of that energy for the work of the cell: its growth, its movement (if it is capable of movement), and the maintenance of that minimum of protoplasmic activity which is essential if life is to continue. The oxidation which takes place in the cell is directly comparable to the burning of wood, coal or gasoline. Both are the combination of oxygen with a carbon-hydrogen compound accompanied by the release of stored energy. The rapid oxidation of substances in furnaces and engines is called combustion; the slower "burning" that goes on in cells is termed *respiration.*

The primary differences between organisms lie in the method by which they secure their food. In fact, this is the distinction between the typical plant and the typical animal. The plant kingdom (with some exceptions) is characterized by organisms with cells capable of manufacturing their own organic food out of common inorganic substances in the environment, which are absorbed into the cells. The animal kingdom, on the other hand, consists of organisms lacking this ability; they must secure their food in ready-made form, usually *ingesting* it—i.e., taking it in—through a mouth or similar opening.

The animal kingdom is therefore dependent upon the plant kingdom for food, while plants are quite independent of other organisms in this respect: they do not have to eat. We indicate this difference by saying that animals are characterized by *heterotrophic* metabolism, wherein organic foods are essential for anabolism to take place; and plants carry on *autotrophic* metabolism, being able to manufacture their own food for anabolism from inorganic substances in the environment. This generalization holds as long as we confine ourselves to the ordinary green plants with which everyone is familiar. Later on in this chapter certain exceptions will be described.

The living activities of an organism are the sum total of all the activities of the individual cells which constitute that organism. Thus, no matter how complex the organism or its activities, its life processes can be studied in simplified form within the boundaries of a single cell. We can reduce metabolic aspects of life to their ultimate fundamentals by confining our attention—as we shall do in this chapter—to the energy changes which characterize autotrophic and heterotrophic metabolism when they take place within the bodies of unicellular organisms.

Green Plant Metabolism.—The common green plants (shrubs, flowers, trees, ferns, grasses, etc.) typify autotrophic metabolism

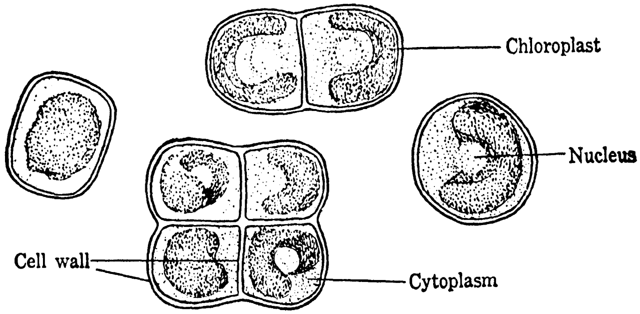


FIG. 7.—Protococcus, a single-celled green plant.

at its greatest efficiency. Such metabolism is reduced to its simplest expression in the unicellular organism known as Protococcus, which forms a delicate green layer over the shaded and protected surfaces of stone walls and tree trunks. Under the microscope, this powdery green material is seen to be made up of many minute spherical or elliptical cells, sometimes flattened where several cells are packed closely together. Each cell is a complete and independent organism. If we examine the cell carefully we discover that the uniformly green color of the plant is due to the presence of a green body in the cytoplasm, which is known as a *chloroplast.* In Protococcus, there is one large chloroplast in each cell. Each chloroplast is really a specialized portion of the cytoplasm saturated with a mixture of pigments, bright green in color and known as *chlorophyll.*

Chlorophyll is one of the most important substances found in the living world. It is a compound of carbon, oxygen, hydrogen, nitrogen and magnesium which, when associated with protoplasm, makes possible the synthesis of food from carbon dioxide and water. The chlorophyll in each chloroplast intercepts the light rays (in nature coming from the sun) and utilizes the captured energy to dissociate the atoms of the carbon dioxide and water, reassembling them into carbohydrates with energy added during the process. Organisms with chlorophyll in their protoplasm have the tremendous advantage of being able to utilize the vast amounts of solar radiation continually reaching the earth. When sunlight becomes transformed into the potential energy of food, metabolism upon high levels is possible.

To return to Protococcus. The cell remains perfectly still, bathed by sunlight and surrounded by an atmosphere containing water and carbon dioxide. The chloroplast absorbs energy from the sunlight and with it makes its own carbohydrate food. Sugar is the first food manufactured by this process. As the carbon dioxide and water in the cell sap of Protococcus become used up, new supplies diffuse in from the atmosphere. Once sugar has been synthesized, the manufacture of other foods is not difficult. Sugar molecules become transformed into starch, and, in a somewhat more complex fashion, fats are synthesized from the sugars. As a by-product of this activity, oxygen is released. The following formula, indicating what happens in the synthesis of sugar, demonstrates this release of oxygen:

$$\text{Carbon dioxide} + \text{water} + \text{sunlight} \longrightarrow \text{sugar} + \text{oxygen}$$

Or, to put it in terms of a chemical formula:

$$6\ CO_2 + 6\ H_2O + \text{solar energy} \longrightarrow C_6H_{12}O_6 + 6\ O_2$$

This introductory phase of autotrophic metabolism, involving the use of chlorophyll, is called *photosynthesis.* It can take place only in light, and only in an environment containing the essential raw materials, namely, carbon dioxide and water. The importance of this process of green plant fixation of carbon into foods essential for animal existence will be discussed later when we study the interrelations among organisms.

In order to manufacture proteins essential for protoplasm-building, Protococcus must secure from the environment the elements nitrogen and sulphur; these are absorbed in the form of the soluble salts, nitrates and sulphates. The nitrogen and the sulphur unite with the sugar molecules to form *amino acids* and these in turn combine to form proteins.

In addition to food manufacture and protoplasm-building, Protococcus carries on the destructive activities characteristic of katabolism. These involve absorbing oxygen from the air, combining it with foods, and thus releasing energy through respiration.

Chemically, this process is the direct opposite of photosynthesis. In its simplest form, the oxidation of a single sugar, it can be represented as follows:

$$\text{Sugar} + \text{oxygen} \longrightarrow \text{carbon dioxide} + \text{water} + \text{energy}$$
$$C_6H_{12}O_6 + O_2 \longrightarrow CO_2 + H_2O + \text{energy}$$

Thus the energy the plant takes into itself through photosynthesis is released for use through respiration. Energy is stored up in a form that is more convenient for the plant to use than the energy of sunlight and one that is available both day and night, so that the all-important continuity of protoplasmic activity is never broken. In other fields, we know that energy-in-action (kinetic energy) is often transformed into potential energy in this fashion, to be expended at a later time in a convenient manner. When an engine raises the hammer of a pile driver to the top of the shaft, the energy expended by the engine is stored up in the hammer for use when it falls, driving the pile into the ground. The photosynthetic reaction is similar to the raising of the hammer. It is a change requiring energy for its accomplishment, at the same time converting the energy into a form capable of being released later for special use. The respiratory reaction is comparable to the fall of the hammer; it is the employment of the potential energy to accomplish work. Thus the two opposite chemical reactions are equivalent, as far as energy exchanges are concerned, to the two opposite movements of the hammer of the pile driver.

Just as the raw materials for food manufacture must enter the cell of Protococcus during photosynthesis, so the products of respiration—carbon dioxide and water—must leave the cell whenever respiration is proceeding more rapidly than photosynthesis;

other waste substances, such as the products of protein breakdown, are excreted through the cell wall from time to time. The katabolic activities of respiration and excretion do not proceed nearly as rapidly in a green plant as in an animal, since the motionless life of the plant cell does not call for a great expenditure of energy.

The life of Protococcus is the life of the typical green plant. An unexciting existence, but one in which vastly important activity is quietly, invisibly, continually in progress. Animals, because of

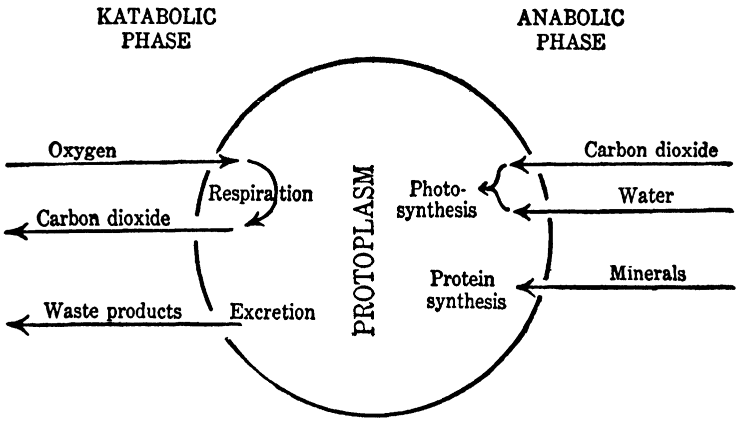


FIG. 8.—Diagram of metabolic processes in a plant cell.

their type of metabolism, are essentially parasites and highway robbers, deriving their sustenance by snatching food supplies from other plants and animals. The plant, by comparison, is an industrious citizen, producing food substance for the entire world of animal life.

Animal Metabolism.—Animal metabolism is reduced to its simplest expression in the unicellular organisms known as *Protozoa.* There are several thousand different kinds of protozoans of diverse forms, living their lives unseen in the numerous ponds and puddles of the roadsides. We shall use as an example the common slipper-shaped Paramecium.

The whole organism is a single cell, but a complex and highly organized bit of protoplasm it appears to be as we look at it through the microscope and compare it with Protococcus. The outermost region of the cytoplasm and the cell wall are modified to form a mechanism for locomotion—hundreds of tiny hair-like *cilia* are capable of vibrating in unison to make movement of the organism possible. Paramecium can swim about rapidly, seemingly continually prying about the débris in the water in search of food. There is a groove running halfway down one side and terminating in a mouth and gullet; it is in this portion of the cell that food is caught and enters into the cell. Once within the Paramecium, the bacteria or other unicellular forms of life serving as food become surrounded by a portion of the cytoplasm in the structure known as a *food vacuole.*

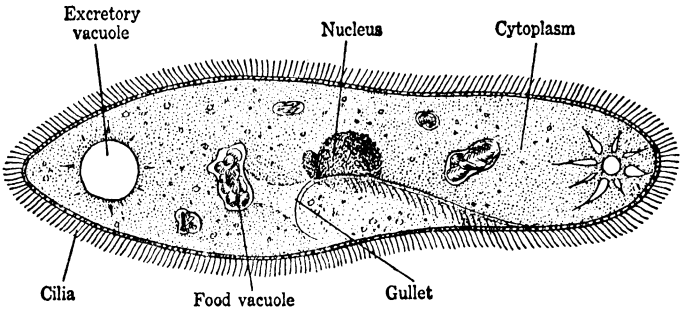


FIG. 9.—Paramecium, a single-celled animal.

This food contains carbohydrates, fats and proteins like the food of all animals; but they are not ready to be used immediately by the Paramecium. Their complex molecules must be broken down into smaller molecules soluble in water. Only then can they pass from the water in the vacuole into the actual structure of the protoplasm and be used for fuel or building materials. The chemical reactions essential for this breakdown are brought about by certain substances called *enzymes* which are secreted into the vacuole. Enzymes are organic *catalysts*; that is, they increase the velocity of chemical reactions. It is believed that organisms use enzymes to produce nearly all the chemical changes which constitute metabolic activity, but the rôle of enzymes that carry on digestion is best known. In Paramecium the digestive enzyme activity goes on in the food vacuole, just as in human beings it is carried on in the digestive tract. Then the food materials, reduced to a soluble form, are absorbed into the protoplasm and used to build up the protoplasmic structure, or oxidized to yield energy.

As the oxygen in the Paramecium is exhausted by the respiratory process, new oxygen is absorbed into the cell from the environment, where it is found dissolved in the water, since all water in contact with the atmosphere contains a certain amount of the gases of the air in solution. At the same time, the carbon dioxide which is formed in excess in the cell diffuses out into the water. This intake of oxygen and outgo of carbon dioxide is termed *external respiration* to distinguish it from the respiratory

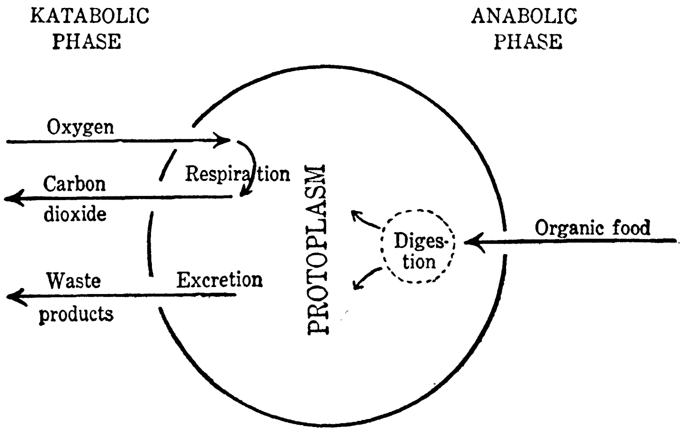


FIG. 10.—Diagram of metabolic processes in an animal cell.

chemical reaction that goes on in the cell. It has already been shown that external respiration goes on in Protococcus whenever the rate of internal respiration exceeds that of photosynthesis; but it is much more rapid in Paramecium, since the latter organism must oxidize a great deal of food to provide the energy for its constant moving about.

With respect to oxygen, external respiration is an *assimilative* process on a par with digestion and the absorption of food. With respect to carbon dioxide it is excretory. The other excretory processes in Paramecium are carried on in a more complex fashion than in Protococcus. Water and nitrogenous compounds formed by the breakdown of proteins collect in small *contractile vacuoles* which gradually enlarge until one edge touches the cell wall, wherepon the vacuole contracts rapidly, forcing its contents out into ie surrounding water. Similarly, the food vacuole, after all the igestible portions of the food have been absorbed, makes its way) the cell surface and discharges the undigested residue into the 'ater. These two processes are similar in both form and function) urination and defecation in human beings.

Within the limits of a single cell, Paramecium exhibits all the iaracteristics of animal metabolism. On the katabolic side, they iffer only in degree and complexity from those of Protococcus nd other plants; but with respect to anabolism, they are very ifferent.

Colorless Plant Metabolism.—Although most of the common lants are green, because of the presence of chlorophyll, there are iany plants which have no chlorophyll and hence cannot carry n photosynthesis. These colorless plants are known as *fungi* and *acteria.* The former include the mushrooms and bracket fungi f rather everyday occurrence and many small and inconspicuous lants, such as the molds, mildews, wilts, blights and rusts that row upon living plants and frequently cause much crop damage. 'hen there is the vast assemblage of microscopic one-celled color-:ss plants—the yeasts, classified among the fungi, which are ac-ve in fermentation and bread-raising, and the bacteria which ause diseases and decay.

Most of the colorless plants live upon the bodies of other or-anisms and hence are heterotrophic; but a few of the bacteria re able to carry on a primitive type of autotrophic metabolism. 'he latter organisms may represent the forms of metabolic activity vhereby the first protoplasmic colloids lifted themselves definitely ut of the realm of non-living matter to become organisms. Such re the sulphur and iron bacteria, and the bacteria subsisting upon nmonia and its derived products.

Sulphur bacteria are found in stagnant pools, where they form scum on the surface of the water. The simple cells, lacking the hloroplasts found in Protococcus, are united end to end in slender hread-like filaments. In the water surrounding these bacteria are arious inorganic substances, including carbon dioxide and sul-hur (or hydrogen sulphide). The sulphur is absorbed into the acterial cell and there oxidized; as a result, some energy is re-eased and the protoplasm uses this energy to transform carbon dioxide into food. Here in the sulphur bacteria we find a process of carbon synthesis taking place similar to photosynthesis in Protococcus, except for one detail. Instead of sunlight, the energy for the process comes from the oxidation of the sulphur or its compounds.

Other autotrophic bacteria, also independent of light, oxidize iron salts; there are even some forms which subsist upon selenium and methane. Most important of all, from the human point of view, are the autotrophic bacteria which oxidize ammonia—the end product of animal decay. Since they change ammonia into nitrites during the process, these are known as nitrite bacteria. Still other bacteria, the nitrate bacteria, secure the energy necessary for their food manufacture by oxidizing the nitrites into nitrates.

The heterotrophic colorless plants all get their nourishment from organic material in the bodies of other organisms, living or dead. The bacteria and fungi which cause decay utilize as food the organic substance associated with dead protoplasm. Such scavengers in the biologic realm are known as *saprophytes*. The colorless protoplasm of the bacterial cell is not able to take in solid food particles and digest them within the cell; if this could be done, bacteria would be classified as animals. Instead, the protoplasm produces enzymes similar in function to those found in Paramecium; these enzymes are excreted by the cell into its environment and act upon the complex organic compounds of the dead protoplasm, producing simpler substances capable of being absorbed into the bacterial cell and there utilized in its metabolism.

As an example, when a tree dies there is left a residue of wood which is composed largely of cellulose. Decay fungi capable of "digesting" wood produce several enzymes which eventually change the cellulose into sugar. During the process, these fungi secure organic material for their metabolism, and release carbon dioxide and water as waste products of their katabolic activities. When an animal dies and its body decays, bacteria act upon the carbohydrates present in the same way. In addition, the proteins are broken down into ammonia and various organic acids.

Disease bacteria are unicellular plants of microscopic dimensions; they are the smallest cellular forms of life known to the biologist today. They have the same protoplasmic make-up as the decay bacteria, but unlike the latter they usually feed upon organic substances associated with living protoplasm. Such a habit of living is known as *parasitism*, and the organism is a *parasite*. The carbohydrates and proteins in the host cells (human blood and various tissues in the case of bacteria causing human diseases) are, after digestion, absorbed into the bacterial cell and there converted into bacterial protoplasm or used as a source of energy. Waste products known as *toxins*, substances poisonous to human tissues, are frequently produced as a part of the katabolic process of bacterial metabolism.

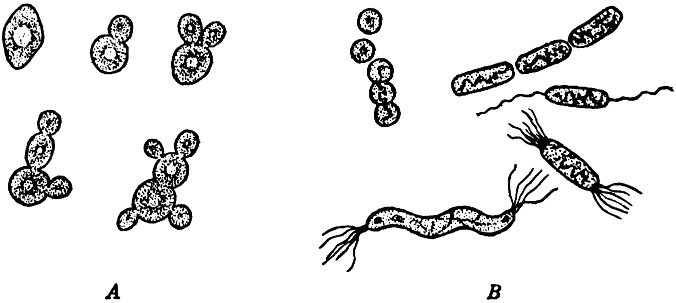


FIG. 11.—Single-celled colorless plants. *A*, yeast; *B*, bacteria.

The yeast plant is also microscopic; the invisible single-celled organisms are continually floating about in the air. Its food is generally sugar, which is abundantly present in most fruit juices. When a cluster of grapes is picked, there may be yeast cells on the skin of every grape. As the juice is squeezed out in a wine press, some of the yeast cells go with the sugary solution. The yeast protoplasm produces enzymes which break down the sugar molecules into alcohol and carbon dioxide as end products. This katabolic activity on the part of the yeast plant, resulting in the production of alcohol, is a respiratory process, bearing the special name *fermentation*. The same yeast plants, mixed with bread dough, feed upon the carbohydrates in the dough, release some alcohol and large amounts of carbon dioxide. This gas forms bubbles in the mixture and causes the bread to rise.

The Difference Between Animals and Plants.—The difference between the two great kingdoms of life is fundamentally a difference in their metabolic activities. Ordinarily we think of animals as organisms which move about, whereas plants are rooted to the ground and are incapable of movement. But the biologist knows that this distinction does not hold throughout the entire realm of life. There are many one-celled green plants, and bacteria as well, which swim about almost as freely as Paramecium; while one frequently comes upon types of animals, such as corals and sponges, which remain attached to a single spot and obtain food by simply setting up currents of water which carry it to their mouths.

If we had to consider green plants and animals alone, we could say that plants are autotrophic, and animals, heterotrophic organisms. But the large number of heterotrophic colorless plants destroys this distinction. Careful examination of the metabolic activities in both green and colorless plants, however, reveals that, whether they take in inorganic or organic materials, they always *absorb* them from the surrounding medium. They do not, like animals, *ingest* them first and then carry on the processes of digestion and absorption within their bodies. This explains why most plants lead sedentary lives, dwelling within or upon the source of their food material, while animals wander about in search of things to devour.

The difference between ingestion and absorption as the initial stage in anabolism may not appear very great, yet it is basic to all the other obvious differences between plants and animals. A plant is an organism constructed for the efficient absorption of nutritive materials and, in the case of green plants, the utilization of the solar energy. An animal is an organism especially adapted for securing and ingesting foods. Although the higher, more complex plants and animals seem very unlike in form and structure, among the simpler, primitive representatives of both kingdoms there is often little difference between a plant and an animal. There are even some organisms which are both plant and animal. These are found mostly among a group of unicellular organisms called *flagellates* because they move about in the water by means of a single, long, whip-like thread of protoplasm, called a flagellum, which they stretch out and snap toward them, thus pulling themselves forward. Some flagellates are green plants whose metabolic activities are in every respect similar to those of Protococcus; some are animals, lacking chlorophyll and securing all their food by ingestion. Finally, there are some flagellates that not only contain chlorophyll and carry on photosynthesis, but are capable of ingesting organic foods as well. These are true plant-animals, belonging, by right of their metabolic activities, to both kingdoms, displaying in themselves the true unity of life. For wide as the gulf may seem to be between ourselves and the plants, we are fundamentally of the same nature as they, and with them share membership in a single great world of life.

Chapter Summary

All organisms have in common a unique system of energy changes known as metabolism, whereby protoplasm takes in, transforms and gives off energy. There are two aspects of this metabolic activity: a constructive aspect known as the anabolic phase, in which protoplasm is built up and energy stored, and a destructive aspect known as the katabolic phase, in which energy is released and protoplasm consumed. Katabolism usually involves oxidation of protoplasm or organic substances within the protoplasm; such oxidation within the cell is known as respiration.

The chief differences between organisms are related to their types of metabolism, to the method by which they secure their food during anabolism. There are three types of metabolism, which differentiate living things into three major groups of organisms. These are (1) green plant metabolism, in which the organisms manufacture their own organic substances from the inorganic materials of the environment; (2) animal metabolism, in which the organism ingests previously synthesized organic materials from the environment, usually taking them in through a mouth; (3) colorless plant metabolism, in which the organism absorbs organic materials from the environment, materials which previously made up the bodies of other plants or animals or even were a part of living bodies at the time of absorption.

Both colorless plant metabolism and animal metabolism can be carried on only when there has been previously green plant metabolism; for it is only by the latter process that organic materials—the basis of protoplasm and life—are synthesized from the common inorganic substances found in the physical environment. Green plants are independent of other organisms, while colorless plants and animals are dependent upon green plants for their food.

For this reason, green plants are called autotrophic organisms; colorless plants and animals are known as heterotrophic ones.

These three types of metabolism involve rather complicated sets of tissues and organs in the higher plants and animals, where the organism is made up of millions of cells. Therefore, each type can be seen to best advantage where the organism is a single cell.

Green plant metabolism is reduced to its simplest terms in the single-celled Protococcus. The cell-organism is characterized by a green structure in the protoplasm, known as a chloroplast; it is the presence of such chloroplasts that gives plants their green color. The importance of the chloroplast lies in the fact that it intercepts solar radiation and uses the captured energy to break up the carbon dioxide and water molecules, preparatory to reorganizing the atoms as sugar and starch molecules. Thus green plant metabolism requires (1) a source of energy such as sunlight, (2) chloroplasts, (3) raw materials in the form of water and carbon dioxide. This process of synthesizing carbohydrates from inorganic materials is called photosynthesis, and is an important phase of green plant metabolism. After manufacturing this carbohydrate food, Protococcus absorbs nitrates from the environment and changes the carbohydrates to proteins. Thus materials for respiration and cell growth are provided by the two synthesizing processes. All of the foregoing has been a part of the anabolic phases of metabolism in Protococcus. Katabolism involves taking in oxygen, combining it with the foods the plant has manufactured, and thus releasing energy by respiration.

Animal metabolism is reduced to its most elemental form in one of the single-celled animals, Paramecium. The cell-organism in this case lacks the green chloroplasts and therefore cannot carry on photosynthesis. It is dependent upon an external source of organic food; such food is taken in, or ingested, through a special part of the cell where there is a gullet and mouth developed for this purpose. To get to the food supplies, Paramecium swims about as a result of the rapid vibration of many small cilia all over its surface. The food particles (minute plants or animals) enter Paramecium through the mouth and become part of a food vacuole, where enzymes produced by the protoplasm break down the complex organic compounds into simpler ones. This is a primitive sort of digestive process. When the food has been reduced to soluble form, it is assimilated by the protoplasm where it can be used as a source of energy or of new protoplasm. The katabolic phases of metabolism involve, as in Protococcus, the absorption of oxygen and the oxidation of organic compounds, with the accompanying release of energy and carbon dioxide. The intake of oxygen and outgo of carbon dioxide is often called external respiration to distinguish it from cell respiration, which is the actual oxidation of protoplasm or food. Waste products which are not gaseous are eliminated through special excretory vacuoles not found in Protococcus.

Colorless plant metabolism, characteristic of the whole group of fungi, is reduced to its essential characteristics in the bacteria. A few of these are autotrophic, such as the sulphur, nitrite and nitrate bacteria. Like Paramecium, they lack chloroplasts; unlike Paramecium, they do not need to feed upon plant and animal remains but are able to get their energy by the oxidation of sulphur, ammonia or nitrites. Those that feed upon ammonia and nitrites are important in the conservation of nitrogen salts in the ground, where they can be used by green plants in synthesizing proteins. Most of the bacteria are heterotrophic, and live either as saprophytes or as parasites. They differ from unicellular animals in that they do not ingest their organic food, but instead excrete enzymes into the environment which act upon protoplasmic materials, rendering them soluble and otherwise suitable for absorption within the bacterial cell. After absorption the organic substances are used for cell growth and cell oxidation. Yeast is another unicellular organism carrying on colorless plant metabolism; its food is generally sugar, which is changed to alcohol by the yeast enzymes during katabolism.

In considering these types of metabolism, as they are simplified in the single-celled organisms, we can see that the essential difference between the plant and animal kingdoms is one associated with the type of metabolism. A plant is an organism which absorbs its food—whether this is inorganic or organic—from the surrounding environment. If the food is inorganic, the plant can, by the process of photosynthesis, utilize solar energy to convert the carbon dioxide and water into carbohydrates; if it is organic, it is usually acted upon by enzymes outside the cell and absorbed when soluble and usable. An animal, on the other hand, ingests organic food and carries on the process of digestion and rendering the food available for the cell, after the food is taken in. Both plants and animals carry on respiration as the most important aspect of katabolism.

QUESTIONS

1. Compare katabolism in Protococcus and in Paramecium.
2. What is the chief difference in metabolism between Protococcus and a yeast plant?
3. What is the chief difference between a plant and an animal?
4. Are all heterotrophic organisms animals? Give examples.
5. Are green plants the only autotrophic organisms? Give examples.
6. Describe the process of photosynthesis as it takes place in Protococcus.
7. Why is chlorophyll considered such an important substance?
8. Why is oxygen given off from plants?
9. Oxygen is also taken into plants. Why?
10. Describe the anabolic activities of Paramecium.
11. Compare the activity of a food vacuole and that of a contractile vacuole in Paramecium.
12. How does external respiration differ from cell respiration?
13. What, if any, is the significance of autotrophic colorless plant metabolism? What organisms exhibit such metabolism?
14. Describe anabolism in the heterotrophic bacteria.

GLOSSARY

amino acids (am'i-nō) Nitrogenous substances out of which proteins are built up.

anabolism (an-ab'ŏ-lis'm) The constructive phase of metabolism, whereby energy is stored and food accumulated for use in protoplasm-building or katabolism.

autotrophic (ô'to-trŏ'fic) That type of organism or metabolism which is able to transform inorganic materials such as carbon dioxide and water into organic ones such as carbohydrates. All green plants are autotrophic organisms.

bacterium (bak-tē'ri-um) pl. *bacteria.* A very simple colorless one-celled plant.

catalyst (ka'ta-list) A substance which speeds up a chemical reaction without taking part in it.

chlorophyll (klō'ro-fil) Green pigment, made up of carbon, hydrogen, oxygen, nitrogen and magnesium.

chloroplast (klō'rō-plast) A protoplasmic structure containing chlorophyll, necessary for photosynthesis and common to all green plants, giving them their characteristic color.

cilia (sil'i-a) Minute hair-like outgrowths covering the cell wall of many Protozoa; used for locomotion.

contractile vacuole Vacuole found in Paramecium and other Protozoa, which functions as an excretory structure.

enzyme (en'zīm) An organic catalyst.

external respiration Exchange of gases between the cell and the environment.

food vacuole Vacuole found in Protozoa, containing particles of ingested food.

heterotrophic (het'er-ō trō'fic) That type of organism or metabolism which is dependent upon organic food, which is either absorbed (colorless plants) or ingested (animals).

ingestion (in-jes'chun) The taking in of solid organic food, usually through a mouth.

inorganic (in'or-gan'ic) Not containing carbon; sometimes also applied to substances not elaborated by living things.

katabolism (ka-tab'ō-liz'm) The destructive phase of metabolism, whereby food is consumed and energy released.

metabolism (me-tab'ō-liz'm) The sum total of all the physical and chemical changes taking place in protoplasm, in the course of which energy is taken in, transformed and utilized in living activities.

organic Substance containing carbon; or one produced by living organisms.

parasite An organism feeding upon the organic materials associated with the living tissues of another organism.

photosynthesis (fō-tō-sin'the-sis) The chemical reaction performed by green plants in the presence of sunlight and with the aid of cholorophyll, in which carbon dioxide and water are united to form sugar.

protozoa (prō-tō-zō'a) The group of one-celled animals.

respiration The process of oxidation of organic materials taking place during katabolism within the cell.

saprophyte (sap'rō-fīt) An organism feeding upon the organic materials associated with dead plants or animals; most of the mushrooms are saprophytes.

CHAPTER III

CIRCULATION AND RESPIRATION IN THE HUMAN BODY

CIRCULATION

Human Cells and Their Environment.—Each of the million billion cells of a man's body is busily engaged in living its own life and performing the tasks whereby it serves its community, the body as a whole. Each one carries on its own series of metabolic activities in a manner similar to that in Protococcus, Paramecium, or any other one-celled organism. There is one major difference: unicellular organisms must secure the materials for metabolism from a natural environment which has not been constructed for their special benefit, whereas the cells of the human body have an environment especially prepared for them which provides them with everything they need. This environment, like that of Paramecium, is a liquid one. Every cell of the body is surrounded by a liquid, known as the *tissue fluid,* although in places where the cells are packed tightly together, this fluid may be present only as a thin film between them. Dissolved in the tissue fluid are the digested food substances and the oxygen which must make their way into the cells, and, likewise, the carbon dioxide and wastes which are continually being produced in the process of metabolism. But the million billion cells are so tightly packed together that food and oxygen are absorbed from and waste products given off into the watery surroundings at an extremely rapid rate. The tissue fluid would be choked with wastes and starved for lack of food and oxygen if it were not for the blood stream, which courses through all parts of the body, carrying substances to and from each part, and which freshens the tissue fluid as a brook freshens a pond through which it runs.

Circulation.—The blood does not enter the tissues itself, but is carried about within a system of blood vessels. The walls of the smallest of these blood vessels, the capillaries, are so thin that the oxygen and foods which the blood brings make their way easily through them and into the tissues, and the carbon dioxide and other wastes diffuse into the blood and are rapidly carried away.

The circulatory system is the great transporting medium of the body. The blood runs through the lungs, where it gets its supply of oxygen from the air and unloads carbon dioxide into the air. It picks up foodstuffs from the intestines and carries wastes to the kidneys, sweat glands, and liver. As its system of canals serves the Dutch nation, so the circulatory system serves the body, moving materials from one place to another as they are needed. The flow of the blood which makes this movement possible is maintained by the energetic pumping of the heart. The channels through which it flows are the blood vessels—the capillaries, arteries, and veins.

The Blood Vessels.—The vessels through which the blood flows away from the heart are called *arteries*. The largest of them, the *aorta*, which carries the blood as it leaves the heart to go to the body tissues, is about an inch in diameter, but this artery almost immediately sends off branches and becomes smaller. Arteries branching off from the aorta run to all parts of the body. On the average, they are about a quarter of an inch in diameter. Their walls are thick and elastic. The arteries divide and divide again, until they form extremely minute vessels known as *arterioles*. The arterioles again divide to form the *capillaries*. These latter form a thick network through every tissue of the body. The average capillary is about six ten-thousandths of an inch in diameter. Its walls are composed of cells that are inconceivably thin. Through these walls materials can easily make their way back and forth between the blood and the tissues. For practically every cell in the body, there is a capillary flowing close by. Although a single capillary is likely to be scarcely a thousandth of an inch in length, it has been claimed that all the capillaries of a man's body put end to end would reach two and a half times around the earth.

The capillaries join one another to form *venules*, which correspond in size to the arterioles. These combine to form *veins*, which come together to form the few large vessels that empty into the heart. In general, the veins are slightly larger than the arteries, and their walls are much thinner and less elastic. The blood is forced through them partly by the pressure of blood coming through the capillaries and partly by the squeezing on them of the other tissues, because of movements of the muscles. The veins possess pocket-shaped valves which keep the blood from running backward. (See Fig. 12.)

There is only one exception to the rule that arteries empty into capillaries and capillaries into veins. The capillaries that collect food from the small intestines join to form the *portal vein* which runs to the liver and branches out into another capillary network,

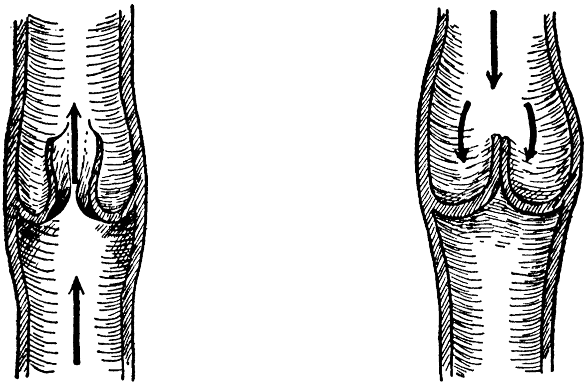


FIG. 12.—Valves of a vein in action.

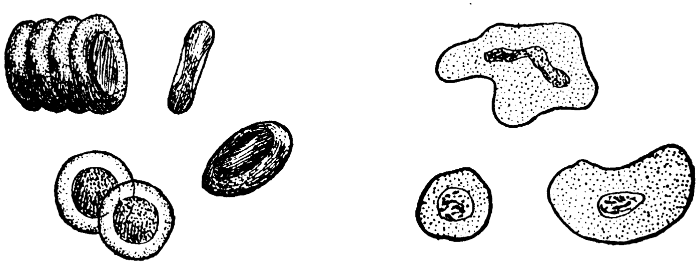
just as an artery might. These capillaries open into minute, cell-lined cavities, known as *sinusoids*. Another set of capillaries takes the blood from the sinusoids and carries it to an ordinary vein which transports it toward the heart.

The Blood.—The blood which flows through these vessels may be described as a rapidly moving tissue. It is made up of cells like any other tissue, but these cells are floating in a liquid—called the blood *plasma*—and are carried through the circulatory system in the swift current of that liquid.

The plasma is composed of water containing proteins held in suspension. It also holds in solution food and waste materials and a variety of chemical substances which play a part in regulating the activities of the body.

The cells of the blood are of two kinds, the *red* corpuscles and the *white* corpuscles. The former are disk-shaped bodies, hollowed in on both faces, so that they are thicker around the edges than in the center. They are very small, about three ten-thousandths of an inch in diameter and eight hundred-thousandths of an inch thick. Strictly speaking, they are not true cells, since they do not contain nuclei, but they are derived from true cells located in the marrow of the bone. Before they leave the bone marrow, they lose their nuclei and become the mere disks that we find in the blood.

When they are looked at under the microscope, these corpuscles appear yellow, but in the mass they give the blood its red appear-



A *B*

FIG. 13.—Blood corpuscles. *A*, red corpuscles; *B*, white corpuscles.

ance. The redness is due to the presence of a substance known as *hemoglobin* which forms a great part of their structure. Hemoglobin is a protein which contains four atoms of iron in each molecule. It is extremely important in the economy of the body, since the iron atom is capable of forming a loose chemical attachment to oxygen. The hemoglobin thus serves to transport oxygen from the lungs to all parts of the body. When it is combined with oxygen the hemoglobin is red; when it loses its oxygen, it is a bluish purple. For this reason the blood in our arteries, which is carrying oxygen to the tissues, is bright red, while that in the veins, which has given up its oxygen to the cells of the body, is blue.

If one turns a microscope upon the web of a frog's foot, one may see the red corpuscles being carried through the capillaries from the arteries to the veins. They are whirled along by the blood current and are sometimes so thickly clumped together that they appear almost to block the narrow capillary channels in which they flow. Indeed, there is an incredible number of them in the blood of as large an animal as a man. Usually blood counts indicate that there is something like 75 billion to a cubic inch, which brings the total amount in the body of a man of average size to about thirty trillion.

Every day about ten per cent of the red blood corpuscles in the body are destroyed, which means that every day three trillion new ones must be produced in the marrow of the bones, where there are cells which multiply at a rapid rate and finally undergo changes which transform them into corpuscles. Naturally, these cells must be provided not only with much protein—which is necessary for the growth of all cells in the body—but also with a considerable quantity of the iron that forms so essential a part of every molecule of hemoglobin. In the course of their breakdown, red blood corpuscles are engulfed by cells in the spleen and liver. Much of their protein and iron is removed by these cells and thus conserved by the body for its use. Nevertheless, some iron is lost, and hence foods containing iron are indispensable in our diet. Spinach, whole wheat foods, eggs, and lean meat are familiar dietary items which are rich in iron. Egg yolks and molasses hold it in especially high concentration.

The so-called white blood corpuscles are really colorless in appearance. They are considerably larger and only one five-hundredth as numerous as the red corpuscles. They are true living cells with nuclei. Indeed, most of them can move about independently by *ameboid movement,* so called because it is the type of movement displayed by a certain one-celled animal known as *Ameba.* In Ameba, the cell continually changes shape as it moves. Small protrusions of protoplasm called *pseudopodia* (false feet) flow outward from the body of the cell; then the body is drawn forward until the pseudopodia become again a part of the general mass; whereupon, another set of pseudopodia are projected, and the process is repeated. Instead of having a special gullet through which food passes to enter the cell, Ameba can project a number of pseudopodia around a food particle until the protoplasm completely surrounds it and it is held in a vacuole inside the cell.

White blood corpuscles look and act very much like the free-living Ameba. Not only do they move independently about in the blood stream itself, but they may squeeze through the capillary walls and wander out among the tissues. Like Ameba, they are capable of engulfing solid particles, which, in the case of the corpuscles, are the bodies of bacteria and the particles that are produced when cells are destroyed. Thus the body is freed from materials which might harm it.

The white corpuscles that engulf bacteria are formed, like the red corpuscles, in the marrow of the bones. Those that engulf cellular materials are the same cells which, in the spleen and liver, take care of the broken-down red corpuscles. They have merely broken loose from their moorings to wander about in the blood stream and tissues. Wherever cell destruction occurs in the body—because of a bruise, burn or some other attack upon the tissues—these cells make their way to the spot. The pus formed in abscesses is made up chiefly of white corpuscles that have crowded about a place where destruction of tissue has occurred.

There are also certain white corpuscles formed in the *lymph nodes* (see below). They are incapable of independent motion and do not engulf particles, but perform the function of manufacturing certain substances which are essential for growth in the cells of the body.

The Clotting of the Blood.—The blood is a liquid which flows, usually under pressure, within a closed system of tubes and chambers, the heart and blood vessels. The slightest break in this system allows this liquid to escape, just as water escapes from a broken pipe. If the escape is not soon prevented the body loses a greater part of its blood, and death ensues immediately, since the cells are deprived of essential materials, notably oxygen. Some method of plugging all leaks in the circulatory system is therefore indispensable. The coagulation or clotting of the blood performs this service. Clotting is brought about by a series of chemical reactions between substances in solution in the blood which result in the synthesis of a solid protein substance, *fibrin*. Fibrin is deposited in the form of a network of fine elastic fibers, which holds the corpuscles within its meshes and thus provides an obstruction through which the blood cannot pass. Clotting does not take place inside the circulatory system because of the absence of a substance, *thrombokinase*, which is needed to start the chemical reactions that yield fibrin. Thrombokinase is found in the tissues outside of the blood vessels and is also released through the disintegration of certain minute particles in the blood called *platelets*. Whenever the blood escapes from the circulatory system and wets some foreign surface, platelets break down, yielding thrombokinase, which, together with that in the tissues, sets going the process of fibrin formation.

It takes about five minutes for the blood to clot sufficiently to stop bleeding in a small wound in which only the capillaries are cut. The blood oozes out rather slowly, and not much is lost during the period that clotting is taking place. When an artery is cut, however, the blood spurts out rapidly with each beat of the heart, so that a clot does not form, and death from bleeding will occur unless the flow of blood through the artery is stopped. This can be accomplished by tying off the artery—as is done in surgical operations—or, as a first-aid measure, by tying a tourniquet around the limb at a point above the place where the artery is cut and twisting it tightly so as to shut off the flow of blood until the wound can be treated surgically. A tourniquet should always be loosened every five or ten minutes to allow some blood to the limb, since otherwise the cells will die for lack of oxygen.

In some diseased conditions, notably in the hereditary disease *hemophilia,* clotting takes place very slowly. If it is extremely slow, the slightest wound may cause death. Sometimes bleeding through the capillary walls occurs without known damage to the capillaries, and a "bleeder" may die in this way without ever receiving a wound. This suggests that the clotting reaction is not merely a device for meeting emergencies, but that it is continually needed to reinforce the very thin walls of the capillaries. Occasionally a clot may form inside a vein or artery as a result of some damage to the walls of the vessel. Then, especially if the clot occurs in a vein, the individual must be kept very quiet, lest pieces of the clot break away and be carried to the capillaries where they may completely shut off the circulation in some important region of the body. A clot in the vein of the leg may cause death when particles of it stop circulation through the capillaries of the lungs.

The Heart.—As nearly everyone knows, our body cavity is divided into two parts by a muscular membrane known as the *diaphragm.* Below the diaphragm, in the abdominal cavity, the stomach, intestines and liver are located. Above it, in the chest cavity, are the lungs and heart. The heart is placed just under the breastbone and just above the diaphragm. It lies about in the mid-line of the body, although most people believe it is on the left side because the lower tip of it, which is the part that beats the hardest, is turned toward the left. (See Fig. 15A.)

The heart is a muscular bag, divided into four chambers. The upper left chamber is called the *left auricle*; the upper right, the *right auricle*; the lower left, the *left ventricle*; and the lower right, the *right ventricle.* There are openings between the auricles and ventricles, but the right and left sides of the heart have no connection with each other. The blood from the veins enters the auricles —that which has come from the lungs, the left auricle; that which has come from the body, the right auricle. The two auricles contract together, pushing the blood into the ventricles. A fraction of a second later, the ventricles contract and push the blood out into the arteries. The right ventricle pumps it into the arteries running to the lungs, the left ventricle into those running to the bodily tissues. There are valves between the auricles and the ventricles which close when the ventricles are contracting so that the blood will not run back into the auricles. There are also valves in the arteries that close while the ventricles are being filled with blood, so that blood will not run back from the arteries into the ventricles. The ventricles have much thicker walls than the auricles, since they have the job of forcing the blood through the arteries, capillaries, and veins and back again to the heart. The walls of the left ventricle are the strongest of all, since it must pump blood throughout the entire body.

The Circuit of the Blood.—Perhaps the best way to understand the action of the heart and its connection with the whole circulatory system is to take an imaginary ride on a red corpuscle as it makes a complete round of the system. Let us climb aboard our corpuscle just as it enters the right auricle. It is, of course, not really red just now, since its hemoglobin has been completely robbed of oxygen by the tissues of the body, and it has taken on a purplish hue.

The auricle has just been contracting, and the blood that was about to enter it has been held up for a moment, but now the

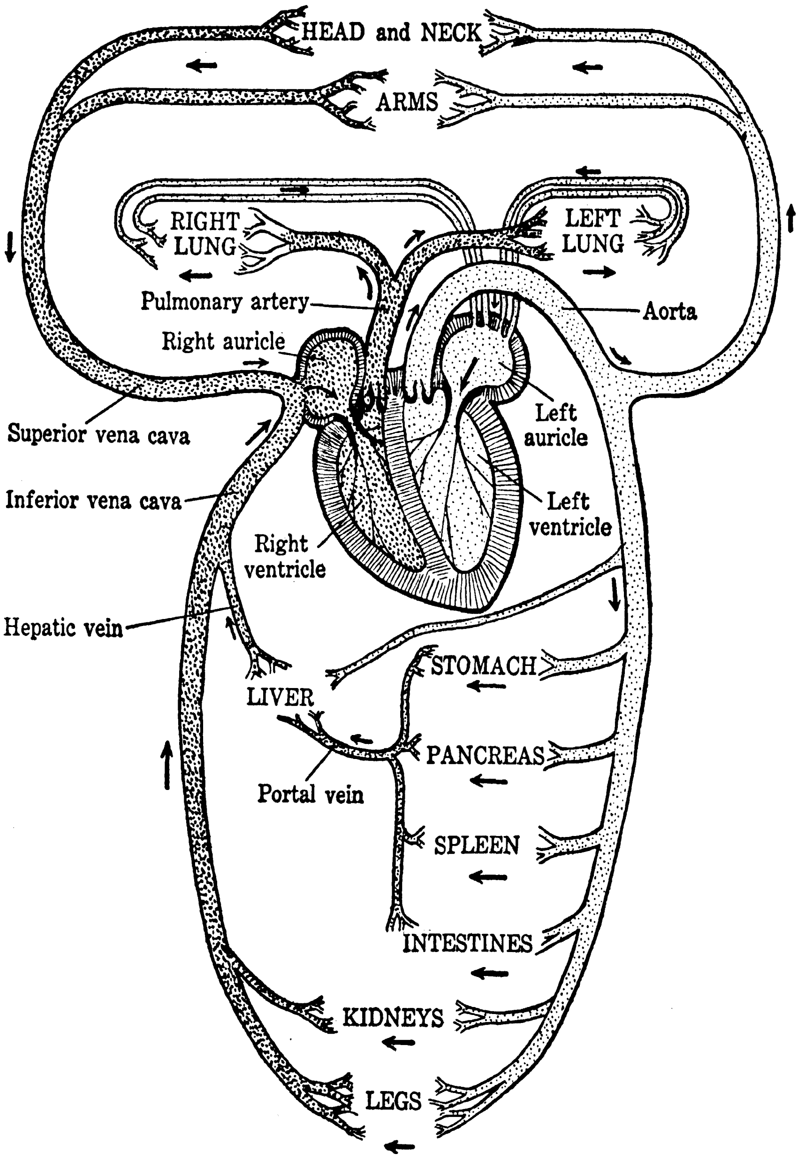


FIG. 14.—Diagram of the circulatory system. Light dots, oxygenated blood; dark dots, deoxygenated blood.

auricle relaxes; its muscular walls are no longer squeezing in on the auricular chamber; the chamber increases in size and allows the blood containing our little corpuscle to enter. About a half a second passes, and then, suddenly, the auricle contracts. The blood is driven through the opening into the right ventricle.

It has hardly time to enter before the walls of the ventricle give it a terrific squeeze. A set of three valve flaps located at the opening between the ventricle and auricle snaps shut, thus keeping the blood from going back into the auricle. Its only course out of the ventricle is through the artery which leads to the lungs. Our blue little red corpuscle rushes out with millions of its fellows. It comes to a place where the artery branches and is whirled along down one of the two possible paths. There is another branch, another, and another. The pathway is becoming somewhat narrow; the blood is moving more slowly. Presently the corpuscle is crowding through a minute capillary, located close to the inner surface of the lungs. So small is the passageway that the corpuscles cannot pass two abreast. Now the oxygen of the lungs is combining with the hemoglobin of the corpuscle, which begins to lose its bluish tinge and take on the crimson hue from which the corpuscle derives its name. The capillary through which it is passing joins with another capillary. The corpuscle makes its way into a tiny vein. The vein combines with another to form a larger one. Combination after combination takes place until our little red corpuscle comes to the place where one of the veins from the lungs empties into the left auricle of the heart. From the auricle, it is pumped into the ventricle. The muscular walls of the ventricle close down with even greater vigor than did those of the right lower chamber. The blood is driven into the largest artery of the body, the great aorta. The aorta leaves the heart in an upward direction, but it soon bends over and takes it course downward through the body cavity. Our little corpuscle, swept along by the rapid stream of the blood in the aorta, passes one artery after another branching off toward the various parts of the body. First there are the arteries which lead to the muscles of the heart itself, then those branching to the head and arms. Lower down there are branches which go to the digestive organs.

Let us suppose that our corpuscle continues down the aorta, into a large artery that passes down the leg, and finally into a capillary meshwork in one of the muscles of the foot. Here, as it slowly struggles through the narrow channels, its oxygen leaves it and diffuses through the thin capillary walls into the muscle cells, and, having again assumed a bluish purple tinge, it makes its way into one of the veins of the leg. In the veins, its progress is considerably slower than it was in the arteries, but the pocket valves keep it from backing up whenever the pressure becomes too slight to force it forward. So, having no chance to retreat, our corpuscle pursues a steady course up the leg, into the body cavity, and finally into the large vein known as the *inferior vena cava,* which takes it back to our starting place, the right auricle of the heart.

The flow of blood from the right ventricle through the lungs and back to the right auricle is called the *pulmonary circulation,* and the flow from the left ventricle through the body generally and back to the right auricle is the *systemic circulation.* Blood in the pulmonary arteries is blue and in the pulmonary veins, red; while in the systemic circulation it is red in the arteries and blue in the veins.

Rate of Blood Flow.—The average length of time spent by a corpuscle in making a complete trip around the circulatory system is probably about fifty seconds. The journey which we have just outlined would take a little longer, since our corpuscle went all the way to the foot and back. At any rate, the blood is driven through the body with a surprising rapidity, and it consequently serves as an efficient transportation system for bringing things to the cells of the body and taking other things away.

The total amount of blood that flows through each part of the system must always be the same, since otherwise the blood would pile up in the regions of slowest total flow. Hence it must move more rapidly through the arteries than through the veins because the artery channels are narrower. It flows most slowly in the capillaries, since, although a single capillary offers a very narrow passageway, the total width of all the capillaries if they were laid side by side is much greater than that of the arteries and veins laid side by side.

Blood Pressure.—When any liquid flows through a pipe, the highest pressure is at the point where it starts, and the pressure falls the longer the distance traveled. In the circulatory system, blood pressure is highest at the point where the blood leaves the ventricles, and lowest at the point where it enters the auricles. The force which decreases the pressure is the friction offered by the walls of the vessels through which it passes. This friction is greatest in the walls of the arterioles, capillaries, and venules because these passageways are so narrow, and hence the pressure drops most rapidly between the small arteries and small veins.

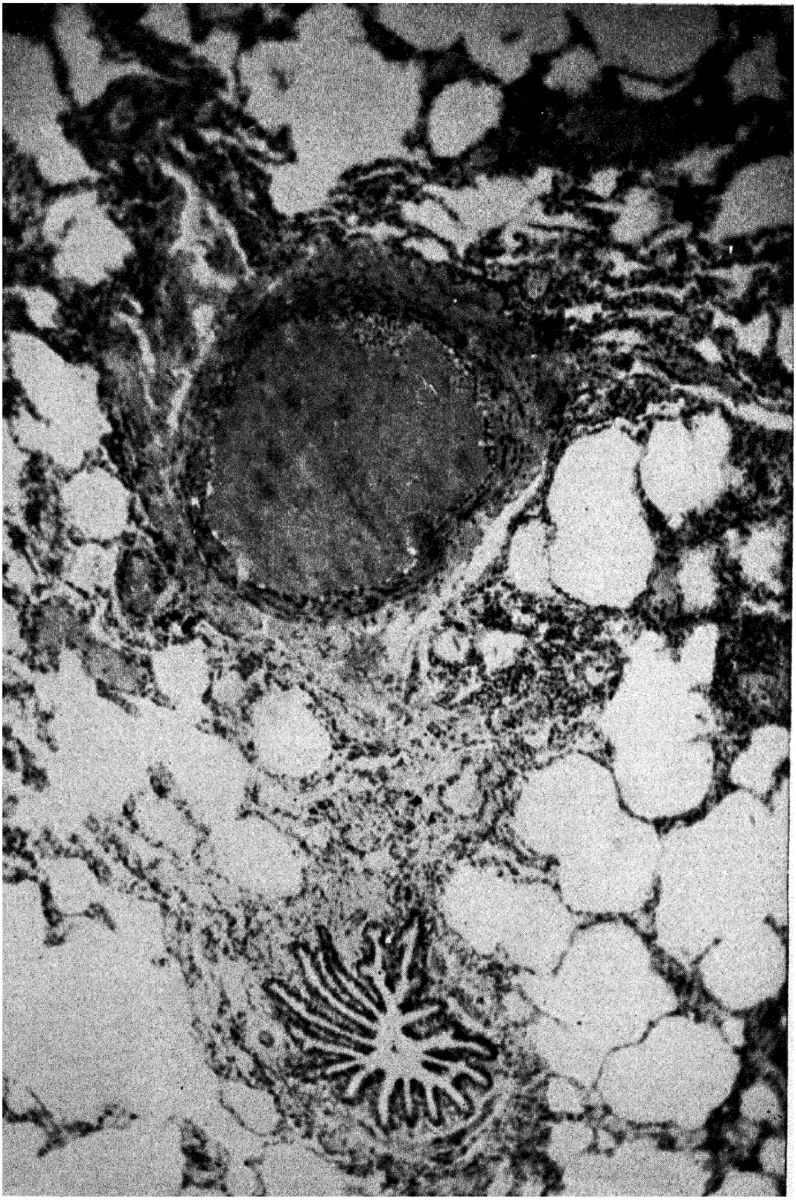
Since blood is pumped intermittently from the heart into the arteries, the pressure in the arteries rises and falls with each beat of the heart; and because of their elasticity the arterial walls give way to the waves of blood that are sent out with the closing of the ventricles, so that wherever an artery comes close to the surface of the body we can feel it pulsating with each heart beat. However, the elasticity of the walls tends to "smooth out" the pulse, since the walls behind each wave of the pulse continue to squeeze upon the blood even after the wave has passed by, so that by the time the blood reaches the capillaries, the pulse has entirely disappeared and the blood flows at a slow, even pace which is determined by the amount of pressure the elastic arterial walls exert upon it.

When the heart beats strongly and rapidly, it forces more blood into the arteries and stretches the walls farther, thus increasing their elastic pressure, just as the pull of the rubber band becomes greater, the more it is stretched. In this way, the pressure on the blood going through the capillaries is increased, causing it to flow more rapidly through them, and much more blood passes through the body in a given time than when the pressure is lower.

Whenever our muscles are active, the rate of metabolism in their cells increases enormously, and the blood must carry more substances to and from them than when we are resting. The body immediately reacts to the situation by an increase in blood pressure, which speeds up the circuit of the blood. This increase is brought about in two ways: The heart beats more rapidly and forces more blood into the arteries with each beat, and at the same time the arterioles in the inner parts of the body contract, so that there is less room for the blood to flow through these parts; hence a larger amount of blood is forced into the arteries running to the muscles of the limbs and trunk, and their elastic walls squeeze the blood through the muscle capillaries at a rapid pace

The Lymph System.—The pressure of the blood against the walls of the capillaries causes a considerable amount of the water which forms the base of the plasma to seep through these thin walls and to become a part of the tissue fluid. This surplus liquid in the tissue fluid must be drained away in some manner. It is, in fact, collected into a system of minute vessels known as the *lymph capillaries* which come together to form larger vessels, the *lymph ducts*. The lymph ducts finally combine to form two large vessels, one on the right side of the neck and the other on the left, which empty into the veins not far from the place where they enter the right auricle of the heart. The lymph ducts, like the veins, are provided with valves that keep the liquid from backing up; hence it is slowly pushed through them by the movements of the body, especially those of breathing. At the points where the vessels empty into the veins, the blood pressure is so low that the lymph is easily forced into the circulatory system.

The lymph system is an auxiliary to the circulatory system, but not a real part of it. Rather, it is a one-way drainage system. Its capillaries are believed to open at their ends. At any rate, various solid particles—important among them, the bacteria which have been attacking the tissues—make their way into it. While these solid particles are microscopic in size, they are still too large to make their way through the walls of the blood capillaries, and the body would rapidly become clogged with them if the lymph system did not carry them away. Scattered along the courses of the lymph vessels are bunches of tissue called *lymph nodes* or, sometimes, lymph glands. Here the lymph is forced through layers of cells which take up and destroy solid substances, so that these substances become filtered out of the lymph before it makes its way into the blood. The lymph nodes do much to keep disease from spreading from one part of the body to other parts. Occasionally, when they are overworked, they swell and become hard. Nearly everyone has experienced at one time or another these little kernels or lumps appearing in the neck, armpit, or groin—the places where lymph nodes are found in greatest abundance. The tonsils and "adenoids," which surgeons have to remove so frequently from the throats of small children, are composed of the same sort of tissue as the lymph nodes. They are useful in filtering out bacteria and other substances that



Human lung. Microphotograph showing alveoli (the open spaces), bronchiole (the roughly star-shaped object toward the bottom), and a blood vessel (the large, round object in the upper center).

so easily get into the tissues of this region; but, once diseased themselves, they act as a source of infection, rather than a protection against it. Occasionally lymph nodes in the neck or other regions become diseased and badly swollen and have to be removed.

Respiration

The Respiratory System.—One of the most important functions of the circulatory system is to help bring oxygen to the cells of the body and to take carbon dioxide away. In the one-celled Paramecium, the process of external respiration involves merely the diffusion of oxygen into and of carbon dioxide out of the cell, together with the oxidative chemical reactions. In the human body, the same sort of respiratory process goes on for each cell; but, in addition, oxygen and carbon dioxide must be brought to and from the cell from the air outside the body, and this must be done at a fairly rapid rate, since the cells are packed so closely together and their metabolism goes on more rapidly that it does in the cells of the lower organisms. The respiratory system functions to bring air containing much oxygen and a little carbon dioxide into sufficiently close contact with the blood that the latter may take up oxygen from the air and transport it to the tissues while it gives off the carbon dioxide which it has brought from the tissues. This system is composed of the lungs, plus the passages running from them to the exterior. Its parts are shown in Fig. 15.

The air we breathe, after it is taken into the nose or mouth, passes through the *larynx*, or voice box, and down the *trachea*, otherwise known as the windpipe. A little less than halfway down the chest cavity, the trachea divides into two branches, called *bronchi*, one going to the left and the other to the right lung. The bronchi proceed to divide again and again into smaller and smaller bronchi, until the air is making its way through tubules that are scarcely a hundredth of an inch in diameter. Each of these tubules, known as *bronchioles*, widens at its end to form a group of air sacs, and the outer edges of each air sac are folded into minute cup-shaped cavities, known as *alveoli*. A few alveoli are also found in the sides of the bronchioles themselves. The arrangement at the end of the bronchiole is shown in Fig. 15 B.

The alveoli are crowded closely together in the lungs, and just outside each alveolus is a thick network of blood capillaries. The walls of the alveoli are nearly as thin as the capillary walls; and consequently it is very easy for oxygen of the air to make its way through such thin membranes into the blood, and also for the molecules of carbon dioxide to leave the blood and get into the air that fills each alveolus. The blood which comes into the lungs from the heart has given up a great deal of its oxygen to

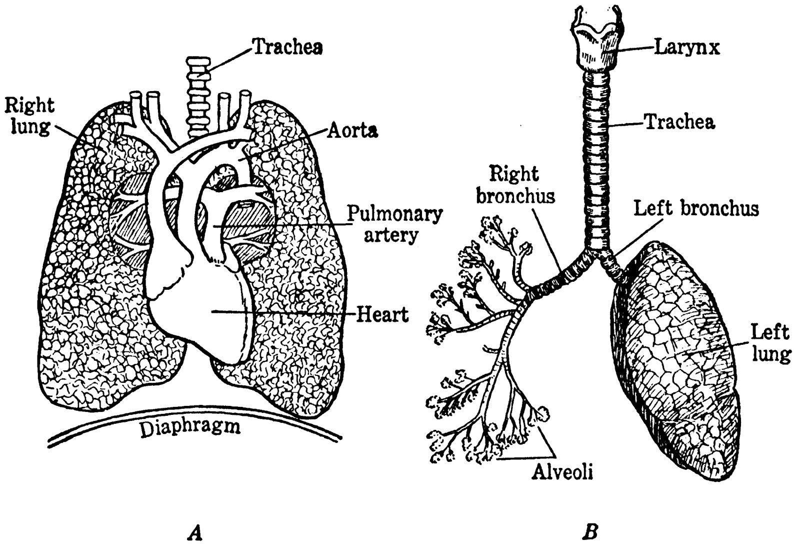


FIG. 15.—Diagram of respiratory system. *A*, heart and lungs; *B*, front view of lungs and air passages.

the body tissues. There is a sort of "oxygen vacuum" in this blood, and the oxygen in the alveoli rushes in to fill this vacuum.

The fact that oxygen makes a loose chemical union with hemoglobin enables the blood to carry much larger amounts of it than would be possible if it simply dissolved in the blood plasma. The body could not possibly maintain itself on the oxygen that might be brought to the cells in the latter manner. Nearly everyone knows of the danger involved in running a motor car in a closed garage. The carbon monoxide gas which escapes from the exhaust has the property of combining with the hemoglobin in such a way as to take the place of oxygen. The oxygen cannot be transported to the tissues, and the body is asphyxiated as surely as it would be if the windpipe were stopped and breathing shut off completely.

When the blood, rich in oxygen, leaves the lungs, it travels back to the heart, where it is pumped out through the aorta and is carried to every part of the vast network of capillaries which branches throughout all the tissues of the body. Every cell in these tissues is continually using up oxygen; and to make up the shortage thus produced, the oxygen in the blood leaves the hemoglobin and diffuses through the capillary walls into the tissue fluid and thence into the cells themselves.

The burning of food substances in the body cells not only consumes oxygen but produces carbon dioxide, which, becoming thus concentrated in the tissue fluid, diffuses rapidly into the blood. Here a series of chemical reactions enables it to be carried in high concentration in the blood just as oxygen is. Upon reaching the lungs, the carbon dioxide diffuses into the air in the alveoli, since its concentration is lower in the alveoli than it is in the blood.

The exchange that takes place in the lungs is indicated by the difference between the ratios of gases in the air which we inhale and in that which we exhale. Water vapor and certain other gases being disregarded, the air that we breathe in is about 79 per cent nitrogen, 20.96 per cent oxygen, and .04 per cent carbon dioxide. That which we breathe out is 79 per cent nitrogen, 16.6 per cent oxygen, and 4.4 per cent carbon dioxide.

How We Breathe.—The lungs are located in two air-tight cavities, separated from each other by a region in the middle of the chest which contains the heart, certain large blood vessels, and various other structures. Each of the lungs is encased in an elastic membrane, the *visceral pleura*, which encloses it on all sides like a bag, except at a point on the inner side where the bronchus, blood vessels, and nerves enter. Since a lung itself is a closed system of tubes and sacs, open only at the point where the bronchus enters the trachea, the whole arrangement is like a very large, thin sack (the lung) crumpled up and stuffed inside a smaller sack (the visceral pleura).

At the point where the bronchus enters each lung, the pleura folds backwards and continues around on the outside, lining the chest wall, the diaphragm, and the region between the lungs.

This outer layer is called the *parietal pleura.* It lies immediately over the visceral pleura, and their surfaces are in contact so that they rub back and forth over each other with each breath that is taken. Inflammation of these surfaces is the cause of that very uncomfortable disease, pleurisy, in which pain is experienced with each breath that is taken into the body.

Since there is no air in the space between the two pleura, the elastic lungs are forced to expand by the pressure of the outside air, and the two pleural membranes are pressed closely together. Any air getting inside either of the lung cavities would cause the lungs to collapse. In cases of tuberculosis, the chest wall is sometimes punctured and one of the lung cavities filled with nitrogen gas. The lung collapses and is put entirely out of commission; thus it receives a complete rest which often puts an end to the progress of the disease. Then the gas is drawn out and the opening in the chest wall closed, so that the lung is forced to expand and fill the cavity, whereupon the other lung may be collapsed and allowed to heal.

Since the vacuum between the lungs and the wall of the chest cavity allows the air outside to force the lungs tight against the wall, any expansion of the chest cavity will result in the entrance of more air into the lungs. Inhalation and exhalation of air are brought about by increasing or decreasing the size of the chest cavity. When we inhale, our rib muscles contract, causing the ribs to rise and spread outward, thus increasing the diameter of the chest cavity from front to back and side to side. At the same time the diaphragm, which arches up in a sort of dome over the stomach, liver, and other abdominal organs, is contracted and flattens out, increasing the depth of the chest cavity and pressing on the organs beneath it, thus causing the abdominal wall to bulge outward. In ordinary quiet breathing, we exhale simply by a relaxation of the muscles of inspiration, allowing the ribs and diaphragm to return to their normal position; but when we breathe hard or blow, it is possible to force air out of the lungs by contraction of the muscles of the abdomen. Singers are taught to breathe by drawing down the diaphragm as far as possible, since filling the lungs in this fashion allows the abdominal muscles to control the rate at which air is expired. Athletes also learn this trick of "belly breathing," for it enables them to exhale more rapidly and thus to move air in and out of their lungs at a faster rate.

Movement of Substances

Filtration.—It should now be evident that the chief problem the body encounters in its task of maintaining the life of its cells is that of moving substances in and out and from one part of the body to another. This problem faces all organisms, plant and animal, small and large. In general, these movements are of two sorts, movements through passageways and movements through the tissues. The former are illustrated by the flow of the blood and the substances which it carries through the circulatory system and the flow of air through the respiratory passages. In animals, these movements are usually brought about through muscular contractions, as in breathing or the beating of the heart, although other means may be employed. The movement of liquids and gases through passageways is always from a region of high to one of low pressure. Not only is this true of circulation, but also of respiration, for it is the difference between the air pressure inside and outside of the lungs that produces movements of air in both directions. If the pressure inside a passageway is higher than that outside, and if its walls are thin, the materials being moved may be squeezed through the walls. Such a movement is called *filtration*. It occurs in the circulatory system, where the pressure coming from heart and arteries forces part of the water in the blood out through the walls of the capillaries.

Diffusion and Dialysis.—The passage of substances through the tissues of the body is brought about chiefly by the general phenomenon of *diffusion*, which involves simply the movement of molecules in a gaseous mixture or liquid solution from regions of high concentration to regions where the concentration of the substance being moved is low. For instance, if an odorous gas of some sort is released in one corner of a room, the odor will gradually permeate the entire room as the molecules of the gas move from the corner where they are in high concentration to all other parts. Eventually, provided the weight of the gas is about equal to that of the atmospheric gases, the odor will be as strong in one part of the room as another, since diffusion will continue until the concentration is equalized in all parts of the space provided.

The reason is that the molecules of a gas move about freely and very rapidly in all directions, striking against and bounding off one another like a set of billiard balls on a table; thus they gradually wander away from any region of concentration and become evenly distributed. Molecules in water solution (as well as the dissociated particles of molecules, called ions) also move about in this free manner and hence tend to distribute themselves evenly throughout the solution. For instance, if you drop a pinch of salt into a cup of water, it will sink to the bottom, and the water at the top will have no taste of salt about it. But if you leave it in the water for some time, the salt will dissolve and its ions will diffuse throughout the cup, so that the water at the top will be as salty as that at the bottom.

The substances which the cells of the body consume and produce during the course of metabolism are usually moved to and from the cells by being held in solution in water and by diffusing toward the cells as these substances are metabolically consumed or away from them as they are produced. Thus carbon dioxide is continually diffusing into the blood in the capillaries of the systemic circulation, since its concentration in the tissues is continually increased by metabolic activity, while oxygen diffuses out of the blood, since its concentration in the tissues is continually being decreased.

In both these instances, the diffusing substances must cross membranes, namely, the capillary walls. At the same time there are substances which are in different concentration on either side of the capillary walls and which do not diffuse through the walls because they cannot pass through them. The walls are *semipermeable*, allowing certain substances to go through and holding others back. The diffusion of substances through semipermeable membranes is called *dialysis*. Usually substances in true solution can pass through a dialyzing membrane, whereas substances in colloidal suspension cannot, because the submicroscopic openings in the membrane are not large enough to allow colloidal particles to pass through them. Thus, the protein substances which are held in colloidal suspension in the blood are kept from passing into the tissues, while oxygen, food material, and various other substances dissolved in the blood pass out freely. The fat-like membranes which surround the individual cells of the body will allow fat-soluble substances to pass through them much more readily than substances which are not soluble in fats. By means of this *selective permeability* of dialyzing membranes, only those substances which the cells can use are allowed to reach them or enter them, and useless or harmful substances are kept out.

How Movements Are Facilitated.—There are many ingenious devices whereby the movement of substances through the body is caused to go on more rapidly than if the simple process of diffusion were allowed to operate alone. The transport of oxygen by the hemoglobin of the blood is a case in point. Oxygen first enters the body by becoming dissolved in the water of the blood plasma. Oxygen dissolved in water is the sole source of supply for plants and animals that live under water; indeed, oxygen dissolved in the tissue fluid is the sole direct source of it for the individual cells of the body. But the oxygen that could be carried in solution in the plasma would not be nearly enough to furnish the body with all that it needs. Blood leaving the lungs carries with it the equivalent of about twenty parts by volume of gaseous oxygen to every one hundred parts of blood, while the amount carried in solution is only one part in two hundred. The rest is carried in chemical combination with the hemoglobin. The amount of hemoglobin that will combine with oxygen depends upon the concentration of oxygen in solution in the blood. In the lungs, so much oxygen passes into solution in the blood that nearly all the hemoglobin combines with oxygen. In the tissues, the oxygen in solution diffuses rapidly out of the blood, so that only about half as much remains dissolved in the plasma. A great deal of oxygen immediately leaves its chemical association with the hemoglobin and is also available for diffusion into the tissues, and the hemoglobin returning to the lungs contains considerably less oxygen than that which leaves them. Thus, with only a small variation in the total amount of oxygen carried in solution, there is a considerable variation in the total amount carried by the hemoglobin.

Obviously, the reaction between the hemoglobin and the oxygen in solution must go on very rapidly because the blood remains only a second or two in the capillaries where all the chemical action must be accomplished. Naturally, it can take place most readily where the hemoglobin and the plasma come into direct contact, namely, at the surfaces of the red corpuscles. The amount of surface available for the reaction would not be nearly as great if it were not for the minute size of the corpuscles, since the smaller any body is, the larger is its surface in proportion to its volume. Thus, a cube with a volume of a thousand cubic inches has a surface of six hundred square inches, whereas a cube one-inch in volume has six square inches of surface. In the frog, where metabolism is not nearly as rapid as in a warm-blooded animal like man, the red corpuscles are considerably larger than ours because the hemoglobin-oxygen reaction does not need to go on as rapidly as it does in our blood stream.

Dialysis of substances through membranes is frequently speeded up considerably by providing small structures with large membrane surfaces. The small size of most living cells is probably in part accounted for by the fact that if sufficient amounts of material are to diffuse into and out of them, there must be a large surface in proportion to their total volume. Hence, all large organisms are multicellular. The air sacs of the lungs, with their cup-like alveoli, provide a large surface for the movement of oxygen and carbon dioxide relative to the total volume of air in the lungs. When filled to capacity, the lungs hold about two cubic feet of air; the total surface of the alveoli is about two thousand square feet. The small size of the capillaries in both the lungs and the tissues again offers a tremendously large surface for dialysis in proportion to the volume of the blood.

Osmosis.—Since water is continually being filtered out of the blood because of the blood pressure on the capillary walls, and since there is no pressure in the tissues to force it back in, it would seem that before long the blood would be so completely robbed of its water that the pressure would fall to zero. Indeed, that is what would happen if it were not for the fact that the blood proteins do not pass out with the water. The result is that in the blood where the capillaries join the venules, the proteins held in suspension are in high concentration. Conversely, the water in this blood is in relatively low concentration—lower than its concentration in the tissues outside. Consequently the water diffuses back through the capillary walls wherever the blood pressure is so low that filtration does not take place. This passage of water from a solution of low concentration (with a consequent high concentration of water) through a membrane to a solution of high concentration (low concentration of water) is called *osmosis.* Obviously, it is simply another case of diffusion, with the exception that in this case it is the water itself and not the substances in solution that diffuses. It takes place when on one side of a membrane there is a concentrated solution or suspension of a substance that will not pass through the membrane. It is possible to demonstrate osmosis by half-filling a membranous bag with water holding some substance, such as egg white, in solution and placing the bag in a pan of pure water. If the substance in solution is unable to pass through the membrane, and the water does pass through it, the bag will gradually fill with water until it is tightly distended. Indeed, the pressure inside may become so great that the bag breaks. The pressure exerted when water passes through a membrane into a solution of a substance which cannot pass in the opposite direction is called *osmotic* pressure. It is the osmotic pressure of the water entering the circulatory system from the tissues that counterbalances the pressure which causes it to filter out and maintains blood pressure at approximately the same level over long periods of time. Osmotic pressures of this sort play a part in countless vital processes. By osmosis water is supplied to all our cells and tissues; and by the proper balancing of osmotic pressures, the proper amounts of water are allocated to each cell and tissue.

These balances must be maintained at all times. For instance, after severe bleeding and in some disease conditions, it is necessary to supply water to the blood by injecting it into the veins. When this is done, the water must contain salts in solution in concentration equivalent to that in the blood plasma, for otherwise the water rushes into the corpuscles and the osmotic pressure becomes so high that they burst. On the other hand, cells placed in water where the concentration of solutes is greater than that of the water in the cells will lose their water and shrivel up. In short, a living cell requires a water environment that is balanced with the water in the cell.

Chapter Summary

Each cell of the human body lives in an artificial liquid environment, called the tissue fluid, from which oxygen and foods make their way into the cell and into which carbon dioxide and waste materials make their way in their passage from the body. The chief function of the circulatory system is to provide rapid transport for these substances to and from the tissues.

Blood is pumped through the circulatory system by the heart, a muscular bag divided into four chambers, the right and left auricles and the right and left ventricles. The blood leaves the heart through the thick-walled elastic arteries, which branch until they form minute arterioles; these branch further to form the microscopic capillaries that are thickly distributed through every tissue of the body. The capillaries join to form venules, which unite to form the thin-walled veins that carry the blood back to the heart. The blood leaves the heart under high pressure, and passes in slowly dying pulsations through the arteries to the capillaries, through which it flows smoothly without a pulse. The pressure gradually decreases as the blood flows through the system until it reaches its lowest point where the veins enter the heart. When the muscles are active, blood pressure is increased so that the blood can carry the oxygen more rapidly to the active cells.

The circulatory system is composed of two blood vessel circuits. The first runs from the left ventricle of the heart through the arteries to the capillaries in all regions of the body, and back along the veins to the right auricle. The second runs from the right ventricle along the pulmonary arteries to the capillaries of the lungs and through the pulmonary veins to the left auricle. Passing through the first circuit, the blood gives up oxygen to the tissues and receives carbon dioxide. In the second circuit, it gives up carbon dioxide to the air in the lungs and receives oxygen.

The basis of the blood is a liquid, the plasma, in which float the red blood corpuscles, which transport oxygen by means of its chemical union with the hemoglobin which they contain, and ameba-like white blood corpuscles, which engulf the bodies of bacteria and other waste solids. Clotting of the blood, which is essential to keep the organism from bleeding to death, is effected by the formation of a network of fibrin in the plasma. Thrombokinase, which is present in the tissues and is also released by the platelets in the blood whenever bleeding starts, initiates the series of chemical reactions that results in the formation of fibrin.

The lymph system is a one-way drainage system of capillaries and ducts which removes solid wastes and bacteria from the tissues, passing them through lymph nodes, where they are absorbed and rendered harmless, and finally emptying into the blood stream in the region of the neck.

The plan of the respiratory system is as follows: The trachea, or windpipe, runs from the throat to a point halfway down the chest cavity, where it divides into two bronchi, one going to the right lung and the other to the left lung. The bronchi branch profusely in the lungs until they form millions of tiny passageways, called bronchioles. At the ends of the bronchioles are air chambers, the walls of which are creased so as to form smaller chambers called alveoli. Each alveolus is surrounded by a capillary network, so that exchanges of carbon dioxide for oxygen can take place over a large surface area. When the walls of the chest are raised and the diaphragm is pulled down, air is sucked into the lungs. A contrary set of movements pushes it out.

Substances are transported through the body by movements through passageways or through tissues. Movement through the latter is effected by the following processes:

Filtration, the forcing of liquids through membranes by mechanical pressure. Blood pressure, for instance, forces water through the capillary walls and into the tissues.

Diffusion, the movement of molecules or ions in a gas or in solution from a region of high concentration to one of low concentration.

Dialysis, the diffusion of substances in solution through a semipermeable membrane.

Osmosis, the diffusion of water through a semipermeable membrane from a region where it holds substances in dilute solution to one where it holds them in concentrated solution.

When substances are transported on surfaces or through membranes, movement is facilitated if the structures involved are very small, so that their surfaces are large in proportion to their volumes.

QUESTIONS

1. In what sort of an environment do the cells of the body live?
2. Describe the circulatory system and tell how the blood flows through it.
3. Describe the blood.
4. Where is thrombokinase found, and why is it so important to human life?
5. Why is there no pulse in the capillaries?
6. Describe the lymph system, and discuss its importance.
7. Describe the structure and functioning of the respiratory system.
8. What is the importance of the vacuum that exists between the visceral and parietal pleurae?
9. Define each of the following and give an instance of its occurrence in the body: filtration, diffusion, dialysis, osmosis.
10. What is the significance of the small size of each of the following: the red blood corpuscles, the capillaries, the alveoli? Explain.

GLOSSARY

alveolus (al-vē'o-lus) pl. alveoli (al-vē'o-lī) A very minute air chamber in the lungs.

Ameba (a-mē'ba) A protozoan which moves about by means of pseudopodia.

ameboid movement Movement by means of pseudopodia.

aorta (ā-or'ta) Large artery which carries blood from the left ventricle on its way to all parts of the body except the lungs.

arteriole (ar-tēr'i-ōl) A very small artery.

auricle (ô'ri-k'l) One of the upper chambers of the heart.

bronchus (bron'kus) pl. bronchi (bron'kī) One of the branching passageways for air in the lungs.

bronchiole (bron'ki-ōl) One of the very small passageways for air in the lungs.

dialysis (dī-al'i-sis) Diffusion of a substance through a semipermeable membrane, leaving behind substances that cannot diffuse through the membrane.

diaphragm (dī'a-fram) A muscular membrane which separates the chest cavity from the abdominal cavity, the movements of which help to force air in and out of the lungs.

diffusion Movement of gases or substances in solution from regions of high concentration to regions of low concentration.

fibrin (fī'brin) A solid protein, the formation of which brings about the clotting of the blood.

filtration Movement of a liquid through a membrane as a result of mechanical pressure.

hemoglobin (hē'mo-glō'bin) A protein pigment which is the chief constituent of the red blood corpuscles and which serves to transport oxygen.

hemophilia (hē'mō-fil'i-a) An hereditary disease characterized by the failure of the blood to clot.

larynx (lăr'inks) The voice box, located at the point where the trachea enters the throat.

osmosis (os-mō'sis) Passage of water or other solvent through a semi-permeable membrane from a region of low concentration of substances in solution to a region of high concentration of solutes.

osmotic pressure (os-mot'ic) Pressure produced by osmosis.

parietal pleura (pa-rī'e-tal plū'ra) The outer of the two membranes which line the lungs.

plasma (plaz'ma) The liquid portion of the blood.

platelets Small, solid structures in the blood which disintegrate and release thrombokinase when the blood wets a surface outside the blood vessels.

portal vein The vein passing from the intestines to the liver.

pseudopodia (sū'dō-pō'di-a) Temporary protrusions of protoplasm employed by Ameba in locomotion.

sinusoid (sī'nus-oid) One of the minute cavities in the liver into which blood from the portal vein flows.

thrombokinase (throm'bō-kī'nās) A substance which initiates a series of chemical reactions resulting in the formation of fibrin.

trachea (trā'kē-a) The windpipe.

ventricle (ven'tri-k'l) One of the lower chambers of the heart.

venule (ven'ūl) A very small vein.

visceral pleura (vis'er-al plū'ra) The inner of the two membranes which line the lungs.

CHAPTER IV

DIGESTION, ASSIMILATION AND EXCRETION IN THE HUMAN BODY

DIGESTION

Outline of the Digestive System.—Digestion in man is essentially the same process that it is in Paramecium, the breaking down of the large molecules of food substances so that they become small enough to pass through membranes and enter the protoplasm. But while in Paramecium digested food enters directly into the protoplasm from the simple food vacuole, in man a complex digestive system is provided, whence the food enters the blood stream to be taken to various parts of the body, where it may be used in the cells immediately or, quite as frequently, stored for use at a later time.

The digestive system is composed of a twisting, irregular tube, the *alimentary canal,* and a number of glands which pour digestive secretions into it. (See Fig. 16.) The structures of the alimentary canal, in the order in which food passes through them, are as follows: the *mouth*; the *throat*; the *esophagus,* a thin tube extending from the throat to the stomach; the *stomach,* a pear-shaped bag in which the food is held for some time after being swallowed; the *small intestine,* a narrow, coiled tube, about an inch or two in diameter and some twenty feet in length; the *large intestine,* a somewhat wider tube, about five feet long and shaped like an inverted U; the *rectum,* in which the feces, or waste materials left after the passage of food through the alimentary canal, are held until they are expelled through the opening to the exterior, known as the *anus.*

The walls of the esophagus, stomach, small intestine, large intestine and rectum are composed of sheaths of muscular and connective tissues, with epithelial linings inside and out. The contractions of the muscles serve to push the food through the

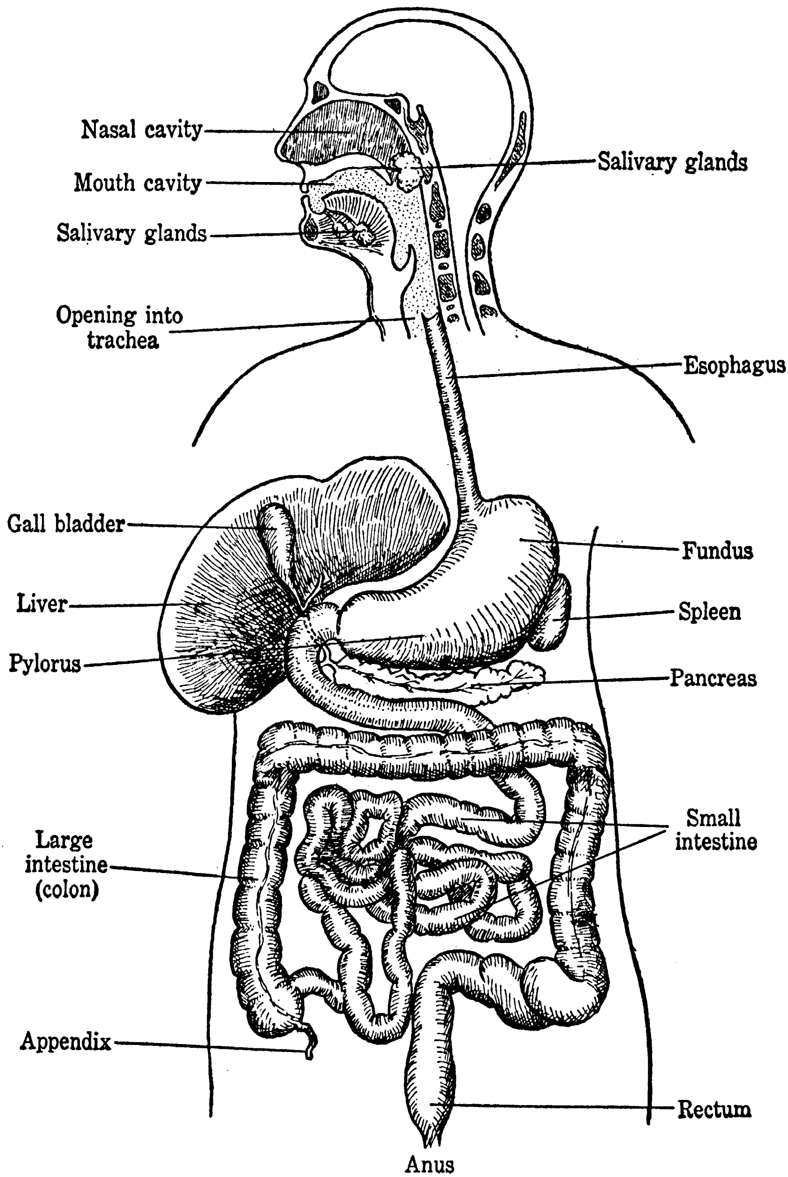


FIG. 16.—The human digestive tract.

digestive tract and to churn it about, breaking it up and thoroughly mixing it with the digestive secretions.

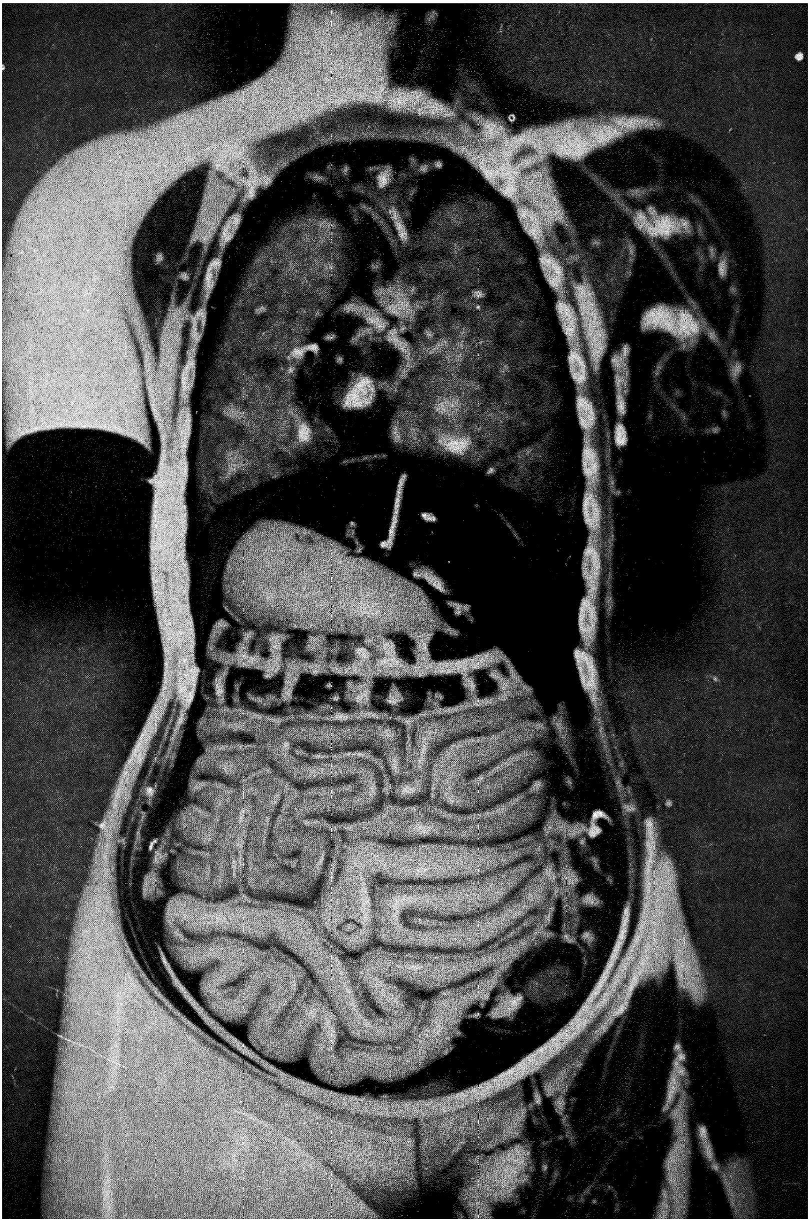
The glands which produce the digestive juices are: the *salivary* glands, which empty into the mouth; the *gastric* glands, located in the walls of the stomach; the *liver*, located somewhat to the right, just below the diaphragm and above the stomach, the digestive function of which is to secrete bile into the small intestine; the *pancreas*, a long, thin gland lying just below the stomach, also emptying into the small intestine; finally, small glands which line the walls of the small intestine and secrete their *intestinal juice* into that organ.

The juices secreted by these digestive glands are watery fluids containing a variety of substances in solution or suspension. All of them, except the bile of the liver, contain enzymes, which, as we have already said, are substances that bring about the chemical reactions of digestion.

The Process of Digestion.—Upon entering the mouth, food is usually broken up through mastication and more or less thoroughly mixed with the saliva. This juice is produced by three pairs of glands: the *parotid*, located at the corners of the jaws just under the lobe of each ear; the *submaxillary*, just under each jaw bone; and the *sublingual*, on each side of the floor of the mouth. They empty into the mouth through small tubes, or *ducts*, coming from the cheek in the case of the parotids and from just under the tongue in the case of the submaxillaries and sublinguals. The parotid gland is the one that becomes swollen and sore when we have mumps.

These glands secrete slowly most of the time, thus keeping the mouth moist; but when food enters, their secretion becomes more copious, and, mixing with the food, lubricates it so that it is easily swallowed. The chief enzyme contained in saliva is *ptyalin*, which acts to break starches down into a double sugar. Bread turns sweet if held in the mouth for a short time, because the starch which it contains is converted into sugar.

After mastication, the food is swallowed by an upward movement of the tongue, which pushes it back into the throat. Immediately muscles in the throat contract in such a way as to shut off the openings into the nose and trachea and at the same time push the food down into the esophagus. The muscles of the walls of



Model of the human body cavity, mirror image.

the esophagus contract just behind the food, making a ring-like constriction of the passageway. This ring of constriction moves forward, forcing the food along the tube into the stomach. Such forward-moving waves of constriction in the alimentary canal are called *peristaltic waves*, and they occur in the stomach and intestines as well as in the esophagus. At the point where the food enters the stomach there is a thick ring of muscle, called the *cardiac sphincter.* Normally it is contracted so tightly that nothing can pass through it; but as food coming down the esophagus makes contact with it, it relaxes, allowing the food to pass through, whereupon it immediately contracts so that the food cannot pass backward from the stomach into the esophagus. Occasionally this sphincter does not contract as tightly as it

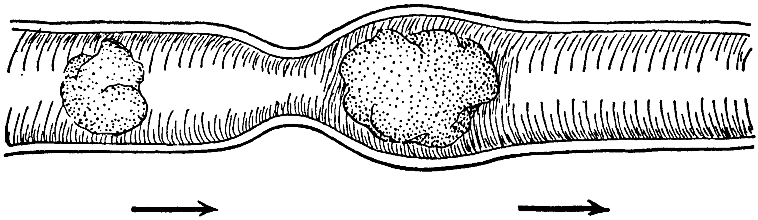


FIG. 17.—A peristaltic wave.

should, and then some of the acid contents of the stomach make their way back into the esophagus, causing the unpleasant sensation known as "heartburn."

The stomach is composed of two parts: a wide, rounded portion, called the *fundus*, on the left side of the body from the cardiac sphincter; and a narrower, tapering section to the right, the *pylorus*, at the end of which is the *pyloric sphincter.* This sphincter does not contract tightly enough to hold back the liquid portions of a meal, but it does keep back the solids until they have been mixed with the gastric juice. When they have been pretty well liquefied, it allows them to pass into the stomach a little bit at a time, so that a meal does not entirely leave the stomach until two to six hours after being eaten.

The gastric juice contains three important substances: *pepsin,* an enzyme which begins the digestion of proteins by breaking them down into less complex substances called *proteoses* and *peptones; rennin,* another enzyme which curdles milk and thus gets it ready for the pepsin to act upon it; and *hydrochloric acid.* This last element of the gastric juice is as important as the enzymes; for, although it has no action whatsoever on the foods, it makes the mixture of food and juices acid, and pepsin can act upon proteins only in an acid medium. The gastric juice that is secreted into the fundus contains very little acid; consequently protein digestion does not take place in the food that is held there, but rather there is a continuation of the digestion of starch by the saliva that has been swallowed. The walls of the fundus exert a steady pressure on the food, forcing it into the pylorus as the latter is slowly emptied through the occasional relaxation of the pyloric sphincter. In the pylorus, however, there is a continual succession of peristaltic waves moving from the region of the cardiac sphincter to the pyloric sphincter about once every three seconds. Since each wave takes approximately ten seconds to move from one end of the pylorus to the other, there are usually three or four waves following one another at any moment. By putting some substance that is opaque to X-rays in the food, it is possible to take moving pictures of these waves. When the pyloric sphincter is closed, the peristaltic waves cannot force the food out of the stomach. Rather, they churn it up, mixing it with the gastric juice and producing a semi-liquid mass of food and juice called *chyme.* From ten minutes to half an hour after the food has been eaten, the sphincter relaxes for a moment, and a small portion of the chyme is squirted into the small intestine. It is immediately replaced in the pylorus by more solid food forced in from the fundus; and from then on the sphincter relaxes at frequent intervals, allowing small amounts of food to enter the intestine, until the stomach is empty.

Although we ordinarily associate the stomach more than any other organ with the process of digestion, it really plays only a minor rôle in the actual chemical breakdown of foods. To be sure, the gastric juice initiates the digestion of proteins, just as saliva initiates the digestion of starches; but both mouth and stomach digestion mark only the very beginnings of the process and, indeed, may be dispensed with entirely. There are many people whose gastric juice contains almost no hydrochloric acid, so that the action of pepsin is practically eliminated, yet they seem to digest their meals as readily as normal individuals. The real function of the stomach is to hold the food in storage so that a whole meal is not immediately forced into the intestine and at the same time to reduce its solidity, converting it into a mass of small solid particles held in a liquid and thus exposed to the action of the enzymes in the small intestine.

The first juices with which the food comes into contact in the small intestine are the pancreatic juice and the bile of the liver, which enter through a common duct a short distance below the pyloric sphincter. The bile is formed by the cells of the liver and stored in a small sac, the gall bladder, which is located on the lower surface of the liver. When chyme enters the intestine, the gall bladder contracts and the cells of the liver begin to secrete more rapidly. At the same time the pancreas pours its juice into the intestine. Both these juices are alkaline and neutralize the acid from the stomach. The bile contains no enzymes, but its salts mix with the fats in such a way as to make them much more susceptible to *lipase*, the pancreatic enzyme which splits the fats into two absorbable types of compounds, *fatty acids* and *glycerol.* The pancreas also provides one or more enzymes which carry on protein digestion where the pepsin of the stomach has left off. These enzymes reduce some of the proteins to *amino acids,* the ultimate protein constituents that are absorbed into the blood stream. Finally, the pancreatic juice contains an enzyme known as *diastase,* which continues the action of the ptyalin, breaking starches down into double sugars.

There is still some digestive action to occur. Certain proteins are not completely reduced to amino acids by the pancreatic enzymes, and their digestion is left to the action of enzymes found in the intestinal juice. Furthermore, the double sugars must become single sugars before the carbohydrates can be absorbed into the body, and this is accomplished by three different enzymes of the intestinal juice which act upon three different kinds of double sugars.

The movements of the small intestine are of two kinds: peristaltic waves, which occur from time to time and move for a short distance along the tract, carrying the chyme with them; and somewhat similar contractions which, however, do not move along. These latter serve to mix the food with the digestive secretions and also to bring all parts of it into contact with the walls of the intestine, through which the digested food is absorbed into the blood.

Digestion and absorption of food are completed in the small intestine, except for the residue which is still very watery as it passes into the large intestine. The mass now passes slowly through the large intestine, where most of the water from it is absorbed; and finally the waste materials, or feces, are passed into the rectum, where they are held until they are finally expelled through the anus.

A brief outline of this rather complex process of digestion will help the reader to picture it as a whole. The entire process may be divided into two aspects: the *chemical aspect,* that is, the actual breakdown of the food substances by the action of enzymes; and the *mechanical aspect,* the fragmentation and liquefaction of the food to prepare it for efficient enzyme action, and the mixing of the food with the enzymes. Digestion takes place in three parts of the alimentary canal: the mouth, the stomach, and the small intestine. We may therefore outline it as follows:

Digestion in the Mouth:

Chemical: Beginning of carbohydrate digestion by the ptyalin of the saliva.

Mechanical: Fragmentation of the food through mastication, mixture with the liquid saliva.

Digestion in the Stomach:

Chemical: Continuation of the action of ptyalin in the fundus. Beginning of protein digestion in the pylorus by the pepsin and rennin of the gastric juice.

Mechanical: Liquefaction of food and mixture with juices through peristaltic movements of the pylorus.

Digestion in the Small Intestine:

Chemical: Continuation of carbohydrate digestion by action of pancreatic diastase. Completion of carbohydrate digestion by the sugar-reducing enzymes of the intestinal juice. Completion of protein digestion by the enzymes of the pancreatic juice and another enzyme in the intestinal juice. Digestion of fats by the lipase of the pancreatic juice with the help of the bile salts.

Mechanical: Mixture of digestive juices with chyme by stationary ring-like contractions of the small intestine.

Many people are curious to know the length of time it takes to digest food. This problem can be studied indirectly by putting some substance in the food that is opaque to X-rays and then taking X-ray pictures of the meal as it passes through the digestive tract. Knowing that the process of digestion is completed before the food gets into the large intestine, we can judge just about how long it takes. The meal does not go through in a lump, but parts of it make their way far in advance of others. Some portions leave the stomach within a few minutes after they are swallowed, and there is a continuous exodus of small bits of the meal out of the stomach on their way through the small intestine. At the end of six hours, most of the meal will have entered the large intestine, yet small parts of it will be strung out through the small intestine, and some may still remain in the stomach. At the end of twelve hours, the entire meal is usually completely digested.

Assimilation

The Absorption and Use of Foods.—The wall of the small intestine is not smooth, but thrown into a multitude of folds or

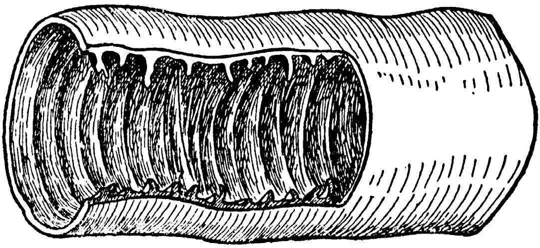


Fig. 18.—Small intestine, showing the folding of the inner wall.

ridges which run around it transversely, as shown in Fig. 18. More important still, the surface of the mucous membrane lining the small intestine is completely covered by closely packed little projections which stand up on it like the pile on velvet. They are much smaller than this, however, being about a fortieth of an inch in length and quite slender in proportion. When they are examined under the microscope, each one is found to contain a network of blood capillaries and a second network of lymph capillaries. (See Fig. 19.) Digested food is absorbed into these minute blood and lymph channels. Here we have another example of small structures affording a large surface for the passage of materials across a membrane. The total surface afforded for the absorption of foods in the intestine is many times greater than that which would be present if the lining was entirely smooth.

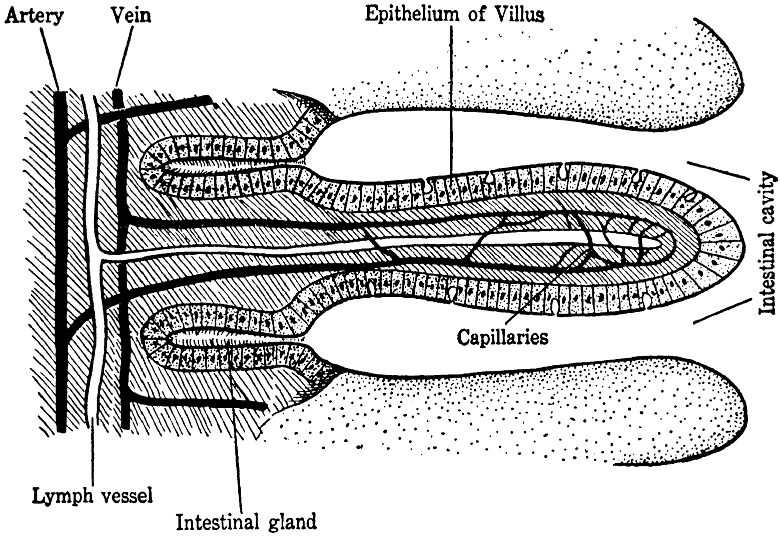


FIG. 19.—Structure of a villus. (After Hardy.)

The single sugars in the intestines make their way through the thin walls of the villi and into the capillaries. Hence they are carried into the portal vein, and through it to the capillaries of the liver. After a meal rich in carbohydrates, the concentration of sugar in the portal vein is quite high; but the blood which leaves the liver to go to the heart has only a trace of sugar in it, since all the surplus has been removed and stored as *glycogen* in certain special storage cells of the liver. Glycogen is a form of starch that is peculiar to animal bodies. The liver regularly holds a considerable amount of it as a reserve supply of carbohydrate for the body. As the tissues use up sugar and its concentration in the blood becomes lower, the glycogen in the liver is turned into sugar and sent back into the blood. By this means the concentration of blood sugar is kept almost constant, no matter if several hours have passed since the last meal was eaten. Glycogen is stored in the muscle cells, ready to be used for fuel whenever our muscles are active.

Sometimes carbohydrates are taken into the body in such excess that they cannot all be burned or stored as glycogen. In this case two things may happen. First some of the surplus sugar may make its way out of the blood and into the kidneys to be excreted in the urine. Second, some of the carbohydrates may be converted by certain cells of the body into fat and stored in that form. Well-fed people store a great deal of food in this way; consequently, individuals who are trying to reduce must avoid not only fats, but starches and sweets as well.

The products of the digestion of fats, glycerol and fatty acids, are first absorbed into the epithelial cells which form the outer linings of the villi. Here, within these cells, they are immediately recombined to form fats. But while the fats in our food are not of the type found in the human body (almost every species has its own particular kinds of fats), those now formed are of the human type. These recombined fats make their way from the lining cells of the villi into the lymph capillaries and are carried through the lymph system to the veins in the neck and emptied into the blood stream. They float about in the blood in the form of extremely small, insoluble globules until they pass through the liver, where they are combined with phosphoric acid to form a compound known as *lecithin.* Lecithin is soluble, and hence can make its way out of the blood stream and into the cells of the body. Very small quantities of it may be used in the construction of the fat-like parts of protoplasm. Most of it is either oxidized to yield energy or else stored as fat. Fat storage takes place in certain specialized connective tissue cells located just below the skin or around such internal organs as the intestines, kidneys, and heart. When not enough fuels are eaten to serve the energy requirements of the body, these fats leave the storage tissues, are reconverted to lecithin, and carried through the blood to the active cells.

Protein materials are absorbed into the blood capillaries of the villi in the form of amino acids. These substances are then carried to the cells of the body, where they may be recombined into proteins to become part of the protoplasmic cell structure in growth or to replace structures that have been worn away. There are about twenty kinds of amino acids, but they can be put together in different combinations to form millions of different proteins. Each kind of cell manufactures its own special brands of proteins. The proteins found in vegetable foods contain fewer of the amino acids used to build up the structures of the human body than those found in such animal foods as meat, eggs, milk, butter, and cheese; hence, an adequate quantity of the latter types of food is desirable in any diet.

The average American diet contains four or five times as much protein as is necessary to replenish worn-out cell structure. The surplus is used for fuel. As the amino acids pass through the liver, a chemical reaction takes place which splits them into sugar-like substances and ammonia. The ammonia is rapidly transformed into urea, which is excreted, and the sugar-like substances are oxidized in the cells. In some way, the consumption of excess protein causes an increase in the rate of oxidative metabolism in the body. This results in the formation of heat. It is a well-known fact that more meat is eaten in winter than in summer, for people unconsciously increase their protein consumption as a protection against cold. Good reducing diets contain little fat and carbohydrate in proportion to protein. The protein raises the rate of metabolism and thus causes the individual to oxidize the fat that has been stored in the connective tissues of his body.

Metabolic Rates.—Every living cell in the body must oxidize food substances at a slow rate if it is to maintain life at all. In addition, even if we rest completely, some energy must go into breathing, digesting food, the pumping of the heart, and similar activities. The total amount of energy that must be expended merely to keep the body alive is approximately 1,900 Calories per day.[1] This is called the rate of *basal metabolism*. Whenever we move about, however, considerable additional energy is con-

[1] A Calorie is a standard unit of energy, the amount necessary to raise one kilogram (2.2 pounds) of water one degree Centigrade (1.8 degrees Fahrenheit).

sumed by the muscles. In a rowing race of about six minutes' duration, an oarsman will consume about thirty Calories per minute, which is seventeen or eighteen times the rate of basal metabolism. But this rate can be maintained only by a trained athlete over a brief period of time. The average metabolic rate for people in sedentary or semi-sedentary occupations who take just enough exercise to maintain health is 2,500 Calories, only 600 Calories above the basal rate. For manual laborers, the rate runs from 3,500 to 5,000 Calories per day.

The greater part of all this energy is wasted as far as doing any work is concerned, because it is transformed into heat. As anyone knows who has had the slightest acquaintance with engines, every mechanism which transforms potential energy into the energy of movement loses much of that energy in the form of heat, and the human body is no exception. But the heat liberated in our bodies is not entirely wasted. An automobile engine runs most efficiently when some of the heat which it generates has warmed it up. And, similarly, metabolism goes on best at a certain temperature; in fact, at just about the temperature that is constantly maintained in the human body by the heat produced in metabolic activity, namely, 98.6 degrees Fahrenheit.

Other Food Substances.—The proteins, carbohydrates, and fats are the "big three" of the food substances and are the only sources of food energy. But many other substances appear in our foods. First there are the *condiments*, such as the spices, which have no food value at all and merely serve to improve the palatability of foods. Then there are the *drugs*—caffeine, alcohol, and the like—which are taken partly for their taste and partly for the effect they have on the nervous system. A certain portion of any alcohol that is imbibed, however, is transformed into sugar and serves as a carbohydrate food. In America, without a doubt, most alcohol is taken for narcotic purposes; but in many European countries it is essentially a staple food product, being taken regularly at meals in rather small quantities. Another important element in our food is *roughage*, the indigestible portion of the material that gives it bulk, enabling it to pass through the intestines readily, thus preventing constipation. Most of this roughage is cellulose, the indigestible carbohydrate which forms the cell walls of plants. Finally, there are three groups of substances taken in with our food that are absolutely essential to the metabolism of the body. They are *water*, *salts*, and *vitamins*.

The Rôle of Water in the Human Body.—Water may be looked upon as the basis of life. It is the matrix in which the business of living is carried on. Life might be defined as the activity of proteins, fat-like substances, and mineral salts in colloidal solution in water. Water is not only the chief constituent of protoplasm, but it forms the major part of the blood and tissue fluids which are so important in transporting substances to the cells.

The daily bodily intake of water is very large. In addition to that which we drink, we secure a great deal from our food, the major portion of which is water. Such vegetables as lettuce and cabbage, for example, are approximately 90 per cent water. Furthermore, the oxidation of sugar results in the production of considerable water within the body.

This great intake is necessary to balance the loss of water through the lungs, sweat glands and kidneys. And thus water serves a further purpose, for the daily stream passing through our bodies washes along with it a great variety of impurities and useless substances.

Mineral Salts.—The mineral salts of the body include the chlorides, sulphates, nitrates, carbonates and phosphates of potassium, sodium, ammonium, calcium, magnesium and iron. Salts cooperate with the proteins in carrying on their activities. They may be looked upon as the regulators of the activity of protoplasm. The rate and nature of this activity depend upon the balance of concentration of the various salts. They are also important in keeping a proper chemical balance in the blood stream and other parts of the body, and they enter into many vitally important chemical reactions.

Salts are found in small quantities in nearly all foods, but especially in meats, dairy products, and leafy vegetables. The only salt that needs to be added to a normal diet is ordinary table salt, sodium chloride. Most vegetarian animals require some special source for this salt, since plants are deficient in it relative to the amount needed by animals. Grazing animals will travel for miles to get to a "salt lick" where they can secure some of this necessary substance. Human beings, however, usually eat much more than is needed for metabolic purposes, and most of it passes out of the body through the kidneys. With us it is essentially a condiment.

Vitamins.—Vitamins are substances that exist in small quantities in our food and that are essential for normal and healthy metabolic reactions. When there is a marked lack of one or more vitamins in the diet, certain *deficiency diseases* appear. Less marked vitamin deficiencies retard growth and reduce health and vigor.

The idea of vitamins as essential elements in metabolism was advanced in 1912. Since then, great progress has been made in discovering various types of vitamins, determining their concentration in foods, working out their chemical composition, and even manufacturing them by methods of chemical synthesis. It is uncertain how many vitamins there are, since new ones are still being discovered. Furthermore, there are instances in which several chemically different vitamin substances have been found which have the same general effects on metabolism, although each may show slight differences in its effects. These are classed as different *vitamers* of the same vitamin.

In short, vitamin study is becoming highly complicated. To simplify it, only the vitamins whose known effects on human beings are of considerable importance will be described here. These can be divided into two groups: the *fat-soluble* vitamins, A, D, and K, and the *water-soluble* vitamins, including certain B-complex vitamins and vitamin C.

Vitamin A is found in all kinds of animal fats except lard, being most concentrated in halibut liver oil. The best sources of it in normal diets are liver, eggs, cream, butter, and fortified oleomargarine. There are also substances in green and yellow vegetables which are changed into vitamin A in the animal body. Hence, such vegetables are good sources for the vitamin.

A disease called *xerophthalmia,* which in its extreme form results in practically complete destruction of the eyes, appears when vitamin A is almost totally lacking in the diet. Less extreme vitamin A deficiencies cause slow growth in children and produce "night blindness" in adults. The latter condition makes driving at night difficult, since the eyes are readily blinded by the glare of headlights on approaching cars.

In xerophthalmia, there is a very high susceptibility to contagious diseases; hence, vitamin A has been termed an anti-infective vitamin. Many people take it in cod liver oil or halibut liver oil to avoid colds. Actually there is little evidence that taking more vitamin A than is provided in regular diets is at all effective in preventing colds or other infections.

Vitamin D has been called the "sunshine vitamin" because it is formed in fatty substances that are irradiated by certain ultraviolet rays in the sunlight. It is not found in great quantity in any of the ordinary foods, and unless intentional provision is made for it in the diet, more vitamin D is secured by irradiation of the fat beneath the skin than from food. But in cloudy northern climates the sun is an undependable source; hence the best way of securing a good supply of this vitamin is to take regular doses of it in capsules or fish liver oils.

Vitamin D regulates the amount of calcium and phosphates in the blood. In young children, lack of it results in the formation of soft bones which are easily deformed. The disease so produced is called rickets; it is very prevalent in northerly, cloudy regions. There is much evidence also that decay of the teeth results, at least in part, from lack of vitamin D during the period of early growth. It is important, therefore, that expectant and nursing mothers and all infants and growing children should take vitamin D in some of its concentrated forms.

Nothing is known about the requirements of vitamin D for adults, but it is generally assumed that an adequate supply will make the body function better because of its regulation of the mineral balance in the blood.

Vitamin D is the only vitamin that is occasionally taken in such great quantity that it causes illness. A very concentrated form, known as ergosterol, is usually responsible for overdoses. To be on the safe side, ergosterol should not be taken except under a doctor's direction.

Vitamin K is interesting in that human beings do not need it in their diet because it is synthesized by bacteria which inhabit the human intestine. There it is dissolved in the fats of the food and enters the body through the intestinal villi.

When this vitamin is absent, the blood will not coagulate. In cases of obstructive jaundice, where stoppage of the bile duct prevents bile from entering the intestine, fats are not absorbed and the vitamin K formed by the intestinal bacteria fails to enter the blood. Before operation to remove the obstruction, the vitamin must be administered to prevent death from bleeding.

Vitamin K is sometimes absent in newborn children and must be provided to prevent fatal bleeding.

The vitamin B complex is a group of vitamins, of which about a dozen are now known, which are usually found together, although not always in the same proportions in each food. The best known are thiamine (B_1), riboflavin (B_2), and niacin.

Good sources of the B complex are milk, fresh fruits and vegetables, and the parts of wheat and rice that are removed in milling.

Oriental populations in which the great dietary staple is polished rice are especially prone to the disease called beriberi, which is characterized by pain and general weakness. This disease can be cured by feeding the husks of the rice that are removed in polishing and also by administration of pure thiamine.

Beriberi is by no means unknown in this country; indeed, although the American diet usually contains enough of this vitamin to ward off this disease, it is believed that thiamine is more likely to be lacking than any other vitamin. Increased thiamine feeding has been found to stimulate growth in children, improve appetite and relieve digestive disturbances, eliminate aches and pains, reduce irritability, and increase energy. Irritable, "run-down" people, however, should not be led to expect that thiamine is a sure cure for their disabilities.

Marked deficiency in riboflavin results in a disease called cheilosis, characterized by cracking of the skin at the angles of the mouth and other abnormalities of the epithelial tissues. Riboflavin is usually deficient also in pellagra, although the most outstanding deficiency in that disease is niacin. Heavy feeding of niacin can relieve pellagra, but for permanent cures the patient must have an adequate amount of riboflavin and probably other B vitamins in the diet.

Pellagra is a very severe disease that often results in insanity. It occurs frequently in our southern states among the poor who depend largely on corn for their nutrition. Corn seems to be lacking in the B vitamins which prevent pellagra. Delirium tremens is essentially a form of pellagrous insanity brought about by the fact that chronic alcoholics eat so little that they fail to obtain a sufficient supply of the B complex.

Vitamin C is found most abundantly in citrus fruits. Tomatoes, potatoes, cabbage, and various other fruits and vegetables are good sources. There is little vitamin C in cow's milk, and hence bottle-fed babies must be given it in the form of orange or tomato juice.

Lack of vitamin C produces scurvy, characterized by weakness, pain, and a readiness to bleed, especially in the gums. This disease was once very common in Europe but disappeared with the introduction of the potato in the European diet. It continued to ravage the crews of ships on long voyages until it was discovered that lemon or other citrus juices would prevent it.

Some authorities believe that mild lack of vitamin C is fairly widespread among people today and that it results in lowered resistance to infection. As with vitamin A, however, taking large doses of vitamin C will not raise resistance to infection above normal.

There is still considerable controversy as to whether the normal American diet does or does not contain sufficient vitamins. A few years ago many authorities felt that there was no need for vitamins above the amount required to prevent beriberi, scurvy, rickets, and other deficiency diseases, and some still hold to this point of view. But so many sound scientists who have carried on vitamin research are convinced that ordinary diets do not contain enough vitamins to maintain full health and vigor that wisdom would seem to lie in the direction of overdoing the matter of adding vitamins to the diet, rather than underdoing it.

There are three ways of attempting to guarantee a sufficient vitamin intake. The first is for the housewife to make a careful study of the vitamin content of foods and of ways of preparing them so as not to lose vitamins in cooking and storage, and then for members of the family to consent to eat plenty of whole wheat bread, milk, butter, eggs, leafy vegetables, and fruits. This is undoubtedly the ideal method, and individuals who are wise about their diets will do their best to change their eating habits and methods of food preparation so as to improve their vitamin intake. But such a program is difficult enough among the well-to-do, conscientious, and educated members of the population. Most people lack the money, time, and self-control.

The second method of supplying vitamins is to "fortify" or "enrich" the foods that nearly everyone eats with synthetic vitamins or vitamin concentrates. Much progress has already been made in this direction. It is reported that, as a result of enriching part of the bread sold in New York City with thiamine, riboflavin, and niacin, the incidence of beriberi and pellagra has been reduced to one-fourth and one-third of what it had been in New York City hospitals. Such enriched bread does not contain the whole vitamin B complex and is doubtless inferior to whole wheat bread, but it is certainly better than ordinary white bread.

Programs of food enrichment and fortification constitute the most practical method of getting vitamins into the diets of the general public.

Recently methods have been developed of producing a yeast that can be mixed with cereals and other types of food to give them a very high vitamin B-complex content along with considerable valuable protein. Here is a promise, at least, of a fairly easy and inexpensive way of making certain that the ordinary diet contains the vitamin B complex.

A third means of obtaining vitamins are the pills and capsules sold in drugstores. There is much controversy over the advisability of buying vitamins in this form. No one doubts the value of vitamin D concentrates for children; but other drugstore vitamins are objected to because they are over-advertised, because they are too expensive, and because it is claimed that they cause people to feel less responsible about securing a good natural vitamin diet. Actually they are not too expensive for many people and they probably include the vitamins that are most important to human health. Furthermore, it has been reported that giving synthetic vitamins to factory employees results in a greater interest in natural diets that are good from the standpoint of protein and salt as well as vitamin content. Thus, all three methods of increasing vitamin intake are of use, although the latter two should be viewed as supplementary to, rather than a substitute for the first.

Excretion

The Excretory System.—There are four avenues whereby substances leave the body: the lungs, the sweat glands, the rectum and anus, and the urinary system. The substances which leave are chiefly of two kinds: first, the *products of katabolism*, the carbon dioxide and water formed by oxidation, and the products formed from the wearing away of the protein structure of the cell; second, the *food remnants*, substances which we take in with our food, but which leave the body without ever entering into the metabolic activities of the cells. Among the latter are the undigested materials in the feces, which never even enter the blood stream; the urea that is formed in the liver when ammonia is removed from the amino acids to prepare them for use as fuel; and, finally, the greater part of the water which passes through the body.

The reader is already familiar with the activities of the lungs. It need only be added that, besides carbon dioxide, a considerable amount of water vapor diffuses out of the blood capillaries into the alveoli and is carried out of the body with each exhalation.

The sweat glands, located in the skin, carry on an excretory activity that is accessory to that of the kidneys. The substances which they excrete are much the same as those which leave the body in the urine, but they are in more dilute solution. The excretory function of the sweat glands is not very important. Their real function is that of cooling the body when it becomes overheated.

The feces, which leave the body by way of the rectum and anus, are not composed merely of undigested food substances. They also contain, in slight concentration, various products of cell breakdown which diffuse from the blood into the intestine. An astonishingly large part of the feces, almost a full third, are composed of the dead bodies of bacteria which live in the intestinal tract. They also contain materials from the digestive juices. Important among the latter are the bile pigments formed from the breakdown of red corpuscles. It is these pigments which give the feces their characteristic brownish color.

The most important organs of the urinary system are the *kidneys*, which are bean-shaped structures situated just back of the abdominal cavity, one on either side of the backbone and slightly below the region of the stomach. From the inner side of each kidney, a tube, known as a *ureter*, carries the urine formed in the kidney to the *bladder*, a small muscular bag at the base of the abdomen. This holds the urine until enough has collected to be passed out through the *urethra,* the tube that carries the urine to the exterior. (See Fig. 20.)

When cut in half, the kidneys are seen to be solid bodies with a small hollow portion near the point where the ureter enters them. The solid part is filled with microscopic tubules which open into the

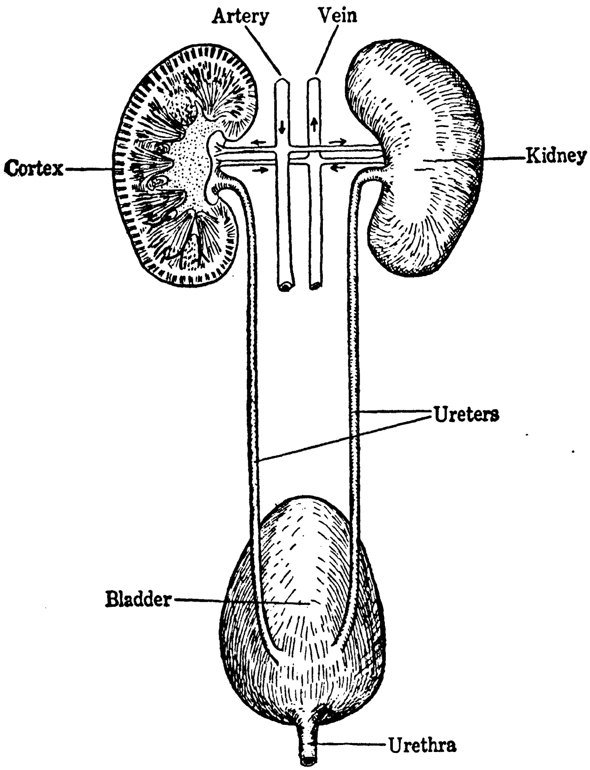


FIG. 20.—Diagram of urinary system, posterior view.

hollow portion and from these openings run up into the outer cortex of the kidney, branching as they go. Each tubule ends in the cortex in a little pouch or cup which holds inside it a tangled ball of capillaries. The blood enters the kidneys under considerable pressure, and some of the water and other substances in it filter through into the tubules at their cup-like ends. Then the blood passes on to another network of capillaries that surrounds the tubule. As the solution of substances from the blood trickles down through each tubule, the cells in the walls of the tubules remove much of the water and other substances which are not excreted and return them to the blood. Thus, a concentrated solution of excretory products, known as urine, is produced in the kidney. This solution passes through the ureters and into the bladder. There is a sphincter muscle at the opening into the urethra which holds the urine in the bladder until it becomes distended. When urination takes place, this muscle relaxes and allows the urine to pass through the urethra.

The substances other than water that are carried out in the urine are as follows:

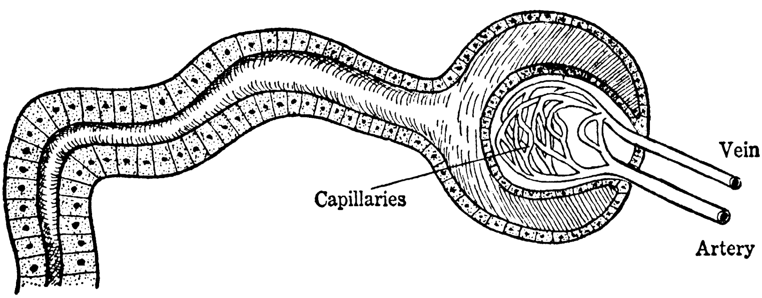


FIG. 21.—Diagram of the end of a kidney tubule.

1. *Urea.* This is chiefly derived from the breakdown of amino acids for fuel purposes, but a small amount may also be produced in cell metabolism.

2. *Products of breakdown of proteins in cells.*

3. *Salts.* When more of a certain salt is eaten than the body can use, the salt is excreted in the urine. Ordinary table salt (sodium chloride) is eliminated in this fashion.

4. *Excess sugar.* Sometimes there is so much sugar in the blood that it cannot all be stored in the form of glycogen. All but a certain percentage of it is then eliminated through the kidneys.

5. *Useless food components.* Alcohol, caffeine, and the like are absorbed into the blood from the intestine and, since they are not used by the body, must be eliminated through the kidneys.

CHAPTER SUMMARY

Our food is digested and absorbed while passing through the alimentary canal, which is composed of the following parts in the order in which the food passes through them: mouth, throat, stomach, small intestine, large intestine, rectum, and anus. In the mouth, the food is broken into particles by chewing and is mixed with saliva from the salivary glands. The saliva contains an enzyme, ptyalin, which starts the digestion of carbohydrates by breaking them down into single sugars. The food is swallowed and carried down the esophagus to the stomach, where it enters the rounded fundus at the left end of the stomach and is passed on into the narrow, tapering pylorus at the right. It is kept from entering the intestine by the contraction of the pyloric sphincter, and is mixed with the gastric juice and reduced to a semi-liquid mass, known as chyme, by the churning of peristaltic movements in the pylorus. Peristaltic movements are ring-like contractions which move down the alimentary canal, pushing the food ahead of them. They occur in the esophagus and the small and large intestines as well as in the stomach. The gastric juice, secreted by small glands located in the walls of the stomach, contains the enzyme rennin, which curdles milk, and another enzyme, pepsin, which reduces proteins to proteoses and peptones.

The chyme passes through the pyloric sphincter a little at a time into the small intestine, where it comes in contact with the bile from the liver, the pancreatic juice from the pancreas, which is a large gland situated under the stomach, and the intestinal juice from small glands located in the wall of the small intestine. The salts of the bile make the fats ready to be split into fatty acids and glycerol by the action of the pancreatic enzyme, lipase. Certain pancreatic enzymes reduce proteins, proteoses, and peptones to amino acids, and an enzyme in the intestinal juice completes the digestion of other proteins not acted upon by the trypsin. The pancreatic diastase completes the reduction of starches to double sugar, and three enzymes of the intestinal juice reduce double sugars to single sugars. Food is completely digested and absorbed in the small intestine, while, as the residue passes through the large intestine, its water is absorbed. The remainder, known as the feces, passes into the rectum and is expelled through the anus.

The food is absorbed from the small intestine through extremely minute, close-packed projections, known as villi, which extend out from the intestinal wall. Each villus contains a network of blood and also of lymph capillaries. Single sugars make their way into the blood capillaries of the villi, then through the portal vein into the liver, where they are converted into glycogen which is stored in the liver cells, to be gradually reconverted into blood sugar as the concentration of sugar in the blood falls. Some is also stored in the muscle cells, ready for oxidation when the muscle becomes active. Excess carbohydrates may be converted into fats and stored in the fatty tissues of the body.

Glycerol and fatty acids are absorbed into the epithelial cells of the villi, within which they are reconverted into fats characteristic of the human body and passed on to the lymph capillaries of the villi. They are carried through the lymph system to the blood stream, through which they are carried to the liver, where they are converted into a soluble compound, lecithin, in which form they may pass into the body cells. Here they may be used for fuel or to form the fat-like parts of the protoplasm, or they may be stored in the cells of certain connective tissues until the body has need of extra fuel.

Amino acids are absorbed into the blood capillaries of the liver and carried to the cells, where they may be recombined into proteins for growth or to replace outworn structures. Or they may be split into sugar-like substances and ammonia in the liver, the sugars being used for fuel and the ammonia being converted into urea. About four-fifths of the protein in our diet is used for fuel. A high percentage of protein in the diet results in an increased rate of metabolism.

In order to maintain the body at rest, a basal metabolic rate of 1,900 Calories per day must be maintained. On the average, sedentary workers require 2,500 Calories of energy per day in their food, and manual laborers from 3,500 to 5,000. Most of this energy is expended for heat; but, while this heat is wasted energy as far as the accomplishment of work is concerned, it is useful for maintaining the body at a temperature at which its activities are carried on most efficiently.

In addition to proteins, carbohydrates, and fats, the following substances are found in our food: (1) Condiments, which merely improve flavor; (2) drugs, which improve flavor and have pleasurable effects on the nervous system; (3) roughage, the indigestible portion, which aids in causing the chyme to pass through the intestines; (4) water, which forms an essential part of the protoplasmic structure and is also a medium for the movement of other substances through the body; (5) salts, which are important in maintaining a proper chemical balance in the body; and (6) vitamins, which are essential for the maintenance of health. Of the many vitamins now known, the following have the greatest practical importance in human metabolism:

Vitamin A: Secured from most animal fats and from yellow and green vegetables. Prevents xerophthalmia and night blindness and stimulates growth in children.

Vitamin D: Produced by irradiation of fatty tissues. Best sources are fish liver oils. Essential during growth to prevent rickets and bring about the formation of sound teeth.

Vitamin K: Produced by intestinal bacteria. Essential for the clotting of the blood.

Vitamin B complex: Found in the germ and husks of grains, in milk, leafy vegetables, and yeast. The following are the best-known vitamins in this complex: Thiamine (B_1) prevents beriberi, stimulates growth, and apparently improves general health and well-being. Riboflavin (B_2) prevents cheilosis. Niacin is the most important vitamin for the prevention of pellagra.

Vitamin C: Found chiefly in citrus fruits, also in tomatoes, potatoes, and yellow and green vegetables. Prevents scurvy.

Improving the diet and the preparation of food, enriching common foods, and taking synthetic vitamins or concentrates are complementary methods of insuring an adequate vitamin supply.

Excretions are of two kinds: the products of katabolism, and food remnants which pass through the alimentary canal or the blood stream but never enter into the metabolism of the cells. Carbon dioxide is excreted from the lungs. Undigested portions of food, products of cell breakdown, dead bodies of bacteria, and materials from digestive juices leave the body through the anus. Of the digestive juice materials, the most important are the bile pigments, which are formed by the breaking down of red corpuscles in the liver. Urea, products of the breakdown of cellular proteins, salts, excess sugar, and other useless food components are taken from the blood by the kidneys and excreted through the urinary system. Similar products are excreted by the sweat glands. Water leaves the body through all of the above avenues.

Urine is collected in the kidneys by branching tubules which come into close contact with blood capillaries. It is carried to the bladder by the ureters and expelled therefrom through the urethra.

QUESTIONS

1. Describe the digestive organs and tell the function of each.
2. Tell what may happen to a bit of protein from the time it enters the mouth until its remnants are excreted. A bit of starch. A bit of fat.
3. Outline all the functions of the liver.
4. What things are necessary in a healthful, normal diet?
5. Outline the processes of excretion.

GLOSSARY

alimentary canal (al′i-men′ta-ri) The passage through which food passes while being digested or absorbed.

anus (ā′nus) Lower opening of the alimentary canal through which the feces are expelled.

beriberi (ber′i-ber′i) A disease marked by inflammation of the nerves caused by lack of vitamin B.

cardiac sphincter (kar′di-ak sfink′ter) A ring-like muscle able to contract and shut off the opening from the esophagus to the stomach.

chyme (kīm) The semi-liquid food in the small intestine.

condiments Non-nutritive food substances eaten for the sake of their taste.

diastase (dī′a-stās) A starch-splitting enzyme. (In this chapter the pancreatic diastase is mentioned, but the term applies to any enzyme that splits starch.)

duct Term applied to many small tubes in the body which carry liquids, particularly those which carry glandular secretions.

esophagus (ē-sof′a-gus) Tube which carries food from the throat to the stomach.

fatty acids A group of substances formed in the digestion of fats.

feces (fē′sēz) pl. Waste materials expelled from the alimentary canal.

fundus Wide, rounded portion of the stomach lying to the left of the cardiac sphincter.

glycerol (glis′er-ol) A substance formed by the digestion of fats. (The common term for it is glycerin.)

glycogen (glī′cō-jen) Animal starch. Stored in the liver and to a lesser extent in the muscle cells and other cells of the body.

lecithin (les'i-thin) Substance into which fats are transformed in the liver to make them soluble.

lipase (lip'ās) Any fat-splitting enzyme. (In this chapter, the pancreatic lipase is mentioned.)

parotid (pa-rot'id) Salivary gland, located below the front of the ear.

pellagra (pe-lăg'ra) Disease caused by lack of vitamin G, marked by weakness, skin affection, and nervous disorders.

pepsin Stomach enzyme which reduces proteins to proteoses and peptones.

peptones Substances formed in the partial digestion of proteins.

peristaltic waves (per-i-stal'tic) Ring-like contractions of the walls of the alimentary canal which move down the canal, pushing the food ahead of them.

proteoses (prō'tē-ōs-ēs) Substances formed in the partial digestion of proteins.

ptyalin (tī'a-lin) Enzyme in saliva which reduces starch to a double sugar.

pyloric sphincter (pi-lōr'ic sfink'ter) A ring-like muscle able to contract and shut off the opening from the stomach to the small intestine.

pylorus (pi-lōr'us) Tapering portion of the stomach to the right of the cardiac sphincter.

rectum Small chamber at the end of the alimentary canal between the anus and the large intestine.

rennin (ren'in) A stomach enzyme which curdles milk.

scurvy Disease characterized by spongy gums and bleeding from mucous membranes; caused by lack of vitamin C.

sublingual Salivary gland located beneath the tongue in the floor of the mouth.

submaxillary Salivary gland located under the jaw bone.

urea (ū'rē-a) Substance formed from the breakdown of proteins.

ureter (ū-re'ter) One of the pair of ducts carrying urine from the kidneys to the bladder.

urethra (ū-rē'thra) Tube carrying urine from the bladder to the exterior.

villus (vil'lus) pl. *villi* (vil'lī) One of the minute, finger-like structures in the wall of the small intestine into which food is absorbed.

vitamin (vī'ta-min) Any one of a number of substances whose presence in the diet in small quantities is essential to health.

xerophthalmia (zē'rof-thal'mi-a) Disease of the eyes caused by lack of vitamin A.

CHAPTER V

MAINTENANCE SYSTEMS IN ANIMALS

The Continuity Between Man and Paramecium.—In the previous chapters we have become familiar with the structures and activities of single-celled organisms, in which the maintenance of life was simplified to its most elemental form; we have also considered the structure and activities of one of the most complex organisms in the world—man himself. We have seen how the human body is organized into systems of cell groups for carrying on the functions of nutrition, circulation, excretion and respiration so that cell metabolism may take place. The division of labor among the cells of the body has resulted in a most complicated set of organs for the securing, absorbing, distributing and transforming of the food and air necessary for cell metabolism and of the waste products resulting from it. Between these two extremes of animal metabolism there are many intermediate body plans, bridging the gap which exists between the simplicity of Paramecium and the intricacy of the human body.

Paramecium can be taken as representative of the oldest form of bodily organization among animals—the single cell. From this one-celled condition all the variety of animal bodies has been developed through the course of evolution. Since there are at present some eight hundred thousand different species of animals known to the zoologist, with perhaps hundreds of thousands more that have not yet been catalogued, it would be impossible in a single chapter to present all the bewildering variations in body plan that are to be found in the animal world. To simplify matters, we shall consider five different animal organisms which typify the most important changes that have taken place between Paramecium and Man. What we shall do is to select from the profusion of types only a few animals which represent innovations and developments which are retained in the human body. As each modification of the maintenance tissues is incorporated into the body design of the following and more advanced animal type, we eventually reach a point where we can see the summation of all these in the human body. By considering each separate innovation, and the animals living today which represent the persistence of that particular stage in the development of the *multicellular* body, we can the better appreciate the structures present in our bodies.

First, in Hydra, we discover a multicellular organism with a very simple digestive tract, almost a complete lack of specialized organs, but with a certain amount of specialization of function among its cells.

Second, in the earthworm we find several advances in complexity over the tissue-animal type represented by Hydra. In the body cavity, or *coelom,* specialized groups of organs carry on circulation and excretion. The earthworm is in reality one of the first animal types to be built up on the organ-plan, developing many different kinds of tissues grouped in special organs for assisting in the maintenance of metabolic activities in all the cells of the organism.

Third, in the fish, one of the simplest *vertebrate* animals, the body plan carries on the multicellular condition with the division of labor among cells, tissues and organs previously incorporated in the worm body plan; with it also is repeated the coelom and the specialized organs for circulation and excretion. In the fish these are more like those of the human, as is the digestive system. Here too we find a set of organs responsible for external respiration.

Fourth, in the frog, there is continued the innovations found in the fish, but to them is added a respiratory system which is basic in design for all air-breathing vertebrates. All of the maintenance organ systems are now practically human in general plan.

Finally, a few minor changes, seen in any mammal, bring the body plan to the condition found in our bodies. Not only are the digestive, circulatory and excretory systems made more efficient, but by becoming warm-blooded the mammal is able to have cell metabolism go on continually regardless of the fluctuating temperature of the environment. Since there is no essential difference between the maintenance organs of man and the other mammals, we have in this fifth stage reached the condition already described in the previous chapters. Our chief interest now will be to de-

;cribe in more detail each of the four noteworthy advances which ıre thus intermediate between Paramecium and Man.

The Colonial Protozoa.—Paramecium and its relatives show ıs that all the essential activities of animal metabolism can be car-:ied on by an organism which is merely a single cell. Among the Protozoa, however, there is a tendency for the cell organisms to ınite in groups, forming colonies of organisms as in the case of *7orticella.* (See Fig. 22A.)

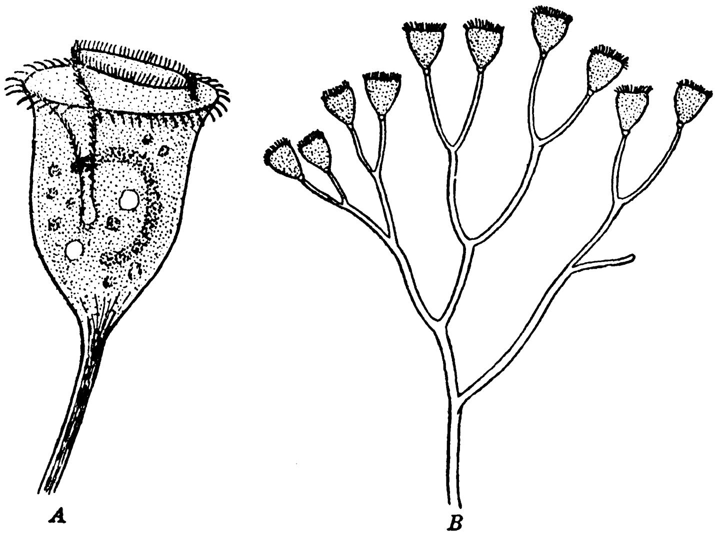


Fig. 22.—Colonial protozoa. *A,* Vorticella individual; *B,* a colonial protozoan.

Vorticella is like a goblet on a slender stalk which can coil it-elf together whenever the animal encounters a solid object, thus ›rotecting the delicate cell. When the protozoan is stretched out ıt full length, the mouth of the goblet reveals a circle of lashing :ilia which by their action create an eddy into which bits of plant ınd animal life are drawn, to be later engulfed and digested as in Paramecium. Oxygen diffuses into the cell from the surrounding vater. Thus the essentials for metabolism are taken care of.

Vorticella is often found singly, but sometimes six or more in-lividuals remain attached to each other by the ends of their stalks. Such a formation of *colonies* of cells is the first step toward the levelopment of the multicellular body. Other Protozoa form large tree-like colonies with an animal at the end of each branch, while still others assume the shape of flat plates or hollow spheres of cells attached to each other. But every cell of the colony retains its individuality as an organism, and there is no specialization of function among the cells.

A Simple Multicellular Animal.—When groups of cells living together begin to show a differentiation of function, they are no longer classed as colonial Protozoa, but as multicellular animals. Probably the simplest multicellular animals are the sponges, but to remain more directly on the line of evolution from Protozoa to Man, we shall describe another very low form of animal life, the Hydra.

Hydra is found in ponds, attached to sticks and stems of aquatic plants. It is about an eighth of an inch in length, and its slender, translucent body can be seen swaying back and forth in the water, searching for food. The cylindrical body is attached by a flattened basal portion, while at the other end there is a mouth surrounded by a circle of *tentacles* which aid in the capture of food and bring it to the mouth. The body wall consists of a double row of cells surrounding the central digestive cavity. The outer layer of cells, known as the *ectoderm*, has within itself groups of cells responsible for sensory, contractile and protective activities, corresponding in function to our muscular, nervous and external epithelial tissues —though differing greatly in structure. The inner layer of cells, known as the *endoderm*, is chiefly concerned with the digestion and absorption of food. The cells lining the digestive cavity are large cells, each with one to five *flagella*, or whip-like extensions of the cell wall. The flagella project into the digestive cavity, creating currents in the water and thus bringing food particles to the individual cells.

In obtaining its food, Hydra touches its prospective prey with one or more of its tentacles, perhaps paralyzing it with some barbs released from the ectoderm cells of the tentacles. Then the food is brought to the mouth by the movement of all the tentacles. The cells surrounding the mouth opening, being ectoderm cells with muscle components, force the food into the digestive cavity. Once within the Hydra's body, the food is acted upon by secretions of certain gland cells of the endoderm; it may be churned about by contractions of the entire body. Some of the food is engulfed by

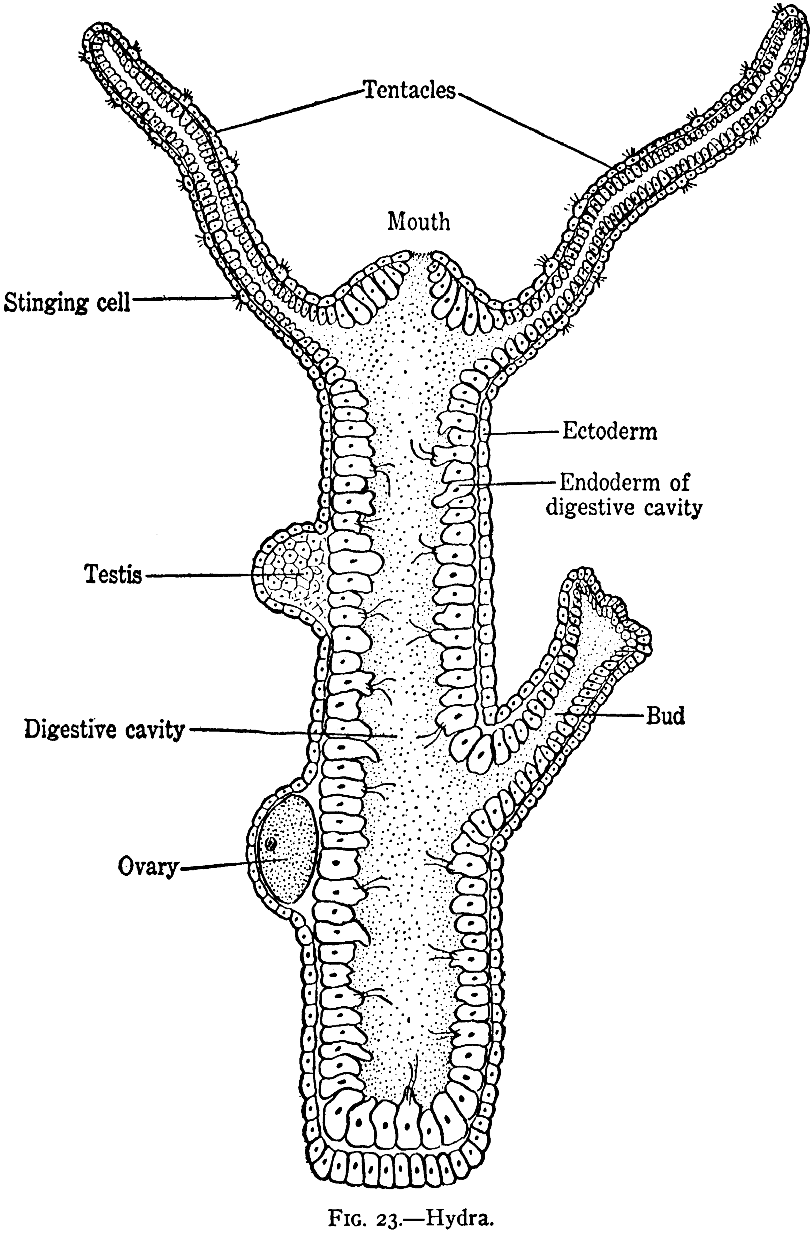

Tentacles
Mouth
Stinging cell
Ectoderm
Endoderm of digestive cavity
Testis
Bud
Digestive cavity
Ovary

FIG. 23.—Hydra.

single cells of the endoderm in typical protozoan fashion, and there digested; other portions of the food are acted upon by digestive enzymes while in the digestive cavity, later to be absorbed into the endoderm cells much as in higher animals. The food passes from the endoderm cells to the rest of the Hydra's body by diffusion or through the jelly-like layer between the two tissues. There is no specialized circulatory system. Waste products likewise diffuse from one cell to the other, eventually passing out of the cells into the environment. Respiratory gases follow the same procedure.

Thus we see in Hydra a body plan designed to delegate certain duties of anabolism to specialized endoderm cells; all the other cells of the body are dependent upon these endoderm cells for their food. There is little further specialization, however, every cell getting its own oxygen and getting rid of its carbon dioxide as well as other waste products of katabolism. The basic living activities associated with animal metabolism are taken care of to a limited degree by some division of labor, but there are no true organs as in higher animals.

The Earthworm.—In the earthworm we find all the fundamentals of the organization of maintenance structures that are found in the human body. In contrast with Hydra, a second opening has appeared in the digestive tract, so that food moves through it from mouth to anus. Surrounding this digestive system is a body cavity, the coelom; hence the earthworm body is essentially a tube within a tube, with the edges of the outer one fastened to those of the inner one at either end. The coelom is divided into a large number of compartments by transverse partitions which extend from the body wall to the digestive canal. The grooves which run around the exterior of the worm, apparently dividing it into a series of small rings, are each of them located over one of these partitions. A portion of the body between two of these rings is called a *segment*. Inside the coelom there are specialized organs for circulation and excretion. The evolutionary modifications from Hydra to the earthworm thus include the development of a two-opening digestive cavity, the appearance of a coelom and the presence of specialized organs.

The food of the earthworm consists of bits of vegetation and animal matter found in the soil. This earthy material is ingested

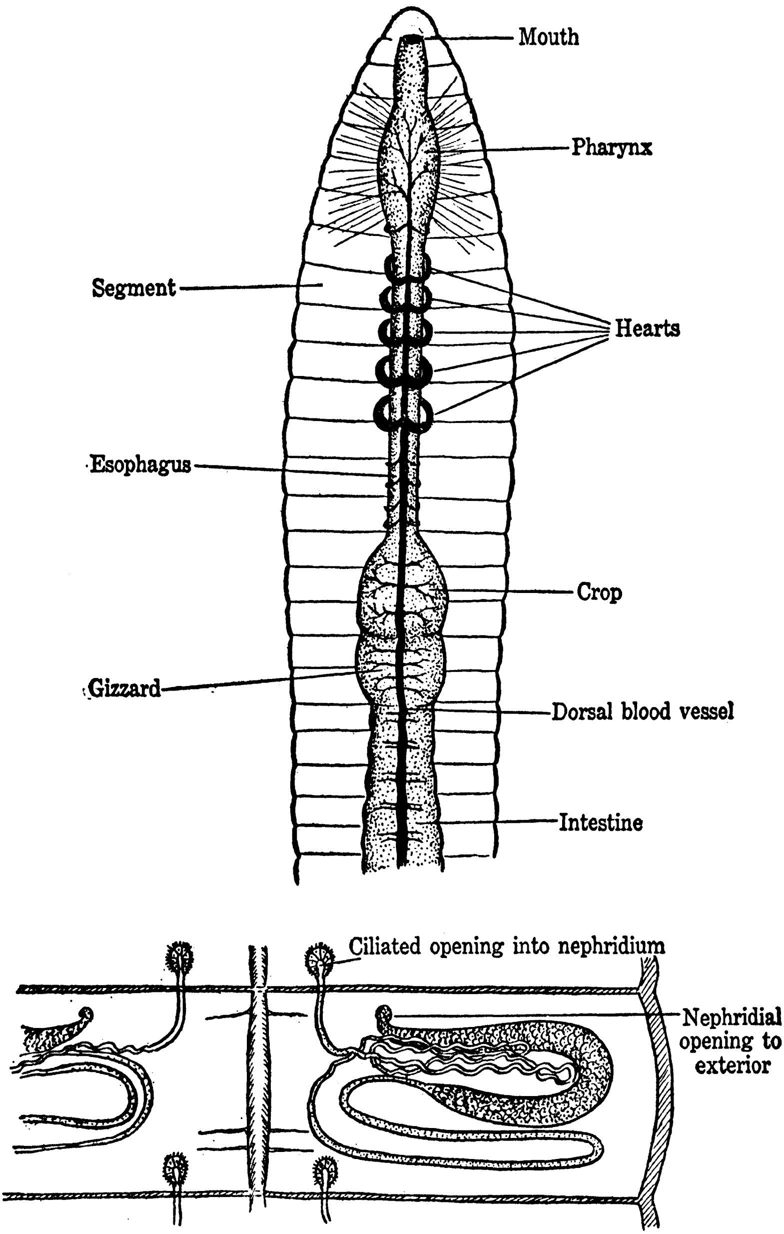


FIG. 24.—Digestive, circulatory, and excretory system of earthworm.

through the mouth at the *anterior*[1] (or head) end of the digestive tract, aided by a muscular pharynx just behind the mouth. The remainder of the digestive canal is differentiated into various special portions, each with a specific function. From the pharynx the food is forced through a narrow esophagus which is without special digestive function, though some glands lying alongside it produce a lime secretion aiding in neutralizing food acids. Leaving the esophagus, the food enters the enlarged thin-walled part of the digestive canal known as the *crop*; here it may be temporarily stored until needed. From the crop the food passes directly into another enlarged portion of the digestive tube, the *gizzard*, which is thick-walled and muscular, serving to grind the food into smaller particles preliminary to digestion and absorption, which occur in the remainder of the tract, known as the intestine. After the complex proteins, carbohydrates and fats have been acted upon by the digestive enzymes, the cells lining the intestinal tract absorb the food.

After absorption, the food must be brought to every living cell of the earthworm's body. For the first time we see in the animal body plan a special set of tissues for the purpose of distributing materials throughout the body. Absorbed food may make its way into the liquid filling the coelom, and thus be brought to the tissues bathed by this fluid; but most of it leaves the digestive cells to go into the blood stream. A circulatory system includes a closed set of blood vessels which have capillary subdivisions extending throughout the body wall and all the organs; the large *dorsal* blood vessel present on the upper side of the earthworm connects with a similar *ventral* blood vessel by means of five pairs of vessels known as hearts which encircle the esophagus. The blood in these vessels holds hemoglobin in solution, and has white corpuscles but no red ones. It is forced forward in the dorsal vessel by rhythmic constrictions of the muscular walls and passes into the hearts which also contract to send the

[1] In most animal organisms, directions are indicated as follows:

toward the head or mouth	the anterior
toward the tail or anus	the posterior
toward the belly	the ventral
toward the back	the dorsal

Thus in human beings, the arms are the anterior limbs; the legs, the posterior limbs. The backbone is a dorsal structure and the breastbone a ventral structure.

blood to the ventral vessel. Valves in both the dorsal vessel and the hearts prevent a backward flow of the blood. Thus a circulating medium carries food from the cells in which it is absorbed (the digestive tract) to all the cells of the body.

Only a few layers of cells on the outside of the earthworm are close enough to the atmosphere to be able to absorb directly the oxygen needed for katabolism or to give off the carbon dioxide. The earthworm has no special set of tissues to take care of external respiration; the outermost skin cells, however, are kept moist with mucus, and have air spaces between them. As air diffuses in and out of these cells some of the excess oxygen goes into the small capillaries and eventually is carried about by the circulatory system to all the body cells. Carbon dioxide in turn is given off from the capillaries into the skin tissues and from them to the atmosphere. In the plasma of the blood there is the red pigment hemoglobin (contained in the red corpuscles in the human body) which increases the gaseous carrying power of the blood stream.

The coelom liquid has already been mentioned as a means of distributing some of the absorbed food. More frequently, waste products of metabolism accumulate in this fluid. These are removed, together with the waste products in the blood stream, by special excretory organs found in the coelom. These excretory organs, known as *nephridia*, consist of coiled tubes which occur in pairs in every segment except the first three and the last. Each nephridium has a funnel-shaped opening, lined with ciliated cells, which goes into the posterior part of the coelom of one segment. The cilia create a current which sucks into the funnel all solid waste particles contained in the coelomic fluid. The tube of the nephridium leading from the funnel passes through the septum into the coelom of the next segment, where the bulk of the excretory organ is located, consisting of a much-coiled tube in whose walls are glands which at the same time are removing nitrogenous material from the blood stream and eliminating it in the liquid found in the nephridial tubes. The excretory organ terminates in an opening in the body wall, through which the waste material is passed out to the environment.

Thus in the body pattern of the earthworm, in so far as it is related to the maintenance of metabolic activities, we find the basic arrangement of digestive, circulatory and excretory organs much as they are in higher animals and man. Further advances involve a more specialized structural division of labor among the organs in each system, and a definite set of tissues responsible for exchange of gases with the environment.

The Vertebrate Body Plan.—All the animal types at the level of complexity which we have so far described have one characteristic in common: the maintenance organs are either without any surrounding supporting tissues or else such supporting cells act as a *skeleton* on the outside of the body. Collectively, organisms with such characteristics are known as invertebrates. The fish is representative of an innovation apart from the maintenance systems, which, however, is such a basic part of the body plan we are now to consider that a few words of explanation are necessary. The fish is a typical primitive vertebrate in its simplest expression. By this is meant that there is a stiffening axis running lengthwise dorsal to the digestive tract and consisting of a series of bony segments known as vertebrae. The whole structure is a backbone, or *vertebral column.* This innovation, added to certain improvements in the maintenance organs, has caused vertebrates to be numbered among the most common and obvious land animals, as attested by the amphibians, reptiles, birds and mammals.

The Fish.—The body of the fish is constructed upon the same essential plan as that of the earthworm, in that it possesses a coelom and a digestive tube passing through the body from mouth to anus. It is also segmented, although the segmentation is not as obvious as in the earthworm. The ectoderm cells have taken over as their special duty the formation of protective tissues (such as skin) and the nervous system. The endoderm cells have become specialized for absorption of food (the digestive tract) and exchange of gases (the respiratory tract). From certain cells in an intermediate layer there are formed the tissues responsible for movement (muscles) circulation of materials (blood vessels and heart), and support. From the coelom is developed a vertebrate body cavity in which the vital organs are located, divided into two parts by the diaphragm as in human beings. The larger cavity contains the liver, stomach, intestines and kidneys; the smaller contains the heart.

The food of a fish is usually smaller fish, or other aquatic animals such as insects and mollusks. Once in the mouth, the food is held firmly by hard projections which grow out of the walls of the digestive tract—the teeth. In addition there is a muscular organ, the tongue, which aids in holding and pushing the food. Both teeth and tongue are distinct improvements over the earthworm mouth. From the mouth the food passes through a pharynx and esophagus into an enlarged portion of the digestive canal which

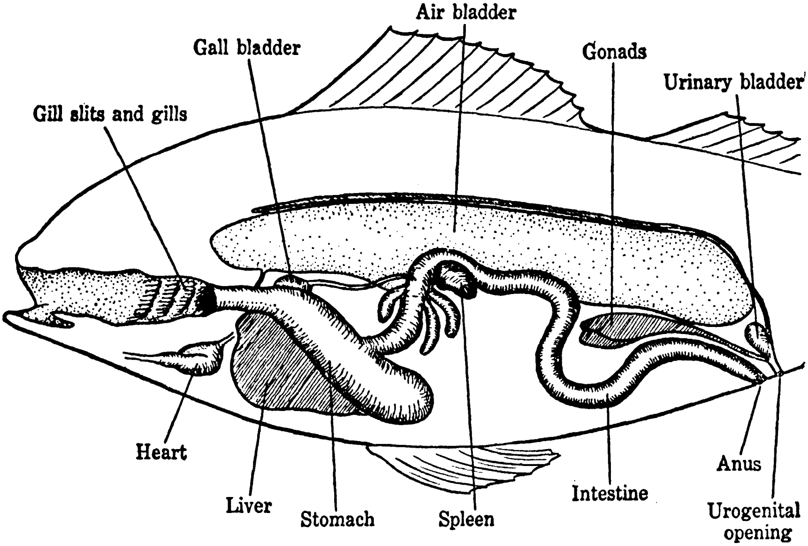


FIG. 25.—Maintenance organs of fish. (Redrawn from Woodruff's *Foundations of Biology,* The Macmillan Company.)

combines the function of a crop and gizzard—the stomach. Here digestion is initiated with the secretion of digestive fluids from the stomach cells. The remainder of the food tube is a slightly coiled intestine with three short outgrowths from it which increase the absorptive surface. Here the digestion of the food is continued, and the simpler food substances resulting from the digestive process are absorbed by the intestinal epithelial cells. Undigested residues pass out through the anus. Even though the twisting of the digestive tract and the presence of specialized organs along its extent make obscure the relationship with the straight food tube of the earthworm, the fish has a digestive tract which is essentially a tube running from one opening in its body to another—from mouth to anus. A new organ, the liver, has appeared; its secretion passes through a gall bladder to a bile duct which empties into the intestine.

The circulatory organs consist of main blood vessels, as in the earthworm, and a capillary system for irrigating all the tissues of the body. There is a single large muscular organ, the heart, which has taken over completely the function of pumping the blood through the circulatory system. The heart, located ventrally below the pharynx, is a two-chambered organ. The blood flows into the first chamber, or auricle, from the large veins; passes into the second chamber, or ventricle, where muscular contraction forces it out into the large arteries. As the blood flows through the capillaries in the intestinal wall it absorbs food present in the digestive tract cells, carrying it in solution to the cells of all the other tissues where it is made available for cell metabolism.

Excretion is the special task of the kidneys, which extract urea and other wastes from the blood stream and pass them on to the bladder and eventually to the exterior via an opening posterior to the anus.

Respiratory organs function in the fish to take care of the gaseous exchange with the environment, replacing the slow and inefficient method found in the earthworm. As the fish moves about, water is taken in through the mouth into the pharynx, passing out through openings in the side of the neck. During this passage, the water—which carries oxygen in solution—passes over delicate tissues forming the *gills*, and some of the air passes through the gill cells into the capillaries with which the gills are plentifully supplied. Gills are respiratory organs designed to carry on gaseous exchange when the gases are dissolved in the water. Once in the blood stream, the oxygen is transported to all the tissues of the fish, supplying the cells with the oxygen needed for metabolism, and removing the carbon dioxide. When the blood passes through the gills this gas is given off as a waste product.

The Frog.—The frog exhibits certain changes in the vertebrate body plan pioneered by the fish; these changes are the result of adaptation to land living. The digestive tract is built on the same basic pattern, though the tube is more coiled to provide as great an absorptive area as possible without requiring too large a body surface. The mouth, esophagus and stomach have the same functions as in the fish, but the intestine has become differentiated into a small and a large intestine; and another digestive gland, the pancreas, aids in the secretion of digestive enzymes. The circulatory system is changed only by the presence of a three-chambered heart. The most significant change of all is the design of the respiratory organs, with the innovation of lungs as organs for

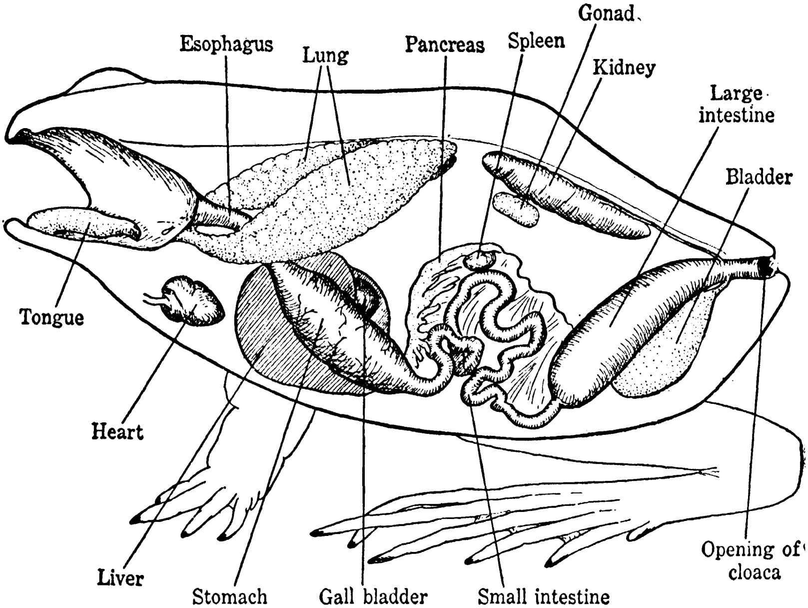


Fig. 26.—Maintenance organs of frog. (Redrawn from Woodruff's *Foundations of Biology,* The Macmillan Company.)

exchanging gases with an atmospheric environment. In the fish there is an outgrowth of the pharynx known as the air bladder; this is a large sac filled with a gas which regulates the level at which the fish can comfortably float. In the lungfishes this air bladder opens into the pharynx and functions as a lung since the blood vessels in its walls absorb the oxygen from the air in the sac. In the frog there are two such sacs connected with the pharynx by a short tube known as the *larynx.* Each sac is a simple cavity lined with tissues rich in blood vessels, and it is here that

Cross section of frog stomach. The stomach is collapsed, so that only a narrow, irregular cavity remains.

exchange of gases concerned with cell respiration takes place. Lung breathing is the method by which such external respiration is carried on in reptiles, birds and mammals.

The Warm-blooded Organisms.—The maintenance organ systems of a typical mammal are built upon the same plan as those of the frog, with one major change which affects the activities of the organism as a whole. The chemical changes which are a part of anabolism and katabolism are, like all chemical reactions,

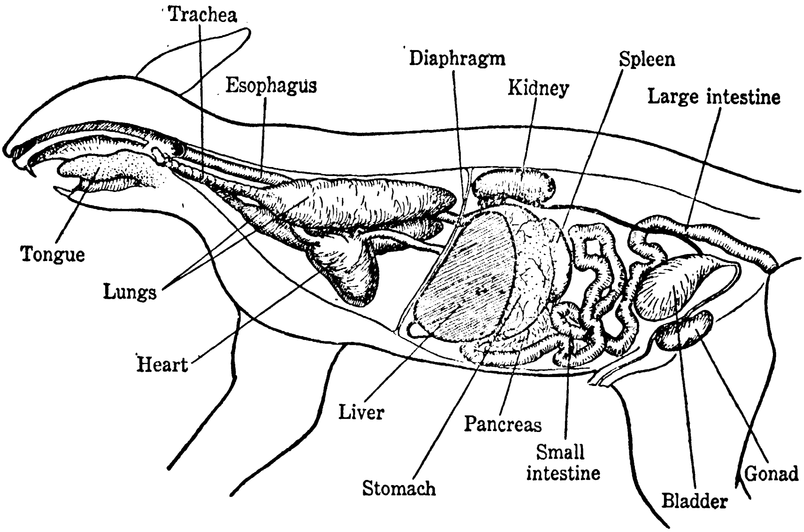


FIG. 27.—Maintenance organs of mammal. (Redrawn from Woodruff's *Foundations of Biology,* The Macmillan Company.)

conditioned to a certain extent by the temperature. Within certain limits, any increase in temperature results in an increase in the rate of the chemical reaction. The frog, and all animals lower in the scale of bodily organization, are *cold-blooded* organisms; the temperature of their bodies varies with that of the environment. When the temperature of the surrounding air or water drops, cell metabolism begins to slow up. Cold-blooded animals usually hibernate or go into a state of suspended activity under these conditions. Mammals and birds, on the other hand, are *warm-blooded.* They have a heat-regulatory mechanism whereby the body temperature is kept relatively constant at the optimum for metabolic activity, irrespective of the temperature of the environment. The change in body plan which has aided in bringing about this condition includes the addition of a skin covering which prevents heat loss during periods of low temperatures. The feathers of birds and the fur of mammals serve this purpose.

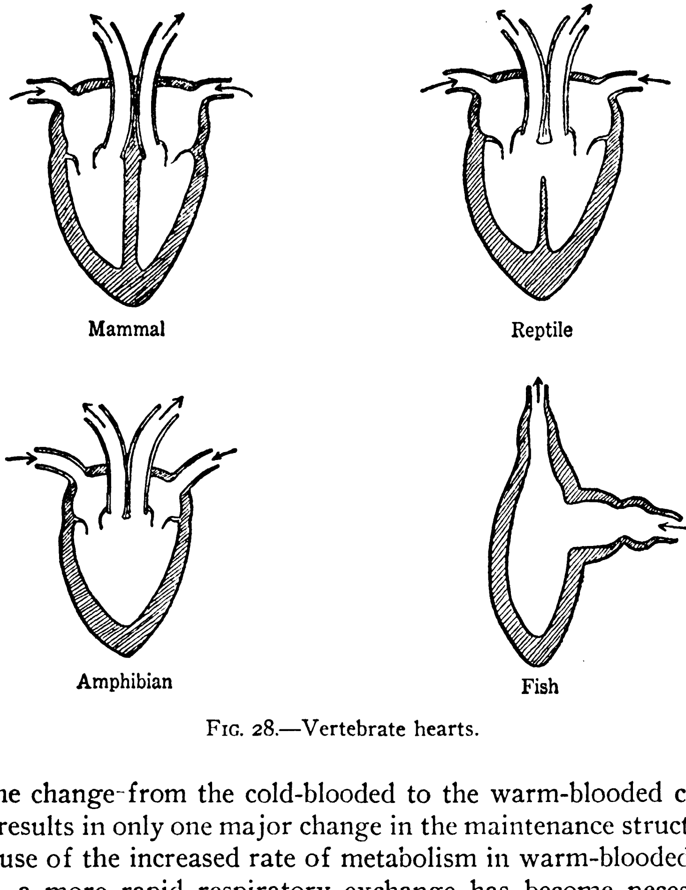


Fig. 28.—Vertebrate hearts.

The change from the cold-blooded to the warm-blooded condition results in only one major change in the maintenance structures. Because of the increased rate of metabolism in warm-blooded animals, a more rapid respiratory exchange has become necessary. Consequently the smooth wall of the lining of the lung has been greatly increased in area and thrown into many closely packed folds to form the system of bronchioles and alveoli found not only in man but in all other warm-blooded organisms.

Man is a typical vertebrate of the mammalian group, hence it is unnecessary to repeat here all the structural features characteristic of his maintenance organs; these have been explained in previous chapters. By keeping in mind the progressive stages by which this complex body plan has become possible, we can see in the existing colonial Protozoa, Hydra, earthworm, fishes, and the frog representative animals which embody successive innovations on a previously existing design, suggesting the origin and relationships of the seemingly complex set of organs in the human body, which are all essential for the carrying on of cell metabolism.

Chapter Summary

The oldest form of bodily organization among animals is the single cell, as represented by Paramecium. One of the most complex forms is that seen in Man. The gap between the two can be bridged by considering certain animal types which have today in their body plan various important innovations which were essential for the evolution of the mammalian and human body organization.

The tendency toward formation of a multicellular body is seen in various colonial Protozoa such as Vorticella; but in such many-celled bodies each cell retains its individuality and there is no division of labor. Slightly more complex multicellular bodies are the sponges, with the beginnings of cell specialization.

Hydra represents a simple multicellular animal without organs but with some specialization of function among the cells. The body wall, surrounding a central digestive cavity, consists of two layers of cells: ectoderm cells responsible for sensory, protective and contractile activities, and endoderm cells responsible for the digestion and absorption of food. The digestive cavity has but one opening, a mouth, surrounded by tentacles which aid in food-getting.

The earthworm represents an animal type much advanced over the Hydra in that the cells are grouped into organs, and that the maintenance activities require much more complex tissues and cell groups. There are two openings to the digestive cavity, an anus as well as a mouth; and the digestive cavity has become an elongated canal with division of labor along its length, resulting in a pharynx, esophagus, crop, gizzard and stomach-intestine. Hydra has no special circulatory system; the earthworm has a set of blood vessels carrying a circulating medium to every part of the body. The earthworm also has special excretory organs, the nephridia. Somewhat like the Hydra, the earthworm carries on external respiration through the cells on the outside of the body wall. And, finally, in the earthworm we see a body cavity, the coelom, surrounding the digestive canal.

Protozoa, sponges, Hydra-like animals and worms are a few of the animals which lack an internal supporting system or skeleton; hence they are called invertebrates. The presence of a backbone and other internal stiffening tissues in the vertebrates has made possible the development of various innovations in the body plan. A good illustration of a simple vertebrate system is found in the fish.

The fish possesses the important organ systems which are found in the earthworm, with added specialization of each one of the maintenance organ systems. The coelom or body cavity becomes divided into two; in the smaller cavity there is the heart, and in the larger cavity the various digestive organs and excretory organs are located. The digestive tract itself includes a liver and gall bladder, as well as a true stomach and coiled intestine. The excretory organs are kidneys much like those of higher vertebrates. Respiratory organs are gills, specialized to exchange gases with the watery environment. The circulatory system includes a muscular two-chambered heart which keeps the circulatory fluid moving.

The frog's body plan is basically that of the fish, with certain changes necessary with the change to a land environment. Most noticeable of these is the substitution of air sacs, known as lungs, for the gills. Minor changes include the division of labor between a large and a small intestine, and a three-chambered heart. All of the maintenance organs are now practically human in design.

With the mammals, warm-bloodedness superseded cold-bloodedness, making possible more continuous metabolic activities irrespective of the temperature of the environment. Associated with this is a more complex respiratory system, with lungs made up of alveoli and bronchioles.

QUESTIONS

1. Why is Paramecium considered representative of the simplest type of body plan found among animals?
2. Is division of labor among cells a necessary step associated with the multicellular body plan? Give reasons for your answer.
3. Why is division of labor among cells advantageous to the organism?
4. Is such division of labor and cell specialization ever a disadvantage? Explain.
5. What maintenance system do Hydra and earthworm have more or less in common?
6. Compare the digestive canal of Hydra, earthworm and fish.
7. Compare the circulatory system of earthworm, fish and frog.
8. How is excretion carried on in the earthworm? How does this compare with excretion in man?
9. Which animal studied in this chapter first exhibits a coelom? Of what significance is a coelom in the development of the animal body plan?
10. What are the warm-blooded animals? Of what advantage to them is it to be warm-blooded?

GLOSSARY

anterior (an-tē'ri-er) That part of an organism toward the head or mouth end.

coelom (sē'lom) The body cavity found between the digestive tract and the body wall.

cold-blooded The condition found among all invertebrate animals and some vertebrates which results in the body temperature of the animal varying with the temperature of the environment.

colonial animal One in which the multicellular condition does not include division of labor among the cells.

crop Thin-walled enlargement of the digestive canal where food may be temporarily stored.

dorsal (dôr'sal) That part of an organism toward the back.

ectoderm (ek'tō-durm) Surface layer of cells, as found on the outside of Hydra.

endoderm (en'dō-durm) Inner layer of cells, as found lining the digestive cavity of Hydra.

flagellum (fla-jel'um) A whip-like prolongation of the cytoplasm, capable of moving about and creating a current outside of the cell.

gills Respiratory organs of aquatic animals, capable of gaseous exchange with water.

gizzard Thick-walled enlargement of the digestive canal, where food may be ground up.

Hydra (hī′dra) Small aquatic animal, composed of two cell layers, having a single opening to the digestive tract.

invertebrate (in-vur′tē-brāt) An animal without an internal skeleton, either without any skeleton at all (earthworm) or with an external skeleton (clam).

larynx (lăr′inks) The voice box, portion of the respiratory tract in the anterior part of the trachea.

mammal A class of vertebrates usually covered with fur and feeding the young with milk.

multicellular The condition of bodily organization involving many cells united together.

nephridium (nē-frid′i-um) Excretory organ of an earthworm, corresponding in function to the human urinary system.

pharynx (făr′inks) Cavity posterior to the mouth, from which the esophagus and trachea open. Throat.

posterior (pŏs-te′ri-er) The part of an organism toward the tail or anus.

segment In the earthworm, a portion of the body between two of the ring-like constrictions.

tentacles Flexible arm-like projections surrounding the mouth in Hydra-like animals.

ventral (ven′tral) That part of an organism toward the belly.

vertebral column (vur′tē-bral) The series of bony segments, or vertebrae, which act as a longitudinal stiffening internal axis among higher animals.

vertebrate (vur′tē-brāt) An animal with an internal, usually bony, skeleton.

Vorticella (vor′ti-cel′a) A colonial protozoan.

warm-blooded That condition found in birds and mammals, in which the body temperature is kept constant irrespective of environmental temperature changes.

CHAPTER VI

THE BODIES OF PLANTS

The Structural Needs of the Plant Body.—In Chapter II we became acquainted with the living organism reduced to its simplest and most basic form; and by studying Protococcus, Paramecium and the bacteria we were able to single out the three fundamental types of metabolism characteristic of living things. In the following two chapters we considered the other extreme of organization, focusing our attention upon the human body as the highest expression of specialization in animal metabolism. We retraced our steps, so to speak, in Chapter V, to show how the complexity of the human body was the outcome of a progressive series of innovations in multicellular organisms from Hydra to the mammals. This increased complexity, this specialization of organs to carry on specific functions, was intimately bound up with the fact that animal metabolism means ingestion of organic food. Hence the changes in the animal body have been associated with the organs concerned with securing, digesting, assimilating and transporting food materials, while the high rate of animal metabolism has made respiratory organs necessary.

Neither digestive nor respiratory systems have evolved in plants. Rather, there has been a development of specialized organs and tissues concerned with the securing of the raw materials for foods, with the manufacture of foods, the transportation of both raw materials and food, the storage of foods, and the provision of support and protection for the larger plant body.

The various stages in the advancing complexity of the plant body may be summarized as follows: (1) *thallus plants,* in which there is little or no differentiation into organs such as roots, stems, or leaves; (2) *primitive non-vascular land plants,* without leaves or conducting tissues; (3) *non-vascular land plants,* with leaf-like expansions, but without conductive tissues; (4) *vascular land* *plants,* with efficient roots, stems, and leaves, in which there is the most advanced division of labor among the cells.

Thallus Plants.—The simplest members of the plant kingdom, corresponding to the Protozoa and lower invertebrates among the animals, are the thallus plants. They include all the colorless plants as well as the simple chlorophyll-containing plants known as *algae.* Two groups of thallus plants, the bacteria and the *blue-green algae,* are so primitive that their cells do not have nuclei, the nuclear protoplasm being scattered throughout the cell.

The more highly developed thallus plants include the higher fungi and the higher algae. Of the latter there are three kinds: the *green,* the *brown,* and the *red* algae. The brown and red algae derive their names from the fact that they have brown or red pigments mixed with their chlorophyll. They are the dominant vegetation of the oceans, while the green algae are the common submerged vegetation of fresh waters.

Algae may be unicellular, or they may appear in the form of a more or less massive plant body, known as a *thallus.* Among the one-celled types are the flagellates mentioned in Chapter II, some of which are true plants and are classed among the green algae. Sometimes these animal-like organisms clump together to form colonies. In one species the plant body consists of a colony of four such flagellated cells, each similar to the other in structure and function, all embedded in a gelatinous mass. In another species there are sixteen such cells to the individual, the cells being arranged in a flat plate. Spherical colonies exist which consist of thirty-two, sixty-four, up to twenty thousand cells. The latter is the case with *Volvox.* Volvox is a minute plant which lives in fresh waters. It is about the size of a pinhead, and it spins its way through the water because the periphery of the sphere consists of hundreds of flagellated green cells, each capable of imparting its share of motion to the whole colony. The only cell differentiation is that associated with reproduction, since only certain special cells are capable of forming the eggs and sperms necessary for sexual reproduction. These few motile plants are interesting in that they show us an evolutionary compromise which has apparently led nowhere. Motility and green plant metabolism are two characteristics which do not go well together, or at least are not mutually

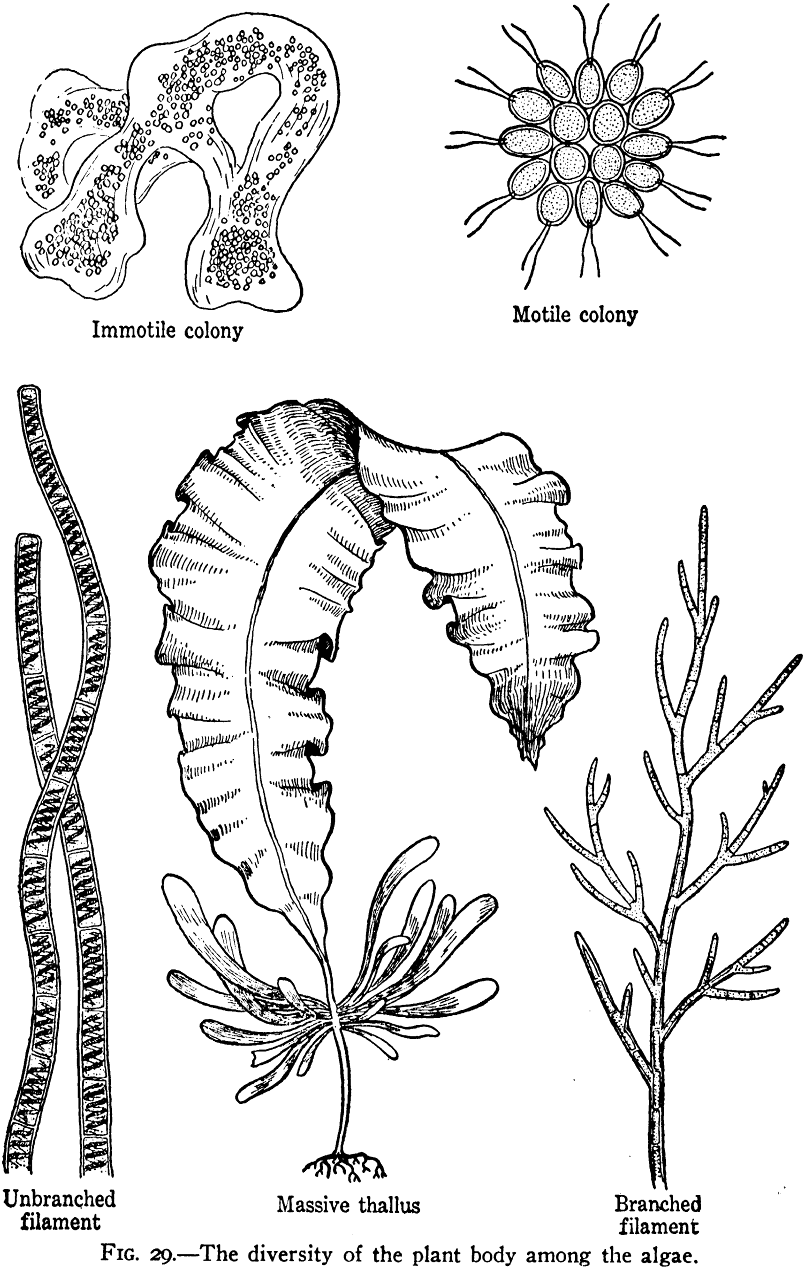


FIG. 29.—The diversity of the plant body among the algae.

essential. The stationary thallus plants were able to lead to a much larger and more efficient plant body, as we shall now see.

The simplest multicellular plant body is a thallus of cells showing no division of labor; such organisms are found among the green algae, forming irregular gelatinous masses in which are embedded indefinite numbers of cells, each a counterpart of Protococcus. More advanced is the multicellular condition in which the cells are attached, end to end, in a single row or thread of cells known as a *filament*. This is a very successful type of thallus, if we judge by the number of species of green, red and brown algae exhibiting this characteristic. Many of these filament plants do not branch, as in the common pond scum, *Spirogyra*. Here every cell is the same as the cell above and below it; thus there is no division of labor. Within each cell is one or more spirally coiled chloroplasts which manufacture the food for the cell as did the chloroplasts of Protococcus, except that here the materials for photosynthesis are secured from the surrounding water. In other cases the filaments develop a complex system of branches which result in larger, bushier plants which often reach a length of several feet.

Flat plates of cells are another type of thallus, found in all the algae but not as common as the filamentous types. Their chief claim to interest lies in the fact that they represent the ancestral algal type from which land plants developed when plant life migrated from the water to the land. In making such a transition, the filamentous type of body was doomed to failure because of the large cell area exposed to the fatal dryness of aerial life. The plate-body type, with its lessened surface area and the great number of cells within the body protected from the atmosphere, was (in the case of the green algae) the one capable of surviving in the new environment and thus paving the way for the higher plants.

The most complex thallus body is found in the massive structure of many of the brown algae. Not only is the body made up of many thousands of cells, but some of the cells have become specialized in performing photosynthesis, others in storing food, others in transporting it, and others in anchoring the plant to the substratum. *Sargassum* is one of the brown algae, found in abundance in semitropical oceans. Although at first growing attached to the rocks along the shore, it is often ripped away during storms and is borne by ocean currents out into the open sea where it remains alive for years. The plant has carried out division of labor to such an extent that certain tissues act as basal root-like holdfasts, others form stem-like portions which support expanded areas which function chiefly for photosynthesis, and still other tissues form little bladders which aid in keeping the plant afloat. The giant kelps, which are also brown algae, generally consist of a well-defined holdfast, stem and broad "leaf." Often these plants reach lengths of several hundred feet, testifying to the success of this type of plant body in the aquatic environment. In fact, no flowering plants can compete with the algae in colonizing the oceans, where the massive thallus type has proved its unique fitness for survival. The longest organism known to science is a giant kelp found off the coast of South America, specimens of which have measured five hundred feet in length.

At this point it might be well to say a few words about those thallus plants which have carried on in the multicellular condition the type of metabolism found in the bacteria. The fungi have specialized in colorless plant metabolism, and thus live either as saprophytes or parasites; we shall hear more of them in the rôle they play in the interrelations between organisms. But it might be well to see to what extent complexity of the plant body has become possible when associated with this type of metabolism.

The higher fungi are typically many-celled thallus plants in which the vegetative body is a branched, interwoven mass of filaments, much like the filamentous algae. Some of these fungi are aquatic, living on fish or dead aquatic organisms, but the majority are terrestrial. Under the general name of molds or mildews are included a large number of fungi whose plant body is a network of filmy threads spreading over the nourishing medium on which it is growing. The common bread mold appears whenever bread is exposed to the air in damp places. The molds appear as white masses of threads, tipped with orange, blue, green or black masses. These colors are due to the spores, which are the reproductive cells of these colorless plants.

Of the larger fungi an important group is the bracket fungi, which live for the most part on dead trees, though a few attack living ones. The most conspicuous parts of these plants are the reproductive bodies—hard, woody structures which appear as

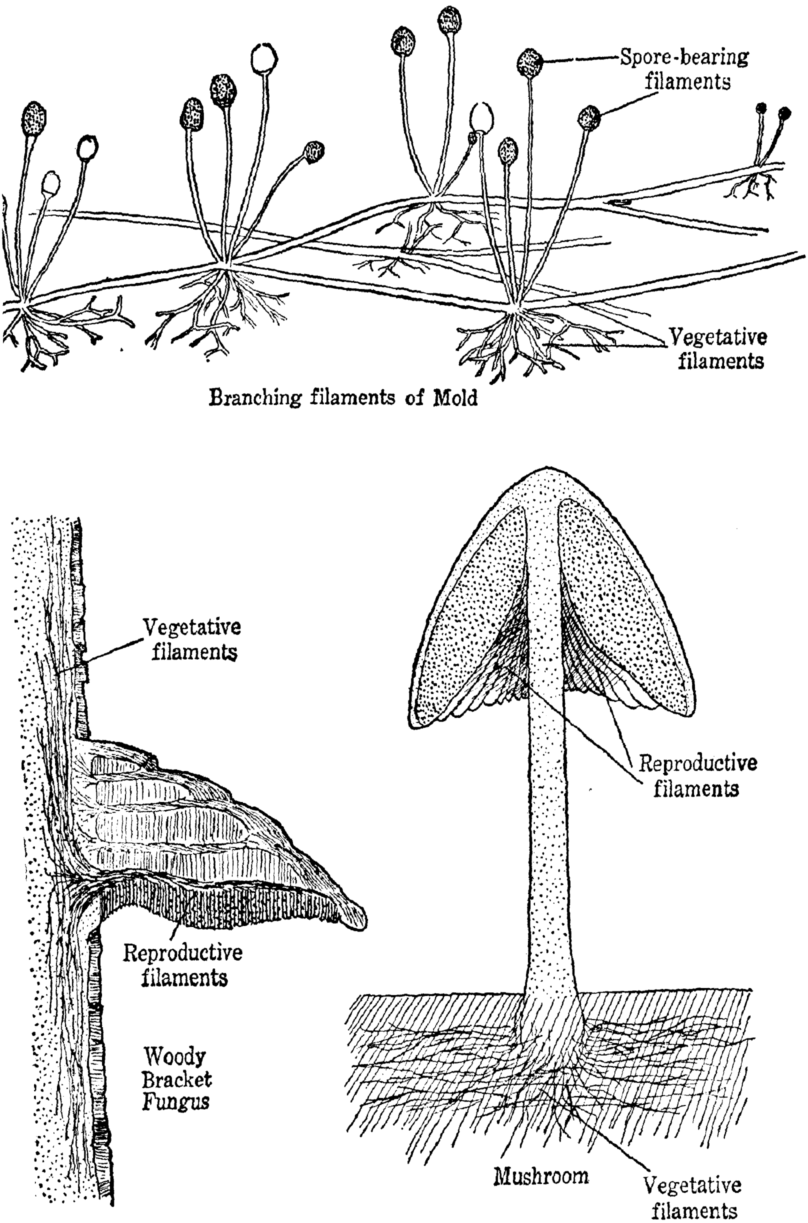


Fig. 30.—The diversity of the plant body among the fungi.

shelves or brackets on the sides of the tree trunks. The actual maintenance part of the thallus is a network of filaments which penetrates through the wood and causes it to rot during the course of the absorption of nourishment from the tree by the fungous parasite.

The most familiar of all the fungi are the mushrooms. In these, again, the main part of the plant is a network of threads or filaments running through the ground in which the organic material is found upon which the mushroom is subsisting. From this subterranean mass of filaments, erect buds grow into the reproductive structures, the common cap-and-stalk portion known as the mushroom.

Primitive Land Plants.—Before plant life could take up land-living, the plant body by necessity had to conform to the new environment and to adjust itself to new demands, chief of which was the securing of the all-important water and the prevention of drying out to a fatal degree. Neither of these was any problem at all for the algae, living as they do submerged in the water most of the time. In an insignificant group of plants known as the *liverworts*, we can see the type of plant body similar to what those plant pioneers must have looked like when life began its insurgent march in the conquest of the land.

A typical liverwort, such as the *Marchantia* found on moist ground, shows three basic modifications of the plant body which are necessary for terrestrial living. First is the compact multicellular body, in which only the outermost layer of cells is in contact with the air and consequently liable to excessive evaporation of water; most of the tissues are separated from the atmosphere by one or more layers of cells. Second is the habit of flattened growth, resulting in a prostrate plant body clinging closely to the damp earth and making possible a contact with the substratum over the entire lower surface of the body. This is most essential, since the substratum is the only source of the water and minerals needed for metabolism. And third is the beginning of division of labor among the cells, resulting in the formation of tissues. The uppermost layer of cells in Marchantia acts as a protective tissue and becomes an epidermis. The several layers of cells immediately beneath, in the well-lighted portion of the plant, are green with chloroplasts and have as their function photosynthesis. Surround-

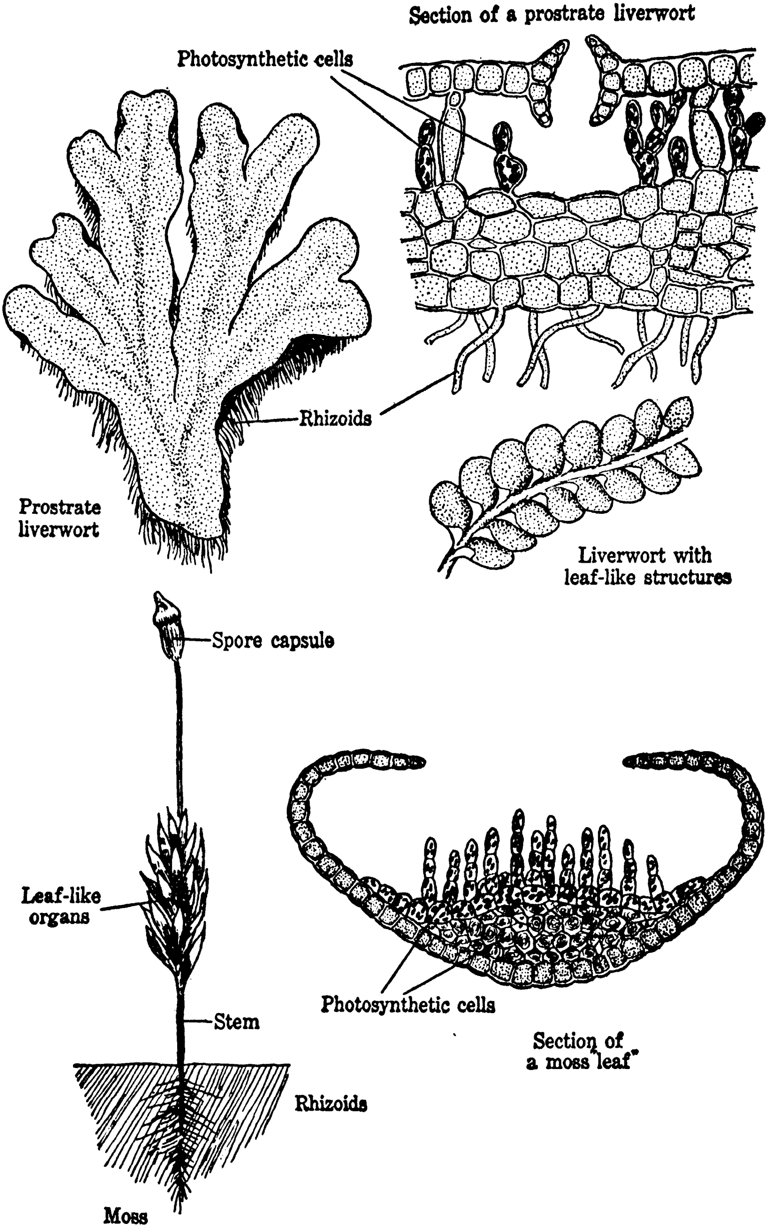


FIG. 31.—The plant body of the bryophytes, the simplest land plants.

ing these green cells are air spaces so that the carbon dioxide and oxygen can circulate freely, coming in through pores in the epidermis. Beneath the photosynthesis layers, where the light is poorer, the cells tend to be colorless and function for storage. The lowermost layer of cells develops hair-like processes known as *rhizoids*, which absorb the water with its dissolved minerals. Thus Marchantia exemplifies the simplest type of plant body, lacking true organs but possessing tissues especially adapted for terrestrial existence. Other liverworts show varying types of this same plant body. All of them are restricted to damp and shaded situations, such as are found in swamps, along the sides of ravines, under overhanging ledges, or on the stones in streams, chiefly because of their primitive reproductive habits which will be discussed in a later chapter.

Non-vascular Leafy Plants.—One of the most characteristic plant organs is the leaf. Each leaf is made up of various tissues necessary for photosynthesis to take place; and when the plant body has leaves, usually photosynthesis is restricted to them. The leaf is therefore the last word in the evolution of that part of the plant concerned with constructive metabolism. Thallus plants have no leaves, neither do most of the liverworts. Marchantia was used as an example of a non-leafy land plant of a primitive type. But relatives of the liverworts, the mosses, represent the stage of the development of the plant body in which leaf-like organs make their *début*.

Mosses advanced over the liverworts in several respects: they adopted the erect habit, restricted the photosynthetic tissues mainly to leaves arranged on a supporting stem, and developed a basal mass of rhizoids for anchoring the plant and absorbing nutriment from the ground. Their chief lack was the inability to develop effective vascular (or conducting) tissues. Lack of such tissues has predestined the mosses to be small and insignificant plants.

The common hairy cap moss of pastures and roadsides is a typical member of the group. Each plant is about an inch in height, and consists of three distinct parts. A tuft of filamentous rhizoids anchors the plant to the earth rather ineffectively, and also absorbs the water and dissolved minerals. In this respect the mosses and liverworts are alike. There is a frail stem, consisting of a closely packed mass of cells, of which the outermost layers may contain chloroplasts whereas the innermost ones lack them. These colorless stem cells show a little specialization for support but not for conduction of materials. The leaf-like organs are attached to the stem, and are the greatest innovation in the plant body, adopted from this group on as standard equipment in all the higher plants. The moss leaf is hardly a true leaf, with the cell specialization found in the leaves of flowering plants; there is usually but a single layer of chloroplast-bearing cells in the thin structure. In some cases, erect rows of cells grow out from the surface to increase the photosynthetic area. In a simple way, the hairy cap moss indicates the division into root, stem and leaf which is the pattern found in all higher plants.

Vascular Land Plants.—At the moss stage we see a terrestrial plant body characterized by distinct tissues for carrying on absorption, anchorage, support, photosynthesis and protection. Additional tissues necessary in making land vegetation widespread and successful include better supporting cells and adequate conductive channels. The first plants to exhibit these in definite organs (roots, stems, and leaves) are the ferns. Today, in temperate regions, these plants make up a small and inconspicuous part of the land vegetation, chiefly because of handicaps in reproductive characteristics which will be considered in a later chapter. In the geologic past, however, the ferns dominated the lands, being the first plants to develop woody tissues; thus they formed our first forests. However, it is in the flowering plants, the most highly developed of the seed plants, that we find the culmination of the vegetative as well as of the reproductive specialization possible in the plant kingdom. Since the root, stem and leaf of the fern are much like those of the flowering plant, it will be sufficient to consider only the latter.

An oak tree, for example, displays a great amount of organization, all with a view toward efficiently carrying on plant metabolism. Its organization is centered around the leaf, the place where the major activities are carried on; and the entire structure of the tree may be said to serve three major purposes: (1) to bring the leaves into maximum exposure to the sunlight, (2) to bring to the leaf an adequate supply of raw materials, (3) to conduct the finished products away from the leaves to the places of storage or of secondary activities. The tree is constructed therefore in such a way as to lift its leaves up into the air where they can get the full benefit of the sunshine. In this position they are brought into direct contact with the carbon dioxide. The two other supplies, water and minerals, can be secured only from the soil, and consequently a system of conveyors is required to bring these substances to the leaf. Conveyors are also necessary to carry the finished products from the leaves to cells where they are to be used. Each of these systems consists of many different kinds of tissues which perform different parts of its general function; these are grouped in three sets of organs—the leaves, the roots, and the stems.

The leaf is beautifully adapted for performing photosynthesis. In the first place, it is broad and flat, so as to expose the largest possible surface to the energy of the sun's rays. Secondly, the arrangement of the chloroplast-containing cells within it is such that those containing the most chloroplasts are near the top where they will receive the most sunlight. Next, the photosynthesizing cells are protected from an excess of sunlight, which would tend to overheat them and dry them up, by a special layer of colorless cells, the epidermis, the outer walls of which are coated with a glossy layer of wax-like material. The fourth provision of these "factory rooms" is an efficient ventilating system for the circulation of gases. The epidermis is perforated by a number of openings, the *stomata*, which communicate with a network of cavernous passageways extending throughout the leaf. Carbon dioxide, entering through the stomata, circulates throughout these passageways, in this way coming into contact with every one of the photosynthesizing cells. In the same way the oxygen given off from the cells by photosynthesis can diffuse through them and out through the stomata. Finally, the leaf contains a network of branching *veins*, which serve as a framework to support its structure and, more important, as a distributing system connected with the conveyors of the stem. Water, flowing up the stem and into the leaf stalk, travels through the veins until it reaches the tips of the smallest veinlets, from which it diffuses into the photosynthesizing cells. The food, manufactured by photosynthesis and stored up in the chloroplasts during the daytime, at night passes into these same veinlets and is transported down the leaf stalk into the stem, which carries it to places of storage or of growth.

The only constant supply of water available for photosynthesis is that which fills the gaps between the particles of soil in which the roots are buried. Hence it is the roots which must receive the water and the mineral salts dissolved in the soil for the use of the leaf. The tips of the roots of any large plant are always in contact with the soil water. It is in certain regions near the root tips where most of the water absorption occurs. At the very tip of the roots growth takes place, and just behind this region the root is covered with a cobweb of tiny hair-like extensions of the outer layer of its cells. These *root hairs* thoroughly permeate the soil for an area of a half inch or so in diameter surrounding the root. It is here that absorption takes place. Diffusion of water and salts through the walls and their absorption into the cell easily occur. Then, by a continual process of diffusion, these substances make their way from cell to cell to the inner portion of the root where they enter the conducting cells, which carry them up the stem of the tree to the leaves.

Aside from its rôle in the absorption of water and food from the soil, the functions of the root are quite similar to those of the stem; namely, to conduct materials going to and from the leaves, to store food, and to hold the tree firmly in place. Both root and stem, therefore, possess conducting cells, supporting cells, and storage cells. In addition, there are protective cells and growing cells in both. The arrangement of the tissues is slightly different in the root than in the stem, but to avoid confusion we shall describe the stem only.

The stem includes the trunk with its branches, down to the smallest twigs. In any cross section of this stem we can identify three regions which perform the important functions outlined above. These are the *wood*, the inner bark or *phloem*, and the outer bark or *cortex*. The wood, which composes the greater part of the stem, has two important functions: supporting the tree and conducting the water from the root to the leaves. The main burden of these two functions is undertaken by two very different types of cells, the location of which can easily be seen by a glance at an oak board which has been cut across the grain. It is traversed by a series of bands, the annual rings, in which light-colored wood alternates with dark. In the light wood are many tiny pores, the openings of long tubes known as *vessels*, which in the living oak extend up and down the trunk and are the conductors of water.

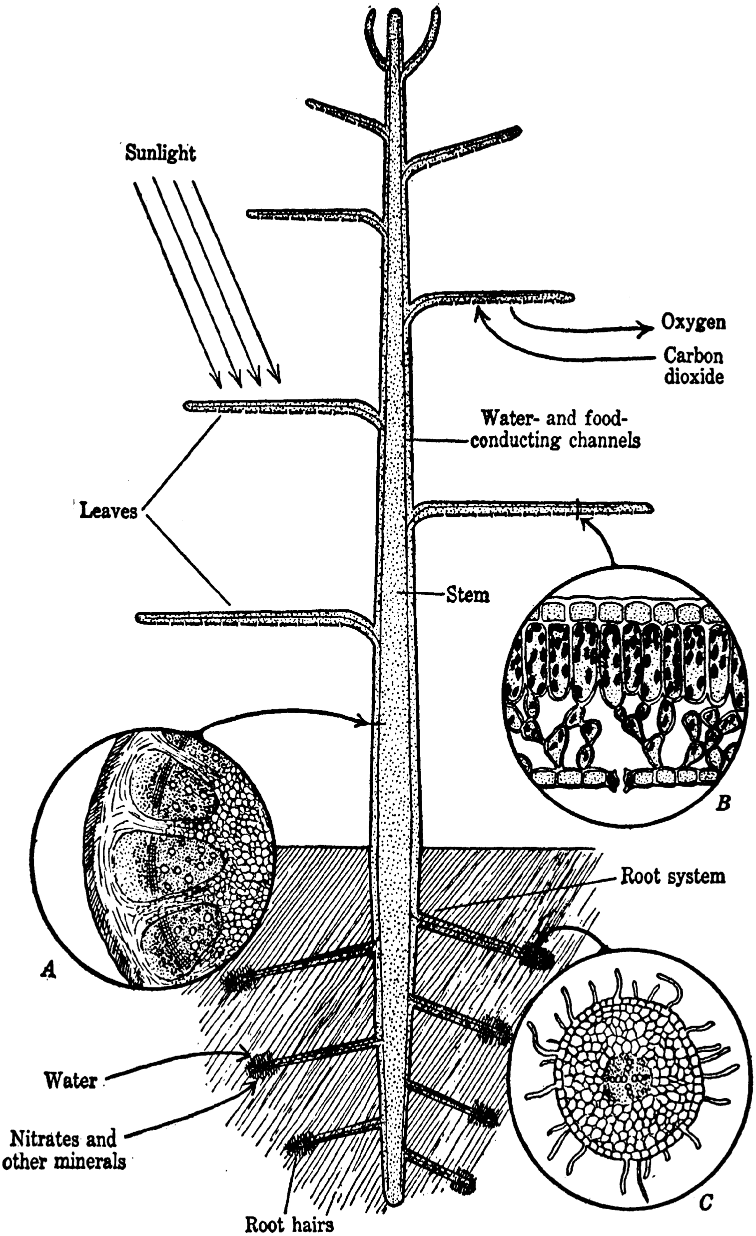


FIG. 32.—Diagram of the plant body of a seed plant (spermatophyte).

The dark wood of the annual ring consists mostly of very slender cells with thick walls, known as *fibers.* These are the supporting cells of the wood, and on the number and strength of them depend the hardness and strength of different kinds of hard woods. Both vessels and fibers are simply the dead skeletons of cell walls. A third type of cells may be mentioned in passing. These are the *ray* cells, seen in the wood block as thin dark bands extending across the annual rings. They serve the purpose of food storage.

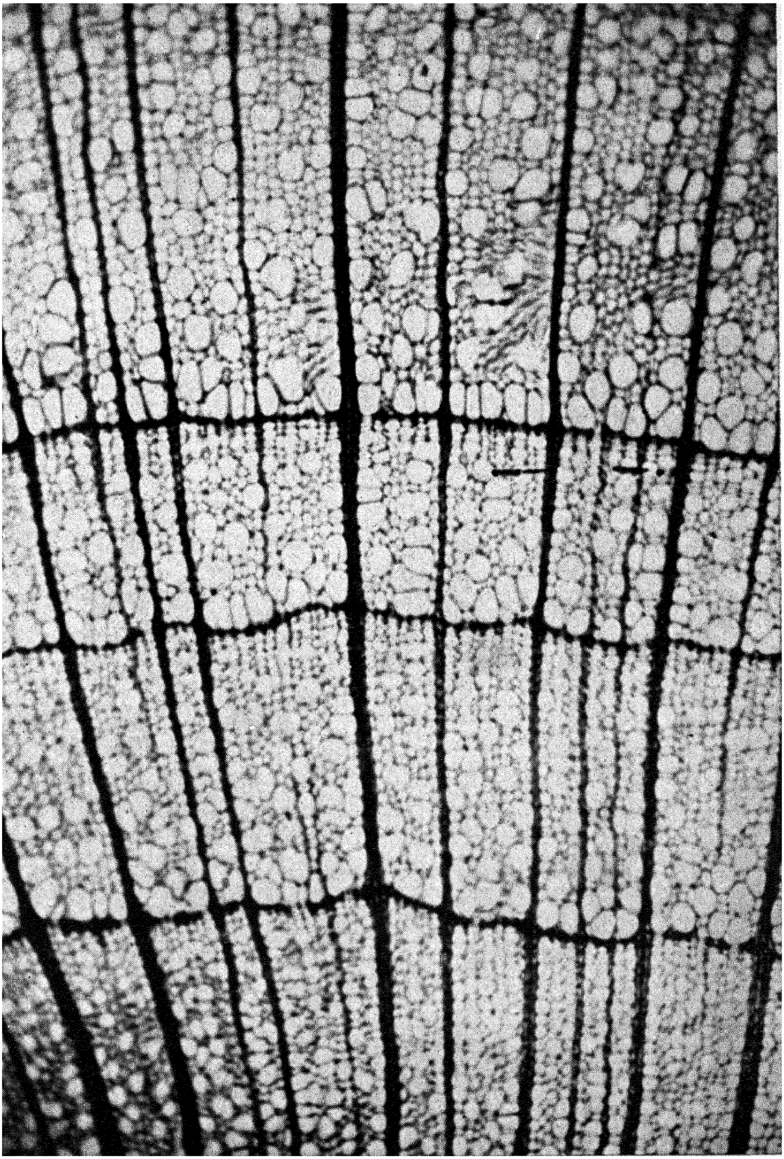
The inner bark, or *phloem,* contains, like the wood, two main types of cells which have the two functions of conduction and support. But in the phloem the conducting cells conduct food rather than water. These cells are called *sieve tubes,* since their end walls are perforated like a sieve. They differ from the vessels of the wood in that they contain protoplasm and have thinner walls. The phloem fibers are, like those of the wood, slender and thick-walled. The outer bark or cortex consists mostly of dead corky cells which are well fitted to protect the inner layers.

The organization and activities of the oak tree are typical of those found in all woody plants. These plants differ from the smaller flowering plants mainly in the ability of their stems to build up annual layers of woody tissue and thus make perennial trunks. In many parts of the world most of the smaller plants are annuals for this reason, growing from seed and reaching maturity each year.

That this type of plant body is most successful on land is obvious when we notice the overwhelming preponderance of seed plants over ferns, mosses, liverworts and fungi. This culminating type seems indeed a far cry from the minute Protococcus, existing practically unknown upon the bark of the forest giant which is at the other extreme of plant organization. Yet both live basically in the same fashion; their metabolism is identical. In between the two we can see, living today, intermediate types of plant bodies which demonstrate to us how the maintenance structures of the one are logically related to those of the other.

Chapter Summary

In Protococcus plant metabolism is carried on within the confines of the single cell which makes up the body of the organism. As we consider multicellular plants, division of labor results in



Section from a woody stem. The large cells are vessels. The dark lines are formed by ray cells.

various aspects of metabolism being taken care of by special groups of cells. Unlike animals, plants have no need of complex digestive, respiratory, locomotor or nervous organs. The evolution of the plant body into higher types has involved development of tissues and organs concerned with photosynthesis, absorption of raw materials, and conduction of these as well as of finished food products from one part of the plant body to another.

The thallus plants represent the simplest type of multicellular plant body, lacking differentiation into roots, stems or leaves. Of these there are two types, the algae and the fungi; the former possess chlorophyll and carry on normal green plant metabolism, while the latter lack the chlorophyll and hence live as saprophytes or parasites.

Some of the flagellated algae, such as Volvox, form motile colonies; but the larger thallus plants, and from them, all the higher plants, have evolved from non-motile forms. Among the latter there are colonial plants with cells embedded in a gelatinous mass, lacking division of labor among themselves. More advanced is the filamentous body, with each plant being a thread-like row of cells attached end to end; such is the common fresh-water pond scum, Spirogyra. In many cases, these filaments branch to form bushy and tufted plants several feet in length. This is a highly successful type of plant body not only among these green algae, but among the other two groups of algae, the brown and the red algae. The latter two are predominantly marine, known as seaweeds. The most complex and massive plant body of all is found among the brown algae, especially among the large kelps, which are differentiated into holdfast, stem and flattened photosynthetic leaf-like portion. The fungi have filamentous and branched bodies which form a tangled mass of colorless threads in contact with the nutrient substratum. From this the reproductive structures grow out, conspicuous in the case of the common mushrooms.

Higher in the scale of plant complexity are the primitive land plants which lack vascular tissues and leaf-like outgrowths. Such are the liverworts, as typified by Marchantia, with its compact prostrate body able to stand terrestrial drying out, its ventral rhizoids, and special photosynthetic tissues.

The moss plants show certain advances over the preceding groups of plants, notably in the erect habit and the division of the body roughly into root-like rhizoids, stems, and leaf-like expansions attached to the stems. This type of plant body can be seen in the hairy cap moss.

To make plant life on land a success, special conductive, or vascular, tissues were needed. These are lacking in the mosses. The fern plants introduce this innovation, possessing true roots, stems and leaves. Built on the same maintenance system plan, the highest group of plants—the seed plants—possess definite advantages in reproductive habits which have made them practically sole victors in the struggle of plants to inhabit the land. A typical seed plant is the oak tree, whose structure is designed to serve three main purposes:

1. To bring the leaf into maximum contact with the sunlight.
2. To supply the leaf with raw materials for photosynthesis.
3. To conduct the manufactured food through the plant.

The leaves, roots, and stem play the following rôles in these processes:

Leaf:

1. Exposes large surface to sunlight.
2. Provides chloroplast-containing cells most abundantly on side nearest the light.
3. Provides a protective layer of cells, the epidermis.
4. Provides a ventilating system, consisting of stomata and intercellular passageways, for circulation of gases.
5. Provides veins, for support, conduction of water to, and food products away from, the leaf cells.

Roots:

1. Absorb water and mineral salts from the soil through root hairs.
2. Conduct these substances to the stem.

Stem:

1. Conducts water from the roots to the leaves, by means of the vessels of the wood.
2. Conducts food materials throughout the plant by means of the sieve tubes of the phloem.

3. Supports the plant by means of fibers in both wood and phloem.

The outer bark, or cortex, of the stem serves to protect it.

QUESTIONS

1. What organ systems are necessary in a high type of multicellular animal which are unnecessary in a multicellular plant such as the moss? Why?
2. What is a thallus plant? Give examples.
3. What type of plant body is exemplified by Volvox?
4. Why are most of the algae aquatic plants?
5. Name and describe the types of plant body found among the algae.
6. What type of plant body is common among the fungi?
7. What two contrasting types of metabolism are found among the thallus plants?
8. What three basic modifications for terrestrial living are shown by a liverwort such as Marchantia?
9. What advances in plant body design are to be seen in the mosses? What important one is lacking?
10. Name the three main purposes for which the structure of a typical seed plant such as the oak tree is designed.
11. What division of labor is to be found among the cells of a leaf?
12. What division of labor is to be found among the cells of the stem of a woody plant?

GLOSSARY

algae (al′jē) sing. *alga* (al′ga) Chlorophyll-bearing thallus plants, mostly aquatic and known as pond scums and seaweeds.

bracket fungus A type of wood-rotting fungus, the reproductive bodies of which are shelf-shaped and occur on the sides of trees and dead wood.

epidermis (ep-i-durm′is) The outer layer of cells of a plant, best seen on the leaf.

ferns A class of plants possessing true roots, stems and leaves; reproducing by spores, not flowers.

fiber Slender thick-walled cell found in the stem and root system of plants, used for support.

filament Thread-like type of plant body, made up of a series of cells attached end to end, common among the algae and fungi.

fungi (fun′jī) sing. *fungus* (fun′gus) Thallus plants lacking chlorophyll; vegetative body a mass of filaments.

liverwort A plant belonging to a class of plants intermediate between the algae and the mosses; green terrestrial plants, generally prostrate and lacking stems and leaves.

Marchantia (mar-kan'ti-a) A liverwort.

phloem Inner bark of the stem, whose chief function is the conduction of food materials in solution.

rhizoid (rī'zoid) A filamentous absorbing structure, carrying on the functions performed by roots of higher plants; found in the liverworts and mosses.

root hair Outgrowth of epidermal cell of root; function, absorption of water and minerals in solution.

Sargassum (sar-gas'um) A type of brown alga displaying considerable specialization of structure.

sieve tube One of the conducting cells of the phloem.

Spirogyra (spī'rōjī'ra) A common pond scum. It is a filamentous green alga.

stoma (stō'ma) pl. *stomata* (stō'ma-ta) Openings in the epidermis of the higher plants, particularly in the leaves, which permit exchange of gases.

thallus (thal'us) A plant body not differentiated into roots, stems or leaves or similar structures.

vascular (vas'kū-lar) Pertaining to a system for conducting materials.

vessel A long tube-like structure found in wood of seed plants, serving for conduction of water.

Volvox A spherical colony of flagellated plant cells.

CHAPTER VII

THE WEB OF LIFE

So far we have considered the living world from the individualistic point of view; but in limiting our attention to the structure and activities of the individual we are likely to get a mistaken idea of the self-sufficiency of any organism, thinking of it as a perfect mechanism capable of maintaining its existence alone in a physical environment. Such biologic isolation is very unusual. On the contrary, few organisms can live as independent units, for there is an entangling web of alliances which binds together the various species of plants and animals and which, like all alliances, is often beneficial to one party while harmful to the other. Because of this interdependence of living things in the balance of nature, organisms must be thought of as parts of a whole rather than as entities in themselves.

This interdependence extends through the whole realm of life. One insect pollinates a flower, another sucks out its juice; the grass stem harbors the young grasshopper, but the pitcher plant drowns and devours insects; some birds scatter the seeds of plants, others destroy the seedlings; man is killed by the ravages of one microorganism but depends upon another for his bread; one fungus deprives us of chestnuts, another makes possible the growth of orchids. Such linkages are not isolated curiosities, they are meshes in the limitless web of life.

Sometimes interdependence involves the assistance which one organism gives to another in carrying out its work of reproduction. Insects, for example, often bring about the pollination of flowers and in return receive food from them. More widespread is the dependence of one organism upon another for the maintenance of life, for protection, or especially for food. It is with these latter relationships that we shall deal in this chapter. In the simplest type of interdependence, there is no organic association among the organisms involved. While dependent upon each other for existence, they live separately. The most important interrelationships of this type are the food linkages, or cycle of food elements, whereby the materials necessary for metabolism are kept in circulation and constantly available for living individuals. They include (1) the dependence of animals upon green plants as the ultimate source of all their organic food, and (2) the dependence of green plants upon bacteria for a constant supply of carbon and nitrogen, with the converse dependence of saprophytes upon green plants and animals for their organic materials.

Of a more complex nature are those interrelations which involve a certain amount of biologic association, or living together. They are of three types: (1) an external partnership of different species known as *commensalism*, literally meaning "eating at the same table"; (2) an internal partnership which is mutually beneficial, neither member of the concern injuring the other, each contributing something to the general upkeep, which is known as *symbiosis;* (3) a partnership which is definitely one-sided, one member of the firm living at the expense of the other, and contributing little or nothing to the partnership; this is known as *parasitism.*

The Dependence of Animals upon Green Plants.—In Chapter II the importance of green plant metabolism to the whole organic world was emphasized. The abundance of green plants which make up the vegetation of the earth, both on land and in water, has made possible the variety of animal life as it exists today. In the oceans, great numbers of algae synthesize carbohydrates from the water and the carbon dioxide dissolved in it, converting these into proteins by utilizing the dissolved salts found in the water. Protozoa and other minute invertebrates feed upon the algae; fishes and larger aquatic vertebrates feed upon these smaller animals, so that the food linkage may extend from microscopic algae to whales and sharks. Without the former there can be none of the latter. In fresh waters, too, the algae are the basic source of all the food for fishes and other fresh-water animals.

Likewise on land, there had to be green plants before there could be a successful migration of animals landward. These plants, probably the ancestors of present-day liverworts, mosses and ferns, had first to colonize the bare wastes of soil and rock. Then their waste products and dead bodies formed a substratum of decaying organic matter upon which more and larger plants could gain a foothold. With the advent of swamps, forests and prairies, land animals were able to secure a constant supply of food substances. An abundance of land-dwelling reptiles, birds and mammals thus became possible.

It is obvious that the plant-eating, or *herbivorous*, animals are dependent upon vegetation for their very existence, but this is not so apparent for the host of *carnivorous*, or meat-eating, animals. But the food chain eventually leads to some inconspicuous plant-eating animal, often microscopic. Thus the ferocious tiger becomes ultimately dependent upon the insignificant grasses which he treads under foot. The large fish eats the smaller one and this one in turn an even smaller fish, and so on, until at length we find the plant-feeding individual who, for all his unknown existence, is still the important link between the animal and the plant kingdom.

The Importance of Bacteria in the Cycle of Food Elements.—Decay is a common biological phenomenon, generally considered an unmitigated evil. It is true that decay does destroy a small percentage of food and other articles of use to us; but, on the other hand, if there were no decay, life would generally slow up, and, because of a lack of essential raw materials for plant metabolism, eventually there would be no living organisms—at least none like the plants and animals of today. Decay is the result of the activity of bacteria and fungi, whereby these organisms tear down the protoplasmic substances that other organisms have built up, in order to get organic food for themselves.

As plants and animals, generation after generation, increase in bulk by growth, they are continually abstracting from the environment the two very important elements, carbon and nitrogen. Therefore it is simple arithmetic to understand that as life increases the number and size of individuals, more and more of these key elements are withdrawn from circulation and locked up in the protoplasmic materials making up living things. Carbon dioxide is essential for photosynthesis, yet there is not an endless supply of it in the world. Only 0.03 per cent of the atmosphere is carbon dioxide; this is the equivalent of about 5.84 tons of carbon over each acre of the earth's surface. Many crops, such as sugar cane, extract 15 to 20 tons of carbon per acre. Even with diffusion of this gas from one part of the atmosphere to the other, at the average plant consumption rate plants would use up all the carbon dioxide in the atmosphere in thirty-five years! With all the carbon locked up in the bodies of plants and animals, living and dead, life would necessarily cease to be a characteristic of the planet.

The carbon must get back to the atmosphere somehow, since life has gone on, according to the fossil record, for over a billion years. Some of it is returned to the atmosphere as carbon dioxide by respiration. There is an interesting interdependence between animals and plants in this respect, best illustrated in a "balanced" aquarium. If just the right quantities of green plants and animals are in the aquarium, it can be covered and left alone for months. During green plant metabolism carbon dioxide leaves the water to go *into* the plant, while during animal katabolism the carbon dioxide goes *out of* the animals. Thus one uses up what the other discards. At the same time, as a by-product of the plant metabolism, oxygen is given off, going *out of* the plant into the water; and, during animal respiration, the oxygen leaves the water and goes *into* the animal. Without the green plants there would be no continuous supply of oxygen to keep the fish, or other aquatic animals, alive; nor would there be any means of removing the carbon dioxide from the water. Conversely, without the animals, there would not be as much carbon dioxide available for the plants. There is the same give-and-take in the case of land plants and animals. The vegetation removes carbon dioxide from the atmosphere and returns the oxygen which is essential for respiration.

Perhaps most of the carbon, however, gets back to the air through the agency of decay bacteria and fungi. These organisms are found everywhere, and they begin decomposing plant and animal tissues as soon as life has left them. Thus the remains of past generations are removed from sight, instead of becoming encumbrances to following generations; and the complex organic compounds which constitute protoplasm are reduced to simpler substances and eventually returned to circulation. For example, wood is a common substance in which vast amounts of carbon are locked up as cellulose. There are many wood-digesting fungi which can excrete enzymes that change the cellulose into glucose and organic acids, finally into carbon dioxide and water. Thus as the wood decays and disappears, the carbon is returned to the atmosphere whence it originally came, ready to be used over again by living plants. All carbohydrates in plant and animal tissue, upon the death of the individual and in the presence of organisms of decay, thus are broken down into carbon dioxide and water, and these two substances are returned to the physical environment to begin a new cycle.

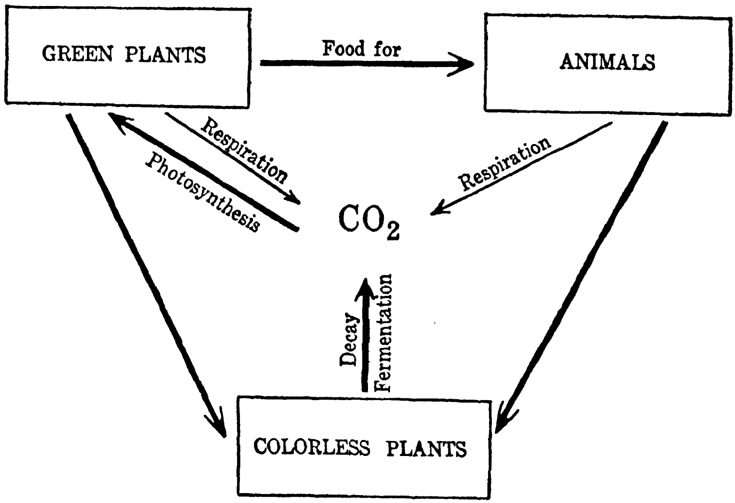


FIG. 33.—Diagram of the carbon cycle.

Nitrogen is the element essential for protein-building, and therefore for producing protoplasm. Few plants (and no animals) can utilize the vast store of nitrogen which exists in the atmosphere, to the extent of four-fifths of all the gases combined. Plants synthesize their proteins from the nitrates absorbed from the soil; thus the supply of nitrates in the earth is the sole storehouse for the nitrogen needed in making protoplasm. As in the case of the carbon cycle, it is obvious that if nitrogen is removed by the tons from the soil, wherever there is vegetation there must be some way in which nitrogen can get back to the soil to make good the loss. Otherwise, it would eventually all become locked up as proteins in the dead bodies of plants and animals.

Here again the rôle of bacteria is an important one. The huge protein molecules are attacked by certain species of decay bacteria, and changed to ammonia. The ammonia, in turn, is used as a source of energy for carbon synthesis by other species of bacteria, known as *nitrite bacteria* because they change the ammonia to nitrites during the process. Still other bacteria (the *nitrate bacteria*) obtain their energy through the oxidation of these nitrites

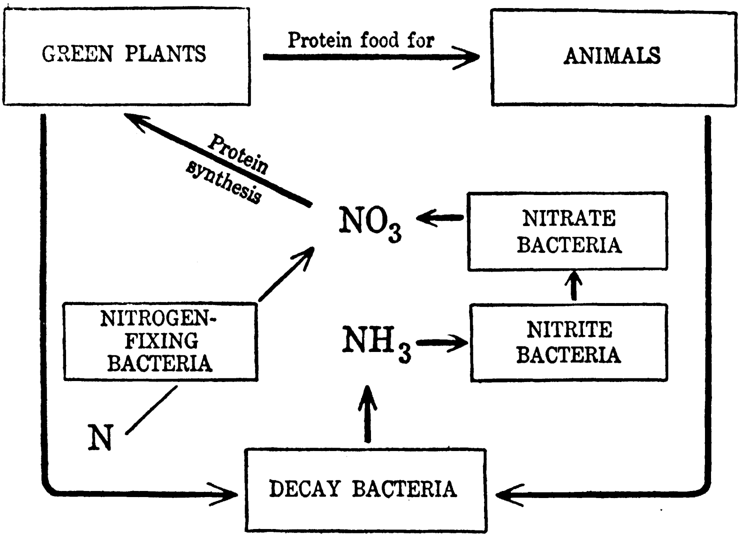


FIG. 34.—Diagram of the nitrogen cycle.

to nitrates. And with the release of nitrates into the soil, the nitrogen is again made available for protein synthesis on the part of green plants—as a result of the chain of decay, nitrite and nitrate bacteria.

But this is not all. New supplies are added to the soil by other bacteria, the *nitrogen-fixing bacteria,* which are able to remove the nitrogen from the atmosphere and leave it in the soil as nitrates. Some of these nitrogen-fixing bacteria are free-living, utilizing the carbohydrate materials in the soil as a source of energy for the fixation of the nitrogen. These soil bacteria are more abundant in light, well-aerated soils in which there is some decay in organic material, than in the heavy, soggy ones. Other nitrogen-fixing bacteria live symbiotically in the roots of various plants related to peas, clover and alfalfa, where they form little nodules. When the plants die and are not removed from the soil, these nodules decompose and add nitrates to the supply available for green plants. Since soils can be enriched in this way, it is wise to alternate crops

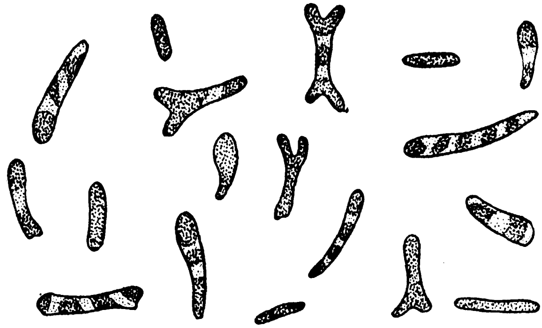


FIG. 35.—Nitrogen bacteria in clover roots.

of such nodule-bearing plants with others which do nothing but extract the nitrates.

Commensalism.—In this type of biological association there often seems to be no obvious advantage to either organism; at

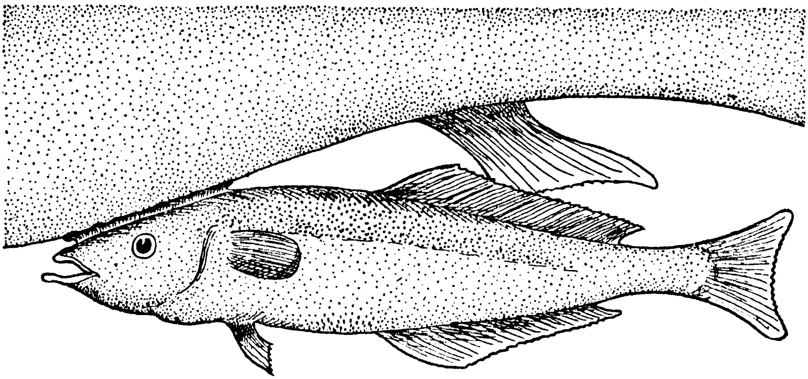


FIG. 36.—Commensalism: shark sucker attached to shark.

other times the two organisms are mutually of aid in getting to the food supply. Some small crabs have as their homes the branching water canals of sponges; other crabs have their "shells" covered with small sea anemones. The young of some fish are always found in company with large jellyfish, so that they can hide under the protective tentacles of the latter when pursued by their enemies. The shark sucker is a fish especially adapted to fasten itself beneath the body of a shark by means of an attachment device on the top of its head, thus getting free transportation and often food remnants discarded by the larger fish.

Symbiosis.—Symbiosis is a type of association between different species, in which both partners benefit mutually from the

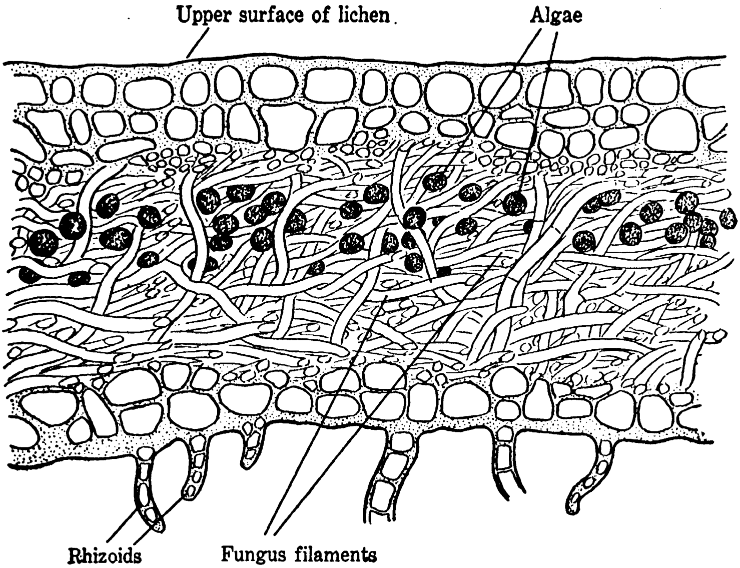


FIG. 37.—Plant symbiosis: section view of a lichen.

relationship. Sometimes both species are plants, at other times both are animals, and in some cases one is a plant and one an animal.

Lichens afford a striking example of the advantages of such a partnership. Lichens are a group of thallus plants, classified with the algae and fungi as the lowest group of plant life. They are usually low-growing, crust-like plants of a gray-green color, growing on bare rock or trunks of trees. One very common lichen, which is known as reindeer moss, forms light-gray cushiony masses on the ground in the northern woods. A very noticeable characteristic of the lichen is its ability to grow on such inhospitable substrata as bare rocks, where no other plants can live.

Lichen plants. Examples of symbiosis.

It attaches itself firmly by means of tenacious hair-like rhizoids on its under surface; there is no other apparent specialization—such as stems or leaves—in these peculiar plants. If we section a lichen, however, we discover the reason for their ability to live as they do. Each lichen is largely made up of a mass of twisted fungous filaments, holding in their meshes many minute spherical single-celled algae. The green algae carry on photosynthesis, thus manufacturing food for themselves. The fungus absorbs some of this food from the alga, but in turn protects the little green plants from drying out. Thus the combination of both plants makes it possible for the species of algae and fungi to live in exposed situations where neither of them could live alone.

Lichens are not the only examples of two plants living together in symbiosis. The bacteria in the root nodules of peas and clover, noted earlier in the chapter, form a combination mutually beneficial. There are also many orchids which live in a symbiotic relationship with certain root fungi.

Termites are well known for their ability to destroy wood. These wood-devouring insects have this special ability (fortunately lacking in most animals) because they have, living within their alimentary canal in a symbiotic condition, certain species of Protozoa that are able to digest cellulose, the termites in reality only indirectly subsisting upon the wood. The Protozoa get a home and transportation, while in turn the termite gets a type of food refused by most other animals and hence very plentiful.

There is a beetle which is commonly a guest in ant nests. The beetle is blind and thus unable to get its own food easily, but the ants take care of him and feed him. In return, the ants are allowed to lick a tuft of hair which grows at the base of the wing covers of the beetle. There are other examples of such insect guests in ant nests which are fed solicitously, and which give in return certain secretions that are evidently considered ample repayment for the time and effort expended on the part of the ants. Other examples of symbiosis are the crocodile bird, which removes leeches and decaying food remnants from the mouth of the crocodile; and the American cowbird which often is found on the backs of cattle, from which it removes various parasites upon which it subsists.

On the other hand, symbiosis may be the result of a plant and an animal living together amicably. Many Protozoa have green algal cells within themselves; the minute single-celled plants provide food for the Protozoa and get shelter plus various other advantages in return. Such single-celled algae are also commonly found in the endoderm of Hydra, giving the animal a bright green color. Here too, the products of plant metabolism are used by the Hydra, and in repayment the algae get protection and the materials needed for their existence.

Parasitism.—In this type of relationship, which is much more common than symbiosis, one "partner" receives all of the benefits, and usually inflicts some damage on the other. The member of the partnership which thus receives all the advantage at the expense of the other, becomes the parasite; while the other organism thus entangled in an association which he cannot escape becomes, whether he so desires or not, the host. Most of the diseases which afflict the human race are the result of man's being drawn into such a relationship—a condition which furnishes the battle ground for the thousands of scientists constantly engaged in medical research. In many cases both the parasite and the host become structurally changed, so that the parasite is better fitted to extract its food from the host and the host is able to carry this extra organic load with the least possible damage to itself. In the parasite such organs as are not needed in the new life, mainly those concerned with locomotion and food-getting, are much simplified; organs of reproduction, on the other hand, become highly complex and specialized, so that enough offspring will be produced to make sure that one reaches a proper host. Most parasites are adapted for a specific host, making reproduction and dispersal a hazardous undertaking.

There are six main types of parasitism, depending upon the kind of organism which functions as host and that which is the parasite.

Most uncommon is the combination of two green plants in such a one-sided relationship. Since the dependent parasite in such cases is green, it can manufacture its own carbohydrate food and thus is partly self-supporting; often this is called hemi-parasitism. Such is the case with the mistletoe, which grows upon woody plants, sending absorbing roots into the host plant, from which it gets its supply of water, and probably a small part of its food.

Indian pipes. A plant parasite.

Also fairly uncommon is the combination of a flowering plant as the parasite and a fungus as the host—the reverse of the common condition in which the fungus is the parasite. Indian pipes are graceful ghostly-white plants which have lost their chlorophyll, the leaves being reduced to small clasping scales on the pale stem; the flower, which is borne at the tip of the stem, is also white. Unable to carry on photosynthesis because of the absence of chlorophyll, the plant gets its food materials from a fungus which

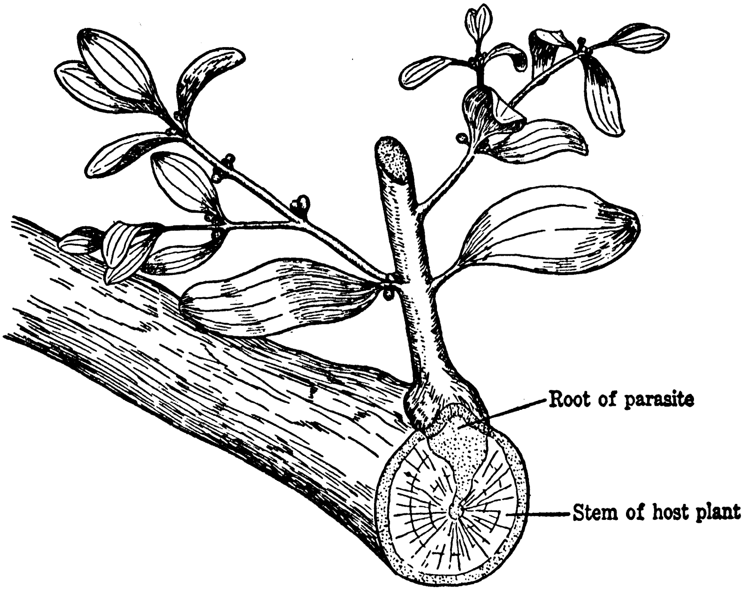


FIG. 38.—Plant parasitism: Mistletoe. (Redrawn from Brown's *The Plant Kingdom,* Ginn and Company.)

grows in association with the roots. The fungus gets its nourishment from the organic débris in the soil.

Very widespread is the parasitism upon green plants by the thousands of species of fungi. Plant diseases cost the human race millions of dollars yearly, as crop plants which were being relied upon to give us our grains, fruits and vegetables become the victims of rapidly spreading parasitic fungi. In many cases the spores of the fungus are carried by the wind and infect the leaves of healthy plants. In the host tissue the spore germinates into a branching mass of filaments which sap the green cells of their food; greedily the fungus spreads from one part of the plant to the other, often destroying all the leaves, with consequent death to the plant. The white pine blister rust, the wheat rust, the chesnut blight, are just a few of the common fungi which have cost us countless millions of dollars' worth of valuable plant life.

Plant diseases closely parallel the features of human diseases. The microorganisms, in this case the spores, penetrate the healthy

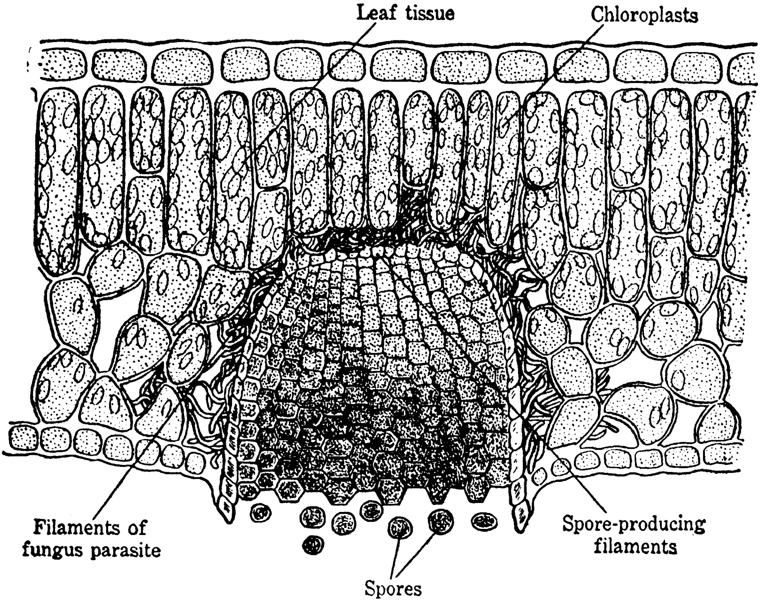


FIG. 39.—Plant parasitism: wheat rust fungus in leaf.

plant in one of three ways: through a wound, through natural openings such as the breathing pores in the leaves, or even through intact surfaces, since some types of spores produce digestive fluids capable of dissolving such surfaces. Sometimes, moreover, the fungus spores become enclosed within the seed of their host, and attack the seedling as it starts growth. Once the spore has gained entrance to the host plant, it germinates into a branching mass of filaments which grow rapidly through the plant, finding accessible tissues where the filaments can send tiny but destructive suckers into the cells where the food supply awaits them. Some fungi attack the leafy parts of a plant, soon destroying the entire photosynthetic apparatus and thus often killing the plant; others eat away the portions of the trunk beneath the bark, leaving a weakened and rotting mass of wreckage behind them. And while this is going on, the fungus begins reproducing, sending off from the surface of the infected plant millions of other spores which are carried by the wind to new hosts. Little wonder that battling plant diseases seems an almost superhuman task! To make matters more complicated, there is often an alternation of hosts, the fungus going from a wheat plant to a barberry, or from a pine to a currant bush, living part of its life on one species, part on another. When the life history of such a fungus becomes known, however, control of the disease is simplified, because eradication of one host usually means protection and salvation for the other.

Green plants also become unwilling hosts to animal parasites. This is particularly true with the great numbers of plant-feeding insects. Aphids, scale insects and gall insects become attached to specific host plants, which often are valuable orchard or timber trees, much to the injury of the latter. Such parasites often completely change the tissues of the host in which they are lodged, stimulating them to abnormal growth. Galls are abnormal swollen portions of plants produced by many different kinds of insects, particularly midges and gallflies. A well-known example is the "oak apple" produced on the twigs of oak trees. The gallfly lays an egg under the bark of the twig; and when the egg hatches, the larva lives on the tissue of the oak and stimulates it to produce the round ball within which the mature caterpillar lies, well protected, during the winter. In the spring, the adult fly bores its way out of its plant cradle and flies away. Similar insect galls are the swellings found on the stems of asters and goldenrods, and on various roses.

One of the best-known forms of parasitism is that involving animals both as hosts and as parasites. When these parasites are merely attached to the exterior of the host animal, they are known as *ectoparasites*. Such an external parasite is a species of lamprey eel, which remains attached to other fish by its sucker-like mouth until the host is destroyed. Lice, fleas and mites often live thus as parasites on the skin of warm-blooded animals. The ox botfly lays its eggs on the hair of cattle; when the larvae develop they bore through the skin and live there until spring. Then they burrow out, fall to the ground and complete their metamorphosis into free-living flies—ready to repeat the whole process again. Human lice cement their eggs to the hair, a new batch of lice appear within a week, and as each new generation appears it feeds upon the roots of the host's hair.

Internal parasites live more completely within the tissues of their host, often in his alimentary canal. Such is the tapeworm, a segmented invertebrate common in the digestive tract of many

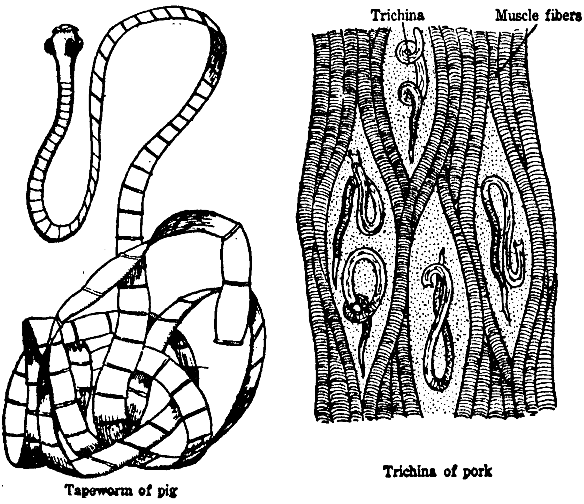


FIG. 40.—Animal parasites.

animals as well as man. The life cycle of the human tapeworm begins when one eats some incompletely cooked beef, pork or fish containing little milky-white cysts, each cyst a larval tapeworm. This becomes attached to the intestinal wall and grows to be several feet in length at sexual maturity. Then new reproductive segments are budded off, pass out with the feces, and when they are devoured by the proper host the cycle is complete. Other such parasites are the hookworm and the pork roundworm, or Trichina.

Sometimes the interrelations between the host and the parasite become so balanced that there are no harmful effects upon the former. There are certain antelopes and similar mammals of Africa which harbor in their blood protozoan parasites known as trypanosomes, without any discomfort to the mammals. However, if the carriers of these parasites (certain species of flies) introduce the trypanosomes into the blood of imported horses or cattle, fatal consequences follow. Thus parasitism, when of long standing, does not necessarily mean injury to the host. Often it can be assumed that when a parasite destroys its host, the interrelationship is a very recent one—as in the case of the infectious diseases which are so often fatal to the human species.

Man does not stand aloof from this maze of interrelationships. He is as much a part of the web of life as any other animal. Dependent upon green plants for the basic food materials of life, man has developed this relationship to the point where agriculture and husbandry have become vital to the existence of every nation. Dependent also upon the bacteria, man has learned that without them his soils eventually become barren; and many are the useful species of these colorless plants which keep the human species going. The common lot of man and his beasts of burden, together with his domesticated animals, comes fairly close to being commensalism. And because he acts as the host for a great number of parasites, man is at all times in danger of succumbing to the voraciousness of these residents within himself. The various ways in which these interrelationships of the human species with various parasites, plant and animal, affect mankind, is the subject matter of the following chapter.

Chapter Summary

The interdependence of organisms results in a complicated web of life, many different species of plants and animals being mutually necessary to one another or affecting each other's life, with resulting adaptation of structures and modification of activities. There are two main types of interrelationship, one involving no organic association whatsoever, the other resulting in a certain amount of living together; the former includes (1) the dependence of animals upon green plants as a source of food, and (2) the dependence of green plants upon bacteria for their carbon and nitrogen materials; the latter includes (1) commensalism, (2) symbiosis, and (3) parasitism.

In the food cycle, plants are found to be the ultimate sourc of all organic foods for animals. In the water it is the algae which are the basis of all animal food, while on land food consists of the grasses and herbage and plant products which are eaten by *herbivorous* animals who may in turn be the food for the *carnivorous* species. Since green plants alone can synthesize carbohydrates, proteins and fats from inorganic materials, they furnish the sole source of these protoplasm-building substances for animals.

Plants and animals are continually abstracting carbon and nitrogen from the environment, locking up these important elements in their bodies, where they might remain forever did not decay take place. Decay is caused by bacteria acting upon the organic substances making up the parts of living and dead organisms. The carbohydrates are changed into carbon dioxide and water by such bacteria; by this means, and as a result of respiration, the carbon gets back to the atmosphere where it may be used over again by plants during photosynthesis. Other bacteria act upon proteins, change them first to ammonia, then to nitrites and finally to nitrates; in the latter form the nitrogen becomes again available for plant use in making proteins. Certain plants such as clover and alfalfa have nodules on their roots which contain bacteria capable of fixing atmospheric nitrogen, transforming it into nitrates and thus enriching the soil with this necessary nitrogen salt.

Commensalism is a type of organic association in which two organisms of different species associate with some advantage usually to one or the other, or both. The shark sucker and the shark, the crabs and the sea anemones, are examples of such an association.

Symbiosis is a type of organic association in which both members of the partnership definitely profit by the relationship, and neither one is harmed. Lichens are examples of symbiosis where both partners are plants, in this case the species being unicellular green algae, somewhat like Protococcus, and fungus filaments. Termites and Protozoa are examples of two animal species living together symbiotically, as are various beetles and ants. The green Hydra represents a type of symbiosis in which one partner is an animal, the other a plant (unicellular green algae).

Parasitism is a type of organic association in which a one-sided relationship results in one member of the "partnership" living more or less at the expense of the other, who is called the host. For the sake of convenience, we can distinguish six types of parasitism:

1. That involving two green plants. The mistletoe is a partial parasite, obtaining its water from a host, usually a woody plant; being green, it can synthesize its own food. This is a rare type of parasitism.

2. That involving a flowering plant as the parasite with a fungus as the host. This is also uncommon; an example is the colorless Indian pipe with its root fungi.

3. That involving a green plant as the host, with various fungi as the parasites. This is widespread, and of great economic significance, since it is the condition which results in most plant diseases. Blister rust, wheat rust, and chestnut blight are a few examples. The fungi may attack and destroy the leaves of the host, or the stems, sometimes the flower and fruit.

4. That involving green plants as the host, and animals as the parasite. Examples of this type of parasitism are the various insect pests, such as the aphids and gall insects, which attack plants. The larvae of many insects destroy leaves and fruits.

5. That involving animals both as hosts and as parasites. Parasitism of this type is the cause of many human diseases, such as those produced by the tapeworm, the pork roundworm, and the hookworm.

6. That involving colorless plants, the bacteria, as the parasites and animals as the hosts. Under this type we find most of the diseases of the human race, caused by microbic infection.

QUESTIONS

1. What are the two main types of interrelationships between organisms, with the various examples of each?
2. What is meant by a food linkage?
3. In what various ways are animals dependent upon plants?
4. In what ways, if any, are plants dependent upon animals?
5. What is the difference between a herbivorous and a carnivorous animal?
6. What is decay? Is it a necessary phenomenon, or could life go on without it? Give reason for your answer.
7. How is the carbon dioxide in the atmosphere kept constant even

though green plants are continually removing it during photosynthesis?

8. What is meant by a "balanced aquarium"?
9. Name the various ways by which bacteria replace nitrogen in the soil in the form of nitrates.
10. Define commensalism and give an example.
11. What is the essential difference between symbiosis and parasitism?
12. Define symbiosis and give examples of:
    (a) A type in which both organisms are plants.
    (b) A type in which both organisms are animals.
    (c) A type in which one organism is an animal, the other a plant.
13. Describe a type of parasitism involving plants as the host.
14. Describe a type of parasitism involving animals as the host.
15. Give as many reasons as you can to prove that parasitism is of great economic importance.

GLOSSARY

carnivorous (kar-niv'o-rus) Flesh-eating.

commensalism (ko-men'sal-iz'm) An external partnership between organisms which may or may not be of special benefit to both; is never harmful to either.

ectoparasite (ek'to-păr'a-sīt) An external parasite, such as lice or fleas.

herbivorous (her-biv'ō-rus) Plant-eating.

host An organism which harbors a parasite.

lichen (lī'ken) One of a group of symbiotic plants, consisting of unicellular algae and fungi living together.

nitrate bacteria Bacteria changing nitrites to nitrates.

nitrite bacteria Bacteria changing ammonia to nitrites.

nitrogen-fixing bacteria Bacteria able to change atmospheric nitrogen to nitrates, such as those found in the root nodules of peas and clover.

parasitism (păr'a-sit-iz'm) An internal partnership between organisms in which one organism lives at the expense of the other known as host.

symbiosis (sim'bī-ō'sis) An internal partnership between organisms mutually beneficial to both members.

termite (tur'mīt) One of a group of insects capable of feeding upon wood, because of symbiotic Protozoa in their digestive system.

CHAPTER VIII

COMMUNICABLE DISEASES

Man's Struggle for Existence.—Among other organisms, the struggle for existence is for the most part a struggle to eat and to avoid being eaten. Civilized human beings have fairly well solved these two primary problems of existence. Few of the people that we know are in danger of death from starvation, and it is even less likely that any of them will fall prey to carnivorous animals. Aside from accidents, murder and suicide, there is just one major cause of human death, and that is disease.

What Is Disease?—Every so often the average person goes into a doctor's office and announces that he is not feeling so well this morning. The doctor feels his pulse, looks down his throat, makes a few remarks containing some long word ending in "itis," and the victim knows that he has a disease. If, instead of asking whether it was serious or not, he should ask the doctor what a disease is, he might get some very learned reply, or perhaps the reply would be, "A disease is anything that goes wrong with you that you need me for." This is about as accurate a definition of disease as can be given. The body machinery is so complex, and there are so many different parts of it that can go wrong and so many ways in which our bodily harmony may be disturbed, that it is impossible to make a single definition which will cover all of the bodily conditions which one could call disease.

Though there is no definition that would be satisfactory for disease as a whole, one can distinguish two main types of diseases, according to one important characteristic. Some diseases can be carried in some way or other from a person who is sick to one who is healthy; these are the communicable or contagious diseases.

In all cases they are due to the presence of parasitic organisms living somewhere in the bodily tissues and usually producing poisons in the course of their metabolic activities. Parasitic invasions of the body are called *infections*; hence all communicable diseases are infectious. The functional diseases which result from failure of some of the bodily structures to work properly or from lack of proper materials with which to work constitute the second type. The diseases due to vitamin deficiency fall into this group, together with many of the most frequent and fatal diseases known to man. In some cases failure to function is due to an infection of the organs; hence our functional disease may be either infectious or non-infectious. Functional diseases will be considered in the next chapter.

The Scourge of Pestilence.—At the time of the Civil War in America, civilized men knew scarcely more about combating contagious diseases than did the Babylonians or Egyptians who lived six thousand years before. Ever since the human race had come into being, disease had been the great enemy of mankind, yet men had made very little progress in understanding its causes or its cures.

Men would be peacefully going about their lives when suddenly an epidemic would appear in their midst. For weeks the death rate would rise and rise until it became impossible to bury the dead and it seemed inevitable that the entire population would be wiped out. Then, as mysteriously as it had come, the pestilence would subside. It would leave thousands dead or maimed. Families or even towns would be utterly destroyed. And no one would know the cause of the affliction. The people would be helpless in their attempts to avert a recurrence.

Man had no more control over epidemic disease than over the winds of the air. The terror-stricken people attributed it to an avenging angel, but prayers did not check it; they thought of it as a legion of devils, but they could not exorcise it. They could hate it, fear it, or become resigned to it. But they could not go forth to conquer it because they knew nothing about it.

The Establishment of the Germ Theory.—Less than sixty years ago scientific workers hit upon the answer to the problem of contagion in what is known as the germ theory of disease. Since that time remarkable progress has been made in the direction of overcoming communicable diseases, since, once men knew what the enemy was, they could attack it intelligently and successfully.

Briefly, the germ theory holds that contagion is carried by extremely minute organisms which live in the tissues of sick plants or animals and which poison or otherwise attack the organism in which they live and thereby bring about the symptoms of illness. These tiny agents of disease make their way by various means from one organism to another, and thus the contagion is spread.

Chief credit for the establishment of the theory goes to the great French scientist, Louis Pasteur, and to the German physician, Robert Koch. Koch went to great pains to prove absolutely that the contagion in the case of the disease anthrax was borne by certain microscopic organisms and by nothing else. He took anthrax organisms from the blood of a diseased animal and grew them in artificial *cultures*, completely outside the body of any animal. He grew them in one culture until they had multiplied immensely and then moved just a few of them to another culture. Then he moved a few from the second culture to a third. He made several of these transplantations until he was certain that not a trace of any disease-causing substance taken from the sick animal could be found in his final culture. Nothing was there but the remote descendants of the organisms that had been in the sick animal's blood. He inoculated mice with these bacteria from his final culture. They all contracted anthrax and died. It could not be doubted that the organisms that Koch put into their blood had caused those mice to develop anthrax, for nothing else had been injected that might possibly have been the cause.

The publishing of these results in 1876 convinced scientists of the importance of combating microorganisms in order to overcome disease. An immense amount of research in the field of bacteriology was immediately started, and discoveries came thick and fast. The organisms responsible for one disease after another were discovered, and methods of combating them were worked out. Death rates from numerous forms of illness began to fall off rapidly. Pestilence no longer appeared as a wholly mysterious and inescapable calamity. It became an enemy, or rather a horde of enemies, quite intelligible and tangible, to be fought and conquered with the weapons of shrewdness and planning that are the chief means of defense that we human beings possess.

Pathogenic Organisms.—The organisms which cause sickness in animals, and in plants as well, may be classified as follows:

A. Plants
  1. Bacteria
  2. Fungi (not always microscopic)
B. Animals
  1. Protozoa
  2. Worms (usually not microscopic)
C. Unknown
  1. Filtrable viruses (most of them too small to be seen, even through the microscope)

It should be pointed out immediately that in each one of these groups—excepting only the filtrable viruses—only a few of the members are agents of disease. Most of the bacteria, fungi, Protozoa, and worms are quite harmless; indeed, many of them are essential to our existence.

Those which do cause illness are spoken of as *pathogenic organisms*; and the majority of them, which are too small to be seen without a microscope, as pathogenic *microorganisms.* For purposes of convenience, however, they may be given the more informal title of microbes.

The next few paragraphs will serve to introduce briefly the various types.

Bacteria.—Bacteria are classified according to shape. There are round, dot-like bacteria, called *cocci*; rod-shaped bacteria, called *bacilli*; and spiral bacteria, known as *spirilla.* Frequently they grow in bunches or chains, and they are often provided with flagella to enable them to move about.

The cocci are responsible for boils and carbuncles, for pneumonia, for meningitis, and for gonorrhea. Some of the diseases caused by various types of bacilli are diphtheria, typhoid fever, tuberculosis, and leprosy. In addition, there is the anthrax bacillus, famous because it was the first microorganism proved guilty of causing illness in man and in the higher animals. Cholera is the only important disease known to be caused by a spirillum.

There are organisms similar to the spirilla, which, however, have certain animal characteristics, though they are usually classified as bacteria. They are called *spirochetes.* The best-known spirochete is the one which causes syphilis.

Fungi.—Ringworm is the best-known disease caused by a fungus. The branching filaments of the organism become im-

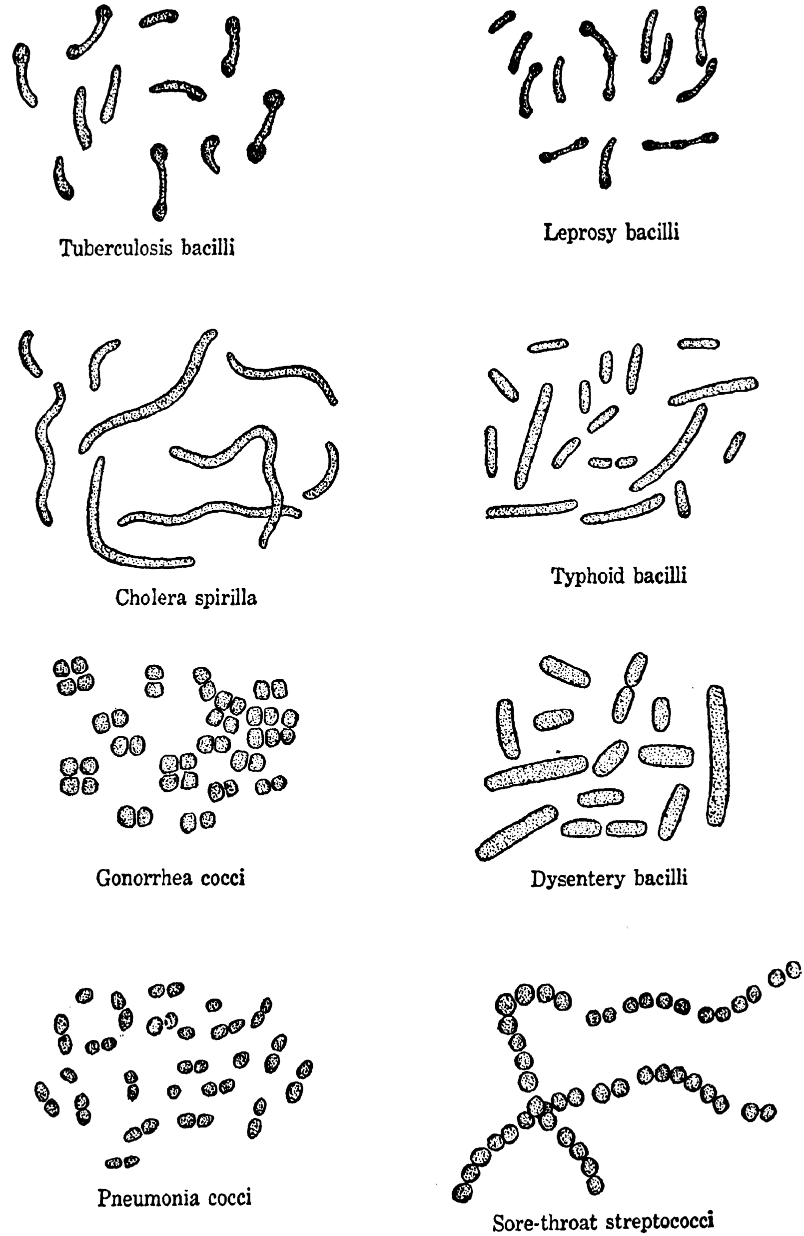


FIG. 41.—Types of pathogenic bacteria.

bedded in the skin. The well-advertised "athlete's foot" is a ringworm disease.

Protozoa.—Only a few of the many species of Protozoa are responsible for disease. The best-known protozoan disease is malaria. The malarial parasite is irregular in shape, lives in the red blood corpuscles, and has the property of breaking up into a large number of *spores*, each of which can grow into a complete new organism.

Parasitic Worms.—There is a multitude of parasitic worms which infest man and other animals. Most of them are not microscopic, and some of them, such as the tapeworm, are quite large. The hookworm, which seems to deprive people of energy and ambition, belongs to this group.

Filtrable Viruses.—While the worms are probably the largest of the pathogenic organisms, the filtrable viruses are the smallest. Indeed, they are the smallest living things known to man. Most of them cannot be seen through the microscope, and all are capable of passing through a porcelain filter. From this last property they derive their name. Infinitesimal as they are, they manage to produce in man some of the most serious diseases which attack him. Smallpox, measles, yellow fever, and infantile paralysis are supposed to be due to their activity.

How Microbes Attack.—One may wonder how organisms as small as these microbes can be so effective in attacking human beings. Three reasons for this may be pointed out.

In the first place microbes, when they enter a warm, moist place where there is plenty of food material—the tissues of our bodies fulfill this requirement almost ideally—are capable of multiplying at a tremendous rate, so that they may overcome the body by sheer weight of numbers. When Koch placed a few anthrax bacilli in the blood of a mouse, he found that within a few hours its body was swarming with billions of these microbes. When actively growing, most bacteria divide in two every twenty minutes or half hour; hence they can multiply a thousandfold in five to six hours.

In the second place, many microbes produce, as excretions, virulent poisons, or *toxins*, which, when they enter the blood, travel throughout the body and cause the symptoms of the disease. Diseases which come on with great suddenness, such as diphtheria, are due to the effects of these toxins, rather than to the direct action of the bacteria.

Thirdly, there are a few microbes which can encase themselves within hard coverings, becoming small pellets known as *spores*, that may float about in the air and withstand all sorts of hard conditions. These spores of bacteria can resist temperatures well above that of boiling water, and below freezing; they can remain in absolutely dry places for an indefinite length of time. Fortunately, however, spores are formed chiefly by the bacteria which cause decay in meats and vegetables, and by very few pathogenic organisms. The organism which causes tetanus, or lockjaw, is a spore-producer; and that is why it is so easy to pick it up if a little dirt gets into a wound, for the tetanus spores are very likely to be found in the dirt.

How the Body Defends Itself Against Microbes.—Having now acquired some notion of the nature of the enemy and the manner in which it attacks the body, let us consider how the body defends itself. Microbes are continually present all around us. Escape from disease would be impossible if it were not for the bodily defenses against them; and the most important methods used in preventive and curative medicine are simply means of building up these defenses.

The Walls.—The chief strength of a medieval castle was the stone walls and moats that surrounded it. Similarly, we are provided with a skin—hard, dry, and impenetrable to microorganisms, save when it is cut, when antiseptic precautions must be taken to prevent the entrance of germs.

Even when microbes get into the respiratory or digestive tracts, as they frequently do, the mucous membranes which line these tracts offer a stout resistance to their attacks. These membranes are covered by the sticky mucus which is secreted by the goblet cells that form part of the membrane. In the respiratory tracts many of the membrane cells are equipped with hair-like projections, called *cilia.* (See Fig. 5 in Chapter I.) The bacteria that are breathed into the lungs become literally mired in the mucus which covers the sides of the trachea and its branches, while the cilia wave back and forth in such a manner as to sweep this mucus, with the bacteria which it holds, up toward the mouth.

In the stomach and intestines, a chemical warfare is carried on against invading microorganisms. The millions of bacteria that we swallow every day with our food are, for the most part, harmless, but many pathogenic ones are also introduced. Luckily for us, when these bacteria enter the dark warm recesses of the stomach, the acid of the gastric juice kills practically all of them. As the food makes its way through the tortuous passages of the intestine, the bile that is poured in from the liver kills more of them. Finally, it is believed by some investigators that there are certain organisms of the filtrable virus type which have their home in the human digestive tract and which cause deadly diseases among the bacteria, just as the bacteria cause diseases among us.

Within the Walls.—Yet, in spite of the stout resistance they meet, microbes are continually making their way into the tissues of the body. But here they meet a defense quite as strong as that encountered on the outside. The blood itself contains substances that are harmful to most microorganisms; and when they have been rendered inert by these substances, the white corpuscles which the blood contains attack them and frequently succeed in completely destroying them.

Immunity.—These defenses, nevertheless, are not impregnable; and, in fact, their strength varies from person to person and may be much greater or less according to our physical condition. We have been overworking; we are tired and out of condition; our blood is temporarily in an unbalanced chemical state. If, under these circumstances, a very few microbes manage to make their way into our nasal passages and lungs, they are able to establish themselves and cause us to have a cold, even though a short time before hundreds of them could have had no effect on us.

The resistance which one's body can offer to the germs of a particular disease is termed one's degree of *immunity* to that disease; if one can successfully resist the attacks of an indefinite number of microbes, one is completely immune to it. If one succumbs easily to the attacks of the microbes of any disease, one is said to be susceptible to it.

Both immunity and susceptibility to particular diseases can be inherited, although the diseases themselves cannot. For example, it has been pretty definitely proved that susceptibility to tuberculosis is inherited. This does not mean that one inherits the disease itself, but simply that one inherits a bodily structure and chemistry that do not offer as stout a resistance to the germs of tuberculosis as that offered by most people.

Natural Immunity.—When a disease is brought by foreigners into a group or nation of people that has not previously been subject to it, it may cause terrible ravages, since that population does not possess the degree of immunity that is possessed by the people who have suffered for centuries from it. Measles, which is a relatively mild malady among us, was very deadly among the inhabitants of Iceland and Greenland, and among the Indians of America and the savages of the South Sea Islands when it was brought to them by people of European origin. It is believed that the Puritan settlements of New England were saved from extermination at the hands of the Indians, not so much by virtue of Puritan valor at arms as by ravages of Puritan-imported smallpox among the Indian villages. On the other hand, many "tropical" diseases, such as malaria, are much more deadly when they attack the visiting white man than they are among members of the native population.

The reason for the greater immunity of races that have long been subject to a disease seems to be that, when a disease first strikes a people, it kills off all those who are especially susceptible to it, leaving only the members of the population who offer it a strong resistance. They pass this ability to resist along to their offspring, so that after the disease has attacked a population for some time, only the descendants of good resisters are left, and these individuals inherit immunity to the disease.

When a person is born with the ability to defend himself against an illness to which other persons are susceptible, he is said to have *natural immunity* to that disease. This means that his bodily defenses against the disease are sufficiently strong to beat off all of its attacks. In every individual natural immunity is incomplete; that is, he is susceptible to certain diseases. But at just these weak places, the remarkably resourceful defense of the body improvises emergency measures against the invading microbes which usually result not only in bringing the patient back to health, but in rendering him immune to future attack.

Acquired Immunity.—Men have long known that many diseases can be contracted but once in a lifetime, or once in a number of years. If one recovers from a case of smallpox, measles, or diphtheria, one does not usually contract it again. In other words, one has become immune. This type of immunity, which is the result of having had a particular disease, is known as *acquired immunity.* It is brought about by the development of an *immunity reaction* either to the pathogenic organisms themselves or to the toxins which those organisms secrete. Immunity reactions may develop against substances other than those introduced into the body by pathogenic organisms. They may be developed against snake venoms, or against the cell substances of all sorts of plants and animals. In general, it may be said that a wide variety of proteins of the type not found in the human body may have a poisonous or harmful effect on the body, but that the body can "learn"[1] to protect itself against them.

All proteins that can produce immunity reactions are called *antigens.* When an antigen enters the body, certain tissues (just which ones is not known) respond by producing *antibodies* which act upon the antigens so as to neutralize their harmful effects. If an individual has a strong immunity reaction, he does not even feel these effects; but if his immunity reaction is weak, a protracted period of illness may ensue. The longer the illness, the stronger the immunity reaction becomes, until finally a sufficient number of antibodies is formed to overcome the antigens, and the individual recovers. Thereafter, whenever these same antigens enter the body, a much stronger immunity reaction occurs, so that no illness is produced.

The particular types of antibodies which attack pathogenic organisms themselves have many names, but we shall refer to them all simply as antibodies. The antibodies which attack toxins are called *antitoxins.* Fundamentally they do not differ from any other antibodies.

Artificially Acquired Immunity.—In the eighteenth century people sometimes deliberately exposed themselves to smallpox in order to become immune to it. Smallpox was so prevalent that they were almost certain to get it sooner or later, so they arranged to have it over with at a time that would best suit their convenience. But having a disease is a troublesome and dangerous way

[1] The term "learning" is not ordinarily associated with such responses as immunity reactions. But what actually occurs is very similar to the organismic modifications that are ordinarily spoken of as learning, namely, the strengthening of an adaptive response through practice. (See Chapter XXIII.)

of acquiring immunity to it. A better method has been discovered, namely, that of inoculating an individual with the microbes of the disease after they have been weakened or killed.

Smallpox vaccination is the best illustration of this convenient method of becoming artificially immunized. When the smallpox virus attacks cattle, it produces only a mild disease, and something happens to it that greatly decreases its *virulence*, that is, its capacity for causing illness. In producing vaccine for artificial smallpox immunity, calves are infected with the virus. They develop skin pustules which contain the virus in high concentration. The pustules are drained, and after the lymph from them has been properly treated, it is used to inoculate persons who wish to become immune to smallpox. The virus from the calf does not make people seriously ill, but it does bring about an antibody reaction that results in immunity lasting over a period of years.

Smallpox vaccination as a practical procedure was introduced by the physician, Jenner, at the end of the eighteenth century, but its theoretical implications were not understood at that time because the germ theory of disease had not yet been established. Soon after he had helped to establish the germ theory, Pasteur showed that artificial immunity could be induced for various diseases by inoculation with *attenuated cultures* of the antigens that produce them. Attenuated cultures are simply cultures in which virulence has been reduced while the capacity for producing antibody reactions remains. The reduction can be effected in many ways. In some cases, as in smallpox, the antigens are passed through the bodies of certain types of animals that have the capacity to reduce their virulence. In other cases they are grown for several generations in an artificial culture medium, sometimes being treated with mild antiseptics. For some diseases the bacteria can even be killed and still produce an antibody reaction when they are inoculated. The typhoid bacillus belongs to this latter class.

Immunity against diseases which are produced by toxins can be secured in two ways. One is to inject some antitoxin along with the toxin. The latter stimulates the body to produce antitoxin, and the antitoxin injected with it keeps the toxin from causing illness. Another way is to attenuate the toxin by treating it chemically. Such attenuated toxins are called *toxoids*. Either toxin-antitoxin or toxoid inoculations can be employed to prevent diphtheria. The latter is the more recent and probably the preferable method.

Theoretically it might be possible to immunize against all diseases by means of inoculation. But in many cases practical means of doing so have not been worked out. Tuberculosis, pneumonia, influenza, infantile paralysis, yellow fever, malaria, syphilis, and gonorrhea are among the more important diseases for which no successful and established methods of immunization have been discovered.

Smallpox and diphtheria are the diseases for which artificial immunization methods have proved most useful in this country. In Asia vaccination against bubonic plague and Asiatic cholera has proved successful. During the war outbreaks of typhoid fever among the armed forces were probably avoided by means of inoculation.

Passive Immunity.—When an individual has already acquired a disease, it is sometimes possible to help him overcome it by introducing into his blood the antibodies that will fight that disease. The most familiar instance of this method is the use of diphtheria antitoxin. Previous to the introduction of antitoxin treatment, diphtheria was an extremely fatal disease, since the bacteria frequently made such a virulent attack that death ensued before the patient could produce enough antitoxin to overcome it. Now the practice in all cases is to inject antitoxin into the blood to tide the patient over until his own body can produce a sufficient amount of its own.

In preparing antitoxin, the diphtheria bacteria are grown in a culture medium inside a flask. When they have produced a sufficient amount of toxin, this toxin is injected into a healthy horse. The horse is capable of reacting strongly against the toxin by producing a great deal of antitoxin. Larger and larger injections of toxin are given the horse over a period of several months, forcing him to produce antitoxin in great quantities. Finally, the jugular vein of the horse it cut and several quarts of blood are drained into flasks. The antitoxin for use with diphtheria sufferers is derived from this blood.

Checking the Spread of Microbes.—Immunity methods have done much to reduce the ravages of disease, but still more valuable have been the efforts to check its spread. One seldom realizes the hardship under which one's enemy labors in carrying on warfare. We are made painfully aware of the successes of the microbes, but we frequently fail to appreciate their difficulties. Microbes are parasites. They can grow and flourish only in the body of some organism that is capable of affording them food and shelter. But just as the microbes begin to succeed in exploiting their host, that ungracious organism either dies or demonstrates its complete lack of hospitality by attacking them with antibodies. If their race is to continue, the microbes must get from host to host by some means or other. Like other parasites they live in a *discontinuous environment.* It is as if the earth were to become uninhabitable to human beings within the next hundred years, so that the only men who could possibly survive would be those who could transport themselves to Mars. We can check the spread of microbes by interfering with their journeys from one host to another. The movement for public health and sanitation is chiefly concerned with this task. Some of the more effective ways of preventing the spread of organisms from host to host are isolation or quarantine, pasteurization of milk, purification of water supplies, elimination of insect pests, and inculcating the habit of cleanliness.

Isolation.—Some microbes—for example, the viruses of influenza and smallpox—can make their way from host to host only when the hosts come into immediate contact with one another, shake hands, or sneeze into one another's faces. For diseases of this sort, isolation or quarantine is valuable in checking their spread.

Quarantine was practiced long before the germ theory became established, since men early realized that disease could pass from person to person. Its systematic and intelligent employment, however, is of rather recent date. One recalls the isolation of lepers described in the New Testament and how they were forced to cry, "Unclean! unclean!" whenever they were approached. This oversevere quarantine was based more on a cruel and superstitious fear than upon intelligent control of the disease, for leprosy is in reality only mildly contagious, and a savagely complete isolation of lepers is not necessary, provided intelligent precautions are taken.

One of the chief difficulties met with in applying isolation measures is the presence of *immune carriers* for many diseases. An immune carrier is a person who serves as a host to pathogenic microbes but whose antibodies are capable of preventing any harm to himself. Nearly everyone is, in a sense, an immune carrier of tuberculosis. That is to say, we all have a few of the germs about us, but most of us have them under rather complete control. Quarantine of persons sick with epidemic influenza is not as effective as it might be because during the epidemic it is probable that nearly everyone carries some of the influenza virus around in his nose and throat. It is thought that diphtheria is spread largely by immune carriers, while the most dangerous of all immune carriers, perhaps, are those who carry the germs of typhoid around in their systems.

Pasteurization of Milk.—Bacteria can multiply wherever they find proper nourishment. Milk is a perfect diet for some microbes, particularly those of tuberculosis, diphtheria, typhoid, and scarlet fever. Hence it is an extremely dangerous source of disease if precautions are not taken to keep it free from contamination and if it is not sterilized by the process known as *pasteurization.*

To pasteurize milk, it is kept at a temperature ranging between 142 and 145 degrees Fahrenheit for thirty minutes and then immediately chilled to 50 degrees or lower. This amount of heat does not kill all bacteria, but it kills the greater part of the dangerous ones. Diphtheria bacilli are destroyed at 129 degrees, typhoid bacilli at 136, and the bacillus of tuberculosis at 138.

It should be emphasized that pasteurization is not a substitute for the completest sanitation around all dairies and that the strictest supervision over dairies is necessary, whether pasteurization is practiced or not.

Purification of the Water Supply.—Certain microbes, notably the typhoid bacillus, live in the digestive tract and are expelled in great numbers in the human excreta. Consequently, sewage is almost certain to contain them. Many cities get their water from rivers and lakes into which sewage has been dumped, and it is frequently almost impossible to secure an uncontaminated water supply for a city. By the use of proper means of purification, however, safe water can be obtained.

During the past twenty years. nearly all cities in this country which did not already have pure water supplies have taken measures to render their supplies safe. Jersey City offers a good example of the manner in which the purification of water can reduce deaths from typhoid. In 1891, while the city was using water from the Passaic River, 101.3 persons per 100,000 population died of typhoid. In 1898 the city got its water from the Pequanock River, a less contaminated stream, and the death rate dropped to 40.6. In 1906 the water was still untreated, but it came from the Rockaway River, and the death rate then stood at only 21.6. In 1913, Jersey City began to treat its water with hypochlorite of lime. This brought the rate down to 10.3. Finally, in 1926, following the use of chlorine as a disinfectant, the rate fell to 1.57 for every 100,000 inhabitants.

With the pure water supplies of the present day, typhoid death rates in cities tend toward 2.0, and nearly all cases can be traced to immune carriers or to impure milk, ice cream, or oysters.

At the present time, water supplies in American cities are usually so free from contamination that typhoid inoculation is scarcely necessary; but in emergencies, when water contamination cannot be avoided, inoculation of the entire populace is essential to prevent the outbreak of typhoid epidemics. In the Louisville flood of the spring of 1937, relief workers first administered typhoid inoculations, then brought food to the people. It is possible that this vigorous public hygiene procedure warded off an epidemic that would have taken many more lives than were lost in the flood.

Life Cycles and Secondary Hosts.—In their travels from one host to another, microbes frequently find it convenient to change their form almost completely in order to render themselves better fitted to meet the hostile environment outside their hosts.

Everyone knows how a frog goes through a stage in which it is a fish-like tadpole and later develops into an animal that lives part of its life on land, with four legs and a breathing apparatus of lungs rather than of gills. Similarly, the butterfly starts out in life as a caterpillar, passes through a stage in which it is completely wrapped in its cocoon, and finally emerges in its adult form, completely dissimilar to the worm-like creature that was its former self. We say that the frog and butterfly pass through a *life* *cycle* composed of several stages. And that is exactly what the microbes do.

One of the most important helps in preventing the spread of microbes has been the knowledge that certain varieties spend a part of their life cycles in one or more *secondary hosts.* Usually the secondary host is an insect. The malarial parasite, for example, lives one phase of its life cycle in a certain type of mosquito. The parasite cannot get from one human being to another if no mosquitoes of that particular species are present in the vicinity. Since the time this knowledge was gained, malaria has been stamped out in many communities simply by killing off mosquitoes in those regions. It can be eliminated in other places as soon as public opinion in those places becomes sufficiently enlightened to lead to an attack on the mosquito.

Under some circumstances, however, mosquito elimination is a difficult and costly business. It is quite impossible in such an immense and poverty-stricken country as India. In Italy, the government has found that the best way to eliminate malaria is to distribute quinine among the people in malarial districts. Quinine attacks the malarial parasite in the blood, and if it is taken regularly will ward off the disease. Once quinine has freed the people from the symptoms of malaria, they develop sufficient ambition to undertake the task of mosquito elimination in their districts.

The heroic work of the American commission for the study of yellow fever in Cuba—in which the members had to use themselves and other volunteers as experimental animals, since yellow fever cannot be given to mice, guinea pigs, or any other animal but man—led to proof that the yellow fever virus is also carried by a mosquito; and this dread disease is also being conquered through the elimination of mosquitoes.

In Africa the germ of sleeping sickness is carried from one human host to another by an insect known as the tsetse fly. It is almost impossible to get rid of this fly, and consequently sleeping sickness is yielding only very slowly to the attacks that have been launched against it.

Another disease that is brought to human beings by an insect is the plague. There are two forms of this disease. The first, and by far the most frequent, is the bubonic plague, characterized by infection and swelling of the lymph nodes. The second, the pneumonic plague, occurs when the same bacillus attacks the lungs. Plague is an extremely fatal disease and has probably been responsible for the most severe epidemics of all time, including the black death. It is in reality a disease of rats and is carried from rat to rat by fleas. When the plague becomes so severe among the rats that they die off in large numbers, the fleas, for want of rats to prey upon, attack human beings, and thus spread the disease to them. It is quite impossible to rid all the rats of their fleas, but the rat population can be kept at a minimum by killing off rats and, better still, by keeping all stores of food in rat-proof warehouses or rat-proof containers. All ships entering American ports from plague-infested regions are required to kill the rats they carry by means of fumigation. Whenever plague breaks out, immediate war must be declared on all rats in the infected area. By this means and by proper quarantine measures, the once terrible scourge of plague can be kept under control.

Soap and Water.—When all is said and done, the modern habit of using a comparatively large amount of soap and water, with the tendency which goes with it toward general cleanliness in all things, is probably as much responsible for the general decline of the death rate as all the triumphs of medical science combined. It is among the cleanly nations that the lowest death rates are found. Soap and water is one of the best of mild antiseptics, and the careful disposal of sewage and other wastes that is part of the habit of cleanliness is certain to bring about the destruction of large numbers of deadly bacteria.

Disposal of Excreta.—There are several diseases of serious consequence to human life and health that are passed from one host to another by way of human excrements. The hookworm, a small animal a quarter to a half an inch in length, attaches itself in large numbers to the wall of the intestine and sucks enough of the victim's blood to produce an anemia that results in weakness and general inefficiency. It is seldom fatal, but it attacks whole populations and renders them unable to live any but the dullest and most unproductive lives. In China and India alone it probably infects from three to four hundred million people. In various parts of our southern states from twenty to seventy per cent of the population have it. For the hookworm to be passed from host to host, human feces must be left on the ground. There the eggs germinate to produce larvae, which enter the body through the soles of bare feet and eventually make their way to the digestive tract. To stamp out the disease, it is necessary to teach an entire population to build properly constructed latrines for the disposal of excreta.

In his *An American Doctor's Odyssey*, Victor Heiser tells a fascinating story of his work with the Rockefeller Foundation in introducing sanitary habits among the peoples of the Orient. Teaching them how to eliminate hookworm was the first step employed. Since the worms could actually be shown to the people, they could understand more clearly the parasitic nature of the disease; and the necessity for cleanliness in combating it helped them to realize the meaning of sanitation. Once the people had been impressed with the importance of sanitation through hookworm eradication, their minds were made more ready to accept other sanitary measures urged upon them.

In addition to typhoid fever, Asiatic cholera and amoebic dysentery pass from host to host through contamination of food or drink by human excretions. Both occur only among populations where sewage disposal is inadequate.

The Standard of Life.—The greater cleanliness of the present day is in part a result of the greater wealth that has come to western European peoples with the discovery of colonization of America and the invention of labor-saving machinery. People who must work twelve to fourteen hours a day for the bare necessities of food and shelter have neither leisure nor facilities for keeping clean.

The higher standard of life which we now enjoy helps in other ways to increase the length of life. Proper nourishment for everyone, and especially sufficient pure milk for babies, helps enormously, since a high degree of natural immunity is dependent upon a well-nourished body, fed on a properly balanced diet.

The effect of the standard of life on health is seen in the differential death rates from tuberculosis for various occupational classes. In England, for example, persons of low economic status are more than twice as likely to die of tuberculosis of the lungs as are those belonging to the upper classes. Much still remains to be done to increase the wealth of great numbers of the population sufficiently to guarantee them conditions of life that will produce healthy and robust constitutions.

Some Triumphs of Disease Prevention.—The germ theory was established in 1876. In 1880, in the United States, 216 persons out of every 100,000 died of diphtheria. Most of them were children. In 1941, the rate for diphtheria was 1.0. In 1880 the typhoid fever rate was 25 and the scarlet fever rate 74. In 1941 they were 0.8 and 0.3, respectively. This change seems to have been largely due to the use of immunity methods and to better public and private sanitation.

This marked decrease in the number of deaths caused by contagious disease means that people now die later in life and that they usually die of some functional disorder. In 1890, the ratio of deaths caused by communicable disease to those caused by functional disease was about 3 to 1. In 1940, it was about 1 to 4. Just four diseases or disease types were responsible for the greater part of deaths due to contagious ailments. Their death rates were as follows:

Pneumonia and influenza	63.8
Tuberculosis	44.5
Syphilis	13.3
Intestinal disorders	12.3

All of these disease types are now reported to be yielding to the newest weapons of attack against microbes, the chemotherapeutic sulfa drugs and penicillin.

Chemotherapy.—As everyone knows who understands why he puts iodine on a cut, microbes can be killed by antiseptic chemicals. As early as 1865, Lister, inspired by Pasteur's work, showed that deaths from surgical infections could be greatly reduced by treating the wounds with dilute carbolic acid.

Lister's success led to a search for drugs that could be introduced into the body to kill germs, thus providing a quick and effective cure of disease. This proposed method of treatment was termed *chemotherapy,* and for many years it remained more a matter of hope than of realization, for it was soon discovered that most substances which were capable of killing microbes were likely to do more harm to the body than the microbes themselves could accomplish.

As late as 1930 there were just two diseases which could be effectively treated by chemotherapy: malaria, treated by quinine, a remedy that had come down from ancient times, and syphilis, treated by arsenic compounds as a result of Paul Ehrlich's discovery of salvarsan in 1910.

Then in the early 1930's reports came out of Germany of a dye, prontosil, which would destroy fatal doses of streptococci in mice with scarcely any damage to the mice. French scientists took up the study and showed that *sulfanilamide* was the substance in prontosil that was effective. Clinical work with sulfanilamide during the next three or four years showed it to be as effective in curing human ills as it was with mice. Other sulfa drugs or *sulfonamides,* such as sulfathiazole and sulfadiazine, were developed, each being most useful with certain diseases. Soon it began to be realized that the dream of chemotherapy had come true. A group of really practical internal disinfectants had been discovered.

The sulfa drugs can serve as well to protect the body against the entry of bacteria as to overcome them once they are within the tissues. Today when a soldier is wounded, he takes a sulfa tablet to prevent internal blood poisoning and also dusts sulfa powder into the wound. This use of sulfa drugs, together with emergency blood serum injections and improvements in surgical practice, has reduced deaths from wounds in American evacuation hospitals from 18 per cent in the last war to 3 per cent in this one.

Epidemics can be quickly controlled by giving a small dose of sulfa drugs to everyone likely to be exposed or to expose others. These drugs afford rapid and certain cures for diseases like gonorrhea which were formerly curable, but by less effective methods. Furthermore, their use has greatly reduced the death rate in diseases that were formerly highly fatal. During the last war, for example, 37 per cent of meningitis cases in the Army proved fatal, whereas today only 2 per cent of such cases die.

Sulfa drugs attack bacteria by preventing their use of para-amino benzoic acid, more briefly known as P A B A. This chemical, which is a member of the vitamin B complex, is formed by the bacteria and employed in carrying on their nutrition. The sulfonamides thus keep the bacteria from their food, and in their weakened state they are destroyed by white blood corpuscles.

Sulfonamides have distinct limitations. They are effective against many types of true bacteria but do not attack animal pathogens or most of the filtrable viruses. Occasionally the bacteria which they attack develop the capacity to produce about seventy times as much P A B A as ordinarily, thus rendering themselves resistant to the action of the drug. Another drawback is that about three out of every hundred persons are especially sensitive to sulfonamide poisoning and cannot be given sulfa treatment.

As if in answer to these sulfa drug problems there has been discovered a group of therapeutic chemicals produced by molds, the best known of which is *penicillin.* Although the germicidal properties of this substance were noted in 1929, its use as a chemotherapeutic was not developed until 1941. Penicillin promises even more miraculous results than those obtained with the sulfa drugs. It attacks a wide range of bacterial organisms. It is more potent than the sulfonamides, yet it can be given in large doses without toxic effects. It rapidly overcomes infections that have developed special resistance to sulfa drugs.

Up to the time of the present writing, difficulties in producing penicillin have made complete tests of its potentialities impossible. Methods of quantity production have recently been developed, and its true sphere of usefulness should soon become known.

The chemotherapeutic discoveries of the past few years probably constitute the greatest medical advance since the establishment of the germ theory and the discovery of the principle of artificial immunity. New drugs and new uses for them are constantly being reported. Final tests of their value await further study, but their promise is great. Astonishingly rapid and complete cures of syphilis with penicillin have been reported, but much more experience will be needed to verify them. A new sulfa drug, *diazone,* appears to effect remarkable results with tuberculosis, but more verification is needed. It is known that sulfa treatment reduces pneumonia deaths from one in every three cases to one in every ten, and there is hope that penicillin will improve this record.

Certain types of pneumonia, caused by filtrable viruses, together with influenza, also caused by viruses, are as yet impervious to chemotherapeutic attack, but it is the bacterial pneumonias that are usually the causes of death. Influenza alone is almost never fatal; the complication of influenza with bacterial pneumonia is what produces the long death lists in influenza epidemics.

Finally, infections of the intestinal tract are reported to be especially easy to control with sulfa treatments. Thus, all the important causes of death from communicable disease seem to be potentially under the control of the new chemotherapeutics, and there is reasonable grounds for hope that by 1950 deaths from communicable disease in America will be negligible in number.

Nevertheless, unless new discoveries change the picture, contagion as a source of illness will continue. Children will have measles, whooping cough, and similar ailments, and the entire population will be plagued by that persistent nuisance, the common cold. But there is no reason to suppose that in the end scientific discovery will not have relegated the microbes of illness to the same oblivion that it seems to be rapidly preparing for the microbes of death.

Chapter Summary

The greatest step in mankind's conquest over contagious diseases was the establishment of the germ theory, which states that such diseases are caused and spread by the activity of microorganisms. The two men chiefly responsible for the establishment of the theory were Louis Pasteur and Robert Koch. It was the latter scientist who, working with cultures of anthrax, finally proved the theory. The disease-causing microorganisms are two types of plants, bacteria and fungi; among animals, protozoa and worms; and finally a group of ultramicroscopic organisms known as filtrable viruses. Their virulence is due (1) to their rapid rate of reproduction, (2) to their production of toxins, (3) in a few cases to the great resistance to adverse conditions which they display.

The defenses of the body against microorganisms are (1) the skin; (2) the mucus and the cilia that line its various openings; (3) chemical substances and hostile microorganisms in the stomach and intestines; (4) antibodies in the blood plasma; (5) the white blood corpuscles. Immunity is the ability to resist disease. Four types of immunity may be distinguished: (1) natural immunity, with which a person is born and which is often characteristic of races; (2) acquired immunity, which is the result of having had a disease; (3) artificially acquired immunity, which is the result of vaccination or inoculation; (4) passive immunity, which is the result of the injection of an antibody to counteract an antigen produced by bacteria. Acquired and artificially acquired immunity are explained by the fact that the presence of disease-causing microorganisms in the body stimulates it to produce a large amount of antibodies to counteract that particular disease.

The disease-causing microorganisms may be combated also by preventing their spread from one person to another. This is accomplished in the following ways:

1. Quarantining, which, however, is made more difficult by the existence of immune carriers.
2. Pasteurization of milk.
3. Purification of the water supply.
4. Learning the life cycle of the microorganism and eliminating the secondary host if there is one. Some examples of secondary hosts are the mosquito which carries malaria, and the flea which carries the bubonic plague from rats to men.
5. General cleanliness, especially adequate disposal of excreta.

Immunity measures and prevention of infection, together with improvements in treatment, have resulted in a tremendous decrease in contagious diseases and in deaths from contagious diseases. The newly developed chemotherapeutics, the sulfonamides and penicillin, give promise of well-nigh eliminating most of the remaining contagious sources of death, namely, pneumonia, tuberculosis, syphilis, and the intestinal disorders.

QUESTIONS

1. Tell about the discovery of the germ theory and its importance to mankind.
2. What are the chief types of pathogenic organisms?
3. How are microorganisms able to cause disease?
4. Describe the defenses of the body against pathogenic organisms.
5. How is immunity acquired? How can it be artificially acquired? What is passive immunity?
6. Describe the most effective methods that could be employed to rid a community of each of the following diseases: typhoid fever, malaria, smallpox.
7. What are the most frequent causes of death among the contagious diseases? Discuss the possibility that chemotherapeutic agents may result in almost eliminating contagious disease as a cause of death.

6. Describe various methods that are used to prevent the spread of pathogenic organisms from one host to another.
7. Discuss the respiratory diseases.

GLOSSARY

antibodies (an′ti-bo′diz) Substances in the blood which act in antagonism to foreign substances such as bacteria and toxins.

antigen (an′ti-gen) A foreign protein which attacks the body and can be overcome by the production of antibodies.

antitoxin (an-ti-tox′in) An antibody which acts in antagonism to a toxin.

bacillus (ba-sil′us) pl. *bacilli* (-ī) A rod-shaped bacterium.

coccus (kok′us) pl. *cocci* (kok′sī) A spherical bacterium.

culture A group of microorganisms grown in an artificial nutritive environment for purposes of scientific study.

filtrable virus (vī′rus) A pathogenic organism so small that it will pass through the pores of a porcelain filter. Most such organisms are too small to be seen through the microscope.

immune carrier A person who carries contagious disease germs about in his system and who may give the disease to others although he himself is immune to it.

immunity Condition of being able to ward off the attacks of disease.

infection An invasion of the tissues by pathogenic organisms.

inoculation Act of introducing bacteria into tissues of a plant or animal. It is frequently done to produce artificial immunity.

microbe (mī′krōb) Popular name for pathogenic microorganisms.

microorganism (mī′kro-ôr′gan-iz′m) An organism so small that it cannot be seen with the naked eye.

pathogenic organisms (path-o-jen′ic) Organisms which cause disease.

secondary host An insect or other organism in which a pathogenic organism spends part of its life cycle.

spirillum (spi-ril′lum) pl. *spirilla* A spiral-shaped bacterium.

spirochete (spī-rō-kēt′) A spiral-shaped bacterium having animal characteristics. The best-known spirochete is that which causes syphilis.

toxin (tok′sin) An antigen in the form of a poisonous substance produced by plants or animals. In this chapter we have dealt only with bacterial toxins.

toxoid (tok′soid) Diphtheria toxin treated to render it harmless so that it may be used to produce artificial immunity.

vaccination (vak-si-nā′shun) Act of inoculating to produce artificial immunity.

virulence (vir′oo-lens) Power of a pathogenic organism to produce disease or death.

CHAPTER IX

FUNCTIONAL DISEASES

THE ENDOCRINES AND THEIR HORMONES

The Ductless Glands.—We have already mentioned the vitamin-deficiency diseases as belonging to the group of functional diseases (see page 79). To this category also belong the diseases that are caused by failure in functioning on the part of the *endocrine* glands of the body. These glands differ widely from one another in location and structure, but all have one characteristic in common. They are not supplied with tubes or ducts, as are the sweat glands, the glands of the digestive tract, and the like, but release their secretions directly into the blood stream, and hence they are often referred to as the ductless glands. The substances which they secrete into the blood are called *hormones*. Each hormone has some special task to perform in regulating the functioning and growth of the bodily organs. When a hormone is either lacking or too abundantly present, a characteristic pathological condition appears.

The six most important of the endocrine glands are the *islands of Langerhans* in the pancreas; the *thyroid* and *parathyroid* glands in the neck; the *adrenal* glands just above the kidneys; the *pituitary* gland, attached to the base of the brain; and the *endocrine glands in the sex organs*.

Insulin and the Assimilation of Sugar.—In Chapter IV we learned that single sugars are absorbed into the blood stream from the small intestine and are carried throughout the body. They are then either assimilated directly into the tissues, where they are used in combustion, or stored in the liver as glycogen. This process of storage and assimilation can be carried out only with the aid of a particular hormone, known as *insulin*, which is secreted by certain ductless glands consisting of groups of cells in the pancreas, entirely apart from the tissues which secrete pancreatic juice. These cells were discovered by a Dutchman named Langerhans, and since they exist in scattered bunches, each group completely surrounded by the other pancreatic tissues, they are called the *islands of Langerhans.*

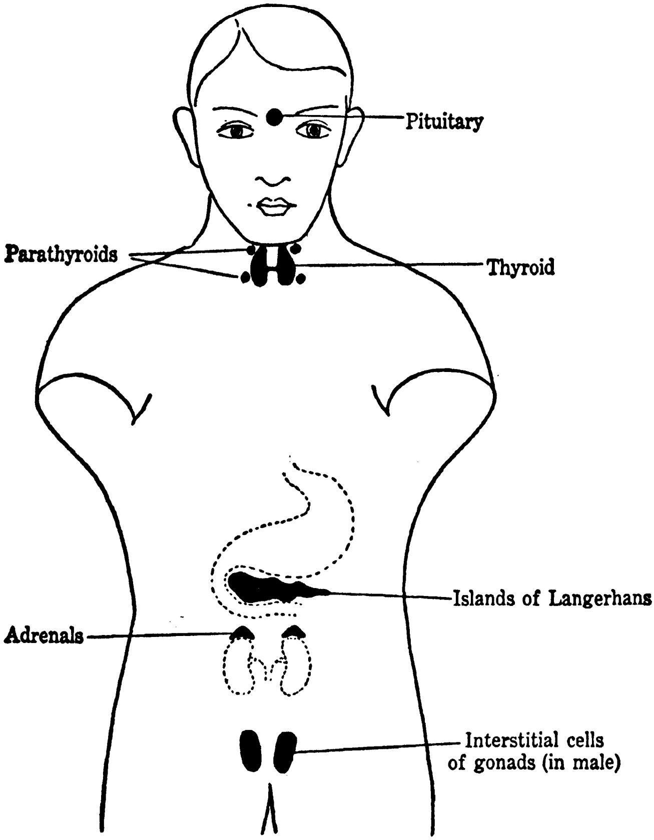


FIG. 42.—Location of endocrine glands.

The function of insulin seems to be that of keeping each cell of the body furnished with a constant supply of carbohydrate fuels so that it is necessary to burn only a minimum of proteins and fats. Occasionally, usually because of failure on the part of the islands of Langerhans to perform their work properly, the amount of insulin in the blood falls so low that the disease known as *diabetes mellitus* develops. Because of the absence of insulin, the liver can no longer store carbohydrate nor can the cells of the body assimilate and burn it, and practically all the carbohydrate food that is eaten remains in the blood stream in the form of single sugar. It is present in such excess that it must be carried off rapidly by the kidneys, and hence the urine contains much sugar, and urination is frequent. At the same time, the cells of the body are forced to burn the protein materials of which they are composed, and the muscles become weak and emaciated. Still more serious results come from the burning of fats. Complete oxidation of these substances takes place only when they are burned along with a great deal of carbohydrate; but since the body is now incapable of burning carbohydrate, their oxidation goes only part way and produces poisonous acid substances which in many cases bring about the death of the patient.

About fifteen years ago a group of Canadian scientists evolved a successful method of extracting insulin from the pancreatic tissues of animals, and at the present time it is only necessary for a diabetic patient to take insulin at regular intervals and to control his diet carefully in order to escape almost entirely the symptoms of diabetes. Usually, however, this régime does not bring about a true cure, since the islands of Langerhans almost never recover their function, and the patient must take insulin the rest of his life.

The Thyroid Gland and the Rate of Metabolism.—Astraddle the windpipe in the mid-region of the neck is the *thyroid gland* which produces the hormone *thyroxin.* Just as insulin creates a preference for carbohydrate fuels over fats and proteins in the metabolism of the body, so thyroxin regulates the rate at which that metabolism goes on. The basic function of this hormone seems to be that of helping oxygen to combine with the various body fuels; and hence the more thyroxin in the blood, the faster the general rate of oxidation throughout the body. Whenever a more rapid rate of combustion is desirable, the thyroid gland usually responds by producing more thyroxin. For instance, the gland becomes more active in winter so that the increased combustion may keep the body warm. It also speeds up its activity whenever the organism has extra work to do and needs "pepping up," as in times of emotional stress or during puberty, when rapid bodily changes are taking place, or again during pregnancy, when special vitality on the part of the mother is required in order to take care of her rapidly growing child. To sum it up, the thyroid acts like the draft of a furnace which automatically opens whenever a little more heat is needed.

The importance of thyroxin in keeping our bodily functions going at a proper rate is vividly demonstrated whenever the gland fails to secrete a sufficient amount of the hormone. Occasionally along in middle life, more often among women than among men, its activity fails, whereupon a condition known as *myxedema* appears in which the individual continually complains of being cold, may even wear an overcoat on warm summer days, fatigues readily, and becomes mentally dull and physically sluggish, while the skin shows a peculiar puffiness, resulting from the deposit of water in the tissues. This condition can readily be relieved by the feeding of thyroid substance, and the cures sometimes effected are amazing.

Still more striking are the symptoms appearing in an individual who from birth onward is lacking in thyroid secretion, since, with the low rate of metabolism, the growth of all parts of the body fails to progress normally. This condition is spoken of as *cretinism*, and individuals suffering from it are termed *cretins*. A graphic description of the cretin is given in Hoskins' *Tides of Life*.

The skin is dry and cold to the touch. It feels thick and seems lifeless. The hair is harsh and dry and falls out readily; even the eyelashes may be lost. The nails are thin and brittle. The teeth are slow in appearing and have little vitality; even with good dental care they are frequently lost. The face is pale and puffy; the upper eyelids are thick, giving the child a sleepy appearance. The hands and feet are broad and clumsy-looking. The bones of the head and face develop at disproportionate rates leading, among other things, to a marked depression of the root of the nose giving it a characteristic "saddle shape." The lips are thick and prominent, the mouth is generally open and drooling. The eyes are dull and lustreless. The face as a whole is completely lacking in animation, never showing the play of emotion or interest characteristic of the normal child. The subjects are often deaf mutes. The muscles are limp and weak. Even the musculature of the internal organs is sluggish, leading among other things to constipation. The higher nervous system remains undeveloped both structurally and functionally and the intelligence grades from feeble-mindedness to complete idiocy.

Here again remarkable improvement in both bodily characteristics and intelligence can be effected by the administration of thyroid hormone, although advanced cases can never be completely cured.

When too much thyroid substance is secreted, another sort of abnormal picture is presented. The individual is thin and overactive, restless and nervous, sometimes even to the point of insanity.

Occasionally the gland enlarges so as to produce the marked swelling in the neck commonly known as *goiter*. There are various causes for this condition, but the most frequent is the lack of sufficient iodine in the diet. Iodine is the chief raw material which the thyroid gland uses in the manufacture of thyroxin. Hence, if a person has not enough iodine in his diet, the gland cannot create enough thyroxin to keep the rate of basal metabolism up to normal. In an effort to do this, it becomes abnormally enlarged.

Iodine is found in salt-water fish and in any other sea food and is usually present in very small quantities in the soil and in the drinking water of seashore communities. Since only a trace of it is needed in one's food, people living near the seacoast rarely have goiter. But in the interior of many countries, where little fish is eaten and the soil and drinking water contain little iodine, goiter is very prevalent. There is a "goiter belt" about the Great Lakes, one in the Rocky Mountains, and a well-known one in the Alps.

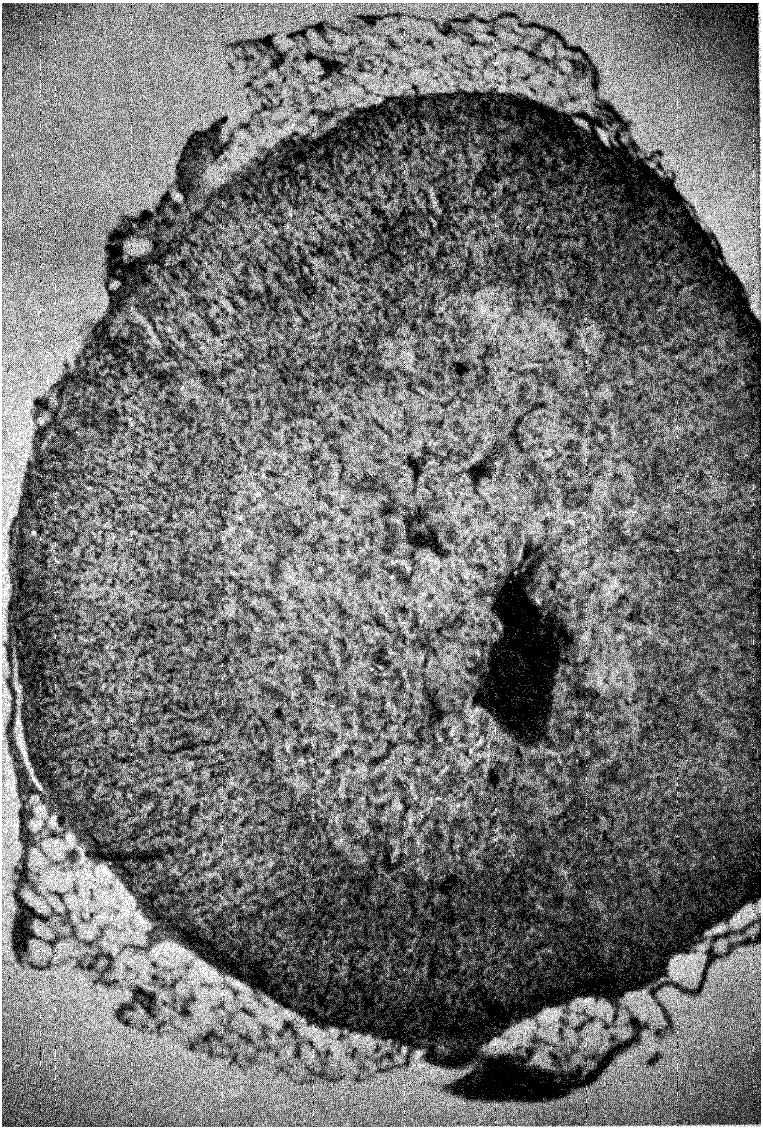
The simplest method of giving the people in the "goiter belts" a sufficient amount of iodine is to put small amounts of it in all the salt sold in those regions. By this method the incidence of goiter among the school children of Detroit was reduced from 36 per cent to 1.2 per cent in the course of seven years. Along with this reduction of goiter there probably went a considerable reduction of the symptoms of thyroid deficiency, namely, physical sluggishness and mental incapacity.

Probably a large number of people who are not considered to be sick suffer to some extent from over- or under-secretion of thyroid. Some doctors at present prescribe thyroid feeding for people who are only mildly fatiguable and sluggish, and encouraging results have been secured in many cases. It has been suggested that one's "personality" is considerably affected by the amount of thyroxin received into the blood, but whether this is true or not, excepting in extreme cases, has not yet been demonstrated.

The Parathyroids.—When the study of the thyroid was in its infancy, it was noted that when the thyroid gland was completely removed in an experimental animal—or occasionally in a human being undergoing an operation for goiter—spasms would sometimes set in within a few hours, the muscles would go into rigid contractions, and, because of inability to breathe, death would often ensue. It has been shown that lack of thyroxin is not responsible for this condition, but, rather, lack of *parathyrin*, the hormone produced by four small *parathyroid* glands lying against the under surface of the thyroids. The most important effect of parathyrin is to keep an adequate amount of calcium salts in the blood. When the hormone is absent, these salts are deposited in the bones, and the amount of calcium in the blood falls, with the resulting rigid contractions of the muscles. Too much calcium in the blood, which may possibly result from an overdose of parathyrin, produces nausea, vomiting, and, in extreme cases, unconsciousness and death. The convulsions from which very young children occasionally suffer are usually the result of insufficient calcium in the blood.

The Adrenals.—The two adrenal glands, situated just above and back of each kidney, are each shaped like a cocked hat. Each is composed of two distinct parts, an outer rind, or *cortex*, and an inner center, or *medulla*. The hormone produced by the medulla will be dealt with in a later chapter. The cortex produces an entirely different hormone, *cortin*, whose function is not fully understood. When it is absent or greatly diminished, a fatal illness, known as Addison's disease, develops. The victim of this disease suffers from insomnia and nausea; his skin takes on a peculiar brownish color; he becomes weaker and weaker and his heart beat grows fainter and fainter until death ensues. In 1929 methods for securing adrenal cortex extract were discovered, and since that time much has been done to alleviate Addison's disease by the administration of this hormone. The hormone is still very expensive, however, and it is difficult to secure it in quantities adequate for complete treatment of the disease.

Interaction of the Hormones: The Pituitary.—The endocrine glands have been spoken of as an "interlocking directorate," since each gland does not carry on its functions independently, but is in continual interaction with the others. While this is true



Section of adrenal gland of rat. The darker region on the outside is the cortex; the lighter region, the medulla.

of all of the endocrines, the one whose functions seem to be most closely intertwined with those of the others is the *pituitary.* This gland is located at the base of the brain and is divided into three parts: the *anterior lobe, the posterior lobe*—which is the part at the base attached to the brain—and an intermediate part between the two lobes. Although the gland is quite small, it is known to produce many different hormones and suspected of producing others. The anterior lobe seems to produce the greatest number, and we shall confine our discussion to the most important and best known of these anterior lobe hormones.

The pituitary hormone that has been known for the longest time is the one which stimulates growth. It is probably responsible in part for the development of our muscles when we exercise them, but we have no way of recognizing this. The best proof of its activity is given by people in whom the pituitary gland is abnormally developed. Occasionally a child starts growing rapidly at fifteen, and reaches a height of seven feet or more by the time he is twenty. His hands become enormous, and his head, and particularly his lower jaw, are exceptionally large. Whenever physicians have examined such giants, they have found an overgrowth of the pituitary gland. Sometimes, when the pituitary does not become overactive until early adulthood, gigantism may not result, but overgrowth of the lower jaw, hands, feet, lips and nose may take place, producing an unsymmetrical arrangement of the features called *acromegaly.* Children and adults with an underdeveloped pituitary gland are also abnormal in appearance. They remain small in stature, their features are always small and childlike, and they are sexually underdeveloped. While the seven-foot prize fighter, the circus giant, and the "powerful Katrinka" probably have an overdeveloped pituitary gland, the small, effeminate boy with a high voice, and the circus midget are victims of a lack of pituitary secretion.

The production of this hormone, however, does not depend on the development of the pituitary gland alone. Thyroxin is known to stimulate the functioning of the pituitary, and hence it is thought that the dwarfing of cretins is fundamentally caused by failure of the thyroid to stimulate the secretion of the growth-promoting hormone. As if in return for the stimulation it receives from the thyroid, the pituitary produces a separate hormone, the sole function of which is to stimulate activity on the part of the thyroid gland. In addition, it is thought to produce hormones which stimulate the parathyroids and the adrenal cortex; some cases of Addison's disease are believed to be due fundamentally to failure on the part of the pituitary. It interacts with the hormones of the sex glands so completely that the function of reproduction is as much under the control of the pituitary as of the hormones of the sex glands.

Diabetes is sometimes produced in animals for experimental purposes by removal of the pancreas. But if at the same time the pituitary gland is removed, the usual signs of diabetes do not appear. Careful study has shown that this is because insulin does its work in opposition to two pituitary hormones, one of which is responsible for increasing the amount of sugar in the blood, and the other for the changes in metabolism that produce the acid poisons resulting from incomplete oxidation of fats. Here we have an example, not of the direct effect of one hormone upon another, but of interactions between the effects produced in the body by various hormones.

Many other examples of interaction between the endocrine glands could be mentioned. The pituitary is by no means the only interactor. Nearly all the hormones seem to exert influences on sexual development. Both the thyroid and the adrenal cortex increase their activity at the age of puberty and also during pregnancy, and they apparently influence the rate at which sex hormones are formed. If there is an abnormal secretion of the adrenal cortex during childhood, sexual maturity may be brought on at an astonishingly early age, and a two-year-old boy may develop a beard and a man's voice.

Hoskins tells of an ancient account of one such child, in which it was reported: "The subject was an infant, a young man, a mature man, an old man, was married and begat children and all in the space of seven years." Such precocious youngsters are said to have a predilection for smoking cigars and discoursing on philosophical subjects, but these assertions may be somewhat exaggerated. When the adrenal cortex is abnormal in mature women, they lose their feminine traits and develop the beard and low voice of the opposite sex. Most of the bearded women of the side-shows have an overdeveloped adrenal cortex.

Other instances might be added of the mutual influence which the hormones exert upon one another. So complex is their action that the most careful labors of scientists during the past fifty years have only begun to unravel the mysteries of their influence upon human health, physical appearance, and personality. Much remains to be done in this difficult but fascinating field of research, and when it is done, we shall know much more about the inner workings of the human organism than we know today.

The Diseases of Later Life

Without doubt, the efficiency with which an organism functions is profoundly affected by the endocrine glands. Although their activities are so complex that scientists are only beginning to understand them, it seems very likely that the glands influence the general tone and condition of the organism in a variety of ways, and that differences between individuals in health, strength, vigor, disease resistance, and even such qualities of personality as aggressiveness and cheerfulness are partly dependent upon the balance of hormones in their bodies.

Of the specific diseases caused by the hormones, however, only diabetes is sufficiently frequent and serious to be one of the major causes of death. The functional diseases which are the real death-dealers are those that develop as the body grows old and its tissues begin to lose their efficiency in functioning. The number of deaths caused by these diseases of later life has increased enormously during the past fifty years. The following table gives the death rates per 100,000 in the United States for the years 1900 and 1933 for the four diseases which were most fatal at the latter date:

	1900	1933
Heart disease	132	228
Cancer	65	102
Apoplexy	71	84
Nephritis (kidney disease)	89	83

During this time the general death rate was falling rapidly, so that even nephritis shows a relative increase in its death rate. As Diehl, from whom we quote these figures, has put it, these diseases "represent the disintegration of the individual's vital machinery before the insidious accumulation of the relatively minor injuries of previous illnesses, of hereditary factors, and of personal habits, the total effect of which is too great for the individual to withstand. Man is mortal, and though life is prolonged by evading acute illness, death must come, then, through some form of wearing out or degenerative process." The very success of the war on the microbes results in an increase in the death rate from diseases which result chiefly from the wear and tear of living.

Arteriosclerosis.—Arteriosclerosis, the hardening of the arteries which occurs sooner or later in most human beings, together with the conditions with which it is associated, is today the prime cause of death. Of the four diseases shown in the table above, three of them—heart disease, apoplexy, and nephritis—are, in older persons, almost universally associated with arteriosclerosis. To be sure, infections of the heart and kidneys frequently occur in youth and may terminate fatally. If these early infections do not result in death, they may so weaken the organ attacked by them that when arteriosclerosis sets in, the individual succumbs to a new attack of heart disease or nephritis.

Hardening of the arteries is caused by the deposit of mineral salts in the tissues of their walls, so that they become inelastic and brittle, like old rubber. Such deposits are laid down whenever the walls are weakened or subjected to strain. We do not know precisely what the most important conditions leading to this hardening are, but the following probably play a part:

1. Infections, toxins, and poisons in the system, such as chronic infections of the sinuses, tonsils and teeth, syphilis, typhoid fever, and the disturbance of the kidney which produces gout. These conditions destroy the tissues in the walls of the arteries. The tissues are then replaced by scar tissue which becomes impregnated with mineral salts.

2. Anything which produces constant high blood pressure, thus putting a strain on the walls. The most definitely known cause of high blood pressure is impairment of kidney function as a result of infection or poisoning. Hard work and worry have also been blamed for increasing the blood pressure, and it has been asserted that the high nervous tension that accompanies modern living is chiefly responsible for many arteriosclerotic deaths. Definite proof or disproof of this theory is lacking.

3. Their hereditary constitution seems to predispose many people to high blood pressure and arteriosclerosis. The age at which the arteries grow hard differs widely, and the difference seems to depend to a considerable extent upon the factor of inheritance.

Death does not result directly from arteriosclerosis itself, but rather from the damage to organs which it may produce. The organ which succumbs is the one which has been most weakened by the wear and tear of life and in which the arteries have suffered most from hardening. In the heart, for example, the valves may not be working properly, and the muscle tissue may have become weakened because of some earlier infection. The organ will be under considerable strain because of the defective valves and the fact that it is pumping against high arterial pressure. A sudden fit of anger or unusual muscular activity may now throw a greater amount of work on the heart muscles; but if the arteries running to the heart are inelastic, they may not allow enough blood to reach the heart tissue, or they may burst. Under these circumstances the cells may be irreparably damaged, and the heart may fail utterly to carry out its task.

We have already seen that kidney disorders may help to bring on arteriosclerosis. If the hardened arteries fail to supply sufficient nourishment to the kidney tissues, they may become so completely atrophied as to make proper elimination through them impossible. Again the result is fatal.

When the arteries to the brain are hardened, there may be a slow dying out of the brain tissues because of a failure to receive oxygen through the blood. This is probably the chief cause of the loss of mental power which accompanies age. When, as a result of overstrain, one of these arteries bursts, an apoplectic "stroke" occurs. Often these strokes result only in a more or less temporary paralysis and loss of speech. But one is likely to succeed another, and, in the end, death may ensue.

The Relation Between Infectious and Functional Disease. —These diseases which center about arteriosclerosis show clearly that the distinction between contagious and functional diseases is a rather artificial one. Properly functioning tissues and organs have a low susceptibility to infection, while, on the other hand, infection is probably the chief cause of lowered organ efficiency.

Although an individual may completely recover from such a disease as scarlet fever, measles, or mumps, his heart, kidneys, and other organs may be permanently damaged. The war on the microbes still remains man's chief problem in his struggle for longer life. But even if pathogenic organisms were driven off the face of the earth, arteries would still harden with advancing age and functional diseases would remain to thwart man's desire for health and long life. We are today as much in the dark concerning how to attack many of our functional diseases as our fathers were concerning the problem of contagious disease. Patient and intelligent scientific research may some day show the way to the conquest of the great functional diseases. How soon, no one can tell. At the present time there is probably no single problem that is receiving more attention from scientific workers than that of discovering methods of attacking the fourth great cause of death, cancer.

Cancer.—The male section of our population is the more susceptible to arteriosclerotic conditions, while almost twice as many women as men die of cancer. This disease occurs when a group of cells loses its normal function and begins multiplying rapidly, so that a great mass of growing tissue is formed in the body. If this mass can be completely removed by the surgeon's knife or by radium or X-ray treatments, the cancer can be cured. But frequently, before this can be accomplished, some of the cells break loose and move through the lymph system to all parts of the body. From this time on it is practically impossible to cure cancer. Death ensues from exhaustion of the body or from interference with the functioning of a vital organ.

Cancer can be caused by long-continued irritation of the tissues at the point where it begins. Cancer of the mouth, for example, is more frequent among men than among women, presumably because in men there is more irritation from smoking. Apparently some inherited readiness on the part of the tissues to react in this manner to the irritation is also a causative factor. It has been shown that certain hereditary strains of mice show a low susceptibility to cancer, whereas in other strains cancer is almost certain to develop. The only method now known of combating cancer is to destroy it in its early stages. This means that from thirty-five years of age onward, individuals should watch themselves for signs of cancer and go immediately to a doctor to check on any persistent sore or lump in any part of the body. Many such conditions will, of course, prove to be harmless; but one case of cancer detected in its early stages and cured will be worth many false alarms, considering that thirteen per cent of all women and seven per cent of all men over forty years of age will die of cancer. Today vigilance on the part of its potential victims is the chief weapon with which cancer can be combated. Tomorrow, the scientific laboratory may find for us a more certain way.

Chapter Summary

The endocrine glands secrete substances known as hormones into the blood stream, where they are carried to all parts of the body. Under- or over-functioning of these organs may result in a variety of functional disorders. When the islands of Langerhans in the pancreas fail to secrete their hormone, insulin, sugar remains in the blood and is not stored by the liver or used for fuel by the body cells. This condition produces the disease diabetes, the symptoms of which are:

1. Copious urination with much sugar in the urine, caused by excess sugar in the blood.
2. Wasting away of tissues and muscular weakness, caused by burning of proteins rather than carbohydrates.
3. Poisoning of the body, caused by partial burning of fats.

Since the discovery of methods for preparing insulin, diabetes can be controlled by daily injections of the hormone, although this treatment does not result in cure.

When the thyroid gland in the throat fails to produce sufficient thyroxin, the rate of metabolism is greatly decreased. In adults, this results in myxedema, in which the patient suffers from cold and is physically and mentally sluggish. When the thyroid is underactive or inactive from the time of birth, the child does not grow properly, and a strangely shaped, feeble-minded dwarf known as a cretin is produced. Both myxedema and cretinism may be avoided or improved by feeding thyroid extract. People who suffer from an oversupply of thyroxin are overactive, nervous, and irritable. Thyroxin is an iodine compound; hence, whenever iodine is missing from the diet, the thyroid gland grows large in order to make up for the lack of iodine. This condition is called goiter, and it occurs frequently in regions where there is little iodine in the soil and water.

The four parathyroid glands are located on the inner surface of the thyroid gland. Their hormone, parathyrin, regulates the amount of calcium in the blood. Undersecretion results in the lowering of the calcium content, which causes spasms that may result in death.

The adrenal glands are located just above each kidney. Each is divided into two parts: an inner center, or medulla, and an outer rind, or cortex. The cortex produces the hormone cortin. When cortin is absent, a fatal condition known as Addison's disease develops.

The endocrine glands influence one another's activity to such an extent that they constitute what is essentially a single system, and they have been called the "interlocking directorate" in control of bodily functioning. The pituitary gland, located at the base of the brain, produces a hormone that stimulates growth. Giants are produced by oversecretion of this hormone, and dwarfs by undersecretion. Oversecretion in adulthood results in acromegaly, a condition marked by overgrowth of the lower jaw, lips, nose, hands, feet, and other structures. The production of this hormone is stimulated by the thyroid gland; and, in return, the pituitary produces another hormone which stimulates thyroid development. It also produces hormones which stimulate the adrenal cortex and the parathyroids, and it interacts with the hormones of the sex glands. It produces two hormones which are responsible for the symptoms of diabetes when insulin is absent. Among other examples of interaction among the hormones are the precocious puberty and masculinization that result from overstimulation of the sex glands when the adrenal cortex is overdeveloped.

With the decrease in deaths in early life as a result of the practical elimination of many contagious diseases, the functional diseases of old age have become the most important causes of death. Heart disease, kidney disease, apoplexy, and cancer are now the chief causes of death. The first three of this group are ordinarily associated with arteriosclerosis, and death may be caused by damage to the heart, kidneys or brain when the hardened arteries burst or fail to carry enough blood to them. Positive cure or prevention of these diseases is at present impossible.

Cancer occurs when certain cells begin to grow and multiply rapidly. Irritation of the tissues seems to be responsible for starting these growths. Cure can be effected by destroying the growing tissues with X-rays or radium or by surgical removal, provided the disease is treated before the cells have begun to move through the lymph system to all parts of the body.

QUESTIONS

1. What is an endocrine gland? A hormone?
2. Give the location and describe the functions and medical significance of the following endocrine glands:
   - (a) Islands of Langerhans
   - (b) Thyroid
   - (c) Pituitary
   - (d) Adrenal cortex
3. What is meant by saying that the glands are an "interlocking directorate"? Illustrate.
4. What is the nature of the connection between kidney trouble and arteriosclerosis? Between heart trouble and arteriosclerosis?
5. Why is a person who has suffered an apoplectic stroke advised not to take heavy exercise?
6. Why is it important to be on the lookout for cancer and to report the first symptoms to a physician?
7. Discuss the relations between functional and contagious diseases.

GLOSSARY

acromegaly (ak′rō-meg′a-li) Disease produced by overactivity of the pituitary gland in adulthood, characterized by overgrowth of the jaw, hands and feet, lips and nose and other structures.

adrenal glands (ad-rē′nal) Two endocrine glands located just above each kidney.

apoplexy (ap′ō-plek-si) Sudden loss of consciousness resulting from the flooding of the brain tissues with blood from a broken artery.

arteriosclerosis (ar-tē′ri-ō-sklē-rō′sis) Hardening of the arteries.

cancer A tumor or group of growing cells that is likely to spread through the lymph system and continue growing until death ensues.

cortin (kôr′tin) Hormone produced in the cortex of the adrenal gland.

cretin (krē'tin) A person afflicted with cretinism.

cretinism (krē'tin-iz'm) A disease characterized by idiocy, malformation, and dwarfism caused by undersecretion of the thyroid during childhood.

endocrine gland (en'dō-krin) A ductless gland which secretes hormones into the blood stream.

hormone (hôr'mōn) A chemical substance, usually secreted by an endocrine gland, which makes its way through the body, usually through the blood stream, and exerts a definite influence over the activities of the cells, tissues and organs.

insulin (in'su-lin) A hormone produced by the islands of Langerhans.

islands of Langerhans (Län'ger-häns) The endocrine glands embedded in the pancreas.

myxedema (mik-se-dē'ma) Disease characterized by mental and physical sluggishness produced by failure of the thyroid secretion.

nephritis (nē-frī'tis) Inflammation of the kidneys.

parathyrin (păr'a-thī'rin) Hormone produced by the parathyroid glands.

parathyroid glands Four small endocrine glands located on the inner surface of the thyroid.

pituitary gland (pi-tū'i-ta-ri) Endocrine gland located at the base of the brain.

thyroid gland (thī'roid) Endocrine gland located in the neck.

thyroxin (thī-rok'sin) Hormone secreted by the thyroid gland.

PART II

REPRODUCTION, INHERITANCE AND DESCENT

CHAPTER X

HUMAN REPRODUCTION

General Nature of Sexual Reproduction.—Man has but one way of reproducing his kind. That method consists, in its essentials, in the union of two reproductive cells, the *egg* of the female

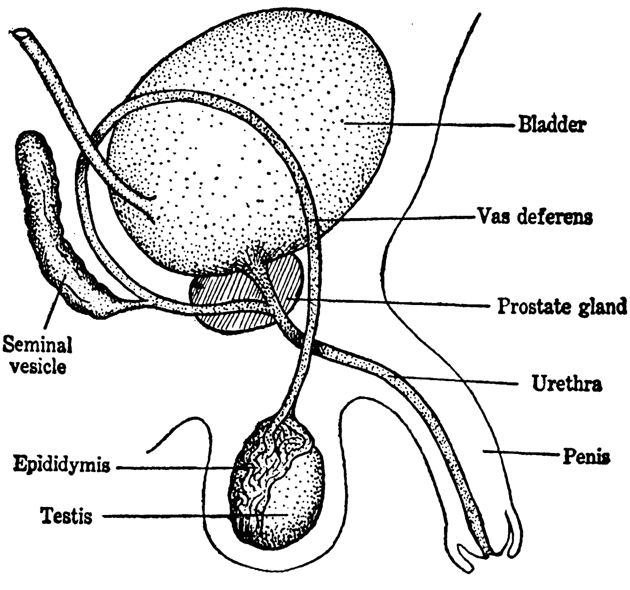
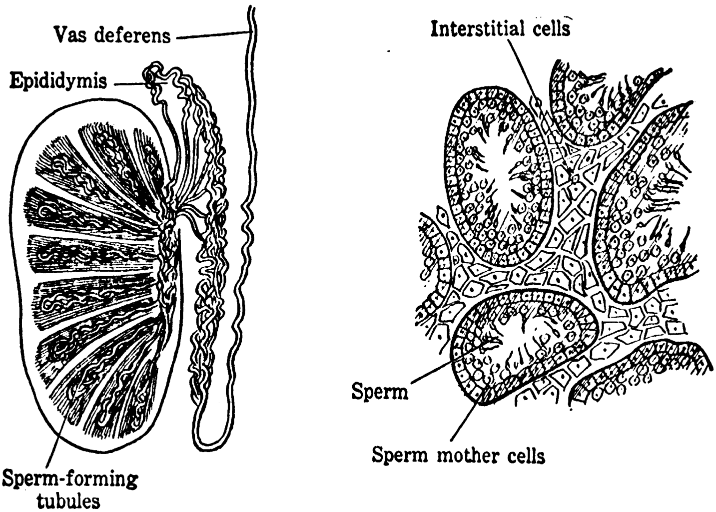


FIG. 43.—Male reproductive organs.

and the *sperm* of the male, to form a single cell, and the growth of that single cell into a new individual. All of the complicated sexual organs of men and women, all of the complex physiological processes which men, and particularly women, must go through, all of the pleasures, pains, desires, and intrigues connected with sexual reproduction exist solely for the successful bringing together of the egg and the sperm to form a new cell, and for the normal and secure growth of that new cell into an adult human being.

The Male Reproductive Organs.—The male reproductive organs have two functions: the production of sperms, and the conduction of the sperms to the penis, whence they are injected into the female.



A *B*

FIG. 44.—*A,* diagram of testis; *B,* cross section of testis. (Redrawn from Martin's *The Human Body,* Henry Holt & Company, Inc.)

The sperms are produced within paired organs, the *testes,* which are contained together in the loose fold of the *scrotum.* Each testis, within its fibrous membrane, consists of two types of structures, the *interstitial cells,* which produce the special male hormones, and the *sperm-bearing tubules.* There are eight hundred to a thousand tubules in each testis. Each tubule is very narrow and much coiled, and at one end all of the tubules join together to form a single common duct, the *epididymis.*

The tubules are filled with rounded cells containing large nuclei, known as *sperm mother cells.* In an adult man these cells are constantly dividing to produce sperms. The sperms, when mature, have an elliptical head, consisting entirely of nuclear material, and a long whip-like tail of cytoplasmic substance, which lashes violently and propels the sperm along. These sperm cells, when formed, pass down the sperm-bearing tubules and out of the testis through the epididymis.

The structures which convey the sperms from the testis are so closely connected with those associated with the excretion of urine that the two together are often spoken of as the *urogenital tract*. From each testis the epididymis opens into a long duct, the *vas deferens*, which passes over the urinary bladder into the lower part of the abdomen. At its end is a sac, called the *seminal vesicle*, into which the sperms pass from the vas deferens. The seminal vesicles are paired as are the testes, and lie back of and below the bladder.

As the sperms pass from the sperm-bearing tubules through the epididymis and vasa deferentia, liquid is added to them through secretions from the walls of the tubes through which they pass, and the sperm-containing liquid is stored in the seminal vesicles, which also add to the liquid mixture.

A tube called the *urethra* runs from the bladder through the penis, serving to carry the urine to the exterior. Completely surrounding this tube, just beneath the place where it leaves the bladder, is the *prostate gland*, which produces a liquid that is mixed with the sperms at the time of ejaculation. The seminal vesicles empty into the urethra through two ducts that run directly through the substance of the prostate and enter the urethra half an inch or so below the place where it leaves the bladder.

The penis is made up of three long cylinders of spongy tissue which run from its base to its head, surrounding the urethra on all sides. Under the influence of sexual excitement, blood flows into the small open spaces which honeycomb these spongy structures, and the penis becomes so engorged with blood that it grows erect and hard. When friction is applied to the erect penis, the muscles in the vasa deferentia, the seminal vesicles, and the prostate gland contract forcibly. The sperm-containing fluid from the vesicles and the secretion from the prostate are forced into the urethra, where they mix to form the seminal fluid or *semen*, which is immediately pushed along the urethra through contractions of the smooth muscles of the penis and forcibly ejaculated from the end of the duct.

The Female Reproductive Organs.—Corresponding to the testes of the male are the paired *ovaries* in the female, situated between the hips. In each ovary of a woman there are, at the time she reaches maturity, about thirty thousand eggs which are located just under the surface. No new eggs are produced during her lifetime. Beside the ovaries are the horn-like openings of the

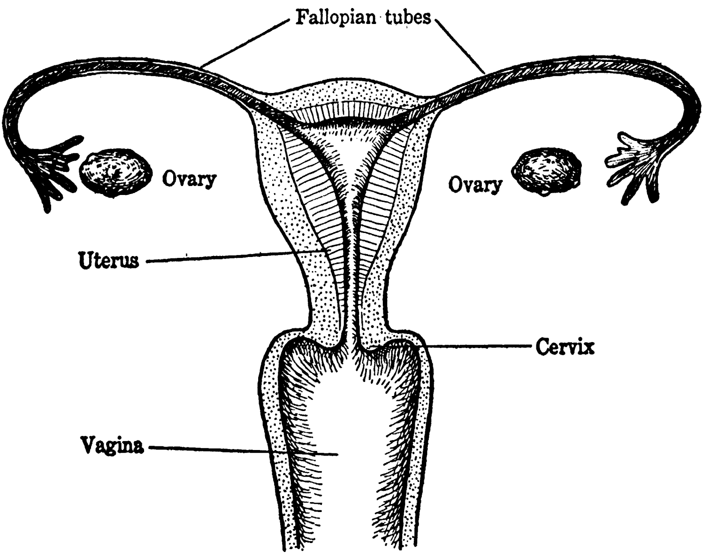


FIG. 45.—Female reproductive organs.

Fallopian tubes. The Fallopian tubes lead to a hollow muscular organ, the *uterus*, or womb, which opens to the outside of the body through a passage, the *vagina*. Between the end of the vagina and the uterus is a muscular constriction, the *cervix*.

The external parts of the female sex organs are spoken of collectively as the *vulva*. At the front there is a slight elevation composed of fatty tissues, called the *mons Veneris*, from which two folds of skin, the *labia majora*, extend downwards and backwards, coming together just back of the vaginal opening. Inside the labia majora is a second pair of folds, the *nymphae*. At the point where they join together in front is a small, sensitive organ, the *clitoris.* During sexual excitement it becomes erect like the male penis; in fact, it develops from the same structures in the unborn child that in the male grow into the penis. Back of the clitoris is the opening of the urethra, and behind it, the vagina, the opening of which in the virgin is ordinarily closed by a thin membrane, the *hymen.* During the first sexual intercourse, the entrance of the penis into the vagina usually breaks the hymen.

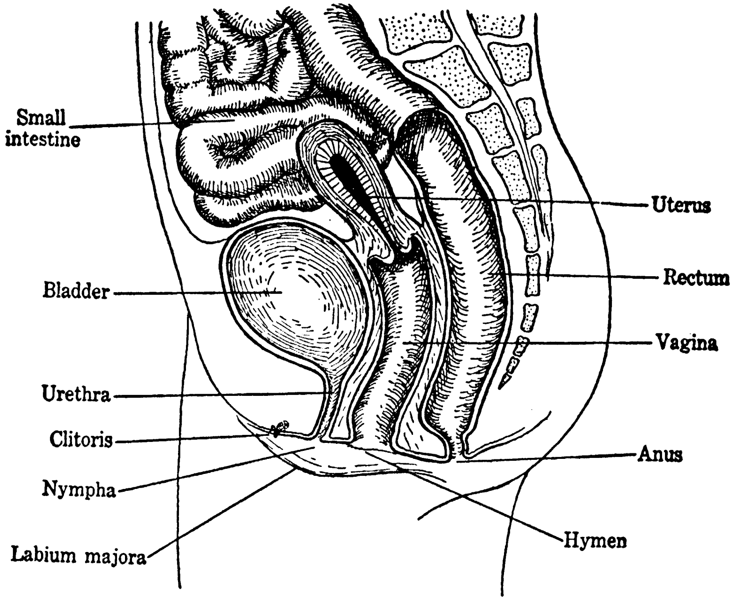


FIG. 46.—Median section of female reproductive tract.

There is a small opening in the center of this membrane, however, which sometimes stretches to permit the entrance of the penis without breaking the membrane; and disease, accident, exercise, or other factors may result in the destruction of the hymen prior to intercourse.

The Production of Egg Cells and the Menstrual Cycle.—In the course of her growth—usually sometime between her eleventh and sixteenth birthdays—a girl arrives at the age when mature egg cells begin to be formed in the ovary. This new development is signalized by the onset of recurrent periods of menstruation, during which a certain amount of blood and débris from the uterus passes out of the vagina. Menstruation occurs fairly regularly, usually about once every four weeks, except during pregnancy, until the age of forty-five or fifty. Then the menstrual periods become more and more infrequent and finally stop. This period of a woman's life is known as the *menopause,* and normally she cannot bear children after this time. Scattered periods of menstruation sometimes occur after the menopause, however, and women over sixty have been known to bear children.

The menstrual period is only a small part of a long process that goes on every month within the female reproductive organs, and

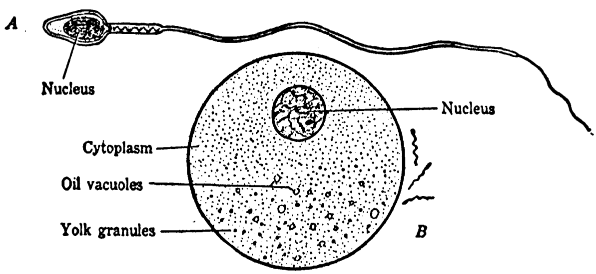


FIG. 47.—*A,* diagram of human sperm; *B,* diagram of human egg, showing relative size of sperm. (After McEwen.)

the events leading up to it begin two weeks or more before the onset of menstruation. The first event is the enlarging of one of the egg cells within the ovary. As the egg enlarges, it becomes surrounded by a sheath of cells, which eventually form a hollow sphere. The egg becomes embedded in a projection on the inner wall of the sphere, which is filled with a liquid. This specialized structure in which the egg develops is known as a *Graafian follicle.* (See Fig. 48.) As the egg and follicle mature, they gradually move up to the surface of the ovary, until they form a bump or a blister on it. Finally the Graafian follicle breaks open and the egg is discharged into the body cavity, but is almost immediately swept into the horn-like opening of the Fallopian tube by a current of liquid which carries it down toward the uterus. If it is not fertilized, it continues down the tube and within a few days is discharged through the vagina. Meanwhile, the wall of the uterus has been growing thicker and thicker and has developed a heavy mucous lining which, if the egg is fertilized, serves to hold it within the uterus and supply it with nourishment. About two weeks after the egg leaves the ovary, however, if fertilization does not take place, menstruation occurs, the lining breaks down and is shed through the vagina. The thickness of the uterine wall is reduced to normal and in a few days the cycle begins again.

The Graafian Follicle and the Corpus Luteum.—A most interesting problem is the timing of this elaborate cycle. How is it that the uterine wall manages to enlarge just as the egg is passing down the Fallopian tube, and is shed soon after the unfertilized egg reaches it?

Recent experiments show that the Graafian follicle produces a hormone, called *theelin.* This hormone stimulates the thickening of the uterine wall. After the follicle breaks, less of the hormone is formed, although the ovary probably manufactures a small amount of it at all times. The cells which line the broken follicle, however, divide rapidly to form a little ball of yellowish tissue called the *corpus luteum.* This structure produces a second hormone, *progestin,* which continues to stimulate the growth of the uterine wall, producing the changes that specifically prepare the uterus for pregnancy. If the egg is not fertilized, the corpus luteum degenerates, the hormones which maintain the growth of the uterine wall are formed in such small quantities that the growth ceases, the wall breaks down, and menstruation begins.

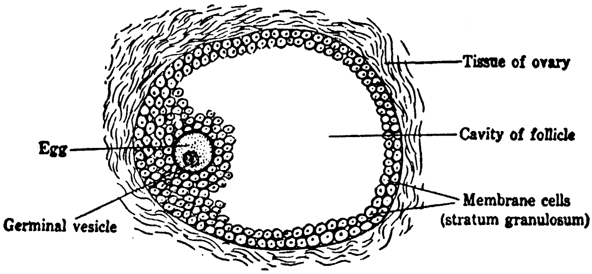


Fig. 48.—Graafian follicle.

Fertilization and Pregnancy.—During sexual intercourse, the penis is inserted into the vagina and the semen is ejaculated into it. The sperms may be forced immediately into the uterus by muscular contractions in the vagina, or they may swim upward until they reach that organ. Sperm cells are so constructed that they tend to swim against a current; and since there is a continuous, slow stream of fluid flowing down the Fallopian tube, uterus, and vagina, the sperm swims upward. If an egg is being transported downward by this stream after coitus has taken place, sperm cells will swim toward it, and finally one of them will meet it, enter, and join its substance with that of the egg. This constitutes the act of fertilization. It usually occurs in the Fallopian tube, but occasionally in the uterus.

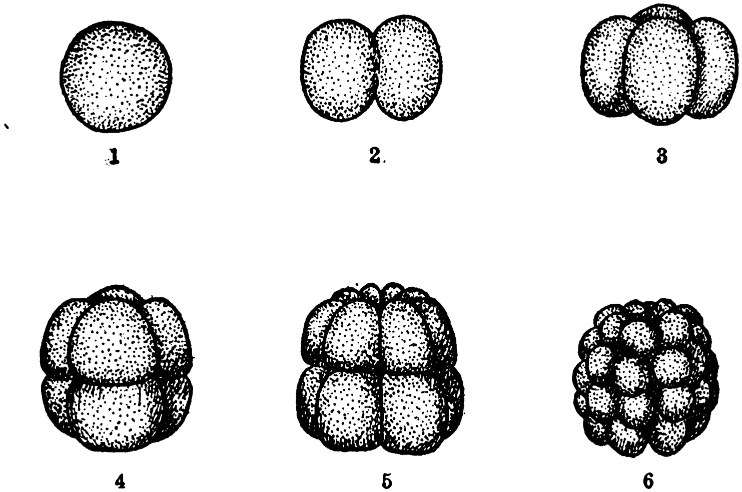
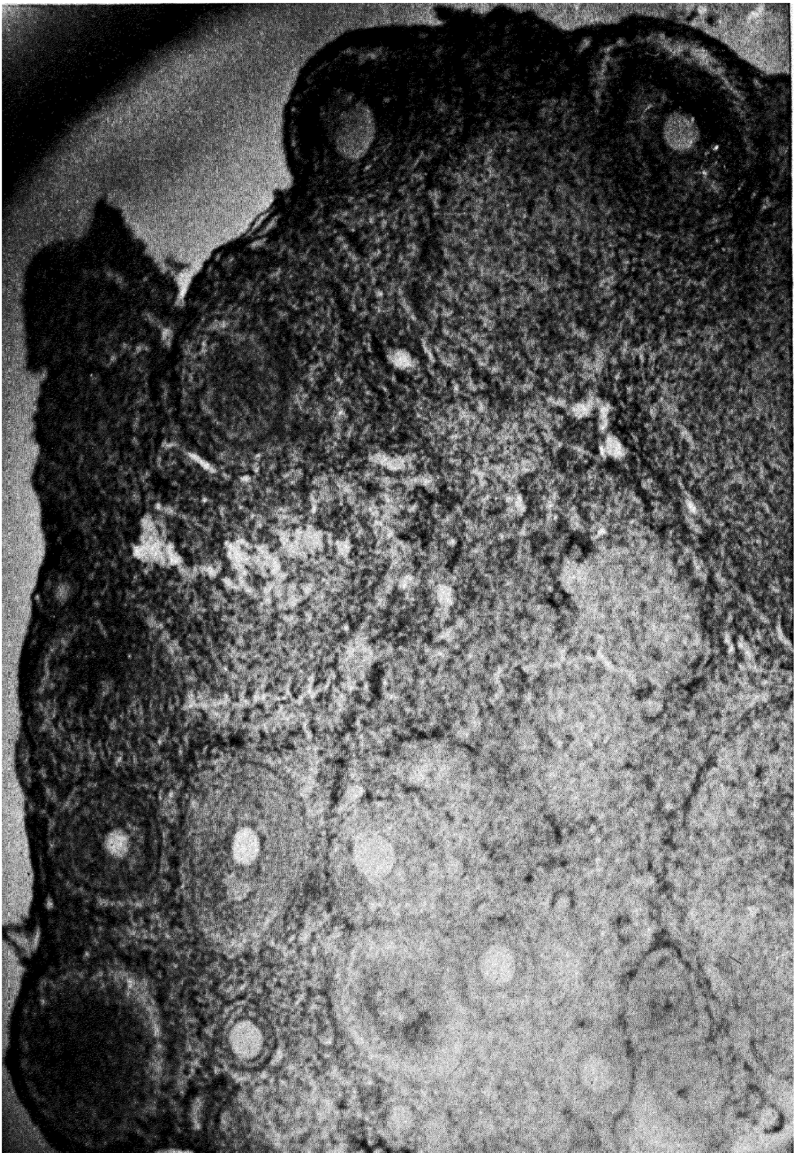


FIG. 49.—Cleavage and growth of the zygote in Amphioxus. In the human egg, this process is complicated by the presence of a yolk.

Collectively, the eggs and sperms are called *gametes.* The egg is the female gamete, the sperm, the male gamete. A fertilized egg, however, is not a gamete, but a *zygote.* In these terms, fertilization is the fusion of two gametes to form a zygote.

Immediately after fertilization, the zygote starts to divide rapidly to produce a cluster of cells, which, upon reaching the uterus, becomes embedded in its wall. In the interior of this mass of cells a cavity forms, on one side of which the new individual, or *embryo,* begins to appear. Its development is very complex because the embryo is a parasite of the mother. Membranes grow out from it and surround it, helping it to absorb food from the uterine wall. At about four weeks after fertilization it begins to take



Section of mouse ovary. The white objects are eggs, surrounded by the cells of undeveloped Graafian follicles.

form and to assume its final position in the uterus. At this age it is only a little over an eighth of an inch long. It is somewhat fish-like in appearance, with the beginnings of gill slits, a segmented back, and a tail. Small bumps on the under side are the "buds" for the arms and legs. At six weeks it is half an inch long, the head has begun to be differentiated, and the arms and legs have grown out, but the gill slits and tail are still present. By eight weeks the human form is attained, even though its length is only about one inch.

The embryo has now taken its final position in the uterus. It is enclosed within a sac, the walls of which consist of two membranes, known as the *amnion* and the *chorion*. Within the inner of these, the amnion, and completely bathing the embryo, is a fluid, the *amniotic fluid*. The membranes are therefore pressed closely against the wall of the uterus, except in one place, where they form a cord running into the embryo, and attached to its abdomen. It is through this *umbilical cord* that the embryo receives all of its food and excretes its waste products.

Opposite the outer end of the umbilical cord, the outer membrane, or chorion, has a particularly close connection with the uterine wall over an area known as the *placenta*. In this placenta the chorion is prolonged into branching projections, known as *villi*, which are embedded in the wall of the uterus. The wall is here filled with capillaries, coming from the circulatory system of the mother. Likewise, the villi of the chorion are filled with capillaries which are connected to blood vessels running up to the umbilical cord, and hence are filled with blood from the embryo. As the mother's blood surges through the capillaries in the uterine wall, oxygen and food materials pass from it across the outer membrane of the wall and that of the chorion, to be taken up by the capillaries of the embryo. Likewise, carbon dioxide and waste materials make their way from the capillaries of the embryo through the chorion and uterine membrane into those of the blood stream of the mother. Thus it is through the placenta that the embryo receives its food and oxygen from its mother, and delivers its waste products to her.

When, after eight weeks, the embryo has taken on the human form, it is no longer called an embryo, but a *fetus*. The further

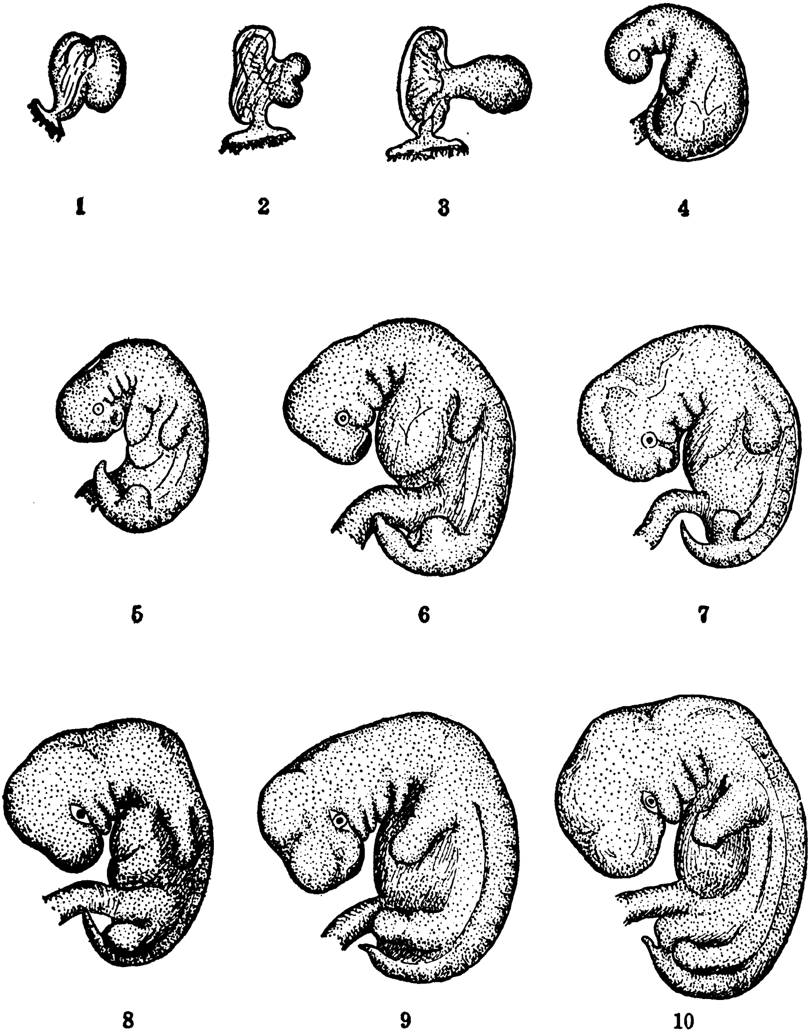


FIG. 50.—Human embryonic development: 4-6 weeks.

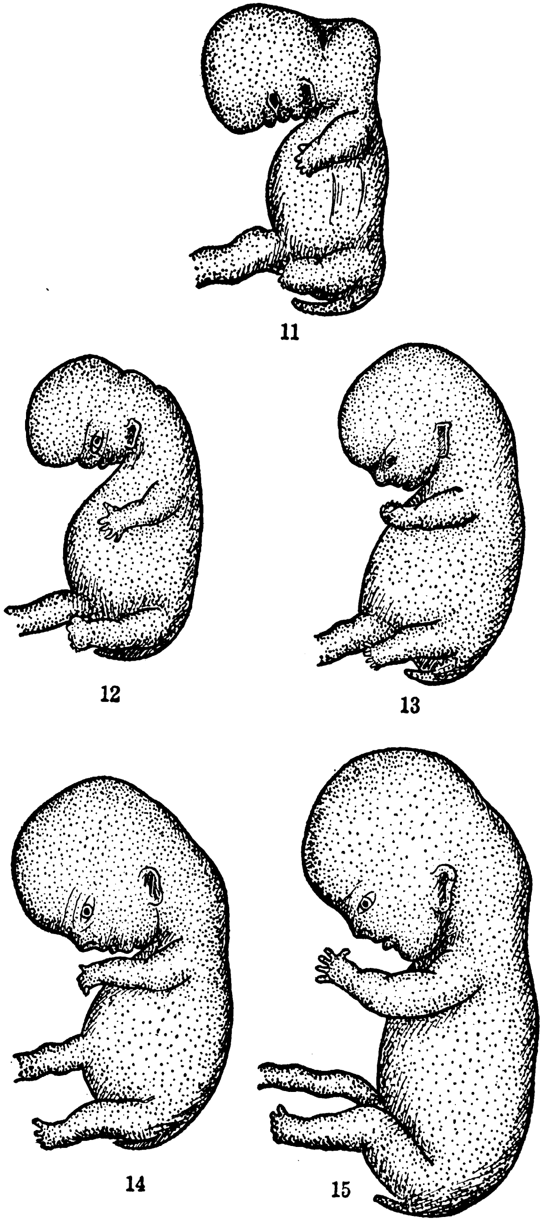


FIG. 51.—Human embryonic development: 7-8 weeks.

development consists simply of the enlargement and perfection of its parts. At four months, the fetal heart has started to beat, and muscular movements sometimes occur. At birth the fetus is about a foot and a half long.

Birth.—At about two hundred and eighty days, or nine months after fertilization, the uterus, now about four hundred times as large as when it first received the fertilized egg, begins to contract. These contractions, at first slight and infrequent, are the beginning of the period known as labor. This period is usually

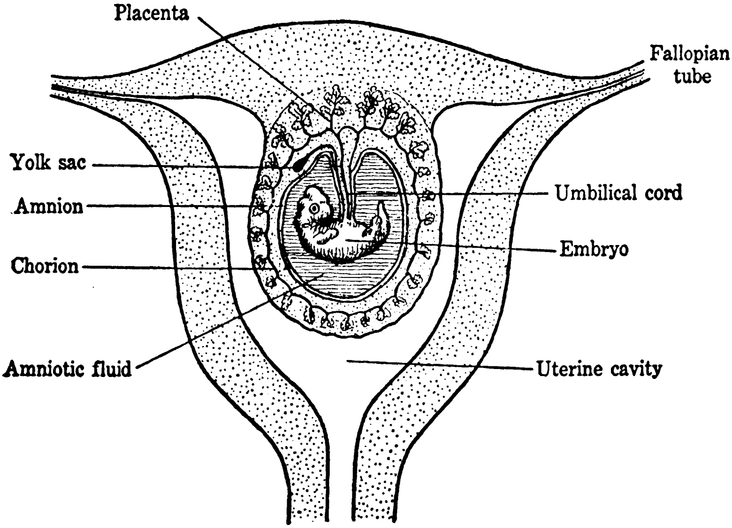


FIG. 52.—Diagrammatic section of uterus with embryo.

divided into three stages. During the first, which usually lasts from twelve to sixteen hours, the contractions of the uterus, which cause the chief pains of childbirth, force the amniotic sac, containing its fluid and the embryo, down toward the cervix, the muscles of which are gradually relaxing, to permit the fetus to go farther and farther through. Finally, the amniotic sac breaks, and its fluid pours out of the vagina. This "breaking of the waters" usually occurs near the end of the first stage of labor. During the second stage, which usually lasts about an hour, the baby passes through the cervix and vagina and is born. Finally, in the last fifteen minutes of labor, the amnion and chorion pass out of the uterus and vagina, constituting the "afterbirth."

In civilized countries, the structure and activity of most women have apparently been modified to such an extent that bearing children is much more difficult for them than it is for animals and for the women of some savage races. Often the doctor, known as an obstetrician, who nowadays is usually present at childbirth, must assist the process by using pairs of pincers, or forceps, with which he takes hold of the child. Occasionally, he increases the contractions of the uterus by administering drugs, one of which is an extract of the pituitary gland. In some cases the fetus is too large to pass through the set of bones, known as the pelvic arch, through which the vagina passes. In that case the obstetrician must cut through the front wall of the abdomen, and take out the fetus. This is known as a Caesarian operation, and it is commonly supposed that Julius Caesar was born in this fash-

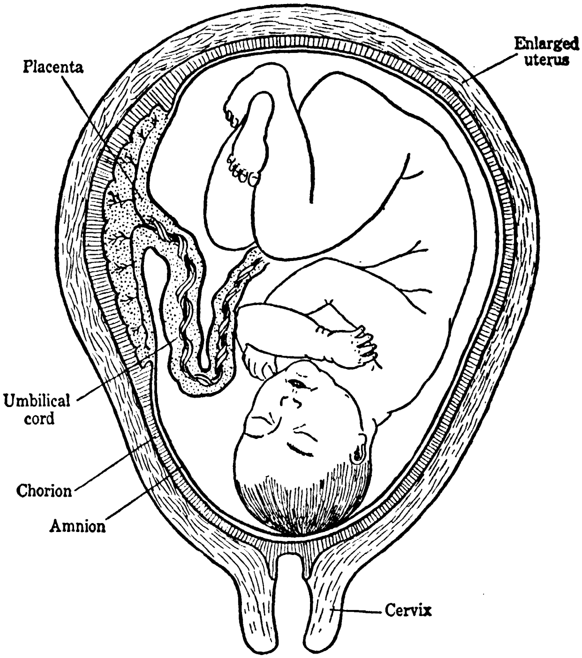


FIG. 53.—Human fetus in uterus just prior to birth.

ion. Although it is not a dangerous operation, it leaves the abdominal walls weakened. Hence, a woman who cannot safely give birth to children in the usual way is ordinarily sterilized after the second Caesarian delivery.

How Twins Are Produced.—Although, as a rule, but one baby is born at a time, twins sometimes appear, as a result of deviations from the normal method of conception and childbirth. These deviations are of two very different types, and lead to the production of two different kinds of twins, known as *fraternal* or *non-identical*, and *identical* twins.

Non-identical twins are no more alike than ordinary brothers and sisters, and have in common only their age. They are produced by the releasing of two eggs at the same time. If these are both fertilized, they become embedded, one on either side of the uterus, and develop there side by side. This production of two eggs at once may be inherited as a tendency, since there are mothers who produce more twins than single children, and whose daughters also tend to be twin-producers.

Identical twins are produced from the same fertilized egg. Exactly how this happens in women we are not quite sure, but the most likely method has been discovered in the Texas armadillo, which regularly produces identical quadruplets. Here the embryo is split at a very early stage into four parts, each of which continues development independently and finally produces a fully formed young armadillo. Our best evidence that this split can also occur in the human embryo is that of Siamese twins, which evidently are the result of such a split which has not been quite complete. Occasionally, moreover, odd monstrosities are born with two heads, four arms, or similar duplications of other parts. These must be the result of the partial splitting of the early embryo.

Identical twins are usually very much alike, both physically and mentally, and in many cases cannot be told apart, even by their best friends. They have often been studied in order to determine the relative effect of heredity and environment on intelligence and personality, since in their case the inheritance of each is exactly the same.

One interesting peculiarity of identical twins is that they are often the mirror image of each other. If one is right-, the other is left-handed. Slight differences in the features of the two sides of the face, which we all possess, are similarly mirrored. The right side of the face of one twin looks more like the left side of the other, and vice versa. This peculiarity is, of course, quite clear to us if we consider the twins to have resulted from the splitting of a single embryo, since the right side of one twin and the left side of the other were originally destined to be the two sides of the same individual.

The offspring of a multiple birth, i.e., triplets, quadruplets, etc., may be all fraternal, all identical, or some may be fraternal and others identical. The famous Dionne quintuplets have been pronounced all identical.

The Hormones of the Gonads.—In both sexes the organs which produce the gametes, that is, the sperms and eggs, are called *gonads*, a term based on the Greek verb meaning "to be born." The ovaries are the female gonads, the testes, the male gonads, and they constitute the primary sex organs in either sex. Hormones are produced in both. The manner in which the ovarian hormones control the menstrual cycle has already been described. But these hormones, especially the one formed in the Graafian follicle, also regulate the development of *secondary sexual characteristics*, and the hormones formed in the interstitial cells of the testes do the same thing for men.

The secondary sexual characteristics are all those characteristics that differentiate the male from the female besides the mere possession of ovaries and testes. Their development begins in the embryo. At the earliest period of embryonic growth the structures that are going to develop into the sex organs are no different in men than in women. But at a fairly early stage the testes become differentiated from the ovaries and begin to secrete their hormones which stimulate the growth of the structures that develop into the penis and prostate gland of the male. It is not known whether the female hormones are produced in the embryonic stage or whether the sex organs of the female develop simply because the male hormones are missing. At birth, the chief differences between boys and girls are the presence of the male and female sex organs in a rudimentary stage of development, a somewhat smaller average size among girls and slightly narrower hips among the boys.

No further differences appear until, at the age of puberty, the sex hormones begin to be formed in great quantities. In the girl, the uterus and vagina increase in size and the menstrual cycle sets in; the hips widen to make room for the bearing of children, the breasts increase in size, and a growth of hair occurs under the armpits and about the external sex organs. A deposit of fat is laid down between the skin and muscles, which gives to the woman's body its characteristic rounded contours. It is this fat deposit which enables women to be comparatively better at swimming than at any other sport, since it decreases the specific gravity of their bodies. All these changes are brought about by stimulation from the ovarian hormones.

The adolescent boy, under the influence of the hormones from the interstitial cells, undergoes an entirely different development. The penis and prostate gland enlarge and sperms begin to form, shoulders broaden, while the hips remain narrow; hair appears more profusely and in a different pattern than in the woman, the outstanding difference being the growth of the beard; the voice becomes deeper, and the muscles become firmer. The muscles of a man are able to burn energy much more rapidly than those of a woman, and consequently the male is capable of greater feats of strength; but it is claimed that because men use up their energy more rapidly than women they are less capable of going without food and sleep.

Among domestic animals, castration, that is, removal of the testes, is frequently practiced, and always prevents the appearance of male characteristics. In the capon and in other fowls this is done to keep the muscles of the bird soft and good for eating. In the case of the horse, however, the operation is performed in order to keep him from developing the untamable spirit of the stallion. In various lands and times, it has been the practice to castrate certain boys to provide eunuchs for harems, choirs or other institutions. These eunuchs grow up lacking in the secondary sexual characteristics of the male. They are beardless, have high-pitched voices and are usually fat and flabby.

The testicular hormone apparently performs its major functions during the few years that a man is reaching sexual maturity. Loss of the testes after this time may fail to produce any changes at all in the male, except, of course, that failure to produce sperms results in complete sterility. There may be no loss whatever in sexual desire or capacity for sexual intercourse; and when such loss does take place, it is probably due to the individual's mental attitude, rather than to physiological changes.

In the female, loss of the ovaries or their failure to produce hormones after the menopause does result in certain slight modifications in the uterus and some disappearance of secondary sexual characteristics. At the time of the menopause, ill health, irritability, and emotional depression may appear. This may in part be due to a lack of balance in hormone secretions, and it can be controlled to some extent by administration of theelin or sometimes of thyroxin until the balance reestablishes itself. But the menopause does not necessarily result in loss of sexual desire or sexual capacity; and when such a change does occur, it is likely that mental attitude plays a considerable part in producing it.

It is now known that the production of testicular and ovarian hormones is stimulated by a hormone produced in the pituitary gland, known as the *gonadotropic* hormone because it stimulates growth and activity of the gonads. It is the hormone that really initiates the changes that occur during puberty, although it does not itself produce secondary sexual characteristics. The presence of testicular or ovarian hormones in the blood inhibits the formation of this pituitary hormone, with the result that as these hormones are produced, the stimulation for their production falls off. It is thought that the timing of the menstrual cycle is dependent on this interaction between pituitary and ovarian hormones.

The Hormones in Pregnancy and Child-bearing.—The bodily changes that take place during pregnancy, the activities of child-bearing, and the beginning of the flow of milk, already prepared for by the growth of the mammary glands during pregnancy, are all regulated by a number of interacting hormones produced in the pituitary, the ovaries, and the placenta. The nature of this interaction is not completely known at present, and it is so complex that we shall make no attempt to describe it. One interesting change in hormone secretion during pregnancy is the appearance in the blood and urine, within a few days after the failure of the menstrual period, of an unprecedented amount of the gonadotropic hormone. Evidence indicates that the increase in the production of this hormone is a result not so much of increased pituitary activity as of manufacture of the hormone in a new structure, the placenta. Since the mere missing of a menstrual period is never a certain sign of pregnancy—irregular menstruation is not at all rare in women—the presence of the gonadotropic hormone in the urine is the most certain early indication of pregnancy. In order to make a test, small amounts of the urine are injected into female rabbits, and, if the woman is pregnant, the animals become sexually active within a few days through the stimulation of the gonadotropic hormone in the urine. By this simple test doctors can make an assured diagnosis of pregnancy much earlier than was formerly possible.

Venereal Diseases.—Gonorrhea and syphilis, the two diseases which are usually contracted through sexual intercourse with an infected person, constitute one of the major health problems of the present time. Gonorrhea is caused by a coccus which attacks the mucous membranes. These membranes in any part of the body are subject to infection, but those of the genital tract are the usual sites. Ordinarily it attacks the urethra in the male and from there makes its way into the prostate, seminal vesicles, and vasa deferentia. It may result in a closing off of the latter tubes, producing sterility. In the female it first attacks the membranes of the vagina and may then make its way into the uterus, the Fallopian tubes, and even into the body cavity, where it attacks the intestinal linings. Occasionally in both sexes it enters the blood stream and, infecting the joints, produces a severe form of rheumatism. In the male it makes its presence known within a few days after infection by producing a severe pain during urination. In the female it may go undetected until it has infected almost the entire genital tract, when it begins to form pus pockets that result in pain and fever. Treatment, which was formerly somewhat difficult, has been made more certain and easy with the development of the sulfa drugs and penicillin. It is important that a good doctor be consulted as soon as symptoms appear. Frequently much harm is done through attempts at self-treatment or reliance upon quack doctors.

When a mother is infected with gonorrhea, the disease may attack the mucous membranes of the eyes of her newborn child. In the past this condition was one of the more frequent sources of blindness. A few drops of silver nitrate solution in the eyes of the newborn child effectively prevent gonorrheal blindness, and in many states such antiseptic treatment is required by law for every newborn child.

Syphilis is a disease of the blood, caused by a bacterial organism, known as a spirochete, which can enter the body through a sore or cut, but which usually enters through the thin membranes of the vagina or those at the end of the penis. When untreated, its symptoms appear in three stages. Two or three weeks after infection, a small hard elevation, known as a *chancre,* appears at the point where the infection entered. This is the *primary stage.* The chancre now disappears, and in the course of six to twelve weeks the *secondary stage* begins. Its symptoms are variable; there may be a swelling of the lymph glands, a rash covering the body, and fever. The secondary symptoms usually disappear, whether the individual is treated or not, and then several years may elapse before the *tertiary* symptoms begin to undermine the health of the victim. Now the spirochetes may attack almost any organ of the body. They may produce hardening and weakening of the arterial walls in restricted regions throughout the circulatory system, although they do not cause general arteriosclerosis. They may attack the heart, the stomach, kidneys, liver, and pancreas. One of the most ordinary types of insanity is produced by syphilitic attacks upon the tissues of the brain.

Syphilis is a very subtle enemy. Occasionally the primary and secondary stages are so slight that the individual never knows that he has contracted it. Even after prolonged treatment it may not be entirely eradicated; and since it may be present in the blood for several years without displaying any symptoms, an individual may have it without knowing it. It is possible at any time, however, to make a blood test, called the *Wassermann test,* to determine whether the germ is present and whether treatment should be started or continued. The treatment, which usually embodies the injection of arsenic compounds into the blood to kill the spirochete, must frequently be prolonged for two years or more; and even after a patient is discharged, he should return occasionally to his doctor for a Wassermann test. All too frequently a patient stops going to his physician as soon as the secondary symptoms disappear; but the spirochete may still remain in the blood, and treatment should never be stopped until the Wassermann is consistently negative.

Syphilis is often called a "hereditary disease." This designation is not exact, since the term "hereditary" should apply only to characteristics of the organism that are determined by the material present in the zygote at the time of fertilization. The fetus, however, can acquire the disease from an infected mother, and many children are born with syphilis and hence are said to have acquired it *congenitally*. Usually the fetus is born dead before the normal time. When birth does take place, the symptoms of syphilis appear in the child, and syphilitic insanity may develop. Congenital syphilis can be treated and cured, or it can be entirely avoided if treatment of the mother begins at least five months before the time of birth. To be on the safe side, the Wassermann test should be a part of the early medical examination of every pregnant mother.

Largely because of the unwillingness of the public to face squarely the issue of eradicating venereal disease, a great deal of unnecessary suffering and illness has been occasioned. The fact that the sulfa drugs are especially helpful in both preventing and curing gonorrhea may make possible its final elimination. If penicillin proves to be as effective against syphilis as it promises to be, it may provide the necessary leverage for the eradication of that disease.

Nevertheless, to stamp out venereal disease in America will require a vigorous public health campaign. Clinics must be established where those who cannot afford to pay may secure free examination and cure, both for their own sakes and for the protection of the entire public. Wassermann tests should be administered as a routine measure to all individuals applying for marriage licenses and to all persons working in occupations where they might pass syphilis on to others. Barbers, cooks, and food handlers in general fall into this latter category. Employers can improve the efficiency of their employees by requiring medical examinations including examination for venereal disease and at the same time be of assistance in eradicating these diseases from the population.

Finally, the public should be educated to seek examination for and cure of venereal disease as readily as it seeks to be rid of other dangerous ailments. Since venereal disease can be contracted by other means than through sexual intercourse, there is no implication of immorality in the request that one submit oneself along with others to a routine examination. Public education in avoidance of venereal disease should accompany education for detection and cure. The surest and best way to avoid it is to avoid sexual intercourse with individuals of promiscuous sexual habits. But such habits are so widespread in our population that merely recommending abstinence will not go far enough in stamping out these diseases. It is possible to take precaution against them both during and after sexual intercourse. Such precaution, medically termed *prophylaxis,* is best effected under the direction and with the help of a competent physician, and no individual should expose himself to infection in this way without securing competent medical advice on prophylaxis. Public prophylactic clinics are needed to encourage the employment of prophylaxis throughout the population. At the same time, it should be made clear to everyone that the best of prophylactic measures may fail, and that the preferable method of prevention is abstinence.

The Normal Sex Life.—The consequences of venereal disease have often been so much impressed upon young people that they develop an attitude of fear and disgust toward the entire range of sexual life. Or feelings of anxiety about sex may develop on other grounds. This is unfortunate, for the sexual function is one that is peculiarly capable of bringing pleasure and happiness to human beings, and sex is never a "problem" unless through ignorance and fear we make it so. The sexual life needs only to be intelligently controlled and regulated to bring to us some of the greatest satisfactions that life can offer.

The sexual relationship should be looked upon as one of the good things of life, to be enjoyed as fully as possible as long as its enjoyment does not endanger one's own welfare and that of others. By enjoyment of this relationship, we mean much more than the purely physical satisfactions resulting from stimulation of the sex organs. The emotional satisfactions, which to a certain extent are built up around this physical core, are generally conceded to be far greater than the purely physical ones. To be sure, it is difficult to draw a hard and fast line between physical and emotional satisfactions, and with happily married people they blend together, the one enhancing the other. But it is possible for physical sexual satisfaction to take place without experiencing any of the thrill of being with an attractive person of the opposite sex or the joy and pride of mutual love; similarly, these emotional concomitants of sexual activity can be at least partially experienced in the absence of the physical relationship.

Considerations both of morality and of prudence make it desirable for unmarried people to abstain from the physical satisfactions of sexual intercourse. This is difficult for many because of the great strength of the sexual appetite. But often the difficulty is doubled by a more or less conscious feeling that the practice of chastity deprives one of the greatest of human pleasures. Through misinterpretation of modern psychological findings, some people have even obtained the impression that chastity in itself may be the cause of mental and nervous breakdown. The truth is that, at least among those who have not become habituated to sexual intercourse, personal happiness and a good adjustment to life do not seem to be highly dependent upon physical sexual satisfaction. The really important sexual satisfactions are the emotional ones, and no young man or woman needs to miss them. The pleasures of companionship and social relations with members of the opposite sex, the consummate pleasures of falling in love and being in love are among the greatest that human beings can enjoy. Older people often look back upon them as "the happiest time of their lives." The enjoyment of such happy personal relationships between young people lays the foundation for happy relationships between husbands and wives, for happiness in marriage is more dependent upon a successful emotional adjustment than upon the purely physical side of the marital relationship.

In all but an exceptional few, however, the purely physical sexual drive will not remain in abeyance during the years between puberty and marriage. It usually expresses itself in voluptuous dreams which, in the male, frequently culminate in the ejaculation of semen. Occasionally boys or men get to worrying about these dreams, believing that the loss of semen is "robbing them of their manhood." This anxiety is encouraged by medical quacks who offer to cure them of their ailment. Actually, it is only a normal physical outlet, and its occurrence is practically universal.

Another form of physical expression which occurs in the majority of both men and women at some time during their lives is self-induced stimulation of the sex organs. Traditionally, it has been called masturbation, but since this designation implies a false notion of the harmfulness of the practice, we shall use the more scientific term, *auto-erotism.* In the past, this practice has been looked upon with abhorrence, and young people have been assured that it is the cause of everything from insanity to shifty eyes and cold, clammy hands. All reliable authorities now hold that auto-erotism is of no harm to anyone unless he worries about it. Perhaps it is the most common source of sexual anxiety. Not only does the young person fear its consequences, but he is likely to get the idea that he is lacking in moral character and will power. However, when ninety per cent of men and seventy-five per cent of women admit in confidential questionnaires that they have practiced auto-erotism—and the likelihood is that most of the others just won't admit it—the "victim" of this habit can at least console himself that his will power and moral character are no worse than those of the rest of the human race. When the individual ceases to worry about auto-erotism, it tends to lose any emotional interest for him, and he may simply outgrow it. The recommended attitude is to exercise as much self-control as possible and not to worry about lapses.

Frequently sexual daydreams lead up to auto-erotism or occur independently of it. While they are harmless enough if they do not occur too frequently, they occasionally come to dominate the thoughts of the individual to an undesirable extent. This means that he is allowing the purely sexual aspects of life, and among them the purely physical aspects of sex, to become too important. It is as if he spent all his time thinking about food or clothing or some other aspect of life which, important enough in itself, should normally constitute only a subordinate part of existence. The person who experiences continual sexual daydreams or who thinks about sex continuously needs to take more interest in his work, his play, his social life. Sexual interest should normally express itself chiefly in social relationships, with real members of the opposite sex, not dream lovers; and as the young man or woman falls in love and marries, it should come to be centered in a particular individual.

In marriage, the sexual aspect of the partnership is obviously only a part of the relationship; yet it is an important aspect of marital happiness. The art of sexual love-making is frequently not understood by married people, with the result that one or both of the partners finds the sexual relation unsatisfactory. This is almost never the result of an incapacity for complete sexual intercourse, but usually of a lack of knowledge concerning it. At the present time it is possible to secure a number of books which describe proper techniques for sexual relations, and some knowledge of the matter should be in the possession of every married couple.

In conclusion, the most normal attitude toward the sexual life is to seek to enjoy it as completely as possible within the limits set by the moral code of the group in which you live. Do not be afraid to think about sex or to talk about it, under circumstances where such discussion is in good taste. At the same time, do not be obsessed with it, or think of it as an all-important aspect of life. If you are concerned with some personal sexual problem, discuss it confidentially with someone who has some knowledge concerning sexual hygiene. The chances are that the problem will fail to appear as important after the discussion as it now does to you, or at least that some good method of solution can be found.

The Control of Population.—With the advance of knowledge concerning the reproductive function, various methods have been developed to prevent fertilization of the egg subsequent to sexual intercourse. Collectively they are referred to as *contraception* or *birth control.* Contraception is usually effected by some method of keeping the sperm cells from reaching the egg. There are various state and national laws which make it illegal to spread information concerning the techniques of birth control, and some states do not even permit doctors to give this information when it might save a human life. It is safe to say that the majority of Americans—and by far the majority of well-educated Americans—favor birth control; but the general indifference of the population, combined with strong pressure from certain minority groups, has resulted in the retention of laws prohibiting the spread of contraceptive information. In recent years, judicial decisions have tended to interpret these laws very liberally, clinics have been established in many of our cities where people can go for medically necessary information, and thinly disguised advertisements of contraceptive techniques are widely distributed. Unfortunately, the safest and most convenient and effective methods are the most difficult to disguise in advertising. In spite of all laws, contraception is very widely practiced, especially among the wealthier and better-educated sections of the populace.

With the advance of knowledge concerning the time of ovulation during the menstrual cycle, it has been suggested that birth control be effected by limiting intercourse to times during which the egg would presumably not be present in the Fallopian tubes or uterus. Apparently it is not illegal to describe this method of birth control, since pamphlets suggesting its use have been widely and openly distributed in the United States mails. It is probably also legal to say that it is one of the least certain of all methods. The menstrual cycle does not work like a clock. Its timing varies from one woman to another and from one time to another in an individual woman. The times given in our foregoing discussion of the cycle are only averages. Least certain of all is the period of ovulation, and "going on time" is a very ineffective method of avoiding fertilization and pregnancy.

The advantages of birth control are that it enables husbands and wives to plan to have children at times when the mother is in good health and the family budget adequate to care for the new member of the family. Inability to control the rate at which children are born has meant untold suffering, ill health, and premature death to millions of women. Without contraception, the only feasible method of avoiding suffering and economic privation for millions of families in which the woman readily becomes pregnant is abstention from sexual intercourse; but this method is all too likely to result in emotional strain and marital unhappiness.

The Catholic Church, and along with it many individuals of other faiths, holds that the employment of birth control methods is morally wrong. Some believe that to prevent the sperm from uniting with the egg after sexual intercourse is tantamount to murder. Polls of public opinion, however, have shown that most people in this country disagree with this point of view. The writers of this book are definitely on the side of this majority, but they do feel that married people ought to consider it both a privilege and a moral obligation to bring as many children into the world as their health and financial opportunities permit. To use contraceptive techniques simply to escape the bother of raising children is a form of short-sighted selfishness that may not only result in a loss of real happiness on the part of the potential parents but be of grave disservice to society as a whole.

Birth control, like so many other types of scientific knowledge, has provided us with a power that can be of the greatest benefit to human beings. But like all other forms of power, it can be used for ill as well as for good. It has enabled many families to avoid tragedy and suffering, but it has also made it possible for individuals to avoid the responsibilities of parenthood, to decide upon "a new car, rather than a baby," thus impoverishing their own lives and resulting in an undesirable decrease in the birth rate among certain portions of the population. In every civilized country in the world, even in countries where the most stringent legal enactments against birth control are in effect, the spread of its use seems eventually to result in a positive decline in the growth of population among the classes in which birth control is widely employed. While most people want children, most of them are satisfied with one or two, and among a group of people in which the two-child family is standard, the population is bound to decline. In America, the wealthiest and most highly educated elements of the population are not replacing themselves, and increase in numbers comes from the poorer and less well-educated groups where birth control is not so widely practiced.

This phenomenon, known as the *differential birth rate* among classes, commonly appears in a country in which the use of contraception is gradually spreading. It is well-nigh universal in civilized countries today. As a result, the greater proportion of the population comes from families who are unable to offer the best cultural and educational advantages to their children. It may be also that the hereditary capacities which the more rapidly reproducing part of the population passes on to its children are inferior to those of the part that practices birth control. Our present knowledge of heredity is not sufficient for us to be certain of this, but it seems highly probable that it should be the case. At any rate, the differential birth rate produces a definitely undesirable condition of affairs.

As birth control information spreads throughout a population, the differential birth rate tends to disappear. The birth rate of the entire country falls so low that deaths exceed births, and the population declines. Some decline of population would probably be a good thing in many countries; but there is scant reason to believe that it would be desirable in our own country, and eventually it would lead to the virtual annihilation of the race if it was not checked in some manner.

"Abolishing birth control" is no solution for this problem. Indeed, such a program would be almost impossible to carry out, since people who have once enjoyed its advantages will offer a very determined resistance toward giving it up. The best solution seems to be, first, to eliminate the differential birth rate by actively disseminating birth control information among the less well-informed members of our population, rather than by attempting to keep that information from them; second, to encourage a higher birth rate among the more able people, thus reversing the differential birth rate and encouraging the production of a better, rather than a poorer, race.

Just how to encourage a high birth rate is a matter to be worked out by trial and experience. Through taxation, financial handicaps can be placed upon well-to-do people who do not have children, and the funds so secured could be used to subsidize early marriages and early births among able young men and women whose desire for an advanced education now leads them to postpone marriage and children. More important still would be some sort of propaganda that would make people in the professional and business classes willing to undergo financial handicaps and other sacrifices in order to have a large family. As long as a young lawyer feels that his status in the community is raised more through the possession of a new Buick than through having four healthy, well-reared children, lawyers and other professional people will buy Buicks rather than have children. We have seen that, by proper public health propaganda, the attitudes of people toward matters of cleanliness and sanitation can be changed. Today there is just as much call for a change in attitudes toward the having of children.

Individuals cannot bring about these changes. They must be brought about by governmental and social agencies. Again we discover that the full value of scientific discovery can be secured only through intelligent social and political action.

Chapter Summary

Sexual reproduction is the only kind found in human beings. In the male, sperms formed within paired organs, the testes, are conducted through the epididymes and vasa deferentia to the seminal vesicles. Here they are mixed with fluid from the prostate gland, and ejaculated through the urethra, a duct which passes through the penis.

In the female, eggs are liberated once a month from the ovaries. They are surrounded by a Graafian follicle, which ruptures to liberate the egg. The egg passes down the Fallopian tube, where it may be fertilized. If not fertilized, it is shed through the vagina, and later on the breakdown of the uterine wall brings about the process of menstruation.

The development of the uterine wall, as well as menstruation, is governed by a hormone from the Graafian follicle. Later the Graafian follicle becomes the corpus luteum, an endocrine gland which secretes a hormone influencing the bodily changes during pregnancy.

If the egg is fertilized, it becomes embedded in the wall of the uterus and develops. Three stages of development are described:

1. At two or three days, a round mass of cells.
2. At four weeks, a fish-like embryo, length 4 mm.
3. At eight weeks after fertilization, a fetus with the human form completely developed; length 1 inch.

The fetus is surrounded by two membranes, the amnion and chorion, which are part of it, and the inner of which contains the amniotic fluid. The membranes are connected to the fetus by means of the umbilical cord. The chorion is closely connected to the uterine walls by means of the placenta, through which the fetus receives its nourishment from the mother's blood.

At the end of 280 days, birth takes place through contraction of uterine walls and relaxation of cervix and vagina.

There are two types of twins: fraternal, or non-identical, and identical twins. The former are produced by the simultaneous fertilization of two different eggs, and the development side by side of the resulting embryos. The latter are probably the result of the splitting of a single embryo at an early age. Identical twins are remarkably similar in physical and mental characteristics.

The hormones produced in the gonads, that is, the testes and ovaries, stimulate the development of secondary sexual characteristics. In the male the secondary characteristics are: the penis and prostate gland; low voice; a characteristic male growth of hair, including the beard; broad shoulders, narrow hips, and hard muscles which burn oxygen more rapidly than those of the female. In the female they are: uterus and vagina, well-developed breasts, female pattern of hair growth, broad hips, and a deposit of fat between the skin and the muscles.

The production of the testicular and ovarian hormones is stimulated by the gonadotropic hormone of the pituitary. The gonadal hormones inhibit the formation of the pituitary hormone, so that there is a cyclical interaction between the two. A complex system of interacting hormones governs the development of the mother's body during pregnancy.

The venereal diseases, syphilis and gonorrhea, constitute one of the most important public health problems of the present day. The establishment of clinics for their prevention and cure, the use of routine tests for their detection, and the education of the public in means of avoiding and curing them are essential if they are to be eradicated.

The most intelligent program for the sex life of the unmarried adult is abstention from sexual intercourse, and enjoyment of emotional sexual satisfactions in the form of social relationships with members of the opposite sex. No apprehension should be felt concerning sexual dreams or nocturnal emissions, or concerning failure to achieve complete self-control over impulses to auto-erotism, popularly termed masturbation.

The practice of contraception, or birth control, has been of great benefit to human beings in that it has enabled them to avoid having children when considerations of health or economic necessity make it advisable. It has, however, resulted in a differential birth rate between the classes, and public measures to spread birth control information among the less well-educated classes and to increase the birth rate among the better-educated classes are necessary at the present time.

QUESTIONS

1. Describe the structure and activity of the reproductive organs in man.
2. Describe the menstrual cycle in woman, naming all of the structures involved, with their functions, and a brief account of the mechanism that causes the regularity of the cycle.
3. Give an account of the development of the human embryo and fetus, including a description of its appearance in at least three stages of its development.
4. What is the relation of the human embryo and fetus to the uterus and to its mother, and how does it obtain its nourishment?
5. What is the difference in relative appearance and in the mode of origin of identical and non-identical twins?
6. What are the secondary sexual characteristics and how are they produced?
7. What is the basis of the "mouse test" for pregnancy?
8. Describe the causes, symptoms, cures, and possible methods of prevention for venereal diseases.
9. Discuss the matter of an intelligent program for the guidance of the sex life.
10. What is contraception? What are its advantages? What problems have arisen as a result of it?

GLOSSARY

amnion (am'ni-on) The inner of the two membranes surrounding the embryo and fetus.

auto-erotism (ô'to-er'ō-tiz'm) Self-induced sexual stimulation. Masturbation.

cervix (ser'vix) A muscular constriction at the base of the uterus, which opens into the vagina.

chancre (shan'ker) A sore or ulcer appearing at the point where syphilitic organisms have obtained entrance into the system.

chorion (kō'ri-on) The outer of the two membranes surrounding the embryo and fetus.

clitoris (kli'tō-ris) A small organ in the upper part of the vulva. It develops from the same structures as the male penis.

CHAPTER XI

REPRODUCTION IN PLANTS AND ANIMALS

All Life Comes from Life.—Reproduction is a universal characteristic of all organisms. Until about fifty years ago, many people believed in the *spontaneous generation* of living things. They thought that organisms might be formed spontaneously out of such non-living substances as horsehair, decaying vegetation, and dung. But with the invention of the microscope, and after much careful research, it was definitely shown that even such lowly forms of life as bacteria and Protozoa come into existence only by a reproductive process. To be sure, it is still thought that hundreds of millions of years ago life slowly evolved from inorganic materials; and it may be that, even today, certain almost inconceivably primitive living things may be forming out of non-living matter. But no organism that we know of is created in this manner, since any organism that could be formed out of inorganic materials would probably be so small as to be undetectable under the most high-powered microscopes. It is only through reproduction that the countless species that are studied by the biologist can come into existence.

The type of reproduction found in man, however, is the result of a long train of evolutionary development, and countless other forms of reproduction are found. In only a few forms of animals are the young carried in the body, attached to the uterus by means of a placenta. Frequently the egg is fertilized entirely outside the body of the mother, and *copulation*, that is, sexual intercourse, does not occur. Indeed, sex is by no means a necessary feature of the reproductive process, and we shall begin our study of reproduction among plants and animals with a description of various forms of *asexual* reproduction, that is, reproduction without the fusion of gametes to form a zygote.

Asexual Reproduction

Reproduction by Cell Division.—Among one-celled organisms, a frequent type of reproduction is by simple division of one cell into two or more. In Protococcus, the protoplasm inside the cell wall simply divides in two parts and a cross wall is formed between them. The daughter cells thus produced usually separate; and as a result of this simple reproductive process, known as *fission*, two new individuals have come into existence and the parent cell has lost its identity.

Fission is also the common method of reproduction not only among all the one-celled algae, but also among the bacteria. Each bacterial cell merely divides into two, a cross wall is formed and the reproductive process is finished. Such fission often takes place several times an hour, so that the number of bacterial generations in a day reaches unbelievable proportions. With the Protozoa, also, reproduction by simple cell division is the rule. Among the yeast plants there is a modified form of fission known as budding. A small projection is formed on the parent cell; this gradually enlarges, and is then cut off by cell division, eventually separating as a new generation.

Division of the Multicellular Body.—Among multicellular organisms, special bodily structures may grow which, breaking or being cut off from the parent, form new organisms; or the parent may be divided to form new organisms without the formation of special structures. This method of asexual reproduction occurs frequently in plants and is not unknown among the lower animals. The following is a list of varieties of this type of reproduction:

1. *Regeneration.*—Among many of the lower animals, a part of the animal that is lost may grow out again from the point at which it was broken off. This process is called *regeneration*. The regeneration of legs occurs in insects, crabs, starfish and various other forms. One animal, known as the brittle starfish, protects itself by breaking all its long, slender legs in pieces whenever it is attacked, whereupon the comparatively small central part lies under a rock and awaits the regeneration of new legs. Some animals possess so great a power of regeneration that they can reproduce by breaking or being broken into many parts, with each part regenerating to form a whole new animal. This method is

most common among certain simple animals called flatworms. If a flatworm is cut into two hundred pieces, each piece will regenerate all the rest of the animal and become a new individual.

2. *Budding.*—In a few animals, a new organism may grow as a bud upon the parent, finally breaking off and beginning an independent existence. This is one of the ways in which Hydra reproduces, as shown in Fig. 23.

3. *Runners.*—Those who have seen strawberries growing are familiar with the fact that each strawberry plant can put out long, horizontal, leafless stems. These stems run along the ground for two or three feet, then root at the tips. A new strawberry plant grows up at the tips of the runners. As soon as this plant has reached a good size the strawberry grower can cut the runner and separate the plants, while if left alone, the runners die away. Many other plants can reproduce by means of runners; and the difficulty of getting rid of such weeds as crab grass and hawkweed is largely due to the fact that they can quickly spread over a large field by means of runners.

4. *Rootstocks.*—Rootstocks are long, scaly, underground stems that often look like roots, and enable the plant to spread in the same manner that runners do. Witch or quack grass is one of the persistent weeds that spreads itself by this method.

5. *Tubers.*—A farmer grows new white potato plants by placing in the ground sections of a potato. The botanist knows that the potato is not a seed. Potato seeds are produced from the white flowers which appear on the tops of potato plants in late summer. The potato is, then, merely a swollen underground stem which contains a large amount of stored food. Hence, when the farmer plants a potato, he is planting about the same part of the plant as he is when he plants a rose cutting. In the native home of the potato, each tuber survives the winter underground, producing a new plant the following spring.

Besides these natural methods of asexual reproduction, gardeners have long been accustomed to spreading cultivated plants in still other ways, the most important of which are:

1. *Separating.*—Whenever plants have thick or fleshy parts—such as roots, stems, or bulbs below ground, these may be broken apart at the right season and both parts will grow into a new plant. By this method, the same individual may be spread all over the

world and kept alive indefinitely. The cultivated saffron crocus, for example, cannot be reproduced by seed, yet this variety has been grown and propagated by separating the bulbs since the time of the ancient Cretans 4,000 years ago.

2. *Cuttings.*—If a willow twig is cut and placed upright in the ground, it will sprout roots at its base, while the buds at its tip will grow and produce leaves. Finally, if the surroundings are favorable, the twig will grow into a new willow tree. Roses are also propagated by cuttings, or slips; and sugar cane is grown by planting sections of cane in the ground, which then grow into new plants.

3. *Grafting.*—Grafting is the process of splicing a branch of a desirable variety of tree on to the cut stem of another that is growing. If care is taken to place the two cut ends together so that the growing layer of one coincides with that of the other, they will grow together, and the branch will form the whole top of the tree, bearing its own particular variety of fruit, since its character is not changed in the slightest by its residence on a foreign stock. This method is extremely valuable for obtaining good fruit from a tree of poor heritage, and must be used in propagating such valuable fruit trees as the seedless orange.

Practically all of the organisms which may reproduce by the above asexual methods can also reproduce sexually. Indeed, it is not at all uncommon for organisms to be able to reproduce in several different ways.

Parthenogenesis.—One form of asexual reproduction, known as *parthenogenesis*, is peculiar in that it is obviously an evolutionary development from sexual reproduction. The females of the species produce eggs which develop without having been fertilized by a sperm cell. Frequently some of the offspring in a given species are produced sexually, and others parthenogenetically. A queen bee, if her eggs are fertilized, produces either workers or new queens; but she sometimes lays eggs that have not been fertilized which develop by parthenogenesis into males. Natural parthenogenesis is particularly characteristic of the insects, although it is not unknown among other forms. It occurs also in a few plants, such as the dandelion, in which seeds may be formed without the assistance of male structures.

The eggs of many animals can, moreover, be stimulated to parthenogenetic development. By the action of various chemicals sea urchin eggs can be made to divide and produce active young animals. The eggs of starfish, as well as those of some marine worms, have also been caused to produce young parthenogenetically, the method varying with the animal. This phenomenon is known as *artificial parthenogenesis.*

Formation of Spores.—The most important type of asexual reproduction in plants is by means of *spores.* This method occurs in almost all kinds of plants, from the bacteria and unicellular algae to the largest trees, although in many forms it alternates with sexual reproduction. Spore-formation occurs also in one group of Protozoa, but is not found in other animals. A spore is a single cell, frequently covered by a tough cell wall to prevent drying out, which is capable of traveling about until it reaches a favorable location; thereupon it *germinates,* growing into a new organism. In many of the lower forms of plant life, spores may be formed in almost any cell simply by division of the cell into several other cells. In most of the higher fungi and filamentous algae, as well as in the land plants, however, they grow in special organs, known as *sporangia.* Among the fungi, the sporangia usually constitute the most conspicuous part of the plant, the remainder being composed of filaments embedded in the host or in the medium on which the fungus lives.

In the case of the mushrooms, the subterranean mass of colorless vegetative filaments develops an upward-growing stalk which eventually expands into a cap. The under side of the cap is made up of many radiating partitions, upon each of which thousands of spores are produced. These spores are scattered in millions by the wind, escaping in clouds of fine "dust" such as can be seen in the ordinary puffball, a relative of the mushroom which bears its spores within a tough outer coat. When a mushroom spore settles upon a suitable substratum, it germinates into a new underground mass of filaments. Thus the common cap and stalk of the mushroom is but an elaborate structure to produce spores.

The formation of spores constitutes an exceptionally effective method of reproduction. In the first place, the tiny spores may be formed in incredible numbers. In the second place, they can be carried about in the air until they reach some spot favorable for the plant's growth, and thus the plant organism can take advantage of every opportunity for life that the environment affords. The air is at all times filled with spores of various types of fungi. A piece of bread left in almost any exposed position will in a few days show a covering of mold. The mold is a fungus which germinates from spores that are universally present in the air. Finally, spores are effective for reproduction because they are so resistant to heat, cold and drying. A change in its environment may kill the parent plant, but its spores may retain their capacity for germination over a course of years until they finally reach an environment in which the plant can grow.

Sexual Reproduction and Alternation of Generations

The Evolution of Sex.—Even in the Protozoa and unicellular algae simple types of sexual reproduction are found, usually in

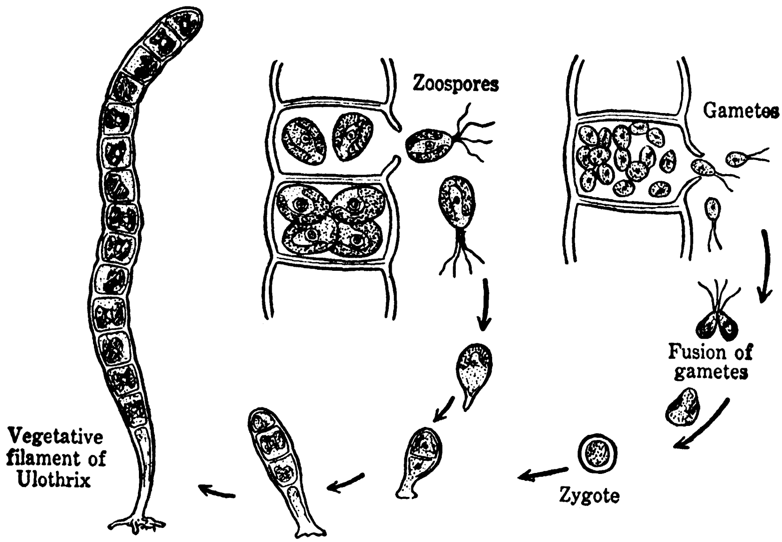


Fig. 54.—Reproduction in Ulothrix.

organisms that reproduce asexually as well. In all probability, the first living things reproduced asexually, and sexual reproduction evolved from the asexual type. It is thought that this course of evolution took place more than once and in more than one way; but among the algae we find certain transition steps between asexual and sexual reproduction which suggest the method by which sexual reproduction might develop from spore formation.

Many of the algae produce a type of spore that, instead of floating in the air, swims about in the water, appearing exactly like a unicellular flagellate plant. Because of their motility, they are called *zoospores,* which means animal-like spores. For example, in the filamentous green alga, *Ulothrix,* any cell of the filament can undergo division inside its cell wall to form several zoospores, each of which has four flagella. The zoospores escape

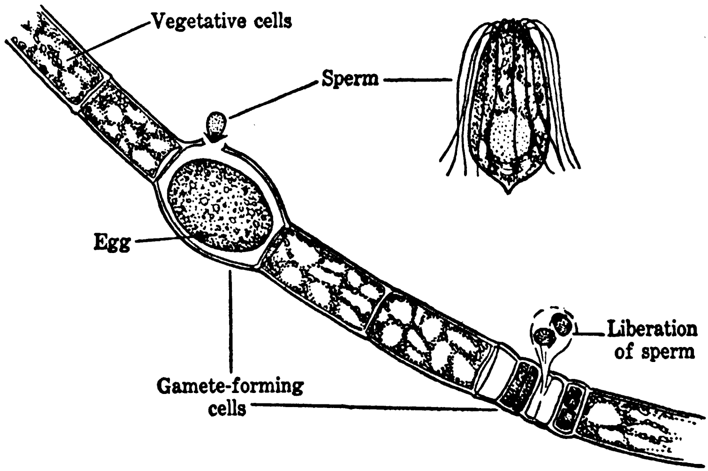


FIG. 55.—Reproduction in Oedogonium.

through a hole in the cell wall and swim about in various directions until they have traveled some distance from the parent plant. Then each spore comes to rest and grows by cell division into a new Ulothrix filament.

At other times, however, the Ulothrix cell breaks up into a larger number of smaller swimming cells, each of which has two, rather than four, flagella. These cells escape from the cell wall and swim about, just as the larger ones do; but before they begin to divide to form a new filament, each one fuses with another of the same kind, and the new filament develops from the cell that is formed by the fusion of two of the tiny, two-flagellated swimmers.

Certainly this is not a great change from the formation and germination of the four-flagellated zoospores. Nevertheless, the border line between asexual and sexual reproduction has been crossed. The cells that fuse before germination are no longer zoospores, they are gametes, and the cell they form is a zygote. For any reproductive cell that must fuse with another before growth of a new organism takes place is a gamete, the cell formed by the fusion is a zygote, and the type of reproduction involved is sexual.

But although Ulothrix reproduces sexually, there are no sexes. It would be impossible to say which of the two gametes was the sperm or the egg, since they are exactly alike. In another filamentous alga, *Oedogonium,* however, the differentiation into egg and sperm appears. In preparing for sexual reproduction, certain cells of Oedogonium transform their contents into large gametes, incapable of movement and therefore forced to remain within the cells in which they are formed. Each of these large gametes is abundantly provided with stored food. Other smaller cells of the filament produce relatively smaller gametes, in greater numbers; each of these has a circle of cilia at one end. When released, these gametes can swim about; eventually one finds the opening in the cell wall surrounding a large gamete, enters and fuses with it to form a zygote. This is destined to grow into another Oedogonium filament. When such gametes are formed, differing in size and capabilities, we see a stage in the evolution of sexual reproduction wherein one large motionless gamete functions as a receptive "egg," while a smaller, active gamete becomes a typical "sperm." This type of sexual reproduction has not, however, reached the condition found in higher plants, where the gametes are produced by special organs rather than by individual cells of the body.

The latter evolutionary advance is to be seen in many other algae, notably the brown and red seaweeds, where the plant body has segregated the reproductive ability to certain special cells and tissues which become sex organs, whose sole function is to produce the gametes. The remaining vegetative cells are incapable of doing so. Male and female sex organs are at first found on the same individual, but further specialization has resulted in the appearance of these organs in different individuals. Thus sex becomes the natural result of segregation of the gamete-producing organs upon different individuals.

The Alternation of Sexual and Asexual Reproduction.—In the more primitive thallus plants, sexual and asexual reproduction seem to occur independently of each other, often on the same

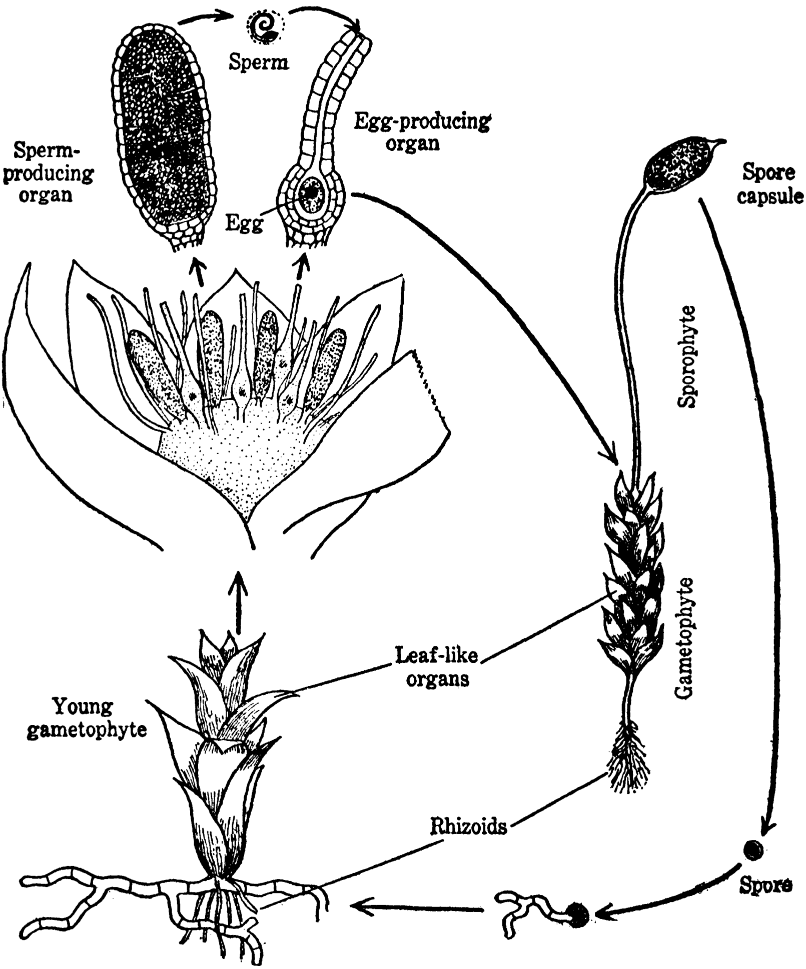


FIG. 56.—Reproductive cycle in a moss.

plant, as environmental conditions vary. But in the higher algae, the liverworts and mosses, and all plants above them in the scale of complexity, there is a definite alternation of a plant reproducing sexually with one reproducing asexually by means of spores. The plant producing these spores is called a *sporophyte*; likewise the gamete-producing plant is known as the *gametophyte*. In the sequence of reproductive events, a sporophyte gives rise to a

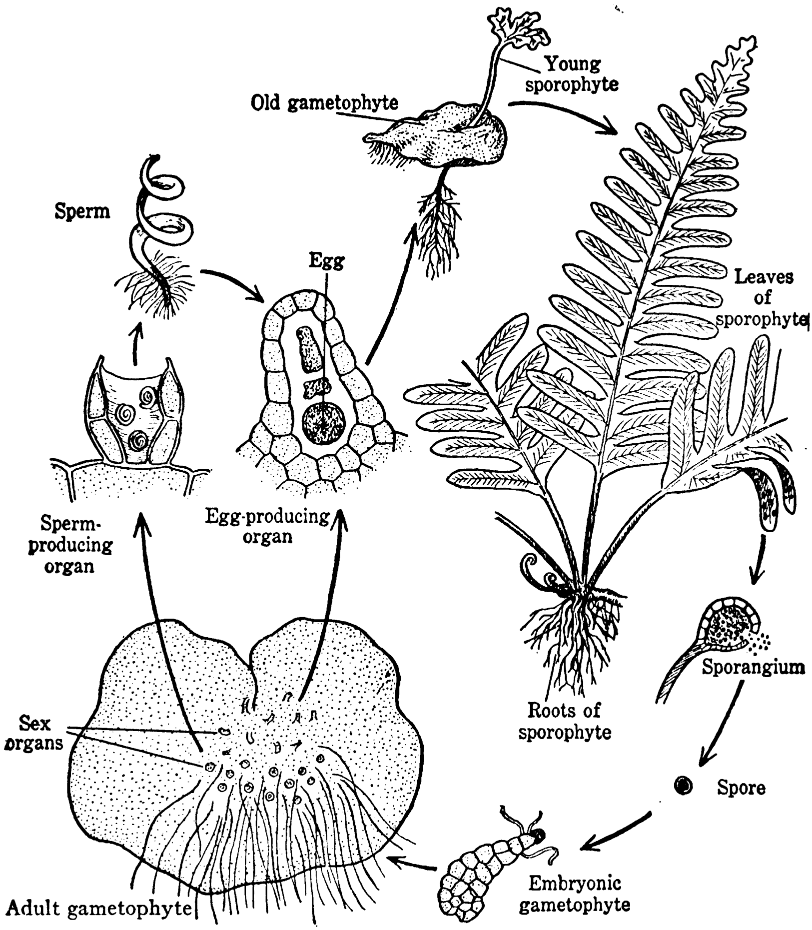


FIG. 57.—Reproductive cycle of a fern.

gametophyte, a gametophyte to a sporophyte. Yet both gametophyte and sporophyte can reproduce vegetatively at various times.

In the common moss we see a small erect green plant, with leaf-like structures arranged around an upright stem. When the plant is ready to reproduce, sex organs are developed at the tip of the stem, surrounded by "leaves." The sperms emerge by the hundreds from the sausage-shaped male sex organs, and in wet weather they wriggle over the film of water that covers the moss until they are attracted by chemical exudations from the flask-shaped female sex organs. They then enter the long neck of the flask, swim down it, and fertilize the single egg found at the bottom. The zygote germinates in this place. It does not grow into another green moss plant, but into a brown leafless plant, consisting of a stalk with a spore-containing capsule at the tip. Thus the gametophyte of a moss is a green, leafy plant; and the sporophyte is a dependent plant getting its sustenance from the gametophyte. When the spores fall to the ground they grow into a leafy green moss gametophyte. Thus there is a regular alternation of sexual and asexual generations.

In a typical fern this rhythm of reproduction involves two generations which are both green. The leafy fern plant is a sporophyte, producing spores in clusters of sporangia usually found on the under side of the fern leaves, and looking like rusty brown spots. The spores, after they fall to the ground, germinate into little heart-shaped green plants about the size of a dime. These cling to the damp earth, attached by rhizoids on their under surface. They are the gametophytes, producing male and female sex organs much like those of the moss, hidden among the rhizoids. The sperms swim to the female sex organs and there fertilize the eggs. The zygote develops into a new leafy fern plant, another sporophyte generation. It is important to note that in the ferns, the spore-producing plant is leafy and independent, in contrast to the leafless sporophyte of the mosses. The gametophyte, on the other hand, has become relatively less important.

The Gametophytes of the Flowering Plants.—In the group of seed plants, which includes most of the plants familiar to us, such as trees, grasses and flowers, the sporophyte generation is the only one visible to the naked eye, the gametophyte having become so reduced and inconspicuous that special microscopic study is necessary in order to detect it at all. The visible parts of the reproductive structures are all part of the sporophyte. In all seed plants except the conifers and a few relatively little-known types this reproductive structure is known scientifically as the *flower*, even though in many of them, such as the grasses and various

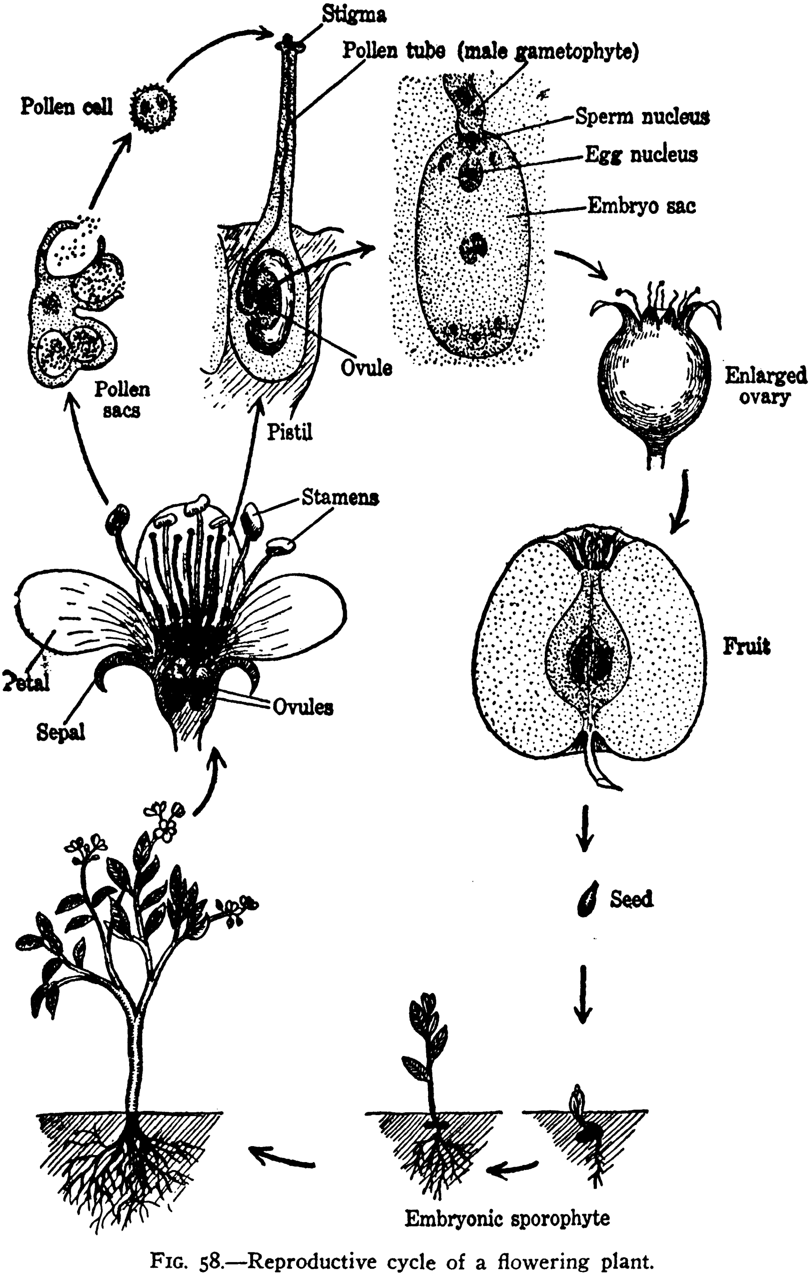


FIG. 58.—Reproductive cycle of a flowering plant.

trees, its parts have become so reduced or modified that the layman does not ordinarily think of it as such. A typical flower consists of four sets of parts, the *sepals, petals, stamens* and *pistils.* The sepals and petals are accessory parts of the flower, not necessary for the actual reproductive process. The former are usually green and useful in protecting the flower when in bud; the latter are frequently brightly colored and aid in attracting animals for pollination. More important are the stamens and pistils, for they produce the spores and gametes. Just as in sexual reproduction we found a progression from organisms producing gametes that are all alike to those whose gametes are differentiated into large and small types, so in the evolution of asexual reproduction by spores as a prelude to sexual reproduction, the condition where all the spores are alike gradually changes into one in which the spores are differentiated into large and small types. The latter condition holds true in some of the relatives of the ferns, but is most characteristic of the seed plants. The small spores grow into gametophytes which produce only *male* organs, while the large spores grow into gametophytes which are *female.*

Returning to our flowering plant, we find that the stamens produce, in the pollen sacs (in reality sporangia), a large number of minute pollen grains, which are developed directly from spores.[1] When the flower opens, these pollen grains are shed from the pollen sacs, and are transported, either by the wind or by animal agencies, to the pistil of another flower. Here they land on a sticky surface which holds them firmly, and stimulates the growth from each pollen grain of a long slender filament of protoplasm, called the *pollen tube.* These pollen tubes penetrate down the pistil to its lower portion called the *ovary* which contains one or more *ovules.* Each ovule encloses within a series of protective layers the vestiges of a sporangium and, when young, one or more large spores. Each of these large spores later develops within its coverings into a structure consisting of several nuclei, known as the *embryo sac*—in actuality, the female gametophyte. One of the embryo sac nuclei is the female, or egg cell. The male gametophyte is, at its greatest extent, merely the germinated pollen grain, with its long tube that

[1] The pollen grain when first formed in the young bud is a spore; but when the flower opens each grain has become two-celled, and is therefore a young gametophyte.

finally reaches the ovule, enters it, and penetrates to the embryo sac. The male gamete, a single small nucleus, then passes down this tube, emerges from it, and fertilizes the egg; and a similar nucleus fuses with a second nucleus of the embryo sac, which gives rise to nourishing tissue for the embryo. Fertilization in the higher plants therefore takes place far within the sporophytic tissue of the female reproductive organ. The only visible act of union, that of pollination, makes the contact between the immature male gametophyte (the pollen grain) and the sporophytic tissue of the pistil.

Thus in the flowering plants, the sexual generation has been reduced to the lowest possible terms, being an inconspicuous and microscopic phase of the reproductive cycle. The sporophyte, on the other hand, has become the dominant generation. The evolutionary value of this reduction of the gametophyte for land vegetation is obvious. Reproduction by motile sperms when the parent organisms are incapable of motion, is practically impossible for land plants. Asexual reproduction, however, by structures capable of aerial dissemination, is far more likely to be successful. Thus reproduction for flowering plants is the culmination of sporophytic reproduction, with the flower as the most complex reproductive organ evolved by any sporophyte. The stamens and pistils, in reality spore-producing organs, have come to be considered male and female sex organs, since the male and female gametophytes produced by them are generally unknown to the layman.

How Pollination Takes Place.—Although, as we have just described, both male and female organs exist together in a typical flower, they are not, as a rule, self-fertilized. Instead, the pollen of one flower, after being released by the anther, is carried in some way to the stigma of another. In land plants the two ways by which pollen is usually carried are by wind and by insects. The oak tree, as well as most other trees in this region and most grasses, produces great quantities of pollen which is carried long distances by the wind until a few grains happen to reach the stigma capping the pistil of some other plant. Plants with conspicuous flowers, however, depend on insects to carry the pollen from flower to flower. The color and odor of flowers, as well as the fantastic forms of many of them, such as the orchids, are simply devices which in-

Pollen grains in stamen. The small, dark objects within each grain are the nuclei.

duce the insects to visit them, thereby transporting the pollen from one plant to another.

As an example of the extraordinary devices that plants have developed to insure cross pollination by insects, let us look at one of the more complex types, that of the lady's-slipper. In this orchid, one of the petals is modified into a large inflated sac, or lip, seamed with creases and with an opening at the top. In the showy lady's-slipper, which is our present model, this lip shades from white to a delicate shell pink, and, flanked by broad sepals and petals of pure white, forms perhaps the most beautiful and aristocratic of our wild flowers. The bee, attracted by the color of the flower and its faint but delicious fragrance, alights on top of the lip. Its eye is attracted by the white creases that line the surface, and it follows them until it drops into the hole in the center. Once in, it is prevented by recurved flanges from escaping from this hole, but it soon sees the light of two small openings at the base of the lip, toward which it crawls. Before it reaches these exits, however, it must push its way, first under the arched knob of the stigma, against which it rubs, depositing pollen obtained from the flower last visited; and secondly, against the rounded surface of one of the two anthers, from which it picks up a sticky mass of pollen for distribution to the next flower. Thus the bee cannot escape from the trap of the lady's-slipper's lip until it has cross pollinated the flower. There are hundreds of other mechanisms for cross pollination, adapted to hundreds of different insects, but always the principle is the same. The insect must first reach the stigma to deposit foreign pollen on it, and later the anthers, from which it receives a new load of pollen.

The Seed.—As soon as the sperm nucleus has united with the egg nucleus, the fertilized egg, or zygote, divides, and starts the growth of the embryo. At the same time, another nucleus of the gametophyte generation, which has also been fertilized by a nucleus from the pollen tube, divides rapidly to produce a large tissue of food-storing cells, known as the *endosperm*, which obtains nourishment through the stalk of the ovule and supplies it to the embryo. Meanwhile the outer coverings of the ovule grow to keep pace with the increasing size of the embryo and endosperm; and the whole ovary is growing larger and larger, soon becoming, as the other parts gradually wither away, the most prominent part of the flower. Finally, when the embryo has finished growing and is surrounded with the densely packed food material of the endosperm, the outer coverings become hard and tough, and the whole structure, now a ripe seed, breaks away from its stalk, leaving a scar which is quite noticeable in seeds such as the bean. The ovary now opens up, the methods of opening varying with the plant, and the seeds are scattered, although sometimes the whole ovary is detached from the plant with the seeds.

The ripe seed, then, contains within it an embryo plant, belonging to the new sporophytic generation, and consisting of a short, rudimentary stem, two simple leaves and a small bud between the leaves. The embryo is usually surrounded by densely packed food materials, although these are sometimes stored within the seed leaves themselves, and is protected by one or more tough seed coats, remnants of the parental sporophytic generation. The food thus stored within seeds is the most important source of our own nourishment. All cereal grains are the seeds of grasses; hence all flour, bread, and rice are the products of plant seeds. Other important food-producing seeds are nuts and such vegetables as beans and peas.

Although such a seed seems quite lifeless, careful chemical tests have shown that respiration is going on constantly, at an extremely slow rate, within seeds. In this state of suspended animation, or dormancy, seeds can withstand great extremes of temperature and drought. Although some varieties sprout or germinate as soon as ripe, most of them lie dormant for some time, and cannot germinate, for one reason or another, until after a period of months. Then, under favorable conditions of warmth, water enters, bursting the seed coat, and setting into activity digestive enzymes that are packed in with the stored food. As it is digested, the food is absorbed by the embryo, which, by carrying on respiration rapidly, provides energy for its growth. First the rudimentary stem elongates, sending down a root into the ground, and pushing the seed leaves upward until they break through the surface and appear as the pair of simple, usually round or strap-shaped leaves that are the first reward and encouragement of all gardeners. In many plants, such as grasses, lilies, and their relatives, which have only one seed leaf, and in some, such as the peas, which have two, the seed leaves remain below the ground; the part of the plant growing upward is the shoot, which has developed from the bud beside the seed leaf. As soon as the seedling reaches the light, it develops chlorophyll, turns green, and begins to manufacture its own food by photosynthesis. By this time the food within the seed is all used up, and the empty seed coats, if they have not been borne up above the ground by the growing seedling, shrivel away.

In the seed plants, the seed has taken over the function of dispersal of the species that is performed by the spore in the lower forms. Like the spore, the seed may travel far from the parent plant, alighting and germinating in new localities in which plants of its species may grow. Probably this similarity between seed and spore is what sometimes makes it hard for beginning students to understand the fundamental biological difference between the spore, which is a single asexual reproductive cell, and the seed, which is a multicellular embryo, surrounded by protective and nutritive tissues. Methods of seed dispersal are described in Chapter XV.

Sexual Reproduction in Animals.—While alternation of generations is the predominating form of reproduction in the higher plants, sexual reproduction predominates in the animals. It occurs in a primitive form even in the Protozoa; and most of the many-celled animals not only produce eggs and sperms, but, like the human organism, form them in special organs, the ovaries and testes. However, the unisexual condition characteristic of the human race in which one type of individual, the male, produces sperms, and another type, the female, produces eggs is not found in many of the lower multicellular animals. Instead, each individual possesses both ovaries and testes, and hence is neither male nor female. Such an individual is known as an *hermaphrodite*, after the god Hermes and the goddess Aphrodite, who represented the male and female principles, respectively, in the mythology of ancient Greece. In Hydra, for example, primitive testes and ovaries appear as swellings on the sides of the body. The earthworm is also an hermaphrodite. After copulation takes place between two worms, the sperm cells of each member of the pair are mixed with the egg cells of the other, and the fertilized eggs are left behind in a little cocoon-like case in which the embryos develop.

Reproduction in the Vertebrates.—In the large group of animals most closely related to man, namely, the vertebrates, hermaphroditism does not normally occur. In this group, however, we find an interesting course of evolutionary advance in reproductive habits, from the most primitive group, the fishes, to the most advanced group, the mammals, which of course includes the human species. While there are exceptions to the rule, we may say that, in general, as one goes up the scale of vertebrate life, he finds a progressive decrease in the rate of reproduction, together with an increase in the amount of care that is given the young. These changes may be briefly outlined as follows:

1. Fishes: Great numbers of eggs are laid, little provision is made for certainty of fertilization.
2. Amphibians: Fertilization occurs outside the mother's body, but copulation between the sexes makes fertilization more certain.
3. Reptiles: Internal fertilization takes place, with nourishment and protection being given the embryo within an egg covered by a shell.
4. Birds: Fertilization and egg-laying occur as in the reptiles; but after hatching, the young are cared for in nests.
5. Mammals: The young develop within the mother's body and after birth are fed from the mammary glands and cared for in various other ways.

For reasons of economy of structures, in the vertebrates the reproductive and urinary systems are combined into a *urogenital mechanism*. In the bony fishes, the gonads and the urinary bladder both open into a *urogenital pore* which is posterior to the anus. When the ovaries release the eggs, they pass to the exterior through this opening, each egg protected only by a gelatinous mass which swells after fertilization. Similarly, the sperms are released as a mass of "milt." Thus fertilization is external, the union of the eggs and sperms being largely a matter of chance, aided only by the fact that the sperms are usually released over the place in the water where the eggs have been laid. To offset this, fishes are by far the most prolific of all vertebrates. A female codfish lays nine million eggs a year, and most fish lay hundreds of thousands. However, with the exception of some of the sharks and their relatives and a few other fish, fishes are the most negligent in the care of their young. The small sticklebacks of our fresh-water ponds build elaborate nests and care for their young, the father being almost always the more solicitous parent. The marine catfish father incubates the eggs in his mouth. But these are the exceptions rather than the rule. The tiny fish hatch from the eggs a short while after fertilization has taken place, at which time they may be only a sixteenth of an inch in length and quite helpless. Thus in the fishes there is little to insure union of the eggs and sperms, the developing young are relatively unprotected, and parental care is almost entirely lacking.

An evolutionary advance found in the amphibia is the decided congregation of the sexes prior to the release of the gametes, thus guaranteeing to a greater extent the meeting of the sperms and the eggs. But even more effective is copulation. In the frogs and toads, for example, the male clasps the female while she is laying the eggs, and at the same time releases the sperms. Thus, though fertilization is external, the union of egg and sperm is practically certain. The reproductive organs of a frog represent the general plan found in all higher vertebrates, including man. The testes are small oval organs, found in pairs in each male frog, one under each of the kidneys. Each testis is connected with a kidney by many small ducts so that the sperm cells pass from the testes through the kidneys and out through the ureter, which opens into the common meeting place known as the *cloaca*, into which the anus also opens. The ovaries are likewise beneath the kidneys, with the coiled oviducts above them. Each oviduct has funnel-shaped opening which is in the coelomic cavity; the other (posterior) end of the oviduct is slightly enlarged to form a distensible bag known as the uterus, which in turn connects with the cloaca by a narrow short tube. Portions of the ureter and the uterus become united, but their cavities remain distinct. The eggs are released from the ovary into the body cavity; and when the male clasps the female tightly with his fore-legs, the eggs are aided in their forward movement to the funnel-shaped opening of the oviduct. Once there, they pass into the oviduct and toward the uterine end, aided by the current created by the ciliated lining of the oviduct.

Amphibians are somewhat less prolific than fishes, although many of them lay eggs numbering into the thousands. They are,

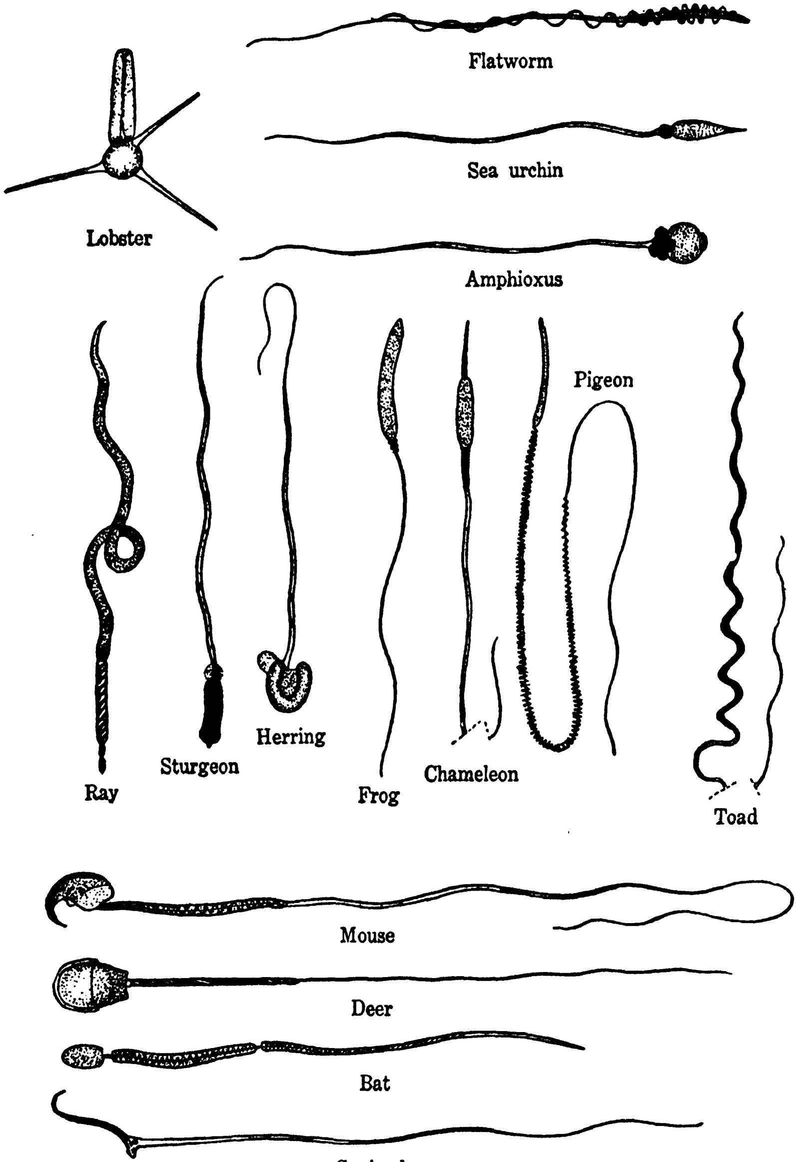


FIG. 59.—Varieties of sperm cells.

however, more certain in their method of fertilizing the eggs, although as a rule they give the young no care. The fertilized eggs

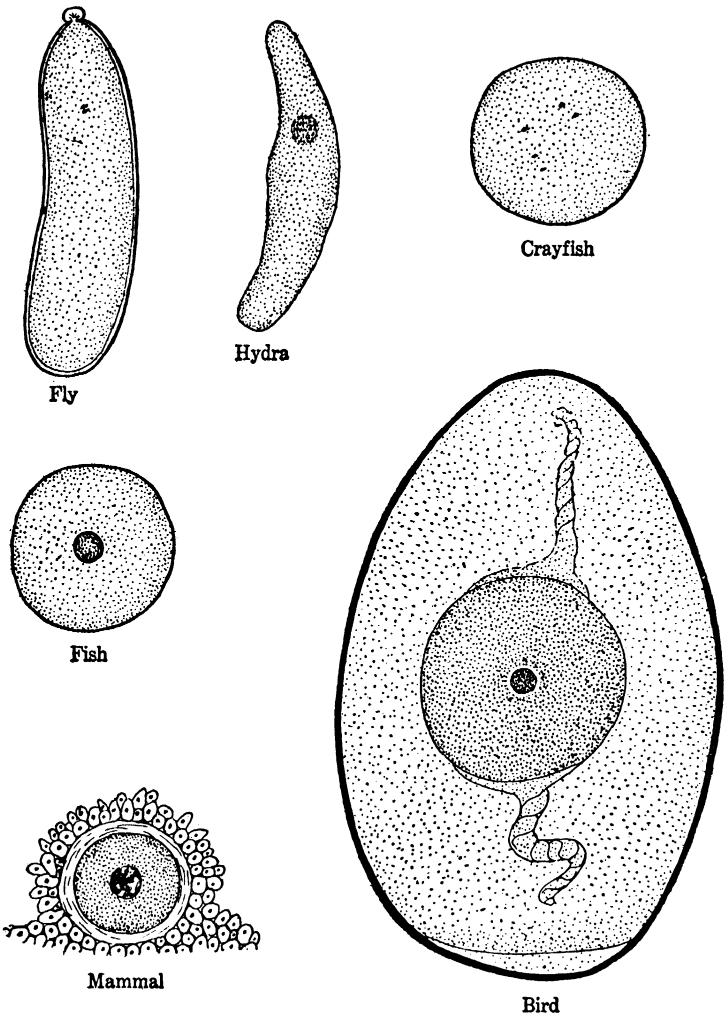


FIG. 60.—Varieties of egg cells. (The egg of the bird is proportionately much larger than is shown.)

contain some stored food, but are protected only by an enveloping jelly. The young hatch from the eggs long before they attain the adult form; in fact, they are no further along in their existence than the four-weeks' human embryo. Thereafter the young tadpole must obtain its food by its own efforts. The eggs and developing young are forgotten by the parents as soon as they are laid and fertilized.

In the reptiles and birds, copulation takes place with the introduction of the sperms into the body of the female. Some of the salamanders show the transition to this condition in that the male deposits little packets of sperms which are picked up by the female and transferred within her body, so that internal fertilization takes place without copulation. Reproductive progress, insuring union of the egg and sperm, has advanced from chance external fertilization in the fishes, more certain external fertilization by previous copulation in the amphibia, to internal fertilization in the reptiles, birds and mammals.

Reptiles and birds are much less prolific than amphibians, although the large sea turtles may lay as many as a hundred eggs at a time. Here reproduction differs from that in lower vertebrates and in mammals in the method of nourishing and protecting the embryo and the degree of parental care. In the case of the reptiles, the eggs are laid in the sand or mud, and development of the embryo takes place at the mercy of the environment, the eggs being usually neglected by the parents. Most of the reptiles, like the amphibians and fishes, are *oviparous*, i.e., the eggs are laid before fertilization or, if after fertilization, the embryos are still within the egg membranes and cannot live outside of them. In a few reptiles, however, the embryos are retained within the body of the mother, as in all mammals including humans, until they are capable of an independent existence. Such reptiles are *viviparous* but do not really nourish the young through maternal tissues as mammals do. The embryos remain in the oviducts until they reach an advanced stage of development, but they are nourished by the food stored in the egg.

In the birds, internal fertilization and the egg-laying habit have become associated with many valuable breeding activities such as the building of nests and the incubation of the eggs by the mother. There is also considerable parental care, so that on the whole reproductive progress has been considerable as we pass from the reptilian to the bird level.

The last great evolutionary advance in reproduction is the *viviparous* condition, with the fertilized egg undergoing its development within the maternal tissues, getting its nourishment from the wall of the uterus. There are certain sharks in which the yolk sac of the egg becomes attached to the wall of the uterus, and forms a placenta-like organ through which nourishment is received from the mother. It is in the mammals, however, that this condition is most widespread and highly developed. Our consideration of the reproductive organs and reproductive process in man makes it unnecessary to describe those of other mammals, which greatly resemble the human structures and functions.

In the case of mammals, the certainty of sperm meeting egg is the result of the internal fertilization by means of copulation; the developing embryo is protected by the maternal tissues and nourished by them, thus being removed from the various hostile influences of the environment; the young, when born, are nourished by the mother's milk; and they are taken care of by the parents and instructed in the activities necessary for their self-preservation. Such animals as the duckbill and the spiny anteater, both of which lay eggs, are exceptions among mammals, as are also the marsupials, in which group is the kangaroo, where the young are born in an immature state and carried about in the mother's pouch until they are able to take care of themselves.

Such are the various stages in reproductive specialization which link the algae with the oak, the Protozoa with man. Through them we can see a consistent progress from unspecialized reproductive structures and activities, the transition from asexual to sexual reproduction, the origin of sex, and the gradual improvement in insuring that the union of the gametes will guarantee that the zygote will develop into a mature individual.

Chapter Summary

Reproduction is a universal characteristic of living things, but the methods by which new individuals come into existence vary in the complexity of the structures and activities concerned. The simplest type of reproduction is by cell division, common among the unicellular organisms; this occurs in Protococcus, Paramecium and the bacteria. The formation and separation of a new organism by cell division is called fission. This is a form of asexual reproduction, without the fusion of a pair of cells (gametes) to form the new individual. Asexual reproduction undoubtedly is the most primitive type of reproduction.

In the multicellular organisms, there are various ways in which asexual reproduction may take place:

1. By regeneration, where a part broken off an animal can grow into a new animal, as in the case of the starfish.

2. By budding, where a new organism develops as a bud upon the parent, and finally separates to lead its own existence, as in Hydra.

3. By runners, where creeping stems form new plants, as in the strawberry and various grasses.

4. By rootstocks, or underground stems, as in witch grass.

5. By tubers, or underground stems swollen with stored food, as in the white potato.

6. By various artificial methods among plants, such as grafting.

Parthenogenesis is sometimes considered a form of asexual reproduction. It is the development of an egg without fertilization by sperm, and is a common phenomenon among the insects.

The most important type of asexual reproduction is by spores, a spore being a specialized reproductive cell which can develop into a new organism without needing to unite with another reproductive cell. Spores are common among plants, being produced in special spore sacs known as sporangia. Such minute asexual reproductive bodies are found among the algae, fungi, mosses, liverworts and ferns. Spores are an effective means of reproduction in that they can be produced in great quantities, they are small and light enough to be carried great distances by the wind, and they are very resistant to desiccation and temperature changes.

Sexual reproduction involves two kinds of reproductive cells, known as gametes. How these may have originated is suggested by the behavior of a green alga, Ulothrix. In this plant, asexual reproduction is by means of swimming zoospores having four flagella. An alternate method of reproduction is the formation of many more, smaller swimming cells with two flagella each; these fuse in pairs before germination. Hence they are gametes and form a zygote.

In Ulothrix both the gametes are alike; there is sexual reproduction but no sex. In another green alga, Oedogonium, we see a beginning of sexual differentiation of the gametes into a larger immotile female gamete (egg) and a smaller, active male gamete (sperm). Another step in the evolution of sexual reproduction is the formation of these male and female gametes in special reproductive organs, rather than in ordinary vegetative tissues. Still more advanced is the condition where the male organs are segregated upon one individual, the female upon another.

In plants there is an alternation of sexual and asexual reproduction; the plant generation which reproduces asexually is called the sporophyte, that which reproduces sexually is called the gametophyte. At the lower level of plant organization, the gametophyte is green, often leafy, and independent, as in the moss. At the tip of the plant the sperms and eggs are borne in special sex organs. After fertilization the egg develops in the place of fertilization to form a brown, dependent sporophyte reproducing by spores produced in a terminal sporangium. These spores, falling to the ground, grow into another gametophyte.

In a common fern plant, the gametophyte is relatively smaller and less conspicuous, though still green. The fertilized egg grows into a sporophyte which is large, leafy and green, the common plant known as the fern. This produces spores which fall to the ground and repeat the cycle, growing into new gametophytes.

In the seed plants the gametophyte has become colorless, parasitic and (in the case of the female gametophyte) microscopic. The leafy green plant with roots, stems and leaves is a sporophyte. The reproductive organ is the flower with four parts:

1. Sepals, usually green, forming an outermost whorl of structures for protection of the rest of the flower.

2. Petals, usually colored, aiding in attracting insects or other animals for the dispersal of pollen.

3. Pistil, for the production of large immotile spores.

4. Stamens, for the production of small spores capable of dissemination by wind or other agencies, commonly known as pollen. A small spore grows into a small male gametophyte, at its maximum development appearing as a pollen tube with several nuclei, the sperm cell being reduced to a nuclear mass. A large spore grows into a microscopic female gametophyte within the pistil, eventually producing a nucleus which functions as an egg cell.

Fertilization takes place when a male nucleus from the pollen tube unites with the egg nucleus in the pistil.

After fertilization, the zygote develops into a small embryo surrounded by stored food and protected by various coats; all of this makes up the seed. The tissues surrounding the original egg, and the bottom of the pistil, develop into the fruit which usually surrounds the seed.

Among animals, sexual reproduction predominates; it is found even in the Protozoa. Among the lower invertebrates, both sex organs are found on the same individual, resulting in a hermaphroditic condition. In Hydra, for example, both types of gonads are produced on an individual; the sperm cells fertilize the eggs while the latter are in the ovary.

Among the vertebrates, the gonads are generally on different individuals. As we progress from fishes to mammals, reproductive advance involves a decrease in the rate of reproduction with an increase in the care given to the young, and the assurance that fertilization will take place.

Among the fishes great numbers of eggs are laid, but little provision is taken to insure fertilization, since the sperms are released into the water where a female has previously released eggs, and fertilization takes place. After fertilization, the eggs are left relatively unprotected and there is very little parental care.

Among the amphibia there is copulation between the sexes prior to fertilization, so that even though fertilization is external, there is considerable guarantee that the eggs will be fertilized. The reproductive system of a frog is basically the design for all higher types of vertebrates including man. The reproductive and urinary systems combine to form a urogenital system; in the male frog, the sperms pass from the testes (located below the kidneys) through the kidneys and out through the ureter to the external opening; in the female, the ovaries, likewise beneath the kidneys, release eggs into the body cavity, where they find their way into the funnel-shaped opening of the oviduct, and thence to the exterior near the anal opening. Fewer eggs are formed than in the fishes, but like them the frogs leave their eggs relatively unprotected and there is little parental care.

In the reptiles and birds, copulation results in the introduction of the sperm into the body of the female, with resulting guarantee that fertilization will take place. These two groups of vertebrates are less prolific than the amphibia or fishes; the eggs are protected by a shell, and in the case of birds there is considerable care of the young.

The last important evolutionary advance of sexual reproduction in the higher animals is the appearance of viviparity—the development of the embryo within the body of the mother, and its release when developed sufficiently to adjust itself to an external existence. During prenatal life the embryo is nourished by the maternal tissues. And in the case of man especially, there is added to the certainty of fertilization by copulation and the internal growth of the embryo, the last and most important aspect of reproduction—care and education of the young until they are capable of taking care of themselves.

QUESTIONS

1. What is meant by spontaneous generation? Do you believe it possible today? Why?
2. Describe fission as a type of asexual reproduction.
3. Name five ways in which multicellular organisms can reproduce asexually, other than by fission or spores.
4. What is a spore? Describe its formation and behavior in (a) mushroom, (b) Ulothrix, (c) moss.
5. Define parthenogenesis. Where does it occur?
6. Describe the transition from asexual to sexual reproduction in Ulothrix.
7. What advance in sexual reproduction is shown by (a) Oedogonium, (b) moss?
8. Define alternation of generations.
9. Compare the gametophyte of (a) moss, (b) fern, (c) oak.
10. Compare the sporophyte of (a) moss, (b) fern, (c) oak.
11. Describe the reproductive organ of the sporophyte of a flowering plant.
12. Describe sexual reproduction in a flowering plant.
13. What is a seed?
14. What is an hermaphrodite?
15. Summarize the important evolutionary changes in reproduction found among the vertebrates.
16. Describe the urogenital apparatus of a male frog.
17. In what ways is sexual reproduction in amphibia superior to that in the fishes?

18. In what ways is reproduction in the birds more advanced than that of the amphibia?
19. In what ways is reproduction in mammals more advanced than that of the birds?

GLOSSARY

asexual reproduction Formation of new individuals without fusion of gametes.

budding A form of asexual reproduction, found in Hydra and yeast, during which a new organism develops as a bud upon the parent, later separates.

cloaca (clō-ā'ca) The common chamber into which the intestinal, urinary and genital canals discharge in birds, reptiles, amphibians and many fishes.

copulation (cop-ū-lā'shun) The coming together of the two sexes in physical contact prior to release of sperms and eggs; sexual intercourse.

embryo sac The female gametophyte of a flowering plant.

endosperm (en'dō-spurm) The nutritive tissue formed within the embryo sac in the development of the seed.

fission A form of asexual reproduction, common among the unicellular organisms, which results in new individuals by simple cell division.

gametophyte (ga-mē'tō-fīt) The plant generation reproducing sexually.

germinate To begin to grow or develop, especially in the case of a spore or seed.

grafting An artificial form of asexual reproduction used with the higher plants to perpetuate a desired variety.

hermaphrodite (her-maf'rō-dīt) An animal with both male and female sex organs.

Oedogonium (ē'dō-gō'ni-um) A filamentous green alga whose gametes are differentiated into sperm and egg.

ovary (*in flowering plants*) A region at the base of the pistil in which one or more ovules are found. After fertilization of the eggs in the ovule, it often develops into the fruit.

oviduct (ō'vi-dukt) A duct for the passage of eggs from the ovary of an animal to the exterior.

oviparous (ō-vip'a-rus) A reproductive habit involving the exclusion of eggs from the body prior to their hatching.

ovule (ō'vūl) Sporangium of a flowering plant producing the large spores which develop into female gametophytes.

parthenogenesis (par'thē-nō-gen'e-sis) Development of an egg without fertilization.

petal One of the inner leaf-like structures of the flower. Usually conspicuously colored.

pistil (pis'til) The part of a flower producing ovules and female gametophytes.

pollen tube The male gametophyte of the flowering plant. It develops from a pollen grain on the stigma, and grows down through the tissues of the pistil to make contact with an embryo sac in one of the ovules.

pollination The transfer of male gametophytes (pollen grains) to the stigma of the pistil.

regeneration The restoration of lost parts by certain animals such as the starfish; also a form of asexual reproduction.

runner A long, creeping stem of plants, used as a means of asexual reproduction.

seed A structure consisting of an embryo surrounded usually by stored food material and one or more seed coats, which serves the purpose of reproduction in the higher plants.

sepal (sē'pal) One of the outermost leaf-like structures on a flower, functioning for protection.

sporangium (spō-răn'ji-um) pl. *sporangia* A structure in which spores are formed.

spore A cell specialized for asexual reproduction.

sporophyte (spōr'ō-fīt) The plant generation reproducing asexually.

stamen (stā'men) Part of a flower producing small spores and male gametophytes (pollen grains).

stigma (stig'ma) The surface at the top of the pistil which receives the pollen, usually covered by a sticky substance.

tuber (tū'ber) A swollen underground stem containing stored food and used for asexual reproduction.

Ulothrix (ū'lō-thriks) A filamentous green alga that reproduces by means of spores and undifferentiated gametes.

urogenital pore (ū'rō-gen'i-tal) Common opening from the genital and urinary organs in fishes.

viviparous (vī-vip'a-rus) A reproductive habit involving internal development of the embryo, as in mammals.

zoospore (zō'ō-spōr) A swimming spore.

CHAPTER XII

THE REPRODUCTIVE CYCLE

Cell Division and Growth.—In the previous chapter we learned that sexual reproduction in one form or another occurs in all but the simplest types of organisms (and in some degenerate ones) and that the essentials of this process are the formation of the sex cells, or gametes, and their union to form the zygote. As soon as fertilization is completed, the newly formed zygote splits to form two cells; these then divide to form four, and the process of cell division goes on until the trillions of cells which form the adult body are produced. Hence we may say that the growth of an individual is essentially a process of cell division, together with the growth of individual cells.

Mitosis.—Practically every cell division which takes place in the formation of an individual goes on according to a certain plan of procedure, known as *mitosis*, which divides the nucleus in such a manner that each of the new cells, or *daughter* cells, receives the identical sort of nuclear material that the original, or *mother*, cell had. The nucleus contains several different kinds of protoplasm organized into a very definite pattern, associated with its important function of transmitting hereditary characteristics; and the process of mitosis is essential to the reproduction of the same pattern of organization in the nucleus of every cell in the body.

Before mitosis begins, the nucleus is more or less completely filled with a number of long, slender, coiled threads, which are of a thicker consistency than the surrounding protoplasm, and, either throughout their length or in certain regions (depending on the organism studied), stain more darkly when cells are prepared for study by the usual methods (Fig. 61,1). They are known as *chromosomal threads.*[1]

[1] In most fixed and stained preparations of nuclei, and therefore in most published drawings and descriptions of them, these threads are apparently connected to each other by slender processes so that they seem to form a continuous network throughout the nucleus. The existence of these connections in living cells,

When a cell gets ready to divide, these threads can be seen to form a definite number of bodies known as *chromosomes,* each of which is believed to be composed of two—or, according to some investigators, four—threads. At any rate, when they appear, each chromosome is a double body which, however, behaves as a unit. Each is composed of two identical halves lying side by side, divided from each other by a fissure which runs the entire length of the chromosome. At first they appear as long, spiral, ribbon-like bands (Fig. 61,2), but they gradually contract, so that when the nucleus is finally ready for division, each chromosome is a thick, straight or curving rod, which is very dark in the usual stained preparations (Fig. 61,3).

Although the chromosomes are clearly visible only during mitosis, their presence within the nucleus in some form or other at all times has now been proved beyond all doubt. *Hence, their number and structure are normally the same in every cell of an individual organism.* Furthermore, the number and structure of the chromosomes that appear in the cells of one kind or species of organism is usually the same as that in every other individual of the species. In other words, nearly every kind or species of organism is characterized by a definite number of chromosomes, which appears whenever one of its cells divides. Thus the onion plant has sixteen chromosomes, while Indian corn has twenty; cattle have thirty-eight chromosomes, and man, forty-~~eight~~. six.

When the chomosomes are fully contracted, the membrane surrounding the nucleus disappears, and there is formed a spindle-shaped structure which is very narrow at its two ends, or *poles,* and broadest at the middle, or *equator.* It is composed of a firmer type of protoplasm than the surrounding cytoplasm, and, in killed and stained cells, appears to be traversed by a number of threads, the *spindle fibers.* The chromosomes range themselves along the equator of this spindle, so that they are spread out over a flat surface traversing the middle of the cell (Fig. 61,4). The halves of each chromosome then split apart and move to opposite poles of the spindle (Fig. 61,5). Finally, the two sets of half, or *daughter,* chromosomes become grouped about either pole. Gradually they elongate, lose their strong staining capacity, and be-

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however, is uncertain; at any rate, since they have no known function, their presence or absence is probably of little significance.

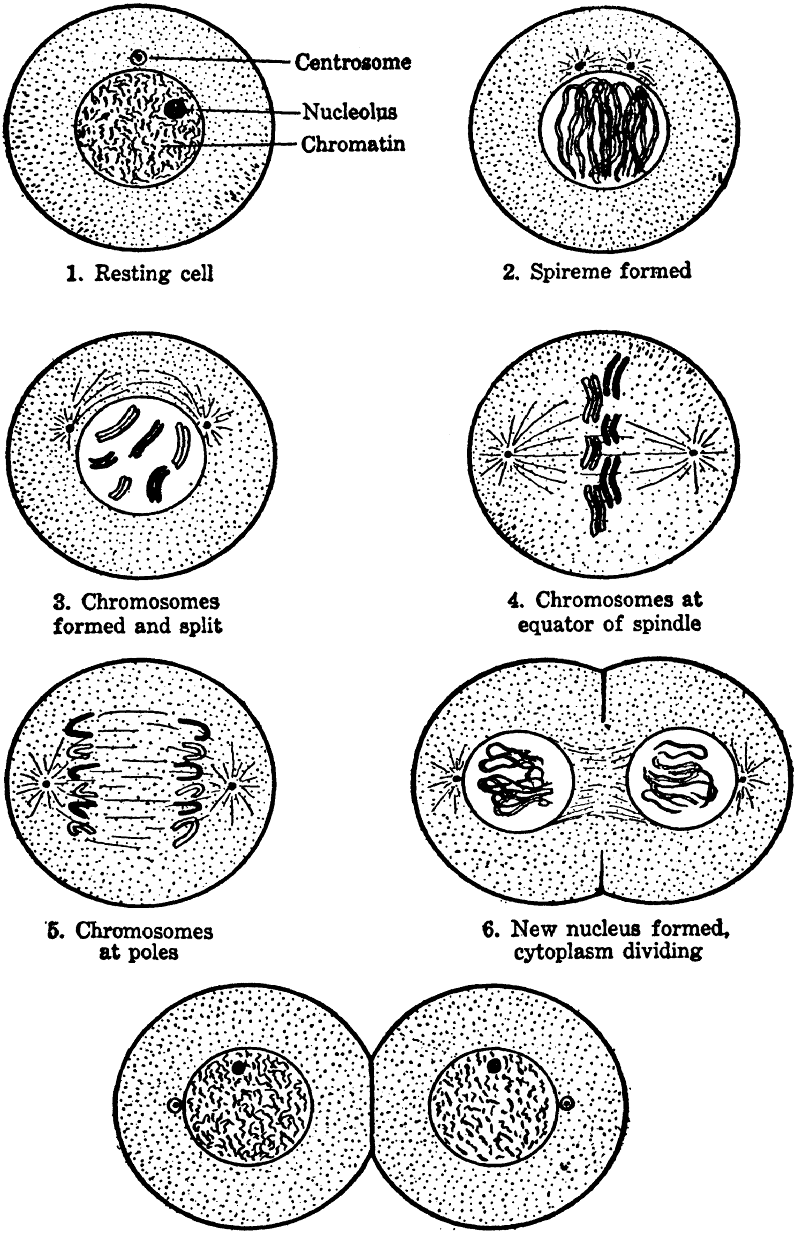

FIG. 61.—Diagram of cell undergoing mitosis.

come reorganized into the series of coiled threads characteristic of the resting nucleus. Meanwhile a new nuclear membrane has formed about each of these new, or *daughter*, nuclei. Since each parent chromosome has contributed half of itself to each daughter nucleus, each of the new nuclei has exactly the same number and kind of chromosomes that the original nucleus had.

While the daughter nuclei are forming, a groove appears around the edge of the cell on the line of the equator. This groove grows deeper and deeper, until the cell is completely divided in two. Each daughter cell grows until it has reached the size of the mother cell, when it in turn repeats the process of mitosis, and so on, throughout the growth of the individual.[2]

The time taken by mitosis, as determined by observations of living cells, varies greatly in different organisms and under different external conditions, but in most tissues under normal conditions the process occupies between one and two hours. Most of this period is taken up by the preparation of the nucleus for division and the reorganization of the daughter nuclei. The actual process of division, from the disappearance of the nuclear membrane until the arrival of the daughter chromosomes at the poles of the spindle, generally takes less than half an hour, and in rapidly dividing animal tissues at high temperatures may be carried through in three or four minutes.

Now, one may ask, why should the cell go through this complicated process whenever it divides? The end result is an equal distribution of the chromosomal material of the mother nucleus to the daughter nuclei. When the chromosome is ready to divide, it is exactly symmetrical in its internal structure, so that each daughter chromosome contains the same substances in exactly the same arrangement as did the original chromosome. Since the daughter chromosomes later form the daughter nuclei, the latter bodies have the same material and the same organization as did the mother nucleus. This equal distribution of the chromosomal substance is of supreme importance, since this substance governs the passing on of hereditary traits. Through mitosis every cell comes to possess the hereditary substance necessary for every characteristic of the organism.

[2] This account describes mitosis as it occurs in the animal cell. The details are somewhat different for plant cells, but the fundamentals are the same.

The following facts, therefore, are the important ones to be remembered:

1. Mitosis occurs whenever cells divide (except in bacteria and others of the lower organisms, and in a few types of degenerate tissue).
2. It is characterized by the appearance of the chromosomes as clearly visible structures.
3. It secures an equal division of the chromosomes, and therefore of the hereditary, material of the nucleus.

Since the chromosomes are the most important of the structures found in mitosis, the following facts about them should be clearly understood:

1. Although they are always present in some form in all nuclei, they are almost never clearly visible except when cells divide. (There is at least one exception to this rule. Chromosomes can be seen in the resting nuclei of the salivary glands of flies.)
2. During cell division, they appear as rods which stain deeply with certain dyes.
3. Their number is the same in all of the normal body cells of an organism, and is usually the same in all normal individuals of a particular species.
4. They are the bearers of most hereditary characteristics. The connection of the chromosomes with heredity will be discussed in the following chapter.

The Germ Cells.—As the young embryo grows, the new cells formed by mitosis take on varying sizes, shapes, and functions, until, in the fully developed fetus, all the great variety of tissues that characterize the human being have developed, all from a single cell. This development of various kinds of cells is called *differentiation.* We do not wish to follow this intricate process except briefly to trace the origin of those cells that eventually develop into gametes. When the embryo is about three weeks old, two small groups of cells, located near the kidneys, differentiate themselves from the rest of the tissues of the body. They continue to divide, but the cells resulting from their division do not develop into bodily tissues. The sole function of this group of cells is to develop into gametes, and consequently they are called *germ cells.* Gradually, the gonads are formed to contain these germ cells, the testes in the male and the ovaries in the female. Within the gonads the germ cells continue to divide, until millions of them are produced. Finally, as the individual arrives at the age of puberty, these cells begin to develop into gametes.

Meiosis and the Reduction of the Chromosome Number.—Now, up to this point, all of the cell divisions which have occurred, from the very first splitting of the zygote, have been mitotic divisions, so that each germ cell contains chromosomes that are identical in structure and composition with those that were found in the zygote. But in the formation of the gametes a process called *meiosis* takes place, which consists of two mitotic cell divisions that differ in interesting and important ways from ordinary mitosis. We may illustrate how these take place by describing how, in the sperm-bearing tubules of the testis, sperms are formed from the *sperm mother cells*, which constitute the last stage in the development of the male germ cells before they finally develop into sperms.

If, during any mitotic division, the forty-eight chromosomes of the human nucleus are carefully studied, it will be found that they can be grouped into twenty-four pairs, each member of a pair being practically identical with its mate in shape and size. In most ordinary mitotic divisions the members of a pair are absolutely independent of each other. Each lines up on the spindle with no reference whatever to the position of the other, and splits into equivalent halves, which are carried to opposite poles.

But when a sperm mother cell starts to divide, *each chromosome lines up beside its mate.* The pairing takes place when the chromosomes are long, slender threads or bands, and is followed by their contraction as in ordinary mitosis. When they reach the equator of the spindle, they are firmly bound to each other, and form a group of twenty-four pairs, rather than forty-eight single chromosomes. (See Fig. 62, in which, for the sake of simplicity, an organism with only six chromosomes, or three pairs, is illustrated.) Then, although each chromosome is split in half as in ordinary mitosis, its two halves do not separate. Instead, *one complete member of each pair goes to each pole of the spindle* (Fig. 62,4). Hence there are at each pole twenty-four double chromosomes. The two daughter nuclei formed by this division divide again almost immediately, and at this division the halves

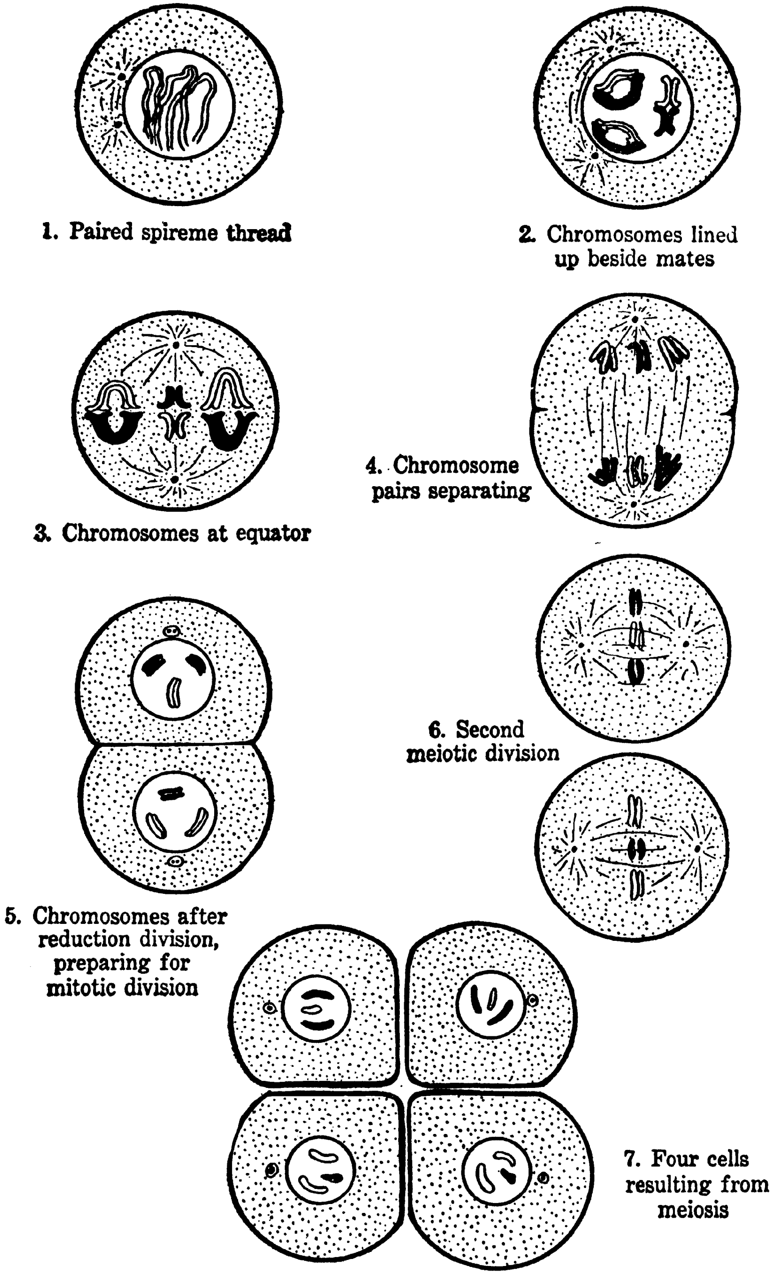

FIG. 62.—Diagram of cell undergoing meiosis.

of each chromosome separate and go to opposite poles of the spindle. Hence each of the four nuclei formed by these two divisions contains chromosomes of exactly the same form and structure as those received by the two nuclei resulting from an ordinary mitotic division, *but there are just half as many per nucleus, and only one member of each pair is represented in any particular nucleus.* The cells which result from this second division form themselves directly into sperms. Thus, by means of the two meiotic divisions, every sperm mother cell produces four sperm cells, each of which has one member of each pair of chromosomes contained in the original mother cell, and hence just half as many as the mother cell contained.

During meiosis, the number of chromosomes in the gametes is *reduced* to one-half the number in the mother cell. Since there are two divisions but only one process of reduction, it is customary and convenient to speak of the first division as the *reduction division,* and we shall follow this custom in our references to reduction. In actuality, reduction is effected by the process of meiosis as a whole, and it is merely an artificial convenience to speak of one of the divisions as *the* reduction division.

Meiosis occurs also in the development of eggs, although in a somewhat modified manner. The mother egg cell is very large. When the reduction division occurs, it divides into two very unequal halves, to form another large cell and a *polocyte.* The latter is a very small cell, containing its full complement of chromosomes, but only a minute portion of the cytoplasm of the mother egg cell. The polocyte divides to form two more polocytes, while the large cell undergoes the second meiotic division to form the egg and another tiny polocyte. The three polocytes disintegrate and disappear, leaving only the one large egg cell as a result of the meiotic process. This egg cell, of course, possesses just one member of each pair of chromosomes; and although meiosis in the male produces four gametes, while in the female it produces only one, the result of this process, as far as distribution of the chromosomes is concerned, is identical in both sexes. Fig. 63 outlines the entire course of meiosis, comparing the formation of sperms with that of the eggs.

The Alternating Cycle of Chromosome Numbers.—In fertilization in human beings, a sperm with twenty-four chromosomes unites with an egg that also has twenty-four. The resulting fertilized egg has a nucleus containing forty-eight chromosomes. Furthermore, since every chromosome of the sperm has its counterpart

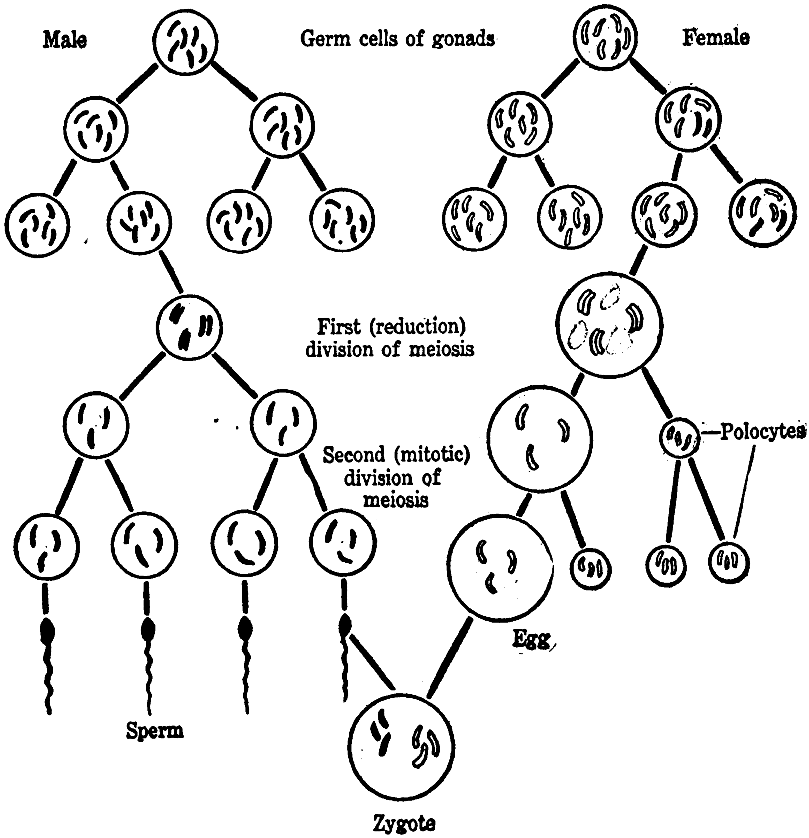

FIG. 63.—Diagram of formation of sperm and egg, with recombination of chromosomes in fertilization. (Redrawn from Woodruff's *Foundations of Biology,* The Macmillan Company.)

among those of the egg, the fertilized egg has twenty-four pairs, one member of each pair derived from the sperm, and one from the egg. It is plain, then, that the pairs of chromosomes that we know to exist in all of the body cells of an individual consist each of one chromosome derived from the organism's mother and one from its father.

This fact may be put into a general law which applies to all sexually reproducing animals. If the chromosome number in the gametes of any organism is n, the number in the body cells of that organism will be $2n$, and will consist of n pairs, one member of each pair derived from the individual's male parent, and one from the female parent. This principle is obviously of great importance when we consider chromosomes as bearers of heredity, and will be referred to in the next chapter. The n number of chromosomes is usually referred to as the *haploid* number; the $2n$ number, as the *diploid* number.

Although in animals the cells produced by the meiotic divisions form themselves directly into gametes, this is not true in most plants. In them meiosis occurs in the formation of the spores which produce the gametophyte, so that this generation has the haploid, or n, number of chromosomes. The gametes of plants are produced on the gametophyte by means of a series of normal mitoses, at all of which only the n number of chromosomes can be counted. As a result of fertilization, the diploid, or $2n$, number is restored, and the sporophyte produced by the zygote has this number. In the flowering plants meiosis takes place in the young pollen sacs and the developing ovules, both processes occurring when the buds are very small, from one to three weeks before they open.

Comparison of Mitosis and Meiosis.—To understand the manner in which hereditary traits are handed on from one generation to another it is absolutely necessary to understand the processes of mitosis and meiosis, since it is through these processes that the hereditary factors contained in the chromosomes are systematically distributed from parents to child. The whole picture may be briefly summed up in the following comparison of mitosis and meiosis:

1. Mitosis occurs in practically every cell division that takes place in the body, while meiosis occurs only at the final two divisions which produce the eggs or sperms.

2. In mitosis, chromosomes line up singly on the spindle, and half of each chromosome is passed on to each of the two daughter nuclei, so that each daughter cell receives both members of each pair of chromosomes. In meiosis, the chromosomes line up in pairs on the spindle, and half of one member of each chromosome pair

is passed on to each of the four daughter nuclei, so that each daughter cell receives one member of each chromosome pair.

3. Mitosis results in the preservation of the chromosomal organization throughout all the cell divisions occurring in the development of an individual organism. Meiosis results in the division of the chromosomal organization into two similar halves, so that when the gametes unite to form a new organism, half the hereditary factors come from the father and half from the mother.

Chapter Summary

The two most important cells involved in sexual reproduction are the gametes, which unite in fertilization to form the zygote. In human beings, the gametes are the eggs and sperms, and the zygote is the fertilized egg. A complete organism develops from this single cell, the zygote, by means of a vast number of cell divisions. Practically all of these divisions are of the type called mitosis, which involves the appearance of a definite number of chromosomes, their gathering at the equator of a spindle, their division into halves, the passing of the half or daughter chromosomes to the poles of the spindle, and the formation of daughter nuclei around the daughter chromosomes while the cell divides in half along the equator of the spindle. Mitosis secures an equal distribution of the chromosomal, and hence of the hereditary, material of the zygote to every cell in the body.

As the embryo develops, the germ cells, destined to produce the gametes, are differentiated from the other body cells. The gonads develop around these cells, and they continue to multiply by mitotic division until, with the arrival of sexual maturity, they begin developing into eggs and sperms.

In the formation of the gametes, there occurs a process known as meiosis, which consists of two cell divisions. At the beginning of the first of these, which is known as the *reduction division,* the chromosomes pair, and the members of each pair split and pass as double chromosomes to opposite poles of the spindle. At the second division, carried through simultaneously by the two nuclei resulting from the first, the halves of each chromosome separate, so that at the end of this division each sperm mother cell has produced four cells, each with half as many chromosomes as the sperm mother cell had. Meiosis takes place in the egg mother cell also, but in a modified form which results in the formation of only one mature egg and three *polocytes.*

When a sperm cell with *n* chromosomes fertilizes an egg cell with the same number, the resulting zygote has *2n,* and these chromosomes may be grouped into *n* pairs, one member of each pair being derived from the egg, and one from the sperm. The members of the pairs act independently during all the mitotic divisions that produce the growth of the new individual to maturity, but pair up in the reduction divisions that produce the sex cells for the next generation. Thus every generation of sexual reproduction involves the change of the chromosome number from *2n* to *n,* and back to *2n.* In plants, the meiotic divisions produce the spores which give rise to the gametophyte, so that this generation has the *n* number of chromosomes, while the sporophyte produced by the zygote has the *2n* number.

QUESTIONS

1. Define chromosomes, and tell briefly of their importance.
2. Describe mitosis, illustrating with diagrams.
3. What is the important result achieved by mitosis which would not be achieved without this process?
4. Compare meiosis with mitosis, noting similarities and differences.
5. Define meiosis and describe it as it occurs in the production of sperms. In the production of eggs.
6. Mr. and Mrs. Jones have a daughter Ann, and Mr. and Mrs. Smith have a son Paul. Ann Jones marries Paul Smith and they have a son John. Starting with the fertilized egg that gave rise to Ann Jones, and the one that grew into Paul Smith, trace out the chromosome conditions, and the changes in chromosome number that occurred up to the production of sperms by John Smith.

GLOSSARY

chromosome (krō′mō-sōm) A heavily staining rod of nuclear material formed during cell division which carries and distributes hereditary traits.

diploid number (dip′loid) The number of chromosomes in the body cells of an animal. The *2n* number.

haploid number (hap′loid) The number of chromosomes in the gametes of an animal. The *n* number.

meiosis (mī-ō′sis) The set of two cell divisions which in animals results in the formation of the sex cells and which reduces the number of chromosomes from the diploid to the haploid number.

mitosis (mī-tō′sis) Cell division which involves the appearance and activity of chromosomes.

polocyte (pō′lō-sīt) Small, non-functional cells formed in meiosis in the female.

reduction division The one of the two meiotic divisions which, according to conventional usage, results in the reduction of the number of chromosomes in the daughter cells.

CHAPTER XIII

THE PRINCIPLES OF HEREDITY

Early Ideas About Heredity.—Since the beginning of human history, heredity has received as much attention from men as any part of biology. Men have always believed that "like begets like" and that by crossing unlike organisms new types of animals or plants can be created. Ever since plants have been cultivated and animals domesticated, men have tried to produce new and better races and to keep their best breeds constant. Furthermore, the lure of creating new forms of life has a fascination that still attracts many into this branch of biology, known as *genetics*. Moreover, people are beginning to realize more and more that careful control of breeding in the human race will make us a better people, and help solve many of our problems.

There have been many efforts to discover the principles underlying heredity, the earlier of which were almost pure speculation. One of the most prominent ideas, which was held generally in the seventeenth and eighteenth centuries, was that the sperm or the egg contains a minute but completely formed organism with its characteristics all there, and that growth is simply the unfolding and enlarging of that organism. Some of the microscopic workers of the day were even so bold as to declare that they had seen, and to picture, a small, folded-up man within the human sperm. Carrying this idea further, they logically assumed that this little man must contain many sperms, each of which had a smaller animal inside, and so on. According to their view, every human being that was ever to inhabit the earth existed already within the sperm of some living man. In fact, a theologically minded scientist declared that the ovaries of Eve contained two hundred thousand million of these little men!

Gregor Mendel and His Discoveries.—The first man to throw any real light on the manner in which inheritance actually takes place was the Austrian monk, Gregor Mendel. Working quietly and patiently in the garden of his monastery at Brünn, he showed that many characteristics of plants are inherited according to definite laws, and that the types of offspring which will result from mating two parents of known pedigree can be rather accurately predicted. He published the results of his experiments in 1868, but they received little attention from the world and were soon forgotten. Then, in 1900, three biologists, quite independently of each other, rediscovered these laws which Mendel had laid down. In the course of their studies they also unearthed the articles which Mendel had written back in 1868; and, realizing that he had preceded them by more than thirty years, they generously gave him the chief credit for his work. "Mendel's laws" immediately became known throughout the world, and in the last forty years have become the foundation of one of the most active and progressive branches of biology.

Although Mendel knew nothing whatever of chromosomes and their importance, recent discoveries have shown without doubt that the explanation of his laws lies in the separation of the paired chromosomes at the reduction division, and their coming together in new combinations in fertilization. We know that within each chromosome there is a large number of particles which are different in some way from each other. Each of these particles, known as a *gene*, acts as a unit to control the inheritance of one or more characteristics. Since the chromosomes in the body cells occur in pairs, the genes are in pairs also; and with the separation and the recombination of chromosomes during reduction division and fertilization, the paired genes also separate and recombine.

A Simple Mendelian Ratio: The Inheritance of a Single Pair of Characteristics.—To demonstrate Mendel's laws and their explanation, let us see what happens in an actual cross between two animals differing in a single characteristic: i.e., in a cross between a pure black guinea pig and a pure brown one. The black parent will contain, situated in a definite part of one of his pairs of chromosomes, a *pair of genes for black.* These may be denoted by the symbols BB. (See chart, Fig. 64.) Similarly, the brown parent will contain, in the same part of the corresponding

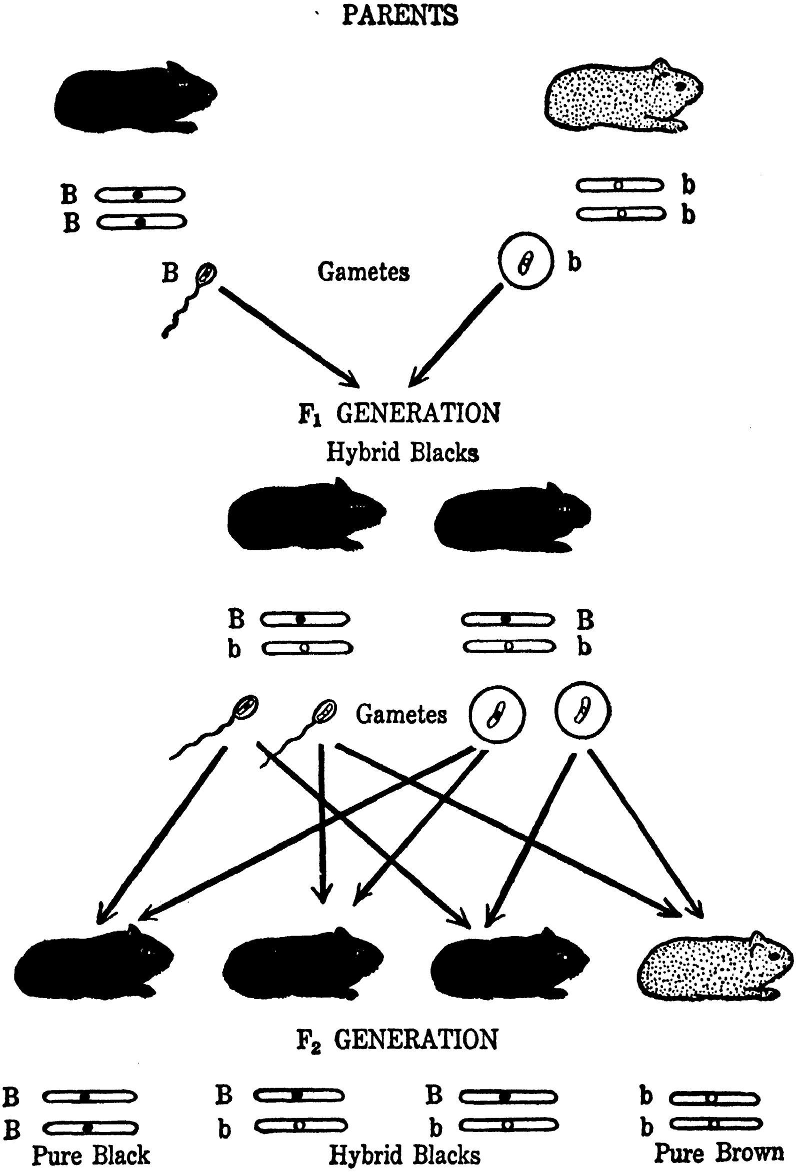

FIG. 64.—Results of a cross between two guinea pigs differing in one character, governed by a single gene pair.

chromosome pair, a pair of genes for brown, denoted by the symbols bb.

Since, at the reduction division, the members of each pair of chromosomes separate and go to opposite poles of the spindle, each sperm of a male black guinea pig will contain but *one gene* for black, B, while each egg of a brown female will contain one gene for brown, b. (See chart.) Hence, if we mate these two, the offspring will contain in their body cells, one gene for black, obtained from their father, and one for brown, from their mother. The appearance of these offspring is, however, quite different from what one would expect. All of them are *just as black as their father.*[1] The only explanation for this that we can give is that the black gene, whenever present, dominates the appearance of the guinea pig, and it is therefore called *dominant.* The brown gene, apparently, can influence the animal's appearance only when it is present doubly, without that for black, and is therefore termed *recessive.* These black offspring of the first generation (denoted by the symbol F_1, as in the chart) may be called, to distinguish them from their pure black father, *hybrid blacks,* and they possess genes denoted by the symbols Bb.

Each of these hybrid black offspring is capable of producing gametes of two types, one containing a single black gene, B, and the other a single brown gene, b. Furthermore, these gametes will be produced in equal quantities, so that half of the sperms of a male hybrid black guinea pig will contain the gene for black, and half the gene for brown. The same will be true of the eggs of a female. Hence, if two of these F_1 offspring are mated, four combinations are possible in fertilization, and these will occur in equal numbers as in Fig. 64.

As a result of this cross, therefore, three types of zygotes are produced, which will grow up into three types of genetically different offspring. One-fourth of the second-generation, or F_2, offspring are the result of the fusion of sperms containing the black gene B, with eggs containing the same gene, and are therefore of the constitution BB, and pure black. One-half are the result

[1] You should *not* conclude from this illustration that the male is more likely to possess dominant traits than the female. If the female were the black one, all the offspring would be black. A dominant gene is always dominant whether it comes from the father or the mother.

of the fusion either of sperms containing B with eggs that have b, or of b-containing sperms with B-containing eggs, and are therefore of the constitution Bb, and hybrid black, like their F_1 parents. The final fourth are the result of the fusion of eggs and sperms, both containing the gene for brown, b, and are pure brown. Hence, in appearance, *three-fourths* of the F_2 offspring are *black* and *one-fourth brown*. This 3-1 ratio is characteristic of the second-generation offspring of a cross between two individuals differing in a single characteristic, governed by a single gene pair. The two types of black guinea pigs cannot be told apart, except by breeding them and finding out what ratio of offspring they produce.

If we describe the offspring of a cross from the standpoint of their appearance, we are said to be describing *phenotypes*, while if we describe them in terms of gene combinations, we are describing *genotypes*. Thus a hybrid black is phenotypically black and genotypically Bb. The ratio of offspring for the cross between hybrid blacks is phenotypically 3 black to 1 brown. Genotypically it is 1 BB to 2 Bb to 1 bb.

Of course, the fertilization of a given type of egg by a given type of sperm is always a matter of chance; and consequently the 3-1 ratio is a chance ratio, such as the 1-1 ratio between heads and tails secured by spinning a coin. Such chance ratios hold good only for large numbers. If you spin a coin twice, you cannot be at all sure that it will show heads once and tails once. But if you spin it 200 times, you can be certain that it will show heads about 100 times and tails about 100 times. Similarly, in any litter of four guinea pigs produced by a mating of black hybrids, you cannot be sure of finding three blacks and one brown; but in 100 such litters you will find approximately 300 blacks and 100 browns. This principle holds good for all the laws of heredity. They express probable ratios and do not predict the sort of offspring found in any *particular case*. These ratios are the result of the "shuffling" of the genes that is effected when the paired genes separate in reduction division and unite with new mates in fertilization. Such separations and unions are called *genetic recombinations*. The recombinations which took place while the guinea pigs were breeding may be summed up as follows:

FIRST GENERATION (BLACKS × BROWNS):

Genotypes, P:[a] Male: BB Female: bb

Gametes, P: B b

Fertilizations:

Eggs / Sperms	b
B	Bb

F_1:[a]

Genotypes	Phenotypes
All Bb	All black

SECOND GENERATION (HYBRID BLACKS × HYBRID BLACKS):

Genotypes, F_1: Male: Bb Female: Bb

Gametes, F_1: B b B b

Fertilizations:

Eggs / Sperms	B	b
B	BB	Bb
b	Bb	bb

F_2:[a]

Genotypes	Phenotypes
1 BB, 2 Bb	3 black
1 bb	1 brown

[a] P = Original parental generation.
F_1 = First generation of offspring (filial generation).
F_2 = Second generation of offspring.

A diagrammatic summary similar to the two above should be employed whenever you are asked to calculate the ratio of types in the offspring to be expected from breeding two known genotypes. First the genetic constitution of the parents is indicated, and from this the type of gametes that they will form is written in the second line. A square to indicate the possible types of fertilization is then constructed, with the sperms along the left side and the eggs along the top. Since each type of fertilization has an equal chance of occurring, the numerical ratios of the genotypes of the offspring are readily calculated simply by counting them up in the square. By grouping the genotypes together according to their phenotypic characteristics, the phenotypic ratio can be indicated in the column opposite the genotype column.

Simultaneous Inheritance of Two Pairs of Characteristics.—Let us try another problem, somewhat more complex. Let us cross a black, short-haired guinea pig with a brown, long-haired one. The gene for black is dominant, as is also that for short hair. Furthermore, *the genes for long and short hair are located in a different pair of chromosomes from those for black and brown.* The two pairs of characteristics are therefore transmitted independently, each according to the manner just described.

With these facts in mind, let us see what the progeny of this cross will be. The first generation should work out as follows:

Genotypes, P:	BBSS	bbss
Gametes, P:	BS	bs

Fertilizations:

	bs
BS	BbSs

	Genotypes	Phenotypes
F_1:	All BbSs	All black, short

The offspring would all be black and short haired, but would be hybrid for both of these traits.

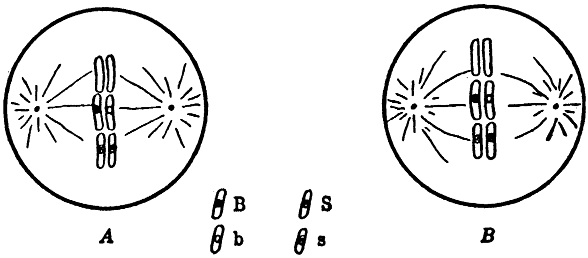

FIG. 65.—Two ways in which the chromosomes containing gene pairs Bb and Ss could line up on the spindle at reduction division. *A*, one daughter cell receives B and S; the other, b and s. *B*, one daughter cell receives B and s; the other, b and S.

Suppose we now breed these hybrid black short-haired guinea pigs one to the other. The first thing we must consider is that the two pairs of genes are in different chromosome pairs. Consequently, reduction division will not always result in the formation of the same kinds of gametes. When these chromosomes pair for reduction division, they may pair with the chromosome containing B, and the one containing S on the same side of the spindle, as in Fig. 65A. In this case the gametes formed will be BS and bs. On the other hand, the B-containing chromosome and the s-containing one may chance to line up on the same side of the spindle, as in Fig. 65B. In this case the gametes formed will be Bs and bS. Since there is an equal chance for each sort of alignment of chromosomes in reduction division, an equal number of gametes of each type will be formed. The results of breeding the hybrid black short-haired guinea pigs can therefore be formulated as follows:

Genotypes, F_1:	BbSs	BbSs
Gametes, F_1:	BS Bs bS bs	BS Bs bS bs
Fertilizations:		

	BS	Bs	bS	bs
BS	BBSS	BBSs	BbSS	BbSs
Bs	BBSs	BBss	BbSs	Bbss
bS	BbSS	BbSs	bbSS	bbSs
bs	BbSs	Bbss	bbSs	bbss

F_2:	Genotypes	Phenotypes
	1 BBSS 2 BBSs 2 BbSS 4 BbSs	9 black short
	1 BBss 2 Bbss	3 black long
	1 bbSS 2 bbSs	3 brown short
	1 bbss	1 brown long

The phenotypic ratio that such a hybrid cross gives is, therefore, 9 black short-hairs to 3 black long-hairs to 3 brown short-hairs to 1 brown long-hair. This 9-3-3-1 ratio can be demonstrated experimentally whenever two pairs of hybrid characters located in separate chromosome pairs are crossed.

Inheritance as the Result of Gene Combinations.—Now, if the reader understands fully what occurs in the two experiments that have just been outlined, he is acquainted with the most im-

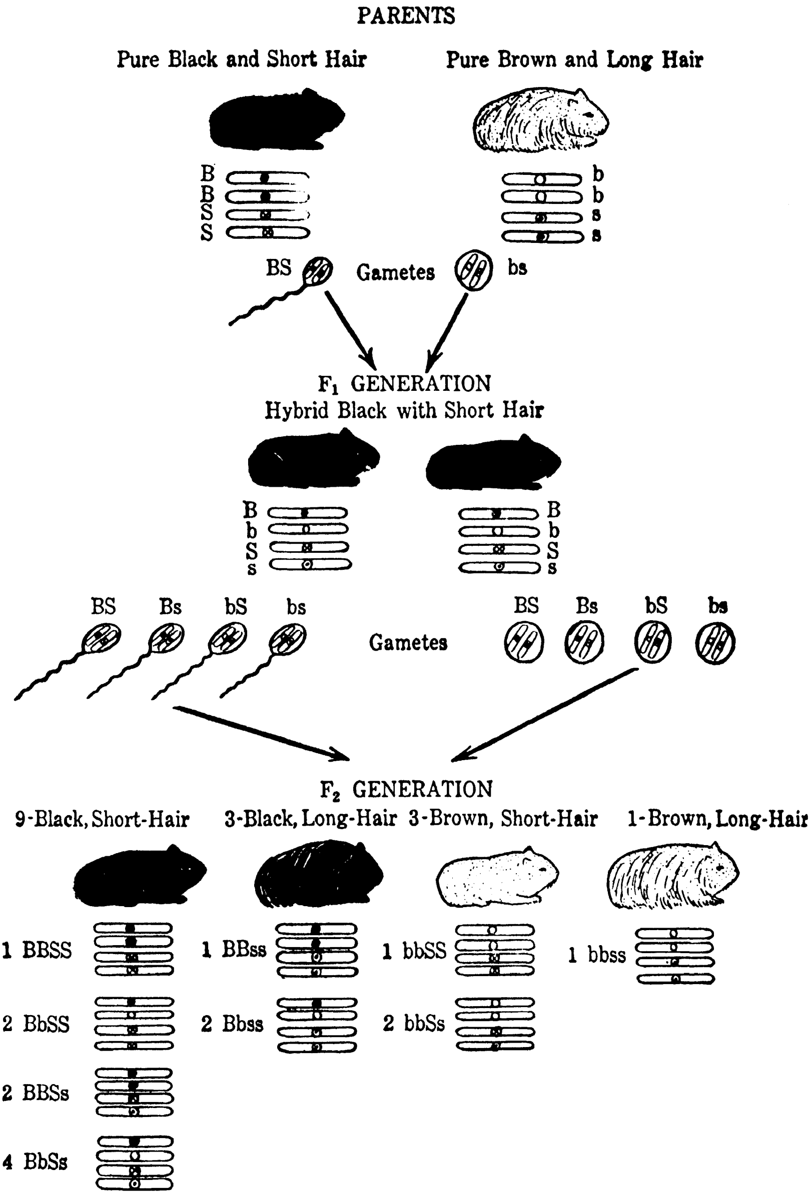

FIG. 66.—Results of a cross between two guinea pigs differing in two characters governed by gene pairs located on different chromosomes.

portant fundamental phenomena of heredity. We may sum up these phenomena in the following manner:

1. Hereditary traits are passed from generation to generation by means of *genes*. Although the exact nature of the genes is not known, they may be thought of as little packets of chemicals, each differing from the others.

2. Each chromosome contains a characteristic group of genes, and the genes in a pair of chromosomes are paired. For example, the gene for brown eyes may be paired with another gene for brown eyes or with a gene for blue eyes; or the members of the gene pair that occupies that particular position in the paired chromosomes may be both for blue eyes.

3. In any pair of genes, the gene for one character is usually dominant over the one for the other character. For instance, the brown-eye gene is dominant over the blue-eye gene, so that an individual who has one gene for brown eyes and one for blue is brown-eyed. One must have both genes for blue in order to be blue-eyed.

4. Every sexual reproduction results in a *recombination* of genes, because of the fact that half the genes in fertilization come from the sperm and half come from the egg. Furthermore, each offspring of a given pair of individuals is likely to receive a different combination of genes from any of its brothers and sisters, since each sperm or egg of an individual is likely to contain a different combination. This difference in the genetic character of the sperms and eggs is the result of the fact that when the paired chromosomes line up on the equator in reduction division, it is simply a matter of chance whether a given member of the pair lines up on one side or the other. Suppose, for example, that a given species has four pairs of chromosomes: 1a, 1b; 2a, 2b; 3a, 3b; and 4a, 4b. Meiosis will result in the formation of sixteen different kinds of gametes in equal numbers, as follows:

1:	1a 2a 3a 4a	9:	1b 2a 3a 4a
2:	1a 2a 3a 4b	10:	1b 2a 3a 4b
3:	1a 2a 3b 4a	11:	1b 2a 3b 4a
4:	1a 2a 3b 4b	12:	1b 2a 3b 4b
5:	1a 2b 3a 4a	13:	1b 2b 3a 4a
6:	1a 2b 3a 4b	14:	1b 2b 3a 4b
7:	1a 2b 3b 4a	15:	1b 2b 3b 4a
8:	1a 2b 3b 4b	16:	1b 2b 3b 4b

Each one of the 16 different sperms can fertilize any of the 16 genetically different eggs; so that, as far as combinations of chromosomes are concerned, 256 different kinds of zygotes can be formed. In the human species, where there are 24 pairs of chromosomes, meiosis can result in the formation of 16,769,024 kinds of gametes; and, as a consequence, there is a possibility of 281 trillion generically different zygotes. And the possibilities of variation are really much greater than this calculation would indicate, since occasionally a group of genes "crosses over" from one member of a pair of chromosomes to the other, thus causing an even greater "mix-up" than is brought about by the chance arrangement of the chromosomes in reduction division. The result of all this shuffling and reassortment of genes is that the hereditary constitution, that is, the assortment of genes, in one individual is never the same as that in another. This universal variation is, of course, just what we observe all about us. Brothers and sisters usually show many resemblances, since their genes are all derived from those of their parents. But, unless they are identical twins, they are never exactly alike genetically.

Blended Inheritance.—As the reader undoubtedly knows, not all characteristics are inherited in this comparatively simple fashion. In characteristics such as height and skin color in man, and often in the color of flowers, the offspring are intermediate between their parents. This "blended inheritance" can be produced in various ways. The simplest is that of *imperfect dominance.* For instance, if a red snapdragon is crossed with a white one, the F_1 offspring are all pink. If these are then intercrossed, they produce reds, pinks and whites in the ratio of 1-2-1. In other words, the pink F_2 offspring are hybrids just like the hybrid black guinea pigs, except that neither the red nor the white gene is dominant, and both have their influence on the color of the flower. The same holds true for a breed of fowl known as the Andalusian. If a black Andalusian fowl is bred to a white one, the resulting offspring are a slaty blue, a highly prized color. These, of course, never breed true to their color but, when mated with each other, produce blacks, blues, and whites in the 1-2-1 ratio.

A similar type of inheritance determines the skin color of crosses between Negroes and white men. Here, however, *four genes,* in two pairs, are active, none of them dominant or recessive. The F_1 offspring of a cross between a pure black Negro and a white man are all mulattoes of about the same intermediate shade. If such mulattoes are bred together, the F_2 offspring are not in a 3-1 ratio of blacks to whites, as were the guinea pigs, nor are they in a 1-2-1 ratio of blacks to mulattoes to whites, as one would expect if there were a single pair of genes for color, neither of which was dominant. Instead, there is a large number of mulat-

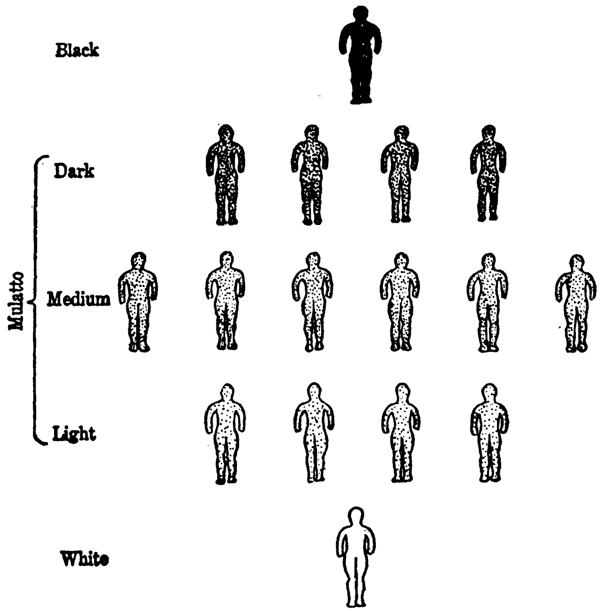

FIG. 67.—Diagram showing the proportions of the various types of offspring as to color found in the second generation of crosses between pure-blooded Negroes and pure whites.

toes of various shades of blackness, and only occasionally does a pure black man or a pure white one appear.

A recent analysis of the offspring of mulattoes has, nevertheless, shown that they may be grouped into five classes: pure blacks, pure whites, and three grades of mulattoes. The frequency of these groups may be expressed by the accompanying diagram, in which the darkness of the shading indicates the blackness of a given type, while the number of figures in a row indicates the frequency of a type. Out of every sixteen offspring there is one pure black and one pure white, and the grades of mulattoes are in the ratio of 4-6-4.

To explain this ratio, let us assume that the black grandparents had four genes for blackness in two pairs, BB and B′B′, while the white grandparents had four genes for whiteness, bb and b′b′. The F_1 mulattoes would then have the genes BbB′b′. Since they contain an equal number of black genes and white ones, none of which is dominant, they are exactly intermediate in color between their parents. They produce four types of gametes, BB′, Bb′, bB′ and bb′. A square showing the possible types of fertilizations will be as follows:

	BB′	Bb′	bB′	bb′
BB′	BBB′B′	BBB′b′	BbB′B′	BbB′b′
Bb′	BBB′b′	BBb′b′	BbB′b′	Bbb′b′
bB′	BbB′B′	BbB′b′	bbB′B′	bbB′b′
bb′	BbB′b′	Bbb′b′	bbB′b′	bbb′b′

By adding the F_2 types, one can see that there is one with four black genes (BBB′B′), four with three black genes (2BBB′b′ and 2BbB′B′), six with two black and two white (BbB′b′), four with one black and three white, and one with four white (bbb′b′). If we assume that the blackness depends on the number of black genes present, the five types of F_2 offspring actually found, and the ratio between them, are easily explained.

This comparatively simple example illustrates *multiple factor inheritance*, which, for the more fundamental characteristics of organisms, is more common than inheritance through a single pair of genes. Usually, however, multiple factor inheritance involves the activity of a very large number of genes, some of which are dominant, some recessive, and some neither. This results in a type of blended inheritance in which it is frequently extremely difficult or quite impossible to detect separation and recombination of individual gene pairs. As a result, offspring cannot be separated into distinct types, but may vary continuously from one extreme of a trait to another, depending on the particular assortment of genes that each individual receives. The transmission of height in human beings is an example of this.

The offspring of tall parents will, on the average, be tall; but among these offspring all degrees of height may be represented, from very short to extremely tall. Similarly, short parents may produce offspring of all degrees of height, although their children will *average* shorter than those of tall parents.

Interaction of Genes.—To add to the complexities of the hereditary picture, we find that the effect that certain genes exert may depend upon the presence or absence of other genes. For instance, guinea pigs of the genotypes BB or Bb will be black and guinea pigs of the genotype bb will be brown, only in the presence of another gene, C, which causes some sort of pigment to appear in the coat. Animals of the genotype cc will always be white, no matter what other genes for coat color are present. Hence, the ratios previously given for interbreeding of black and brown guinea pigs and their hybrids would hold only for animals that were pure for the presence of pigment, that is, of the genotype CC. If several pairs of black guinea pigs, hybrid for both pigment and black, were mated, the ratio in the offspring would be 9 blacks to 4 whites to 3 browns, as follows:

Genotypes, P: CcBb CcBb

Gametes, P: CB Cb cB cb CB Cb cB cb

Fertilizations:

	CB	Cb	cB	cb
CB	CCBB	CCBb	CcBB	CcBb
Cb	CCBb	CCbb	CcBb	Ccbb
cB	CcBB	CcBb	ccBB	ccBb
cb	CcBb	Ccbb	ccBb	ccbb

F_2:

Genotypes	Phenotypes
1 CCBB 2 CCBb 2 CcBB 4 CcBb	9 black
1 ccBB 2 ccBb 1 ccbb	4 white
1 CCbb 2 Ccbb	3 brown

In this short account, we can enter no further into the complexities of the hereditary mechanism. The reader should keep in mind the fact that the sample ratios with which we have dealt in this chapter represent only the simplest of the problems with which the geneticist deals, and that most traits are governed by a multitude of genes whose combined action results from a very complex interrelationship among them. Underlying all these complexities, however, there remains the single simple principle that was worked out by Mendel. Hereditary traits are transmitted from generation to generation by myriad pairs of unit factors, and each animal or plant that reproduces sexually receives one member of each pair from the father and one from the mother.

Inheritance in Human Beings.—Most traits that are of any importance in human beings, such as height, weight, strength, intelligence, and other mental traits, are governed by a multiplicity of gene pairs. Single gene pairs, however, govern a few traits, most of which are abnormal. There is a single gene for dwarfism, a gene for color blindness, and a gene for hemophilia, that disease in which the blood fails to clot and which has recently entered the news because it afflicts the deposed but romantic Spanish crown prince along with several other members of his family. The peculiarly heavy jaw and lower lip which have been found in the same family clear back to their famous ancestor, Charles V, and which is therefore known as the "Hapsburg jaw," is also the product of a single gene. There is a single gene pair for eye color, the gene for brown eyes being dominant over the one for blue; but while this gene pair determines whether the eye is to be light or dark, a number of other genes determine minor variations in color and pattern of pigmentation. A few other single hereditary factors have been discovered in human beings, but multiple factor inheritance is the rule, single factor inheritance the exception.

The Application of Mendelian Principles.—The principles laid down by Mendel have not only been the basis of a great body of scientific knowledge which has been built up around them in the last forty years, but they have also proved of value to practical plant and animal breeders in their efforts to produce better cultivated plants and domestic animals. Such an age-old art as practical breeding has not been revolutionized by these comparatively recent discoveries, but modern genetics has injected into it more precise and careful methods and, above all, the ability to make predictions and be reasonably sure that they will come true. The fundamental principles of breeding, cross breeding followed by the selection for desirable characteristics, have not been changed. They have been made more efficient, however, and many results formerly incomprehensible are now fully explained.

Progeny Selection.—One way in which genetics has been applied to help practical breeding is in regard to the method of selection. Formerly, breeders practiced chiefly mass selection, in which they chose the best-appearing animals in a herd for breeding, or the most vigorous-looking plants in a field as seed bearers. This method is still practiced by the ordinary farmer, but many of the more progressive livestock raisers and agriculturists are finding it inadequate, since so many of the progeny of mass selection tend to "revert to type" and are no better than, if as good as, their forbears.

The more refined method, known as *progeny selection*, is now gaining ground steadily. In animal breeding, progeny selection involves the testing of an animal's breeding qualities by the offspring that it gives before using it regularly as a breeding animal. Two bulls of the same race may be equally large, strong, and vigorous, yet one bull may have daughters with a much greater milk-producing capacity than the other. The reason is that the better bull is pure bred for every gene pair relating to milk-producing capacity, while the other has recessive genes for poor milk qualities which, although they do not affect his appearance, yet produce the inferior offspring when paired with other recessive genes from the cows with which he mates.

Progeny selection has, in several scientifically conducted experiments on fowls, been particularly successful in increasing egg production. Geneticists have found that two pairs of genes, M and L, affect egg production, the dominant genes in each case increasing the production. A hen may be pure bred for both dominants, MMLL, or may have one recessive of each pair, MmLl; in either case her egg production is the same. A rooster that is pure bred for both dominant egg-producing genes, MMLL, will produce good egg-layers when mated with either of the two types of highly productive hens. However, a hybrid rooster, MmLl, although he may look exactly like the pure-bred one, will, when bred to the hybrid hen, give some poor layers. He may thus be detected and eliminated while the pure-bred rooster is kept for all further breeding. By this method one geneticist increased the average annual egg production of the hens in his flock from 114 to 200 eggs in eight years.

To aid in progeny selection, pedigrees of stock are being made more and more regularly. Nowadays only bulls of proved worth are used in the better herds of cattle, while in horse-raising the laurels won by a stallion's offspring increase his worth as much as any he has acquired himself. State registration of pedigreed stock is an outcome of the need for progeny selection, and county fairs and stock shows help advertise the best-bred animals and make them available for breeding purposes.

Inbreeding and Its Effects.—The practice of selection conducted on a scientific basis clearly involves the mating of brothers and sisters, as well as closely related cousins, and, in plants, self-fertilization, since only by this method can the breeder analyze his stock genetically. This mating of closely related animals is known as *inbreeding*. There has always been much argument among breeders as to whether this is harmful or not, although many of the most valuable livestock are the result of continued inbreeding. With the coming of scientific genetics, careful experiments conducted on various animals and plants over a large number of generations have given us actual knowledge about this practice.

The chief outcome of these experiments has been to show that, while there are many exceptions to the rule, desirable traits are *usually* produced by dominant genes, and undesirable traits by recessive genes. With continued inbreeding, more and more pairs of recessive genes are brought together, and the characteristics that they produce appear in a large number of individuals, with a resulting deterioration of the stock. But the very fact that these recessives are brought out into the open can be put to advantage by an intelligent breeder. By selecting only the best of his stock to breed from and rejecting all the inferior individuals, he may completely weed out the undesirable recessives, and the offspring of the carefully selected stock will *breed true* for the qualities desired in a fashion that would be impossible in a cross-bred stock where recessive genes may be hidden for a long time, only to bob up occasionally and cause trouble. Inbreeding, then, is the best way of bringing out undesirable recessives so that they can rapidly be weeded out of a stock; and, once they are weeded out, continued breeding within that stock is the best way of keeping them from getting back in.

Cross Breeding and Hybrid Vigor.—While inbreeding accompanied by selection has no ill effects on a race, there is one great advantage to cross breeding. In every experiment in which

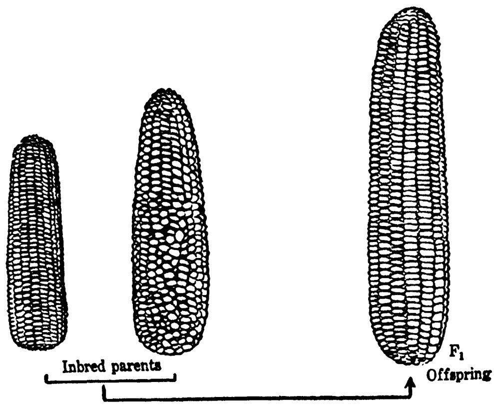

FIG. 68.—Diagram illustrating hybrid vigor in corn.

it has been tried, cross breeding of individuals from different constant, inbred strains has produced offspring bigger and stronger than either parent. The same increase in vigor results from crossing two quite different races, or even species. If the parents are too widely different from each other, the offspring will be sterile, for reasons that will soon be explained, but they will be more vigorous than their parents. This phenomenon, known as *hybrid vigor,* is characteristic of F_1 hybrid offspring, but always decreases in later generations unless the wide crossing is kept up. In Fig. 68 hybrid vigor in a cross between two inbred strains of Indian corn is shown.

The explanation of hybrid vigor lies in the fact that most dominant genes tend to produce desirable characteristics. In the F_1 offspring of widely different parents, the largest possible number of genes are in the hybrid condition, and therefore the largest possible number of dominant genes are active, while the recessive genes are practically all hidden. In later generations, the recessive genes again segregate out and produce their weakening effect.

Hybrid vigor may very profitably be secured in practical breeding. The importation of pedigreed sires from another line is accepted as the best way of improving a herd of cattle or a stable of racing or show horses. If the pedigrees of the parents are known, the nature of the offspring can at least in part be predicted, and the breed kept true by a small amount of selection. In the case of agricultural crops, experiment stations in various parts of the country have devised ways by which farmers can maintain hybrid vigor. The method now recommended is that the farmer have several seed plots in which carefully selected races are kept constant by inbreeding, and that to produce the seed that he plants in his field, he make crosses between two of these races. In fact, corn breeding is now carried out in this way on a large scale.

The Crossing of Different Species.—Often the breeder crosses two organisms differing in many characteristics, some governed by single and some by many gene pairs. The offspring of such crosses are, of course, extremely variable; and when the organisms differ so widely from each other that they are classed as different species, the types of offspring that result from a cross between them cannot be predicted. Those of the F_1 generation are usually very much like each other and intermediate between their parents, but in the following generation the many different characteristics segregate in different ways and form such a number of new combinations that usually no two individuals of this generation are alike. This is the result which to the ordinary breeder is a hopeless confusion but which to the man with foresight, great patience, and persistence, may be a gold mine from which he picks out new races and, by careful selection over many generations, creates some constant variety which everyone can use.

By this method most of our valuable garden vegetables and flowers, as well as a large number of breeds of domestic animals, have been created. The garden strawberry, for instance, is almost certainly a hybrid between the common wild strawberry of our eastern states and a species from Chile. Both were introduced into European gardens in the seventeenth century, where they frequently grew side by side. Since only the female plants of the Chilean species had been imported, crosses between the two naturally appeared and became the source of our large-fruited cultivated forms. A similar origin, though much more ancient and less clear in its details, is ascribed to our cultivated apples and plums. They are presumably derived from crosses between certain wild species of Europe and others native to Asia. Most of Luther Burbank's creations are the result of hybridizing two or three different species and of growing tremendous numbers of offspring, among which the "plant wizard's" keen eye could detect the most valuable individuals which he caused to breed true by means of careful selection. The loganberry, for instance, is the result of a cross between a blackberry and a raspberry.

Among animals, poultry gives us examples of some well-known breeds of hybrid origin. The early American colonists brought with them to this country breeds of fowl derived from strains domesticated in southern Europe, coming originally from India. These were small, active birds, about the size of modern bantams, very fertile egg layers, but not particularly good eating. More recently, Yankee sea captains brought back from the Malay Islands chickens of a different type. They were larger in every way and rather heavy and sluggish, differing in so many characteristics from European fowl that some scientists consider them to be derived from different wild species. By crossing these Malay types with the European race, poultry breeders produced our well-known American breeds, such as the Plymouth Rock and Rhode Island Red, which combine high egg-laying capacity with fine eating qualities.

Sterility in Species Hybrids.—One of the biggest difficulties encountered in crossing different species is the partial or complete sterility of the offspring. The mule, for instance, has been produced for centuries by breeding a mare to a jackass, but is always completely sterile. It is a valuable animal, since it combines the size and energy of the horse with the hardiness, steadiness, and persistence of the donkey, and is superior to both in strength on account of hybrid vigor. Yet in all the centuries that they have been produced, there are only a few authentic records of a mule having foaled. The explanation for this lies in the difference between the chromosomes of the horse and those of the donkey. In the zygote resulting from the fertilization of a horse's egg with a donkey's sperm, there is a complete haploid set of chromosomes of the horse, together with that of the donkey. The number of each is not the same, there being slightly more chromosomes derived from the donkey than those from the horse. During all the mitotic divisions that build up the body of the mule, there is no necessity for association between horse and donkey chromosomes. However, when the meiotic divisions begin in the testes

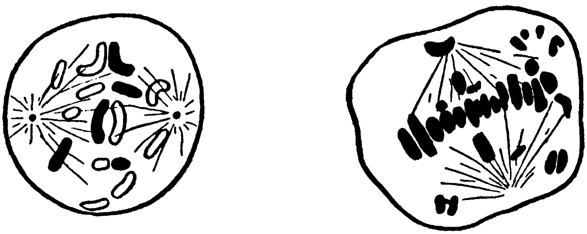

FIG. 69.—*Left,* diagram illustrating what might happen in the reduction division in the offspring resulting from a cross between an organism possessing twenty, and one possessing ten chromosomes in its body cells. Fifteen chromosomes are shown, ten in white, derived from one parent, five in black from the other. Four of the latter have found mates; but one of them, as well as six of the former group, are unpaired. *Right,* drawing of the reduction division in the mule. About fifty chromosomes, paired and unpaired, are present, but they cannot be accurately counted.

or ovaries, the chromosomes cannot pair properly, since many of the horse chromosomes are different from those derived from the donkey parent, and there is a number of extra donkey chromosomes which find no mates at all. These unpaired chromosomes behave very irregularly, causing meiosis to be quite abnormal (Fig. 69). The resulting daughter cells, since they have either too few or too many chromosomes, soon degenerate, so that no functional sperms or eggs are produced.

Other hybrids are only partially sterile. For instance, in the cross between domestic cattle and the wild buffalo, the resulting "cattalo" is sterile if male, but fertile if female; that is, the female will give offspring with either a domestic bull or a buffalo bull. Western cattle breeders have recently been experimenting with this cross in an effort to combine the hardiness and disease resistance of the buffalo with the beef qualities and tractability of domestic cattle, but as yet no widely accepted breed has been created in this way.

Still other crosses cannot be made at all. If, for instance, pollen from a squash is put on flowers of the pumpkin, no seeds or fruit are produced. Moreover, the physical resemblance of two types is by no means a criterion of the ease with which they can be crossed; the breeder has learned that the only way to learn whether a cross between two different species can be made and what the offspring will be like, is to try it. The intricacies of breeding by hybridization and selection are so numerous that they can be mastered only by means of a wide practical experience combined with a knowledge of modern genetical theory, but the results are among the most valuable contributions to mankind.

The Determination of Sex.—People often wonder whether they can control the sex of their children, and how it is determined whether there will be a girl or a boy. In olden days many absurd formulae for producing the desired sex were current; even today people have ways of predicting this fact which they believe to be infallible, and many strange things are done by parents under the belief that a boy, or perhaps a girl, will certainly result. We know now, however, that this all-important fact is decided for the most part, just as are the questions of brown eyes or blue and blonde or brunette, by the chromosomes and the laws of chance.

In human beings, there are 24 pairs of chromosomes in every one of the body cells. In the male, however, there is a pair in which the two chromosomes are very unequal in size, the larger being known as the X-chromosome, the smaller as the Y-chromosome. In the female, the members of the corresponding pair are both alike, and correspond to the X-chromosome of the male. We may diagram the condition thus:

Woman	Man
23 pairs of chromosomes	23 pairs of chromosomes
plus	plus
XX	XY

It will be readily seen that during meiosis in the male, two kinds of sperms will be formed in equal numbers. Half the sperms will contain the X-chromosome and half of them will contain the Y-chromosome. All the eggs, however, will contain an X-chromosome. When an X-containing sperm fertilizes an egg, the XX pair of chromosomes will be formed, and the individual usually becomes a female. When a Y-containing sperm fertilizes an egg, the XY pair of chromosomes will be formed, and the individual generally will be a male. Thus is provision made for an equal number of individuals of each sex to be born, although whether or not a given child turns out to be a boy or a girl is largely a matter of chance. This is the most common chromosome mechanism for sex determination, although a number of others exist.

This equal distribution of the sexes which would be expected under the sex-chromosome mechanism has been borne out by statistics to a certain degree. For instance, the average ratio of the sexes at birth for the human race as a whole is 103-107 boys to 100 girls. This ratio varies from country to country; for instance, there are born in Great Britain only 93 boys to every hundred girls, but in China there are 125 male births to every hundred female. What determines these differences we cannot tell, but very likely the cause is a difference between the number of males and females that die before birth. We know, for instance, that more boys are still-born than girls.

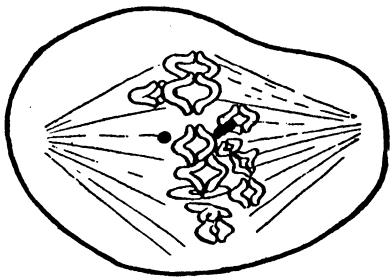

FIG. 70—Drawing of the reduction division in the formation of human sperms, showing several of the chromosome pairs, including the XY pair (in black).

Sex Reversal and Intersexuality.—That chromosomes are not the absolute arbiters of sex determination has been shown by a number of instances of sex reversal. In one case, a hen who had been the mother of several broods of chickens contracted a disease of the ovaries. In a few months she had developed the appearance of a rooster, fought with the other roosters in the yard, and attracted the hens. Finally, when mated to a virgin hen, she (or he, by this time) became the father of a brood of chicks. This has been explained by the fact that the gonads of a hen often contain a little testicular tissue among that characteristic of the ovary. When the ovary becomes diseased and degenerates, this tissue develops and produces sperms, as well as hormones which give male secondary sex characteristics. Similar cases are known in other animals; and in some bisexual plants, such as hemp, males can be turned into females and back again, simply by changing the environment. This is possible in plants because the germ cells are not all differentiated in the young embryo, but new ones are produced before each flowering period. Hence we may say generally that the sex of any organism may be changed if the germ cells have not all been differentiated into egg-producing or sperm-producing types.

A rather striking proof of this fact is the "freemartin" in cattle. Cattle breeders have known for some time that when twins of different sexes are born, the female is usually sterile, although her external genitals are normal in appearance, and her udder is that of a cow. She is known as a "freemartin," and, when examined, is found to possess rudimentary testes rather than ovaries. This abnormality is brought about by the joining together of the blood streams of the twin embryos before the gonads have become differentiated. In this case the gonads of the male, as determined by his XY set of chromosomes, develop into testes, and soon start to produce sex hormones which are carried by the blood stream to his female twin. In this embryo, the gonads are still comparatively undifferentiated, since the differentiation into ovaries occurs later than that into testes, and so the influence of the male sex hormones transported from the twin embryo makes them develop in the direction of testes. The female heredity cannot, however, be easily overridden, and the outcome of the resulting struggle between male and female sex hormones is the intersexual "freemartin."

Present evidence indicates that the sex into which an undifferentiated embryo will develop is determined by the rate of metabolism in its cells at the time of differentiation. At least in the higher animals, the male has a higher rate of cell metabolism than the female; and if these processes, particularly combustion, are comparatively rapid in the young embryo, it develops into a male, and if slower, into a female. The chromosomes normally swing the balance one way or the other by regulating this rate.

In human beings an XY organization tends to speed up metabolism, while cells of the XX chromosome constitution are normally less active; but in either case, if the rate is altered by some disturbing agent, the sex is either partly or completely changed. Using this principle, a German doctor has developed a method in which, by regulating the diet of mothers during the early weeks of pregnancy so as to produce a high or low rate of metabolism in their cells, he claims to be able to produce boys or girls at will. This method has not, as yet, been generally accepted or used.

Sex-linked Characters.—The X-chromosome contains many genes which the Y-chromosome lacks, with the result that males never receive more than one member of these pairs of genes. The traits which these genes govern are called *sex-linked characters.* Dominant sex-linked characters occur more frequently in females than in males, while recessive sex-linked characters occur more frequently in males. Color blindness, a sex-linked recessive, is found in about four per cent of men, but only very infrequently in women. The reason is that, for a daughter to be color-blind, both parents must have the gene for color blindness so that it can occur in both chromosomes. But since a son receives his only X-chromosome from his mother, he can inherit color blindness whenever she possesses one or both genes for it. If a color-blind man mates with a woman both of whose genes are normal, all the sons will be normal, since they will receive their only X-chromosomes from the mother. The daughters, however, will be hybrid normals, since each will receive the father's X-chromosome with its color blindness gene. If these hybrid daughters marry men of normal color vision, all their daughters will be normal—although half will be hybrid normals—since each daughter will receive a normal gene from the father's X-chromosome. Half the sons will be color-blind, since half will receive the mother's X-chromosome with the normal gene and half the mother's X-chromosome with the color blindness gene, and there will be no X-chromosome from the father to "cover" this recessive gene. Thus a son always inherits his color blindness from his mother, whether she is color-blind or not, but cannot inherit it from his father even when his father is color-blind; while a daughter cannot be color-blind unless her father is also color-blind and her mother has at least one color blindness gene. It is only for sex-linked characters, however, that the old saw that "boys take after their mothers and girls after their fathers" is in any sense true. For all other traits, it is a matter of chance which parent a child most resembles.

Chapter Summary

The science of genetics is an old one, and fantastic theories about it once existed. The fundamental laws of heredity were discovered by Gregor Mendel, an Austrian monk.

His laws are explained by the separation of chromosomes in the reduction division, and their recombination in fertilization. Each chromosome contains a number of genes, which are the units that influence hereditary characteristics.

If two organisms differing in a characteristic that is controlled by a single gene pair are crossed, the F_1 offspring will receive one gene from each parent. One of these genes may be dominant over the other, so that the offspring completely resemble the parent which possessed this gene. If these offspring are bred together, their offspring are of three types genetically; but in appearance, three-fourths show the dominant and one-fourth the recessive trait. This is explained by the separation of the genes in the reduction divisions of the F_1 parents, and the number and types of recombinations that are possible.

If animals differing in two characteristics, and pure bred for each, are crossed, the F_1 offspring show both dominants. If the gene pairs are located in different chromosome pairs, they segregate independently of each other, so that four types of gametes are produced by the F_1 individuals in equal quantity. In a cross between two of them, these gametes recombine to form nine different genetic combinations, which give four different types as far as external appearance is concerned, in the ratio 9-3-3-1.

The number of types of gametes formed by an individual, and the number of recombinations possible, depends on the chromosome number, and in most species is very large. This explains the large number of hereditary variations, even among brothers and sisters.

If neither of two paired genes is dominant, the F_1 offspring are intermediate between their parents, and the case is one of imperfect dominance. If a number of genes govern a characteristic, the F_1 offspring of a cross between the extremes of the two types will all be intermediate between their parents, but those of the F_2 generation will show a series of gradations from one extreme to the other. A simple example of this multiple factor inheritance combined with incomplete dominance is given by the results of a cross between a Negro and a white man.

If a large number of genes, some dominant, some recessive, and some neither, affect a single characteristic, multiple factor inheritance in which the action of single genes cannot be recognized, results.

Frequently genes interact in such a way that a combination of genes is necessary to produce a single trait, as when a gene for pigment and another for black must both be present to produce black coat in the guinea pig. Unlike many forms of multiple factor inheritance, however, the action of each gene pair is readily observable.

Among human beings a few instances of single factor inheritance have been discovered, but multiple factor inheritance seems to be the rule.

In plant and animal breeding some ways in which the knowledge of the laws of heredity has been useful are:

1. It has demonstrated the advantage of *progeny selection*, in which the plants and animals to be used for breeding are chosen on the basis of the offspring which they have produced, rather than by their appearance.

2. It has explained and clarified the results of inbreeding. Since recessive genes tend, on the whole, to produce undesirable traits and since inbreeding tends to bring recessive genes together, many undesirable individuals will appear in an inbred stock. When these individuals are weeded out by selection, however, the offspring of the desirable individuals will not only inherit the good traits of their parents but will breed true for those traits, since "hidden recessives" will be eliminated.

3. It has partly explained *hybrid vigor*, or the greater size and strength of the offspring of a cross between two widely different parents. This is due to the activity under these conditions of the largest possible number of dominant genes, which produce most strong characteristics.

The crossing of different species produces very variable offspring, from which careful selection must be made to produce valuable types. Species hybrids are, moreover, often sterile, as the result of the failure of different chromosomes to pair at the reduction division.

The chromosome mechanism for the inheritance of sex in human beings is as follows: A man has in his body 23 pairs of chromosomes + the XY pair and produces two types of sperms in equal quantities, those containing 23 + X, and those with 23 + Y. The woman has in her body cells 23 pairs + an XX pair, and produces eggs containing 23 + X. If an X-containing sperm fertilizes an egg, a female-determining zygote is produced, whereas a Y-containing sperm produces a male-determining zygote.

The sex of an organism may be reversed by an abnormal environment at any time if the germ cells have not become completely differentiated into egg- or sperm-producing types. The sex is directly determined by the metabolic rate in the cells at the time of differentiation.

Hereditary traits whose genes are carried in the X-chromosome but not in the Y-chromosome are called sex-linked characters. A recessive sex-linked character will occur more frequently in males than in females, since it will never occur in combination with the dominant gene. Dominant sex-linked characters will occur more often in females than in males. Males always inherit sex-linked characters from their mothers, since they never receive their X-chromosomes from their father.

QUESTIONS

1. Describe the inheritance of a pair of opposing characteristics governed by a single gene pair, showing the application of the principle of dominance and that of segregation and recombination of genes.
2. Show how genes that are located in different chromosome pairs may segregate independently in reduction division.
3. By means of a diagram, demonstrate the number of genetic recombinations and the number and proportion of different types of offspring as to appearance that will be obtained from crossing two individuals that are hybrid for two pairs of characteristics, the genes for which are located in different chromosome pairs.

4. What is meant by blended inheritance? Incomplete dominance? Multiple factor inheritance? Interaction of genes? Illustrate with examples.
5. What is the advantage of progeny selection?
6. Discuss the advantages and disadvantages of inbreeding.
7. Describe and explain hybrid vigor, giving an example.
8. Of what use is the hybridization of widely different varieties or species to the inbreeder? What are the difficulties encountered in this process? Give specific examples.
9. Explain the sterility of species hybrids, such as the mule.
10. Explain the manner in which chromosome combinations determine sex.
11. Explain why a color-blind man whose father was color-blind but whose mother was not color-blind would not have inherited his color blindness from his father.

GLOSSARY

dominant (as applied to genes) Expressing itself in the appearance of an organism when present with the opposite paired gene.

gene A small particle within a chromosome which influences one or more hereditary characteristics.

genetic recombination A change in gene constitution from one generation to another, resulting from the separation of gene pairs in reduction division and their coming together again in fertilization.

genetics (je-ne′tiks) The scientific study of inheritance.

genotype (jē′nō-tīp) An organism characterized in terms of the genes it possesses.

germ cells The group of cells which eventually gives rise to the gametes.

hybrid vigor Increase of size and vigor in the offspring of a cross between two different varieties or species.

inbreeding The breeding together of brothers and sisters, or other closely related individuals.

phenotype (fē′nō-tīp) An organism characterized in terms of its observable hereditary traits.

progeny selection Selection of animals for breeding purposes according to the progeny that they have already produced.

recessive (as applied to genes) Not expressing itself in the appearance of an organism in the presence of the opposite paired gene.

CHAPTER XIV

THE FACT OF EVOLUTION

The Incontrovertible Fact.—All tribes and nations of men have some story concerning the beginning of things. Some tell how the earth was dragged up from the bottom of the ocean like a fish in a net; others, how some creative deity, armed with a great wind, wrought an ordered world out of primitive chaos. Many think of the origin of the universe as being like the birth of a living thing, as do those who relate how the world was once a great egg which had to be chipped open. Such a myth or theory of the origin of things is known as a *cosmogony.*

Scarcely a hundred years ago the accepted cosmogony among Christian peoples was the story in the book of Genesis, according to which the entire world was created in the course of six days at a date something like 4000 B.C., and man was formed out of dust by a special creative act on the last day. Today the accepted belief is that it is impossible to date the beginning of the universe; indeed, that it is likely to have been always in existence, that aeons ago the earth on which we live began to be formed of material derived from the sun, that about two billion years ago life began on earth in a very primitive form, that all present living forms are the descendants of the simple forms with which life began, and that man himself is a product of this long course of evolution and is kin to all other living things on the earth.

Here is a revolution in thinking as drastic and perhaps as important to the life of man as any political revolution that has ever taken place. Although the observing, experimenting, and reasoning of thousands of men have gone into the bringing about of this change, it was the publishing of Charles Darwin's *Origin of Species* in 1859 that really marked its beginning. Throughout the history of human thought there have been men who have advanced the theory of evolution as an explanation of the coming into being of the world, but none of them offered anything like complete proof for their theory. When Darwin published his book in 1859, he had been working for over twenty years, amassing a tremendous array of facts to back up his views. So cogent were his arguments that the scientific world was forced to investigate them. More and more evidence was unearthed that tended to establish the theory, until, at the present time, no unprejudiced student can possibly reject what the authors of *The Science of Life* have termed "the incontrovertible fact of evolution," and no responsible scientist does reject it.

The universality with which scientists accept the fact of evolution needs to be emphasized, since there is a widespread popular misconception to the effect that they are in doubt about the matter. Scientists are in doubt as to just *how* evolution has come about, but they do not for a second question the *fact that it has occurred.* Chapter XVI will be concerned with the theories about the way in which evolution has taken place. At present we shall consider the fact and the evidence for it.

First, it is necessary to point out just what the fact of evolution is. Many people have a hazy notion that evolution means simply that men have descended from monkeys. That is true, if we understand that our monkey ancestors were not exactly like any of the monkeys of today, and that they were ancestral not only to us but to all the present-day monkeys and apes as well. But man's descent from ape-like and monkey-like creatures has been only an insignificant part of the entire process of evolution. Back of our monkey ancestors were ancient reptiles, the common ancestors of man and all other mammals. Back of the reptiles, the earliest amphibians, who were ancestral not only to the present-day frogs, toads, and salamanders, but to the reptiles, birds, and the mammals as well. The amphibians, in their turn, were descended from fishes, the fishes from worm-like creatures, the nature of which we can only guess at today; and still further back were primitive microscopic protozoans, the ancestors not only of ourselves but of all the animals the world has ever seen. And, finally, we might carry our ancestry back to the primal, undifferentiated bits of protoplasm, from which we believe all life, both plant and animal, to be derived.

The History of Life.—The story of living things as the biologist now views it may be briefly summed up as follows:

Hundreds of millions of years ago—the best estimate at the present time fixes the date between one and two billion years before the present epoch—the first tiny bits of living matter began to appear. There is no way of knowing just what the earliest representatives of life were like, but we may think of them as ultramicroscopic globules of protein colloids forming themselves about the edges of quiet, rock-rimmed pools.

Even today we find that the distinction between the living and the non-living is vague. Certain filtrable viruses, such as that which produces the mosaic disease of tobacco, are now known to be only protein molecules, but yet they can reproduce themselves in precisely the same manner as do living organisms. In fact, they can produce alterations which may be perpetuated and which are therefore comparable to similar changes, or mutations, which are an important factor in the evolution of living organisms. Although such substances as these viruses must be of more recent origin than the complex organisms on which they live, similar proteins, which could exist independently, were probably the intermediate stage between typical non-living substances and the earliest forms of life.

These highly complex proteins, which themselves were probably built up or evolved during long ages of purely chemical activity, must have had two characteristics not found in other non-living things. First, they could divide in two and then build themselves up again, so that a single one could develop into thousands. This was the beginning of growth, reproduction, and heredity. Second, changes could take place within them; hence certain of these proteins came to be different from others. This was the beginning of variation. As soon as these bits of protein became organized into cells, life as we now know it had appeared. Thus the evolution of life itself was a long, slow process, and may have taken place in several slightly different ways on different parts of the globe.

As these primitive bits of life became more abundant, competition arose among them for the advantages of their environment. Those which varied in the direction of developing new methods of exploiting their environment, of adapting themselves to the different conditions of new areas, or of protecting themselves better against unfavorable conditions, were the most successful. Because of the continual slight changes that went on among them, certain types came to exploit the environment in one way, certain types in another; and the various types came to have their own peculiar methods of shielding themselves against destruction.

Any modifications which appeared in these early forms of life which did not make them capable of protecting themselves or adequately exploiting their environment resulted in the disappearance of those organisms from the scene of action. Only those types that had effective means of maintaining their existence survived. The result was that as life went on, there was a continuous, though extremely slow, change going on in all forms. A single type of organism might vary in many ways to produce thousands of new types, some of which won out in the struggle for existence, while the great majority disappeared from the face of the earth. Thus, through aeons of time, new phyla, new classes, new genera, new species were formed through the *natural selection* of those members of the older species that were *best fitted* to survive in the environments in which they found themselves.

This process of *descent with modification* is the central fact of evolution. Present-day forms are simply modifications of earlier ones, with the complete line of their descent running back millions of years to some common group of ancestors. The modification has gone on in such a manner as continually to produce new adaptations to the environment; and thus have come into being all the cunning and often weirdly intricate methods of getting along in the world which living organisms exhibit. The modification in the direction of adaptation has been brought about, in part, at least, by the *natural selection of those varieties best fitted to survive*. And as this endless unfolding of ever new forms of life has gone on, there has been a continual production of more and more complex types, capable of exploiting an ever-increasing range of the environment. The first life must have been confined to shallow, stagnant waters. Perhaps it was not even able to manufacture its own food through the activity of chlorophyll, but had to depend upon picking up energy-yielding inorganic compounds. But at some time chlorophyll appeared, bringing to life the possibility of maintaining itself wherever there was sunlight.

The great plant kingdom began to spread itself abroad through all the waters of the earth. Animals probably appeared after the green plants, since they could not have existed unless food substances were manufactured for them by photosynthesis. They may have descended from certain single-celled plants that lost their chlorophyll, ceased to manufacture food, and began to live as robbers on their more stable and industrious neighbors in the plant kingdom.

As the long ages passed, more and more complex forms came into being. After the appearance of organized cells, there came the joining of those cells into colonies and then the organization of the colonies into multicellular forms. These earliest multicellular organisms, however, have left practically no remains by which we can tell just what they were like. The oldest known remains of living organisms are certain spherical masses of lime laid down in successive thin layers, resembling similar structures built up by the secretion of very simple types of algae in ponds, streams, and shallow seas today, and were probably made by the remote ancestors of these algae. Among the oldest animal remains, dated at about five hundred million years ago, are the shells of various shellfish, some of them nearly identical in appearance with those of modern forms; the remains of primitive crab-like animals; and the tracks and limy casings of certain marine worms. Life was undoubtedly confined to the water, principally the ocean, for long ages after it began, and all of the principal groups of animals were evolved in this medium. Fishes or fish-like forms were the first vertebrates to appear, and they, along with the seaweeds, were the most highly developed forms of life for many ages. Not until about 350 million years ago, after the greater part of the history of life to date had been enacted, did the first plants of any importance make their way on to the land. The first of these were small, rush-like marsh plants which reproduced by spores; but soon there appeared giant ferns and trees related to them and particularly to our modern "club mosses" or "ground pines." At nearly the same time there arose plants whose fern-like leaves bore seeds at their tips—the earliest seed plants. These seed ferns, along with the tree ferns and their allies, formed vast forests which, in an age when the climate was warm and moist, stretched from pole to pole. Most of the coal fields of the present

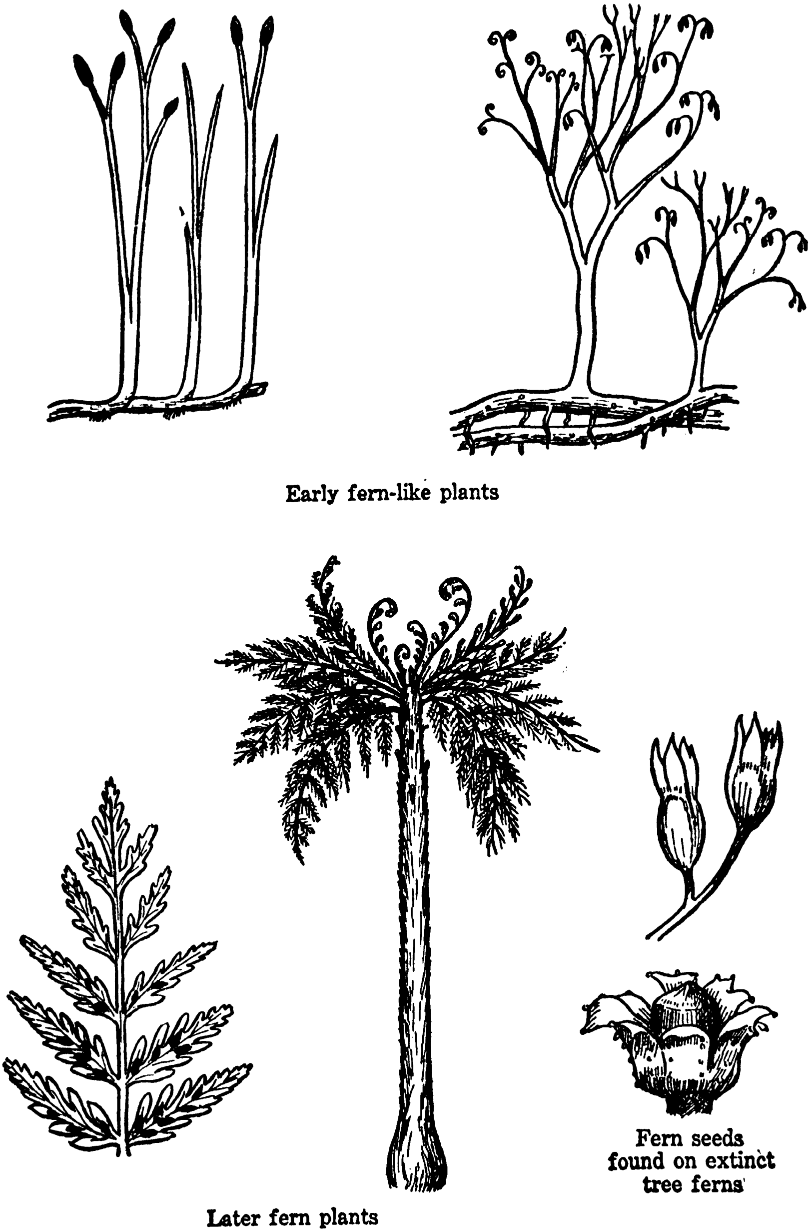

FIG. 71.—Primitive land plants.

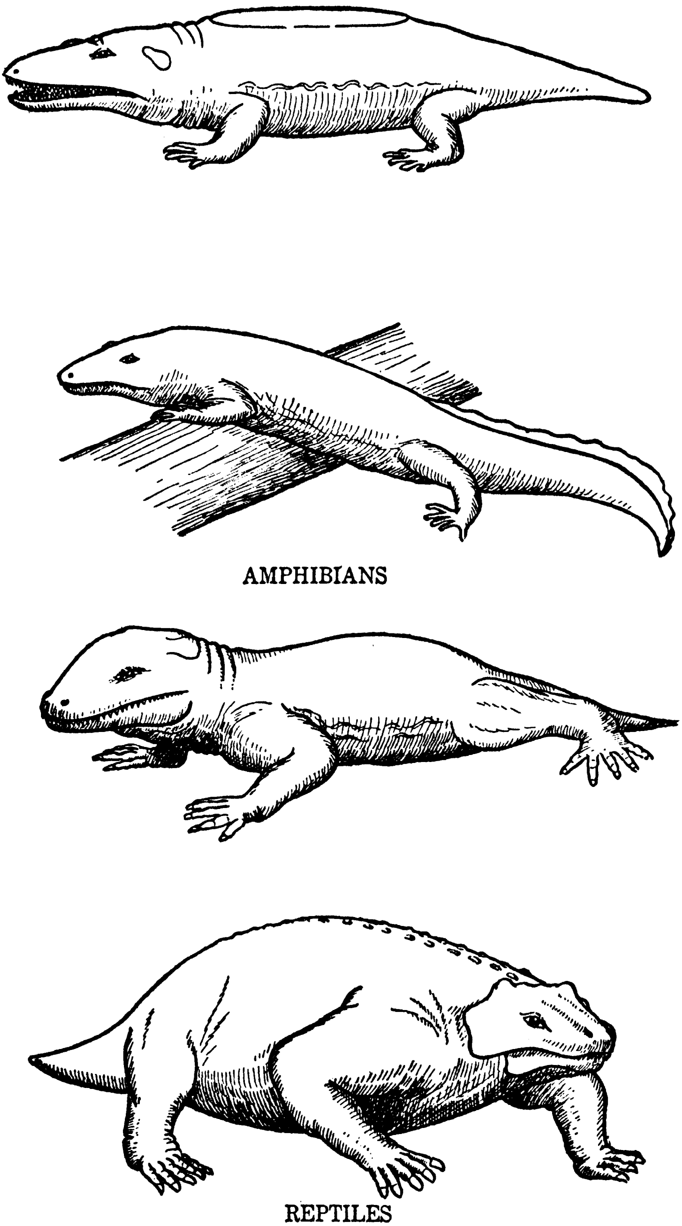

FIG. 72.—Earliest land vertebrates.

day are derived from those ancient forests. Then a long period of cold and windstorms resulted in the killing off of many of these more ancient plants and the coming into dominance of new types of seed plants, many of them cone-bearing. The flowering plants (Angiosperms) did not come to the fore until about a hundred million years ago, bringing with them the types of vegetation we find today.

As soon as the plants had taken up their abode upon the land, animals followed. The first land animals appear to have been forerunners of the insects which, however, had not yet developed wings. As time went on, the insect forms became better and better adjusted to land life, and all their marvelous specialized adaptations were developed. Among the more important of these was the relation that grew up between insects and flowering plants, whereby the insects came to cross pollinate the plants and the flowers furnished food for the insects. This adaptive partnership gave both insects and flowering plants a tremendous advantage in the struggle for survival. Consequently it has had a great influence in producing the present-day characteristics of life, making the flower-bearing plants our dominant plants and the insects our most numerous animals.

Some three hundred million years ago our own ancestors started to come out upon the land. At that time the fresh-water pools and streams were rapidly drying up. Certain fishes whose fins were thicker and more fleshy than those of most of the fish we know began making their way from one pool to another by crawling with the help of their muscular fins. As millions of years went by, their fins were gradually transformed into legs, while their air bladders—structures that are found in practically all fish—developed into lungs. They became the first amphibians, laying their eggs in the water and spending the larval or tadpole stage of their lives there. As adults they were clumsy beasts, still retaining much of the bodily form of the fishes from which they were descended. They found their food in the water and used the land merely to get from one pool or stream to another.

In the course of some fifty million years they gave rise to a class of true land dwellers, the reptiles, who possessed tough, scaly skins and laid their eggs on the land, encased in a protective shell, thus avoiding the tadpole stage in the water. The history of life con-

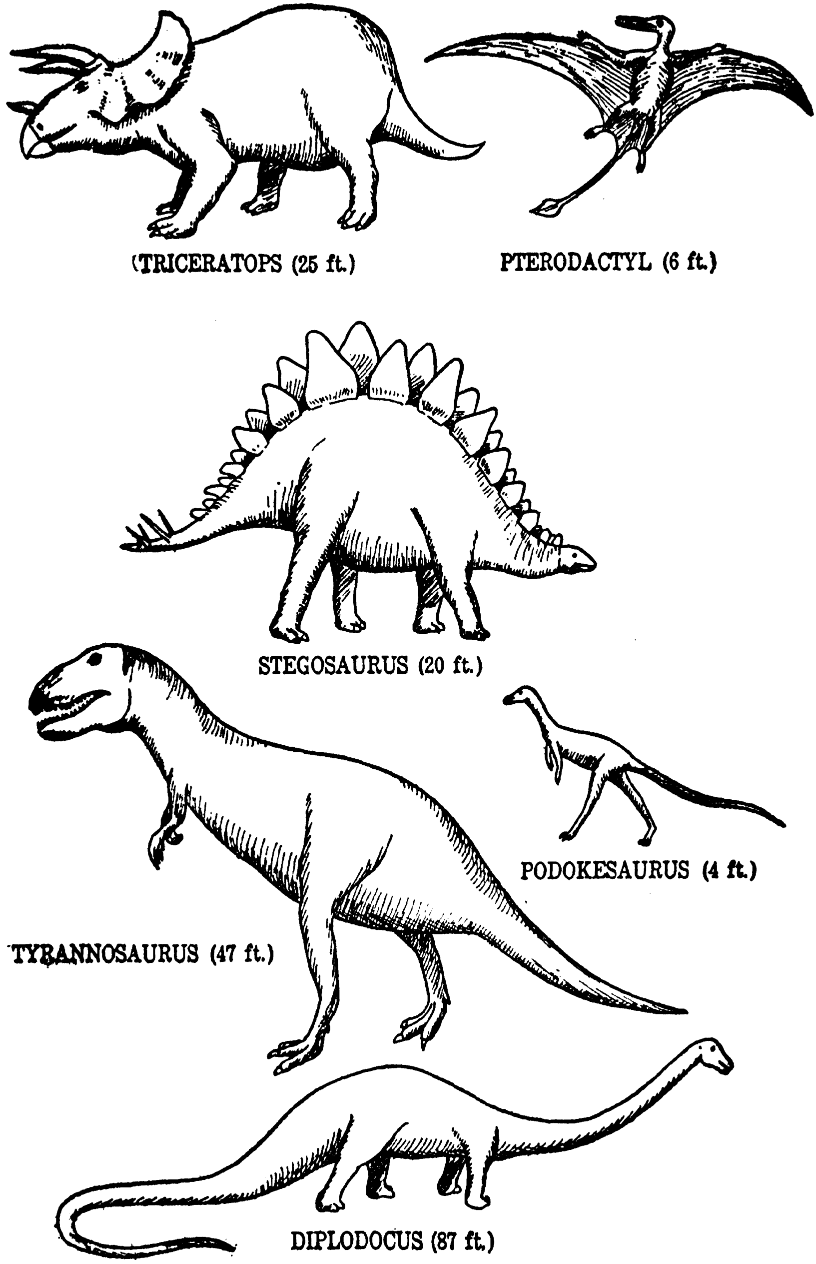

FIG. 73.—Extinct reptiles. (Redrawn from Lull's *Organic Evolution*, The Macmillan Company.)

tains no more interesting chapter than the story of the reptiles. As the first large animals capable of living continuously on the land, they advanced rapidly into this virgin territory. Quickly they differentiated into thousands of forms that seem utterly weird to us, accustomed as we are to the animals of the present day. There were tiny little plant eaters, light and lithe, running about on their slim hind legs and displaying surprising speed and agility in escaping from their fierce and dangerous flesh-eating relatives. There were immense and ponderous feeders upon the heavier vegetation, the largest animals ever to walk upon the earth, with long necks and tiny heads, humped backs and clumsy, triangular tails; there were swift-flying pterodactyls, featherless, with parchment wings like bats and long muzzles filled with saw-like teeth; there were ichthyosaurs that swam like fish and plesiosaurs that navigated over the surface of the sea, their legs transformed into paddles and their tails into rudders. For over a hundred million years these uncanny beasts reigned over the land; and then they mysteriously disappeared, leaving only a few inconsiderable remnants—the snakes, lizards, crocodiles, and turtles—to survive into the present, abandoning the world to the warm-blooded offshoots of their line, the birds and mammals.

While the race of reptiles was still comparatively young, it gave rise to a new type of animal, a group of small, light-boned quadrupeds, with hair covering their bodies, with warm blood coursing through their veins, and with larger brains than were to be found in even the largest reptiles. The reptiles could never have been very intelligent. Their brain cases were small; at the largest, scarcely capacious enough to hold a man's thumb. One of the greatest dinosaurs had a nervous ganglion located far back in its spine that was larger than the brain in its head. It has been suggested that

> If something slipped his foremost mind
> He caught it on the one behind.

But it was probably easy for slips to occur in both regions.

Some time after the appearance of the first mammals, the birds evolved from some group of fast-running or soaring reptiles, substituting feathers for scales to protect their warm bodies from the cold and also to increase their buoyancy in the air, and replacing the bony reptilian tail with a clump of feathers.

For long ages of time, the birds and mammals were strictly subordinated to the reptiles. The mammals were small creatures living on insects. At first they laid eggs like the reptiles—as the reader knows, there are still a few representatives of the egg-laying mammals alive today—but they guarded over their young and

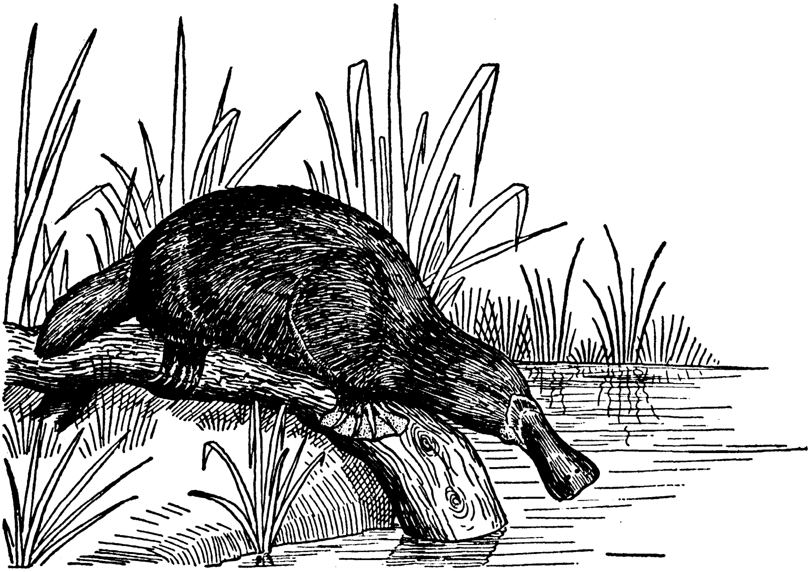

FIG. 74.—The duckbill.

suckled them. Then forms arose that gave birth to their young alive, but in such an undeveloped state that they had to be carried in a pouch fastened to the mother's belly as do the young of the present-day kangaroo and opossum. Finally, at about the time the age of the reptiles came to an end, they developed the modern placental mode of reproduction.

The importance of the mammalian mode of reproduction in making possible the evolution of a being like man can scarcely be overestimated. It is not merely that the family life which has grown out of it has formed the central core of man's existence and has been basic to his social, political, moral, and religious development. In addition to that, the long period spent in the mother's body, nourished by the mother's blood, makes possible a complexity of development that cannot possibly go on in an egg, where the supply of food material contained in the yolk is always limited. More important still is the period of infancy and youth subsequent to birth. The young reptile or the young insect, coming into a world where it must immediately shift for itself, must be born with a set of almost automatic responses with which to meet the emergencies of life. It has no time to learn. But intelligence depends on the ability to learn, and learning depends upon the ability to *make mistakes and then correct them.* Only a young animal blessed with parents to watch over it can afford to be born with this dangerous, but valuable, capacity for making mistakes.[1]

About sixty million years ago, the placental mammals began their course of differentiation and increase. The most primitive of them were probably small, furry, five-toed insect eaters, appearing somewhat similar to the modern woodchuck. From such an animal have been developed all the multitudinous types of higher mammals which we know today. In one direction there was a development of carnivorous forms, with sharp claws, lithe bodies, and dangerous fangs—cats, lions, tigers, dogs, wolves, bears, otters, seals, sea lions, and their kindred. Another direction in mammalian evolution was taken by the herbivorous animals. Since they did not develop the weapons of the beasts of prey, speed in running became essential to them. They began more and more to get up on their toes to run, their claws became thickened to form hoofs, and finally, we find them running on hoofs that have been developed from the claw of only one or two toes. The horses, rhinoceri, and tapirs belong to the order of odd-toed *ungulates* (hoofed animals), and the deer, cattle, camels, and a number of others, to the order of even-toed ungulates. The horses run on a hoof that is derived from a single toe, comparable to our middle finger. The even-toed ungulates run on a "cloven" hoof that is derived from the toes comparable to our third and fourth fingers.

Many other mammalian orders evolved during this period. In the bats, the front limbs were transformed into wings. Elephants grew to ponderous proportions, although it is possible to trace them back to an animal that stood a scant two feet high. The most

[1] Cf. the description of trial and error learning, Chapter XXIV.

remarkable transformation from the small, furry ancestor of the mammals was that undergone by an order that early took to the water and underwent an evolution that produced the whale, the largest animal the earth has ever seen. Early in the period of mammalian dominance, certain rat-like forms, known as tree shrews, started a new line of evolutionary development, involving adaptation to life in the trees. From them arose the order *Primates* —the monkeys, apes and men. This line of development will be considered in a later chapter.

Some Principles of Evolution.—Although a detailed study of the extinct organisms which were the ancestors of our modern forms is the function of the paleontologist rather than the biologist, four principles have arisen from this study which are of primary importance to all students of evolution. In the first place, there is little doubt that evolution, although always a gradual process, was more rapid at some times than at others, and took—and is taking—place more rapidly in some groups of organisms than in others. There was, for instance, a great burst of evolution at the time when both animals and plants were beginning to conquer the land. Not only did many new organisms adapted to land life appear at this time, but there was also a rapid evolution of new kinds of fishes and other marine animals simultaneously. Somewhat later there came a long period, at the time when the coal beds were being formed, when evolution among both animals and plants progressed rather slowly. This was followed by a period of rapid evolution when the giant ferns, fern allies and seed ferns of the coal measures, with their accompanying large amphibians, were largely replaced by the cone-bearing seed plants and the reptiles. Similar periods of rapid and slow evolution have followed each other right down to the present. We are now in a period of relatively rapid evolution. Man has been on the globe for the relatively short period of a million years, but within this time many hundreds of species of both animals and plants have evolved which are adapted only to the regions of human habitation. Rats and mice, lice, fleas, and many other insects may be mentioned, as well as a host of weedy species of plants. Some of these probably have existed since before the time of man, but others are so narrowly adapted to the surroundings of mankind that they must have been evolved more recently than man. At the same time we know of many hundreds of species, some of them formerly the dominant forms of life on the earth, such as the mammoth, mastodon and saber-tooth tiger, which have become extinct within the last two or three hundred thousand years; and a good proportion of them have vanished within the infinitesimally short period of recorded human history.

These periods of rapid evolution always occurred at times of great change in the earth's surface. The rapid development of the earliest life on land was accompanied by a repeated advance and retreat of shallow seas in many parts of the world, particularly the central and eastern United States. The extinction of the species of the coal measures was brought about chiefly by the building up of great mountain ranges and the inundation of a vast ice sheet; similar conditions of mountain building and glaciation have prevailed in recent times. This correlation is easy to explain. If the environment of the earth remains stable, animals and plants become perfectly adapted to the prevailing conditions; hence, any member of a species which varies in any way from the characteristics of the species will be less well adapted than others, and all variations from the species pattern will tend to die out. However, under changing conditions, variations adapted to the new environments will be favored, and the result will be a more rapid change, or evolution.

A comparison of the rapid evolution of man with that of some other animals will serve to illustrate the second principle, i.e., that evolution has progressed at very different rates in different groups of organisms. A number of species of man have evolved and become extinct within the last few hundred thousand years, and one of them has completely altered its distribution and its way of living within the last thirty thousand. On the other hand, many insects, such as ants and termites, have apparently changed little from their ancestors of thirty or forty million years ago, and there is a genus of shellfish now living which has existed in practically the same form ever since the oldest of the well-preserved series of fossil beds was laid down about five hundred million years ago. At present there is no explanation of why evolution should progress more rapidly in some groups of organisms than in others; but evidence from both living and extinct forms points to the hypothesis that groups of organisms evolve very rapidly

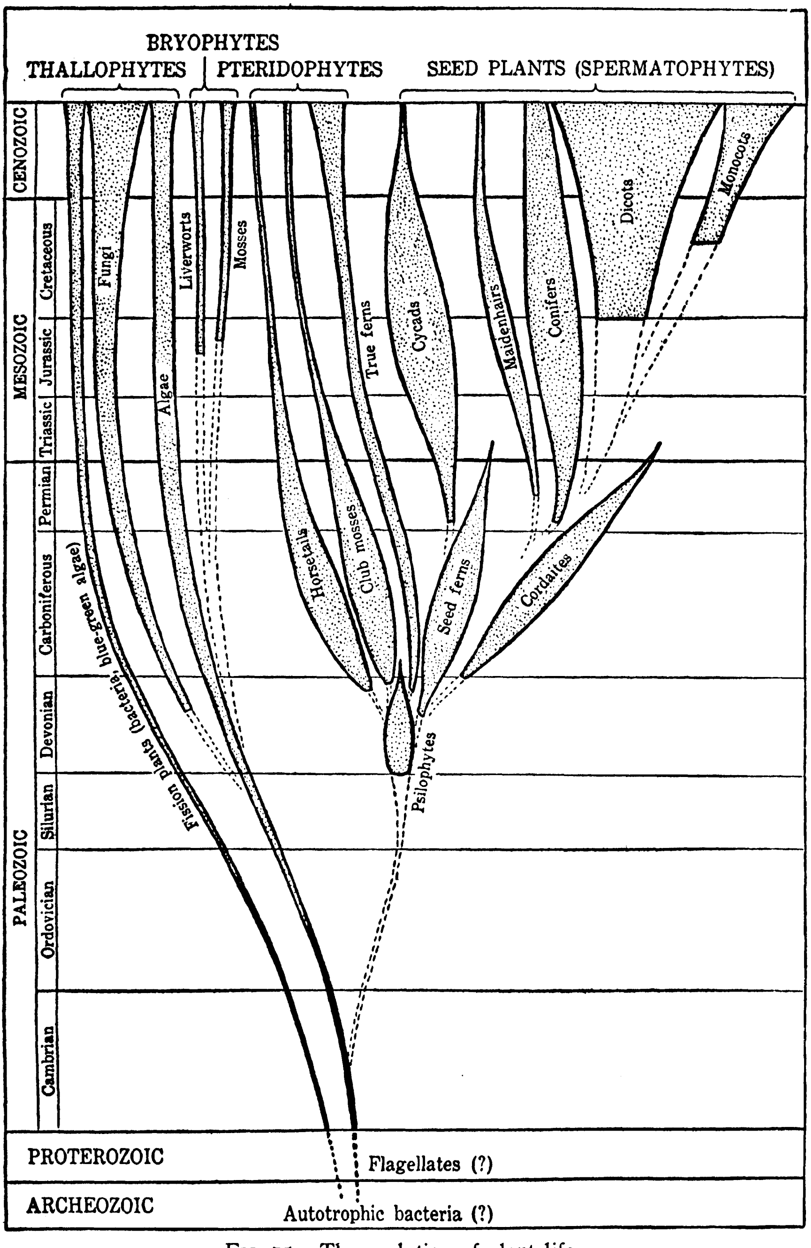

FIG. 75.—The evolution of plant life.

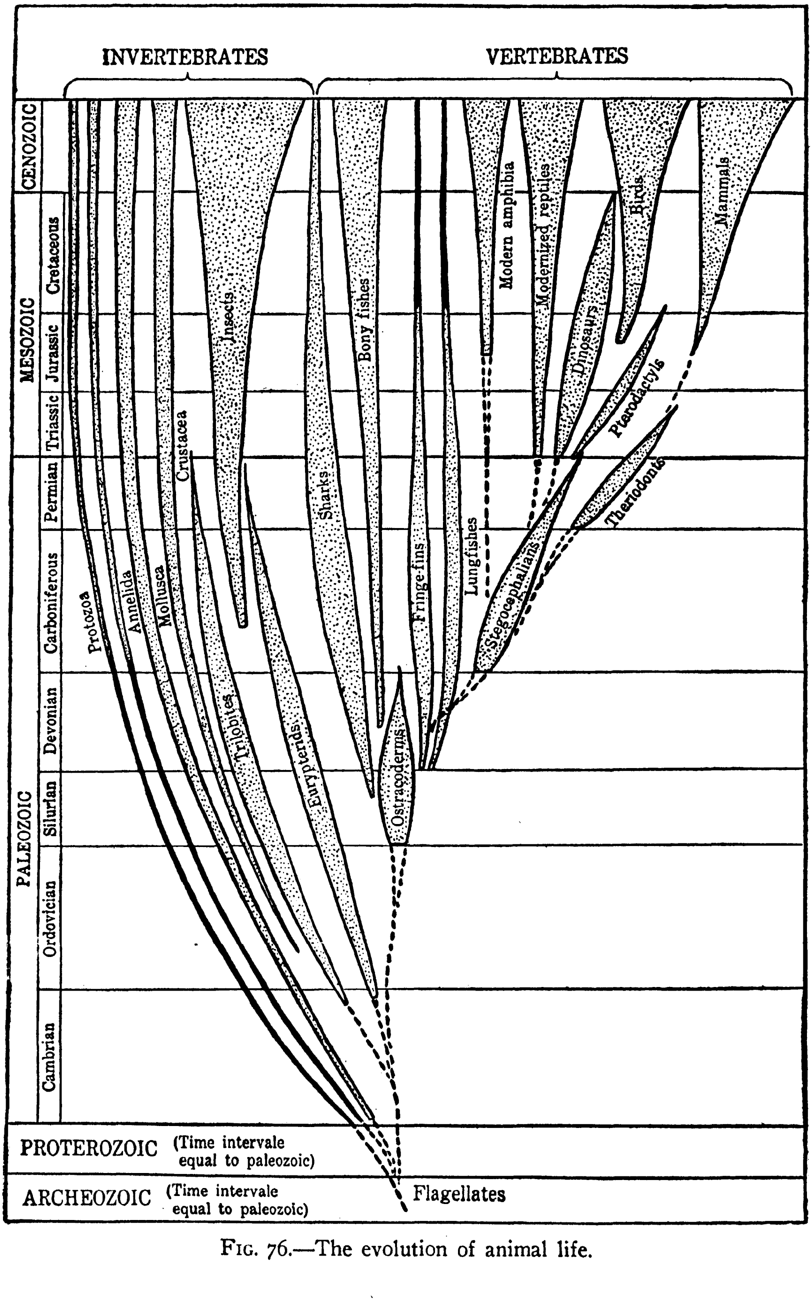

FIG. 76.—The evolution of animal life.

when they first appear, and then their rate of evolution gradually slows down.

A third fact that most modern evolutionists recognize is that new groups of organisms do not evolve from the most advanced, highly specialized representatives of the groups already existing, but from relatively primitive, unspecialized forms. For instance, although mammals evolved from reptiles, they did not come from the most common and highly developed reptiles that existed at the time when the mammals first appeared, i.e., the dinosaurs. The ancestors of the mammals were small, unspecialized reptiles, which occupied a rather lowly position in the life of their day. The evolutionary tree of life, therefore, must be conceived not as a tall pine which sends out new shoots from the tips of the old, but as a much branched shrub which, when one branch is getting old or top-heavy, sends out new branches from near its base, which appear at first insignificant, but finally overtake and surpass the old ones. A further complication of the evolutionary tree, which makes the entire simile of a growing tree rather inadequate as a representation of the true course of evolution, is the importance of hybridization in the evolution of at least some groups of organisms. This point will be discussed more fully later, but we may mention here that any evolutionary tree representing the true course of development of a group of organisms may have in some sections a network of interlocking branches. So, while recent discoveries have tended more and more to confirm the fact of evolution, we know now that its course has not been nearly so simple as it was conceived by the early evolutionists.

A fourth fact that is evident to anyone who knows the world of living organisms, as well as the fossil remains of extinct ones, is that evolution has not always progressed "upward," that is, from simple forms to more complex ones. There are many cases of regressive evolution, or "degeneration," in both plants and animals. For instance, the kiwi of New Zealand and other wingless, flightless birds are undoubtedly descended from winged ancestors. Most modern mammals, furthermore, are simpler and more "lowly" than their forbears of a million years ago or so. The giant deer, tigers, and elephants now known to us only as fossils were far superior in strength and size to their present-day relatives. In addition, there is a whole host of parasitic animals and plants which are extremely simple compared to their free-living ancestors. Lice and fleas, for example, have evolved from more elaborate, probably winged insects, and, as already pointed out, such parasites as the malarial protozoans are much more simple than their non-parasitic relatives and presumably their ancestors. In fact, most biologists picture evolution not as a steady progress of life toward higher levels, but as a fluctuation and diversification of organisms more or less at random, or according to the selective activity of the environment. In some cases a more highly developed body or brain gives the organism an advantage over its competitors or enables it to occupy a new environment, while in others a similar advantage or opportunity is obtained by simplification; in either case the new complexity or simplification will survive only if it is well adapted to some part of the environment available to it.

The Evidence for Evolution.—We may sum up the course of evolution in a few words: Living things have varied; those variations incapable of adapting to their environments have died out; as a result of these and perhaps other causes the life of today has arisen from exceedingly primitive beginnings. This is the fact which no scientist denies. What, then, are the evidences for this fact? The truth of the matter is that there is such a tremendous array of evidence that a lifetime might easily be spent in finding out what it is, criticizing it, and coming to understand it. For purposes of briefly describing this vast array, it may be classified under the following four headings:

1. Evidence from the fossil record of animals and plants that lived in bygone eras.
2. Evidence from the anatomical and physiological relationships between animals of the present day.
3. Evidence from the geographical distribution of present-day forms.
4. Evidence from the science of genetics.

The Fossil Record.—For hundreds of millions of years rivers have been flowing into the sea, bearing with them fine particles of soil which are deposited on the ocean floor or above the water level on river deltas. Thus layers of earth have been piled up, one on top of another, and have gradually been turned to rock through the agencies of pressure and chemical change. On land, similar deposits have been laid down, both by water and by wind. Thus the sedimentary rocks, the shales and sandstones, have been formed.

In the deposits of soil which formed the sedimentary rocks, the remains of plants and animals have been embedded; and, while most of them have quickly rotted away, others have been preserved or at least have left traces of themselves in the rocks that have been formed as the soil deposits were buried beneath the surface and subjected to increasing pressure. Later, through the folding of the earth's crust, these rocks, even those laid down in the bed of the ocean, have been upheaved to form dry land; and wind, frost, and water have worn them down, exposing the records of ancient life which were made in them during the period of their deposition. These records are called *fossils.*

We usually think of fossils as being those great brown skeletons of dinosaurs which look down on us from the main hall of most of our museums, but, as a matter of fact, there are many other types. Some of the oldest known fossils are the shells of seashore animals and the winding tracks made by worms burrowing through the primeval ooze. Other useful fossils are the footprints of animals, while most of our knowledge of prehistoric man has been obtained from a study of the tools which he made and discarded. These may in the broader sense be considered fossils.

Fossils constitute a record of the history of life, but it should not be supposed that this record is anything like complete. In the first place, the vast majority of plants and animals never leave any trace of themselves in the rocks. In the second place, the most ancient rocks have been upheaved into mountain chains and then worn away by weathering to such an extent that the oldest fossil deposits have well-nigh disappeared. Or, when they have remained, the rocks have been subject to such tremendous pressures that nearly all fossil remains have been crushed out of them. Nevertheless, we do have a fairly legible, though by no means complete, record of life extending back over the past five hundred millions of years.

By noting what rock layers lie on top of what others, it is possible to judge the age of the different layers. That is, we know that the ones on the bottom were laid down *before* the ones on top. Of course, we never find all the layers of rocks stacked one on top of the other at one place. But if at one place we find layer A above layer B and at another place layer B above layer C, it is obvious that layer C was laid down first, layer B next, and layer A last of all. Thus, by piecing together the relations of the layers in all parts of the earth, it is possible to put each one in its place, from the oldest to the most recent.

When this is done, and when the fossils in this series of layers are studied, they produce a picture of ever-changing life forms, one type coming after another in regular succession. And thus the history of life can be traced from the study of the rocks as certainly as can the history of the United States be traced from the study of written documents.

It is even possible to assign approximate dates to the rock records by noting the percentage of uranium in a deposit that has turned to lead in the process of radioactivity. Since the speed of radioactivity is known, the length of time that uranium has been turning itself into lead in that deposit can be quite exactly calculated. With certain deposits dated in this fashion, the ages of others can be calculated by their positions relative to the dated deposits.

The fossil record has been divided into five great eras: (1) the *Archeozoic*, extending from approximately two thousand million years ago to approximately eleven hundred million years ago; (2) the *Proterozoic*, extending from approximately eleven hundred million to about five hundred fifty million years ago; (3) the *Paleozoic*, from about five hundred fifty million to something like two hundred million years ago; (4) the *Mesozoic*, from two hundred million to about sixty million years ago; and (5) the *Cenozoic*, from the end of the Mesozoic to the present time.

The entire testimony of this fossil record points to continuous, gradual change from one form of life to another. Before the appearance of a new form of life, the fossil record usually shows *transitional* forms. For example, it is possible to find in the rocks of the early Mesozoic period the so-called dog-toothed reptiles, having characteristics halfway between those of the true reptiles and the mammals. There are also fossil forms which can be classed neither as reptiles nor as amphibians which appear in the fossil record just before the reptiles themselves come on the scene. There is a very famous fossil of a bird, known as Archeopteryx, that lived about a hundred million years ago, and that had feathers like a bird's, but a tail like a reptile's. It also had reptilian teeth and reptilian clawed fingers projecting from its wing.

In some places the fossil record is so complete that one can follow the gradual evolution of the same or similar forms into widely different types. For instance, in deposits laid down on the bottom of an ancient lake in Germany over a period of many thousand years, the series of shells shown in Fig. 77 was discovered. The

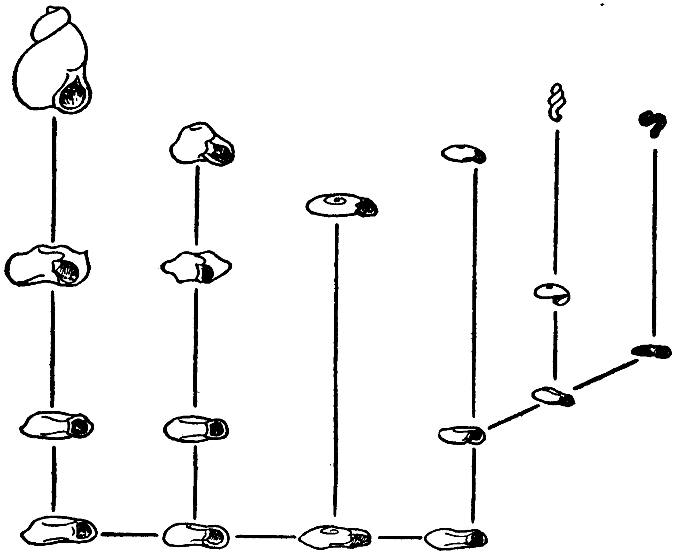

FIG. 77.—Evolution of snails.

four lowermost shells, found in the oldest beds, are probably different races of the same species. From them, as higher and higher beds are reached, is shown the gradual development of seven distinct lines. These terminate in forms so different from each other that, if the intermediate connecting links were not known, they might even be considered different genera. Fig. 77 shows some of the shells found, although, for the sake of simplicity, a number of the intermediate forms are omitted.

There are few forms of life for which the fossil record is as complete as this, yet for certain of our most common mammals fossil "pedigrees" have been worked out that are amazingly detailed. For example, in the fossil beds of the early Cenozoic period are found the remains of a small four-toed animal about the size of a large cat that apparently trotted through the underbrush of

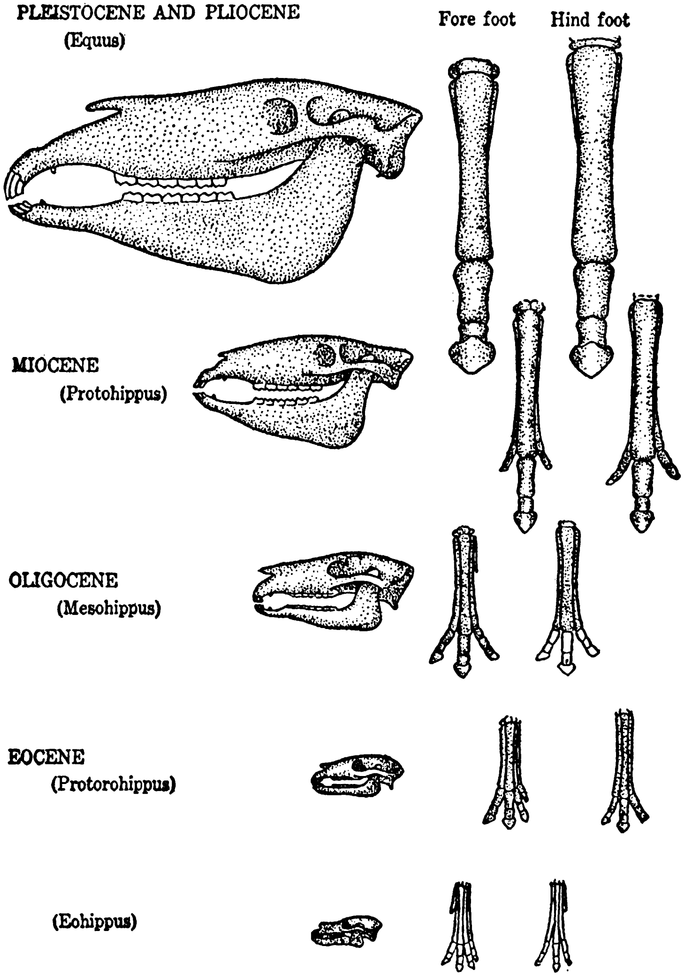

Fig. 78.—Evolution of the horse.

the forest, browsing off the lower leaves. From this animal we can trace a gradual line of descent in which each change is, in itself, very slight, but in which there is a continuous increase in size, a continuous growth in the length and strength of the teeth, and a continuous decrease in the size and function of all toes except the middle one, until this line of fossils leads directly up to the horse of today. It is obvious that the change has come about in order to adapt the horse to life on the plains, where speed is necessary to escape enemies and good teeth are essential for grinding the dry, flinty grass. We have similar lines of fossil ancestors in almost as perfect detail for the elephants, the giraffes, and the camels.

In brief, the fossil record proves positively that life has been changing very gradually, from one form into another, over an almost inconceivable period of time. None of the evidence points to the conclusion that life was originally created in its present form.

Similarities Between Organisms.—We readily recognize that among human beings similarity points to blood relationship; the greater the similarity, the closer the relationship. And this fact is true throughout the world of life. Our similarity to the apes, the dog's similarity to the wolf, and the apparently remote similarity of the whale to other mammals, all are indicative of kinship. Not only do organisms show likeness to one another, but many likenesses are not readily accounted for except on the assumption that the organisms are related. Such similarities range all the way from resemblance of feature to affinity in the fundamental chemical basis of the blood and other tissues, but the most striking and best known are the similarities in *anatomical structure and in embryological development.*

The Evidence from Comparative Anatomy.—Anybody who studies the form and structure of different organisms will find remarkable resemblances between them, and many peculiarities about individual types, which taken by themselves are merely odd vagaries of nature or of the Creator. However, if one thinks of these various types of organisms as being related to each other and descended from a common ancestor, these resemblances and peculiarities immediately become very significant, and point the way to the roads that evolution has taken.

Although we can find resemblances which tell us about evolution in almost any group of animals or plants, we shall here focus our attention on the mammals since it is this group of animals that is most familiar to us. Compare the skeletons of different mammals and see how alike they are in the very different animals! Our arm and hand, the dog's foot, the bat's wing, and the seal's flipper, although each is put to an entirely different use, have almost exactly the same number of bones, arranged in the same relation to one another. On the principle of descent with modification, we can easily explain these resemblances by assuming that the common ancestor of these animals had a forelimb with just so many bones arranged in a certain way, and that his various descendants have had their forelimbs modified only enough so that they would be suited to the purpose for which they were used. The neck of the giraffe has just seven vertebrae in it, each vertebra almost a foot long. The whale, which has no neck at all, and no need of it, has seven very much flattened vertebrae in the place where its neck should be. By this fact we can reason that the common ancestor of mammals had just seven vertebrae in its neck. It was easier, as mammals became adapted to very different surroundings, for the bones to change in shape, than for a bone to be lost or added. So, by a gradual process of change, the long neck vertebrae of the giraffe and the flattened ones of the whale were evolved from the medium-sized vertebrae in the neck of their common ancestor.

Striking as are these resemblances between organisms, there is another type of evidence which we get from comparative anatomy that makes us even more certain of evolution. This is the presence, in almost every plant or animal, of useless organs or bits of organs which to that organism are certainly of no use whatever. If we think of plants and animals as having been specially created, we can interpret these bits of organs only as the superfluous vagaries of an over-enthusiastic and sometimes very bothersome Creator. But if we consider that all organisms are derived from common ancestors through a gradual process of change, we can always find a reason for these supposedly useless afterthoughts of the Creator. They are the relics or vestiges of organs which in more simple, less specialized animals are well developed and functioning. These structures are therefore called *vestigial organs.*

The best-known example of a vestigial organ is the vermiform appendix of man. This little "blind alley" leading off from the large intestine can have no function for us, since thousands of people have had it removed and are living perfectly normal, healthy lives without it. Yet many other animals have a well-developed appendix which is very useful as an extra stomach for the digestion of hard bits of food. The rabbit's appendix is a fine example (Fig. 79). Long ago, however, our ancestors began eating foods that did not require so much digestive labor. Therefore, the appendix has gradually dwindled in our line until it is but a useless vestige.

Another set of vestigial organs in man is a group of muscles around the ear. These, in many animals with large outer ears, such as the donkey, serve to move the outer ear about toward the

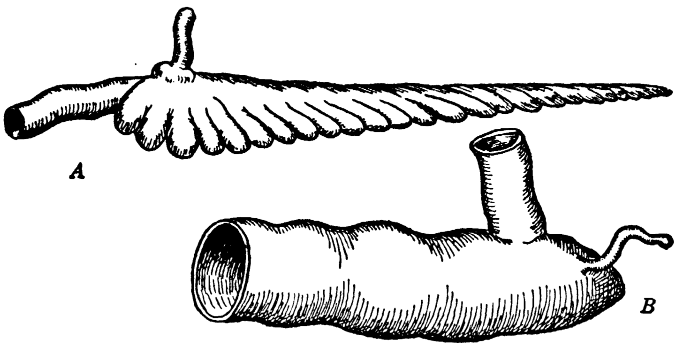

FIG. 79.—Appendix of rabbit (*A*) and man (*B*).

direction from which sound is coming, and hence to help the animal hear more distinctly and to catch the direction of a sound. In man, the outer ear is of very little value anyhow, and few people are able to move it at all. Yet all of us have these muscles which in most people are simply useless vestiges, relics from our ear-wagging ancestors.

The number of vestigial organs which are found in other animals is very large and a few of the more striking examples deserve mention. Everybody who is familiar with horses knows that the horse has, alongside of the longest bone in the lower part of his leg, between the so-called "knee" and the "ankle," two small thin bones, known as splint bones. These slender bones are simply embedded in the flesh beside the main bone, do not support any structure in particular, and have therefore no conceivable function. Yet, when we study the anatomy of the horse's leg, we find that the part below the "knee" is simply the much elongated middle digit and that the splint bones are the remains of what in our hands are the longest bones of the second and fourth fingers. The horse, which walks entirely on its middle fingers and middle toes, has no need at all for these extra digits, but their bones still persist as vestiges beside the large bones of the middle digit.

Many other examples might be mentioned. The vestigial hind limbs of the whale, buried in the flesh at the beginning of its tail; the little hooked claws of the under surface of the python which are all that is left of its hind legs; the vestigial wings of such flightless birds as the New Zealand kiwi and of flightless insects such as certain types of ants—all these show that the animals possessing them have been derived by descent through modification from less specialized ancestors.

The Evidence from Embryology.—Still another line of evidence for evolution is derived from a study of the development of a single individual, from the time when it begins as a fertilized egg until it reaches maturity. We have already seen how all of the higher animals develop from a fertilized egg—even such different ones as worms and mammals. The embryos of the various main groups of animals follow different courses of development, but as a rule animals as distantly related as barnacles and crabs, or fishes and mammals, have embryos which are much more like each other than the adult animals are.

Thus in the development of single individuals of different kinds we see two fundamental tendencies: first, the change from simplicity, as in the egg, to varying degrees of complexity, as in the adults of various animals; and, second, the divergence from the egg, which is much the same in all the higher animals, to very different shapes which adult animals assume. These two trends are essentially the same as the main trends of evolution—from simplicity to complexity, and from similarity to a multitude of dissimilar forms.

Thus the development of an individual is a sort of evolution in itself and tends in part to duplicate the line of evolution which the individual's ancestors have taken. When this fact was realized, about seventy years ago, Ernst Haeckel made the famous statement that "Ontogeny is a short recapitulation of Phylogeny." This remark means that the development of an individual is a brief résumé of the evolution of its race.

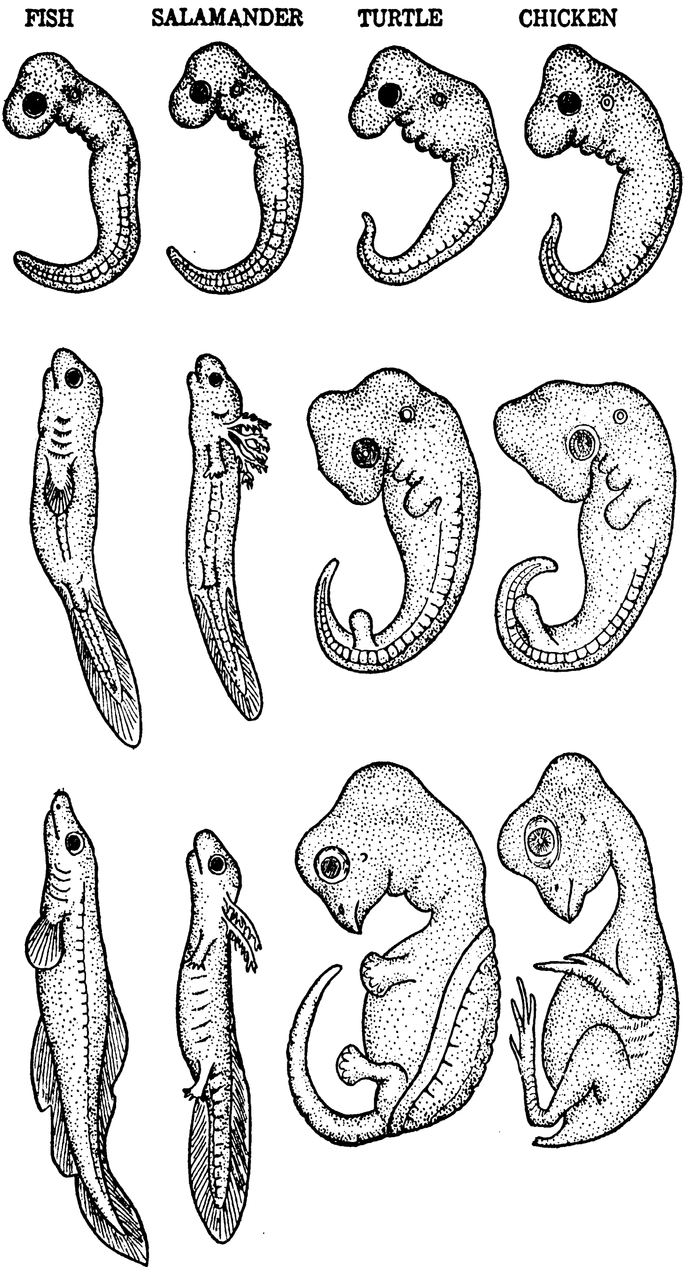

FIG. 80.—Comparison of vertebrate embryos. (Redrawn from Lull's *Organic Evolution,* The Macmillan Company.)

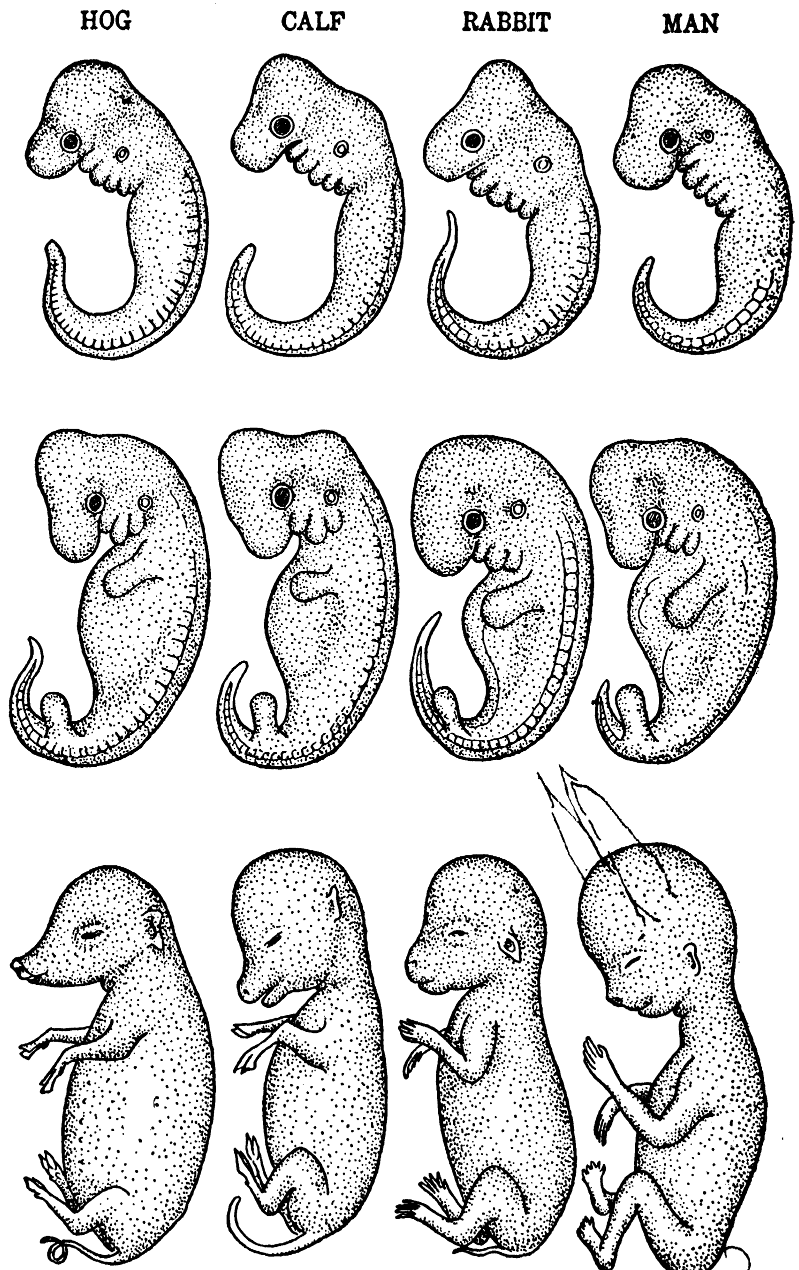

FIG. 81.—Comparison of vertebrate embryos, continued. (Redrawn from Lull's *Organic Evolution,* The Macmillan Company.)

There are two facts which should, however, be kept in mind when one considers this law. In the first place, the embryo never goes through the adult stages of its evolutionary ancestors, but only tends to resemble the embryo of those ancestors more than the adults resemble each other. The human embryo never looks like an adult worm, fish, or reptile, but merely has characteristics in common with the embryos of those animals. Secondly, there are many characteristics of, and many structures in the embryo which have nothing at all to do with the evolution of the race but are modifications which enable it to live in its particular environment. Thus the embryo of a mammal has many structures which are present merely in order to enable it to get food more easily from its mother and are not found in any of the lower animals. These recently developed, useful characteristics are sometimes separated with difficulty from those which reflect the evolutionary ancestry of the organism.

A fine example of this law of recapitulation is given by the development of the human embryo. Quite early in its development it enters a fish-like stage, with rudimentary gill slits and several aortic arches corresponding to the arches which pass through the gills in a fish. At this stage the heart has but one auricle and one ventricle, as in the fish. The backbone contains a long, flexible rod, the *notochord,* found in all fishes, and in more primitive vertebrates. Each vertebra, as in the fishes, consists of several bones. The kidney is not the one which the adult man will use, but an entirely different structure, corresponding to the kidney of fishes. Many other organs resemble those of fishes rather than those of human beings.

At a later stage the embryo loses its gill slits and develops lungs, but it still has a tail. The bones of each vertebra fuse, the heart develops four chambers, and a new kidney, corresponding to that of the reptiles, develops. Finally the human embryo develops the mammalian kidney, still a third structure, and has the general form of a human being. However, even when the human baby is born, it looks much more like the baby of an anthropoid ape than the adults of men and apes resemble each other. In the relative size of the head, limbs, and body, in the possession of a fine coat of hair all over its body, and in the number of ribs present, the human fetus before birth resembles the anthropoid apes more than the adult man.

While, on account of its modified and abbreviated nature, the story of the development of a human infant cannot give us the complete history of man's ancestry, yet it is powerful evidence that man has a common ancestry with the lower animals.

The Evidence from the Distribution of Animals and Plants.—Everybody knows how different are the plants and animals to be found in different parts of the earth. Much of this variation can be explained in terms of climate, temperature, and topography. Nobody would expect to find the same fauna and flora in the arctic as in the tropics, in a desert as in a rainy country, or in fresh water as in salt. Yet every naturalist is familiar with the fact that regions with similar climates do not always contain the same animals and plants, and that other causes besides these present-day ones must be invoked to account for the distribution of the thousands of species of living things that populate the globe. Thousands of otherwise inexplicable facts of distribution are accounted for by the assumption of evolution; and when we study the distribution of plants and animals in combination with the geological record of what has gone on in past ages, certain really astonishing circumstances are readily and interestingly explained.

Among many other striking phenomena of distribution is the fact that, when the white man first entered Australia, there were no placental mammals in that entire continent, with the exception of a few bats and of the native human inhabitants with the mice and dogs which they probably brought along with them. But there were all kinds of marsupials, that is, animals that carry their young in pouches, although the opossum is the only even fairly abundant marsupial found outside of Australia. In addition, Australia contained the only egg-laying mammals in the world. This strange primitiveness of Australian mammals might receive an intelligible creationistic explanation if Australia was not a good place for placental mammals to live; but the fact is that whenever placental mammals have been introduced there, they have got along even more successfully than in their native environments and have tended to bring about the extermination of the less efficient marsupials.

Geological history serves to account for this state of affairs.

During the Mesozoic era Australia was connected with the mainland, and at that time marsupial mammals made their way into it. But before the placentals arrived the land bridge to Asia sank into the ocean. The result was that while the placental mammals well-nigh exterminated the marsupials in all other parts of the world, the latter were enabled to undergo a rather complete course of evolution in Australia to produce many fairly complex animal forms. Confirming this explanation is the fact that the only placentals found in Australia were those that might find means of getting across wide spaces of water, namely, the bats and man, with his parasitic dogs and mice.

The reader will probably be surprised to learn that the flora of the eastern United States, from New York and southern New England southward and westward to the Mississippi, resembles not that of the western part of our continent nor yet that of Europe, but is most nearly related to the flora of temperate Japan and China. Many groups of species, such as the magnolias, tulip trees, sassafras, and the walking fern, are found only in eastern America and eastern Asia.

Now there is no logical explanation for this strange pattern of distribution if it is assumed that these slightly varying floras were placed in two such widely separated regions by a special act of creation. There are many other parts of the world in which such plants could flourish as readily as in the eastern part of America and Asia. Only when we view the phenomenon in the light of known geological history does it receive an intelligible explanation.

In the early part of the Cenozoic era, both North America and Eurasia were much flatter than they are now. They were connected across Bering Strait and were probably closer to each other across Greenland, even if no actual land bridge existed there. Therefore, there was continuous land all around the northern hemisphere. The climate even in Greenland was mild, so that this whole area had a smiliar mild climate. At that time we know, from fossil evidence, that magnolias, sassafras, and other plants were found throughout the northern hemisphere. Later on in the Cenozoic, Europe and the western United States changed greatly. The Rocky Mountains were elevated to their present height and western North America became almost desert. The Alps appeared, and much of what is now northern Europe arose for the first time out of the sea. Finally, the great ice sheet came down from the north. In Europe it almost united with the ice sheet that spread out from the Alps, while in western North America the ice sheet came down practically to the desert and mountain areas and all but a few of the plants which live in a mild, temperate climate were exterminated.

But in eastern Asia and eastern America there have been no great catastrophes to disturb and destroy living organisms. To be sure, the ice sheet inundated the northeastern United States, but there was plenty of flat country with a mild, moist climate to the southward into which the plants could migrate to escape the cold. Hence these genera and families, which once spread all through the northern hemisphere, have persisted only in eastern Asia and eastern America to the present day. And since each group has gone through a different course of evolution in the two regions, different species have been evolved, although the genera have remained the same.

Another striking bit of evidence from geographical distribution is found in the presence of distinct species of plants and animals in small but isolated regions of the globe. The flora and fauna of such areas as oceanic islands, solitary mountain summits, and valleys in mountainous regions, which are cut off by natural barriers to free immigration of organisms, usually contain a large proportion of species which are found only in those areas and which are most closely related to species found in the nearest large region which is similar to them in climate.

For instance, on the Galápagos Islands, five hundred miles off the coast of South America, a large proportion of species are found only on one or two islands of the group. It was Charles Darwin himself who, as a young man, observed this fact, and it did much to suggest to him the theory of evolution. Thus, twenty-three out of the twenty-six species of land birds found on the archipelago are peculiar to it, and many are found only on one island, or on two adjoining ones. Yet all of them are quite evidently related to birds of South America. Similarly, there are several species of giant lizards, all of them peculiar to the islands. There were, originally, eleven different species of giant tortoise, each inhabiting a different island. All of them were closely related to each other, but those living on closely adjoining islands were more nearly related than those on more distant islands.

It would seem strange that a benevolent Creator should present each of these small islands with its own species of tortoise and deny tortoises to many other regions that are just as well suited to them. Yet if we think of these tortoises as having been descended from a common ancestor, we can easily see how that ancestor may have arrived on the Galápagos Islands many thousands of years ago and become marooned there with his descendants. These descendants have evolved, each in his own peculiar way; and those that, from time to time, migrated from one island to another, became isolated in their new home and went through their own course of evolution independently. The same principle would apply to the land birds, lizards, and many of the plants.

Furthermore, there are no land mammals on the Galápagos Islands. Frogs and other amphibians are absent, as they are from all oceanic islands. Yet there are many spots on the islands which are suitable to mammals and amphibians, and such mammals as have been imported have thrived there. From the standpoint of special creation, this would seem to show a sad neglect on the part of the Creator. Yet if we think of mammals as having evolved comparatively recently, we can see how none of them could have crossed the ocean to reach these islands. Amphibians also cannot cross the ocean, since they are not strong enough to cross large bodies of water, and their eggs are very easily killed by salt water.

The Evidence from Genetics.—The final set of facts which shows us that new species have been, and still are, evolving from older forms is the vast amount of variation which men have produced by breeding animals and plants and which they have watched under their own eyes.

Long before the beginning of history primitive man domesticated animals and cultivated plants for his own use. He soon learned to select the individuals best suited to his purposes and, by breeding them, to improve the race. The final result of man's labor is the vast number of breeds and races that almost every one of our domestic animals and cultivated plants possesses. No naturalist, if he found a great Dane, a greyhound, a spaniel, a dachshund, and a Pekingese dog running wild would think of calling them the same, or even closely related species. Not only are they very different in size and shape, but their habits and their diet are quite different as well. Yet there is no doubt that all were derived from a few closely related species of wild dog.

Similarly, most of our cultivated plants exist in a large number of varieties, many of which, if found wild, would be considered distinct species. The cultivated wheats are a fine example. There are scores of varieties: winter wheats, summer wheats, hard wheats, and soft wheats. Many of these, when crossed with each other, produce sterile offspring. Yet all are probably descended from two or three species of wild wheat, of which some are still found in the Orient. Some garden flowers, moreover, have been developed so recently that we know their history. The garden dahlia exists in a large number of varieties. There are single and double types, "pompons," and "chrysanthemum" dahlias, and flowers of almost every color. All of these varieties have been derived, by breeding and selection, from a single species, *Dahlia variabilis*. This species, furthermore, is now known to be the result of a cross between two simpler, comparatively constant Mexican species of dahlia.

In recent years many wild species of animals and plants have been brought under observation and, when bred artificially, have produced a tremendous number of variations. Literally hundreds of different races of the fruit fly have appeared in culture, each of which, when isolated, breeds true. In mice many new varieties have similarly appeared; and among plants the yellow evening primroses and the jimson weed, a common weed with large, coarse leaves, large, pale purple flowers, and prickly pods, are notable for the large number of variations that they have produced when bred under observation. There is little doubt that most species vary under certain limits, and can at times produce new races which breed true when isolated.

Finally, more and more crosses have been made between different species of animals and plants, and in many cases the hybrid offspring have been at least partly fertile. In fact, from some of these crosses, such as those between some different species of tobacco, hybrid strains have been produced which are completely fertile among themselves but which will not intercross at all with either of their parent species. In this way modern genetics has entirely uprooted the old idea that species are absolutely unchangeable entities and that each species is a unit which cannot combine with any other species. Hence the whole conception of a species as a separate, distinct unit breaks down, and our only alternative is to think of species as being evolved from other species and related to each other through common ancestors. Indeed, with what we now know about heredity and variation and the selective effect of the struggle for existence, we should be forced to conclude that evolution *would have to take place*, whether we had any other evidence for its occurrence or not.

Chapter Summary

That evolution has occurred is not a theory, it is a fact. There are various theories, however, as to *how* evolution has occurred. Briefly, evolution means that life began with very simple forms, and over a period of time which may be estimated at somewhere around two billion years it has developed to its present state through a process of descent with modification. The fossil record gives a fairly clear picture of the development of life through the past five hundred million years. Among a vast number of other records is that of vertebrate evolution, showing how amphibians developed from fish, reptiles from amphibians, and mammals and birds from reptiles.

Four principles of evolution are: first, that it has progressed more rapidly at some times than at others, the periods of rapid evolution being associated with great changes in the surface of the earth; second, that at present some groups of organisms are evolving more rapidly than others; third, that the evolution of new groups of organisms is not from the most highly evolved members of the existing ones, but from relatively primitive, unspecialized forms; and, finally, that evolution has not always progressed from simpler organisms to more complex ones. Regressive evolution, or "degeneration," has occurred frequently.

There is a vast array of evidence for evolution which may be summed up under four headings:

1. The fossil record actually carries traces showing the gradual development of living forms from one stage in evolution to another.

2. The similar anatomical plan found in organisms having entirely different modes of life argues strongly for relationship

between these organisms. Another argument is the presence of vestigial structures in some organisms which are apparently remnants of structures that are functional in other organisms. Furthermore, related organisms show similarities in embryological development, and the development of the individual apparently recapitulates that of the race.

3. Geographical distribution of organisms can be better explained in terms of an evolutionary geological history than in any other way, and the presence of unique species in small isolated regions argues strongly that these species have become different from the relatives from which they are separated by going through an evolutionary progress of their own subsequent to the date of separation.

4. The actual production of new species through plant and animal breeding shows that evolution can readily take place if proper selective agents are at work, and the knowledge we have gained in the laboratory of the way in which animals vary would lead to the deduction that evolution would have to take place if sufficient time were given for the operation of natural forces.

QUESTIONS

1. Briefly outline the history of life as recounted in this chapter.
2. Discuss, using examples, four principles concerning the progress of evolution.
3. Give a résumé of the evidence for evolution based on the following outline:
   - A. Evidence from the fossil record
     - 1. How the fossils were formed
     - 2. How the fossil deposits may be dated
       - a. Comparatively
       - b. Absolutely
     - 3. Fossil links in the line of vertebrate evolution
     - 4. Records of continuous evolutionary development
   - B. Evidence from similarities between related forms
     - 1. Anatomical similarities
       - a. Similarities between mammals
       - b. Vestigial structures
     - 2. Similarities in embryological development
   - C. Evidence from geographical distribution
     - 1. Anomalies in distribution explained by geological history
     - 2. Presence of unique species in isolated regions

D. Evidence from genetics
   1. Plant and animal breeding
   2. Experimental production of new species

GLOSSARY

Archeopteryx (ar′kē-op′ter-iks) A fossil bird showing marked reptilian characteristics.

Archeozoic (ar′kē-ō-zō′ic) The first (earliest) of the great geological eras.

Cenozoic (sē′nō-zō′ic) The fifth (latest) of the great geological eras.

cosmogony (coz-mog′ō-ni) A theory or myth concerning the origin of the earth.

fossil Any record of life left in the rock strata.

ichthyosaur (ik′thi-ō-sôr) A type of extinct marine reptile.

marsupial (mar-sū′pi-al) A type of mammal in which the young are carried in a pouch on the mother's abdomen.

Mesozoic (mĕs′ō-zō′ic) The fourth of the great geological eras.

notochord (nō′tō-kôrd) A long, narrow rod located just below the spinal cord in certain fishes and in primitive relatives of the vertebrates. It also appears in the embryos of the higher vertebrates, but disappears before their development is completed.

paleontology (pā′lē-on-tol′ō-ji) The science of fossil organisms.

Paleozoic (pā′lē-ō-zō′ik) The third of the great geological eras.

plesiosaur (plē′si-ō-sôr) A type of extinct marine reptile.

primate (prī′māt) An animal belonging to the order which includes man, the apes, monkeys, and lemurs.

Proterozoic (prō′ter-ō-zō′ik) The second of the great geological eras.

pterodactyl (tĕr′ō-dak′til) A type of extinct flying reptile.

ungulate (un′gū-lāt) A hoofed mammal.

CHAPTER XV

THE OUTCOME OF EVOLUTION

The Diversity of Living Organisms.—The age-long process of evolution that we have described in the last two chapters has resulted in populating the earth with innumerable organisms of the greatest diversity. In order to comprehend this vast array of life, the biologist must do two things. In the first place, he must classify living organisms. This has proved an enormous task; and although the modern system of classification of organisms has been in use for almost two hundred years, hundreds of biologists all over the world still are spending their lives in fitting the known and the newly discovered animals and plants into this system. While an understanding of this classification forms a study in itself, and is summarized in the appendix, a conception of its fundamental unit, the *species*, is essential to an understanding of the nature and evolution of living things. Although undoubtedly somewhat different in its genetical and physiological make-up in different groups of animals and plants, the species may be roughly defined as follows: It is a group of organisms which are more or less variable among themselves, but are distinct in a number of characteristics from the organisms composing the nearest related species. This distinctness is due to the absence or rarity of organisms intermediate between two groups designated as different species, and is produced by some type of isolation which separates them. A discussion of the different types of isolation which are responsible for the differentiation of species is given in the next chapter. Typical species are, for instance, the red fox, individuals of which vary considerably in size, coat color, length of hair, etc., but of which all are sharply distinct from any other species of fox, such as the arctic or blue fox, not only in color, but in body size, the proportions of the parts of the skeleton and muscles, the habits of life, and many other characteristics. Man is a species; although such different races as the yellow, the black, and the white exist, all are connected with each other by many intermediate racial types, and all are markedly distinct not only from man's nearest living relatives, the anthropoid apes, but also from certain extinct species of man. The number of species of organisms is extremely large. There are about 400,000 known in the plant kingdom, and about 800,000 of animals, and hundreds of new species are being discovered every year. The chief object of the study of evolution is, of course, to understand how this multitude of species of organisms came into being; it was not without purpose that Darwin named his classic book on evolution *The Origin of Species.*

In addition to their classification, a further understanding of the species of organisms can be obtained by studying their relationship to their environment. Since the environment of any living thing includes not only the elements and the inanimate objects which surround it, but also the other organisms with which it is associated, this study includes the interrelationships of organisms, as well as their relation to the various types of inanimate environment on the earth.

The dominant principle brought out by this study is the remarkable *adaptation* of all successful organisms to their environment. When we consider the enormous range of environment that exists on the earth—from the tropics to the arctic, from rain forest to desert, from plain to mountain top, and from ponds to lakes, rivers and the ocean—we can see that adaptation to this multitude of different environments is responsible for a large proportion of the hundreds of thousands of species that exist. Another fact equally apparent is that the tremendous ability of living things to reproduce their kind has caused every environment to be filled with as many different organisms as it can support, and that there is, therefore, a continual *struggle for existence* among organisms to maintain themselves.

The Chief Cause of the Struggle—Overpopulation.—Although the reader is probably fully aware of the cause for this great struggle, a few definite examples will demonstrate just how overpowering is the tendency for organisms to reproduce themselves far beyond the ability of the earth to hold the ever-growing volume of life.

Among plants, the trees of the forest serve as an excellent example. In a forest of maples, for instance, each tree produces every year about ten thousand seeds. Of these, about two per cent, or two hundred, grow into seedlings. These are enough to cover the dead leaves of the forest floor with a mass of leafy shoots pushing their way upward toward the light, a sight familiar to anyone who visits such a woods in the late spring. Of these seedlings, however, all but a few are doomed to grow no further. Since, unless brought down by the lumberman's ax, not more than one tree in a hundred of those in the forests dies and leaves room for a young newcomer, not more than one out of every twenty thousand seedlings can ever become a full-grown tree. A competition among twenty thousand, of which only one can win, must necessarily be a keen one.

Animal life gives us the same picture of excessive overproduction. Let us use as an example a pair of rabbits. They can produce a litter of twelve offspring. If each of these grows up, it can be responsible for twelve more in a year or less, so the six pairs of the second generation would have produced seventy-two offspring for the third generation at the end of two years. The following table shows the number of offspring in the succeeding generations:

4th generation:	432
5th generation:	2,592
6th generation:	15,552
7th generation:	93,312
8th generation:	559,872
9th generation:	2,359,232

Thus, at the end of eight years, if all of the offspring grew up unmolested, the descendants of a single pair of rabbits would number over two million. Of course the number of rabbits in the world is not increasing; and since a rabbit can live four or five years, only four out of the possible two million would normally reach maturity. The others would form food for hawks, foxes, or other enemies, or would be made into fur coats or gloves, or would never be born on account of the early death of their possible parents.

Although the rabbit is famous for the rapidity with which it can reproduce, many other animals can do it much more rapidly. The case of the fruit fly, which can produce over fifty offspring in ten days, has already been mentioned, and it is not a very unusual one among insects. At this rate, if all the offspring continued to breed and produce entire families of adult flies, it would take only seven weeks to produce a population of over twenty million fruit flies from a single pair!

Even the slowest-breeding animals could, moreover, quickly populate the entire earth with their kind. The elephant is the slowest breeder of known animals. According to Charles Darwin, the elephant begins to breed when thirty years old and goes on breeding until it is ninety. During that time it produces six young. If each of these six elephants pair to produce a third generation at the same rate, and so forth, after 750 years there would be nearly nineteen million elephants descended from the first pair.

A practical illustration of how fast animals can reproduce their kind is given whenever they are brought into a new country away from their natural enemies. For example, a few pairs of rabbits were brought into Australia by the early colonists, who thought they would make a fine source of game for hunting and for food. The rabbits, however, since they found no hawks, foxes, or any other natural enemies to molest them, busied themselves with reproducing their kind and soon overran the country, becoming the worst pests with which the farmers had to contend. In every Australian community great rabbit hunts were held yearly or more often, in which all the able-bodied men would round up thousands of rabbits in the surrounding fields and drive them into a huge pen where they were slaughtered. Even this had no effect on the prevalence of these animals until natural enemies were brought in from England to cope with the prolific immigrants.

Naturalists sometimes debate the question as to where the struggle for existence is the fiercest, and where it is less severe. There is no satisfactory answer to this question, for the good reason that it is everywhere about equally severe. The difference is in the nature of the struggle. Where conditions of the inanimate environment are exceptionally favorable for life, the struggle is chiefly among the hundreds of different species of organisms which are striving to take advantage of these favorable conditions; where the environment is forbidding, organisms are waging a continual war with the elements, and at the same time must compete with their fellows to obtain the best advantage of such favorable conditions as there are. This can best be understood by taking a glance at life in various environments.

Life in a Tropical Rain Forest.—The tropical rain forest is one of the wonders of the world. Such forests extend over hundreds of square miles in regions such as the great Amazon River basin of South America. Here the necessities for plant life and growth—water and sunlight—are present in abundance, and the temperature is the best possible throughout the year. Vast numbers of plants can grow successfully. Instead of a dozen or so different kinds of trees, such as we are accustomed to see in our own woodlands, four or five hundred can be counted in any tract of this great rain forest. Consequently, there is a tremendous struggle for a place in the brilliant tropical sunlight. Trees send up long bare trunks two hundred feet in the air, growing hastily to escape being shaded and thus deprived of the essential sunlight by their competitors. Great woody vines and creepers, known as lianas, wind their way up the tall, slender trunks, and their foliage covers the top branches in such profusion that scarcely a gleam of light makes its way through the mass of leaves at the top. Because of the struggle for sunlight, the life of the forest is lifted as if on stilts, high above the ground. Below is dimness, the stems of trees, dead leaves, and decaying logs.

In *The Sea and the Jungle*, H. M. Tomlinson has given a never-to-be-forgotten account of a trip that he took through the very midst of the Amazonian forest and of the conflict that he saw going on among the trees and vines. He was, of course, walking along the ground, far below the region of teeming life.

This central forest was really the vault of the long-forgotten, dank, mouldering, dark, abandoned to the accumulations of eld and decay. Every tree was the support of a parasitic community, lianas swathing it and binding it. One vine moulded itself to its host, a flat and wide compress, as though it were plastic. We might have been witnessing what had been a riot of manifold and insurgent life. It had been turned to stone when in the extreme pose of striving violence. It was all dead now.

But what if these combatants had only paused as we appeared? It was a thought which came to us. The pause might be but an appearance for our deception. Indeed, they were all fighting as we passed through, those still and fantastic shapes, a war ruthless but slow, in which the battle was ages long. They seemed but still. We were deceived. If time had been accelerated, if the movements in that war of phantoms had been speeded, we should have seen what really was there, the greater trees running upward to starve the weak of light and food, and heard the continuous collapse of the failures, and have seen the lianas writhing and constricting, manifestly like serpents, throttling and eating their hosts. We did see the dead everywhere, shells with the worms in them.

In the top layer, far over the heads of the travelers such as he who wrote the above description, there is another war going on between a myriad of different animals. The roof of the forest is a solid layer of green foliage, exposed to all the conditions most favorable for life. Bright sunlight, a continual warmth and moisture, and a rarity of violent storms make conditions ideal for plant growth, so that the roof of the forest can be compared to a limitless conservatory or greenhouse of brilliant flowers including not only those of the trees themselves, but in addition a vast number of smaller plants, such as the orchids, which are perched in the uppermost branches of the trees. Grasshoppers and other insects feed on the vegetation; bees, butterflies, and hummingbirds live on the nectar from the flowers, while scores of birds feed on the wealth of insect life, and monkeys clamber up and down the branches, living on an abundance of fruit. These, in turn, are continually sought by the birds of prey—hawks, kites and harpy eagles—which soar overhead or glide through the treetops, always ready to seize any bird or monkey unwary enough to expose itself to their view.

Coloration.—In this world of excessively keen competition between organisms, every species must either be very well protected from its enemies, or be provided with weapons of aggression or defense. For this purpose some of the most striking adaptations have been developed. The most widespread of these come under the general head of *coloration.* The three types of coloration important as weapons for defense or aggression are *concealing coloration, warning coloration,* and *mimicry.*

Concealing Coloration.—The coloration of animals to resemble their surroundings is general in all parts of the world, but nowhere is there such a variety of devices for this purpose as in the tropics. Tropical birds are usually protectively colored. Those living in the dimly lit inner recesses of the forests are colored dull brown and gray; while the majority of them, which live among the exposed, sunny tops of the trees, are brilliantly arrayed in green, red, yellow or blue to match the brilliance of their surroundings. The tiger is striped and the leopard spotted, both of them in order to match the patterns of light and shade found in their native jungles.

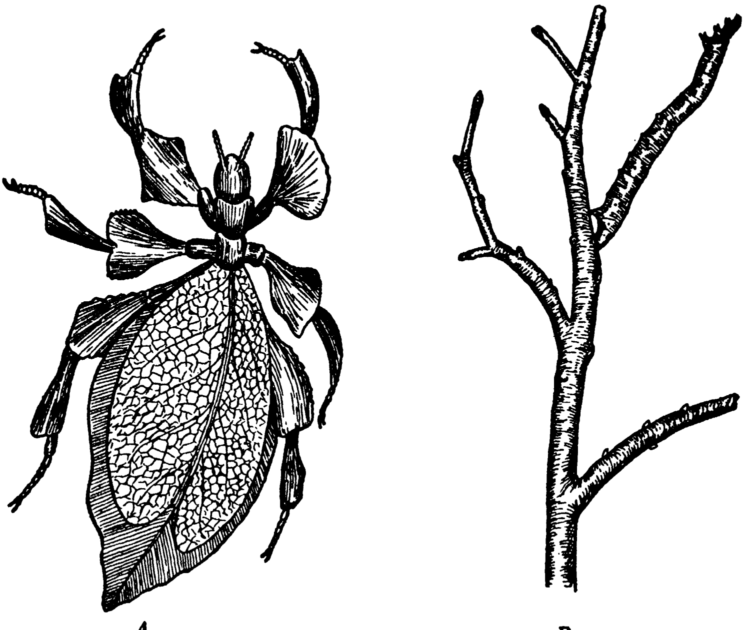

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FIG. 82.—Mimicry of leaf and twig insects.

Insects have the most extraordinary modifications of this sort. Naturalists in the tropics all report the strange phenomena of "leaves" that turn into butterflies and fly away; of "twigs" that become caterpillars and "cocoons" that turn into grasshoppers. Even the markings on the leaves of the trees, such as the spots caused by fungus attack and the droppings of birds, are imitated by insects and spiders. Concealing coloration serves two purposes. It is either for *protection* of hunted animals against their enemies, or for purposes of *aggression*, in enabling predatory animals to stalk their prey unnoticed. In both cases, however, the resemblance to the environment is similar, and is equally close. A striking case of protective coloration is that of a certain butterfly, which not only has the outline and color of a leaf, but also imitation veins and an imitation leaf stalk (Fig. 82). Among the remarkable imitations for the purpose of aggression is that of a certain fly-catching bird of Brazil, whose crest is brilliantly colored and can be spread out in the shape of a flower. Flies are attracted by it, and fly toward the "flower" in search of nectar, only to be devoured by its owner.

Warning Coloration.—This characteristic is possessed by many (though by no means all) animals which have weapons for defense in the form of poisonous fangs or stings, or are noxious or unpalatable to the taste. The deadly poisonous coral snakes are colored with bands of brilliant black, yellow and red; hornets and wasps are as conspicuous as possible in their black and yellow stripes. Ill-smelling bugs and unpalatable caterpillars and grasshoppers are often colored so as to contrast strikingly with their surroundings, and walk about slowly in plain view; a number of different experiments have shown that they are avoided by birds and insect-eating animals.

The advantage of warning coloration to a poisonous or noxious animal is obvious. If a wasp were inconspicuous or similar to other insects, it might be snapped up or crushed before it had time to use its sting; furthermore, the repeated use of the sting is harmful or even fatal to the insect. The safest thing for an animal that relies on such qualities for protection is to have a sign saying "keep away," and to display this sign in plain view.

Mimicry.—Mimicry is the imitation of the color and form of some poisonous or noxious animal by another which is not closely related to it. In some (but apparently rather few) cases the mimic is harmless, defenseless, and palatable, so that its only protection lies in being mistaken for its harmful or noxious model. In other cases the mimic has itself a noxious quality; in this case both mimic and model benefit from the resemblance, since predatory animals quickly learn to recognize a certain type of color pattern as one to be avoided; thus all of the animals possessing this pattern are automatically protected. Mimicry is frequent among tropical insects, and certain groups serve as models for many different, entirely unrelated insects. The fierce, stinging wasps are mimicked by bugs, grasshoppers, and moths, and sometimes the resemblance is so close that even naturalists are deceived at first sight. The usually ill-smelling, unpalatable ants are mimicked by spiders, grasshoppers, bugs, beetles, and caterpillars. One apparently harmless caterpillar of the South American tropics appears inconspicuous when feeding, but if disturbed lifts its head and inflates its thorax, whereupon two raised, opalescent spots on the thorax gleam like eyes; as its discoverer remarks, "the transformation is most impressive, and the effect when the larva is half concealed in foliage is that of the head of a snake or lizard with open mouth and shining eyes."

The rain forest possesses the most intricate interrelationships between organisms of any part of the earth. Parasitism and saprophytism are here extraordinarily well developed, and associations for mutual benefit, both between species and within certain species, are often highly developed. A striking case of parasitism is that of the strangling fig. The seeds of this species germinate high up in the branches of a living tree, but soon send roots down to the ground. The trunk of the fig then grows like a latticework around the host tree, completely choking it. Finally the fig strangles its host to death, and emerges as a tall, leafy tree on its own roots, but still embracing the dead trunk of its victim.

An interesting case of symbiosis is the relationship between ants and a number of different species of plants. These plants usually possess some type of nectar-secreting glands on their stems or leaves. The glands attract certain species of stinging ants, which regularly make their homes on these plants and protect them from the ravages of leaf-cutting ants or of other harmful insects. The various types of social insects, particularly termites and ants, are best developed in the tropics. Termites, small primitive insects somewhat related to the grasshoppers, live in highly organized communities that often contain five or six different "castes" of workers specialized for different functions, and entirely different in appearance from one another. Since these insects are by themselves defenseless and are much sought after by hundreds of different enemies, their only salvation lies in the development of large communities and the building of elaborate nests, either hollowed out of tree trunks, built around the branches, or (in more open forests) rising from the ground as "castles" six or eight feet high. These communities are always the home of many other species of animals, some of them parasitic and feeding on the termites, some "tolerated guests" which neither harm nor benefit them, and some welcomed as symbionts, as in the case of various beetles living in the nests of both termites and ants, which are fed and tended for the sweet secretions that they produce.

The ants are individually more powerful than the termites, and their communities are as a rule smaller and less highly organized. Many of them, moreover, exist for offense as well as defense. There are the marauding army ants, from whose voracious bands every creature of the forest escapes with the utmost rapidity. These have no permanent home, but at the critical time when the larvae are developing into adults they are surrounded by "nests" whose walls are made of the living bodies of hundreds of workers linked together. The leaf-cutting ants march in long processions, each worker carrying over its head a round piece of a leaf; they are so efficient in their work that a small tree can be completely stripped of its leaves in a few hours. Many other species, some harmless and some stinging, exist in such profusion that to attempt to climb a tree in the tropics is to invite a thousand pinpricks of ant stings.

Although there is little in the environment of the tropical rain forest that is unfavorable to life, some organisms have found protection against such unfavorable conditions necessary. For instance, ponds are uncommon in these regions, but during the season of heavier rainfall pools may exist for some time. To protect against the drying up of these pools, one of the pool dwellers, the Surinam toad of South America, does not hatch its eggs in the water, but carries both eggs and tadpoles in little pockets of water on its back. In the case of the plants, the absence of sunlight makes growth on the ground impossible for bushy plants and grasses. Hence the smaller plants are mostly *epiphytes,* i.e., dwellers on other plants, mostly trees. Situated high up in the branches of trees, the roots of these plants are unable to obtain the steady supply of water and mineral salts necessary for continued growth. To overcome this difficulty many of them, particularly the large group of species belonging to the pineapple family, have developed at the bases of their leaves reservoirs of water which are always full. Digestive enzymes are apparently

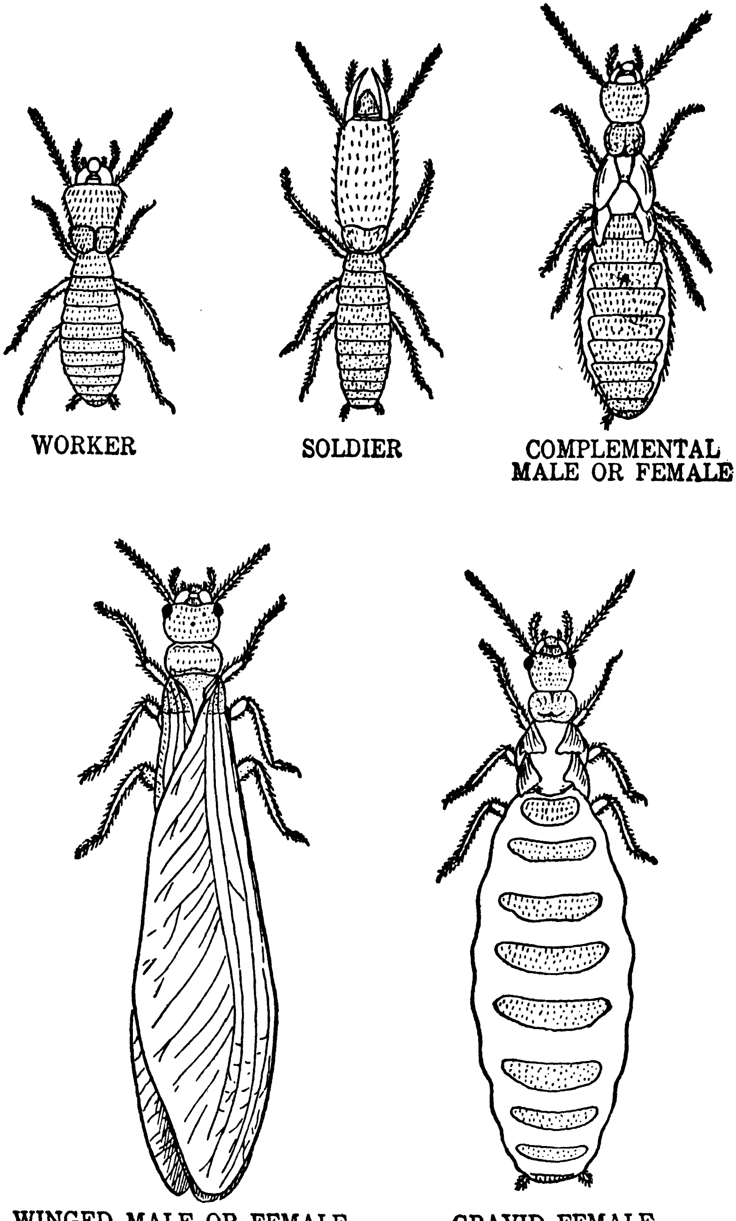


Fig. 83.—Termite differentiation. (Redrawn from Lull's *Organic Evolution*, The Macmillan Company.)

secreted into these reservoirs for the digestion of the bodies of various insects which fall into them, and from these animal proteins the plant must obtain most of its nitrogen and other mineral salts. In some forests these "reservoir plants" are so abundant that the roof of the forest has been likened to a marsh. A powerful indication of the ability of life to conquer new environments is the presence in these reservoirs of scores of different species of aquatic animals, ranging from Protozoa to worms, shrimps, scorpions, the larvae and adults of many different types of insects, and the tadpoles of frogs. Many of these animals live only in these reservoirs; all have apparently developed the ability to resist the digestive secretions.

Life in the Desert.—Where conditions are favorable for life, and the struggle for existence is chiefly between different organisms, the various characteristics and relationships which we have just discussed are prevalent. However, the insurgent, ever-growing swarm of life has caused many living things to spread far out into regions where for the great majority of the time conditions are absolutely inimical and forbidding to life. The less favorable are the conditions for life, the more are organisms equipped, not for competition between one another, but against their common enemies, the elements.

Let us, for instance, look at the life of a desert. In such deserts as those of California, Peru and the great Sahara desert of Africa, rain falls only once every year, every four or five years, or even less often. The rainfall, when it does come, is in the form either of little showers, the moisture from which is evaporated before it dampens the soil at all, or of great torrents which wash away the soil rather than soaking it. Any organism, therefore, which would live in the desert must be able to withstand excessive heat and long periods of extreme dryness. Furthermore, in the absence of a blanketing layer of moist air, the nightly temperatures of the desert are often quite low and the changes in temperature sudden and extreme. Finally, the desert is often swept by sudden and fierce windstorms, against which all living things must be protected.

In spite of these hostile conditions, few deserts are totally devoid of life. In most of them the ground is dotted here and there with a number of different plants. These are of two general types: those that carry on a slow, persistent activity and growth all the time in spite of the unfavorable conditions, and those that carry on life only during the short intervals when conditions are favorable. Of the former type, the most interesting are those that store up water for themselves and use it slowly and economically during dry weather. The best known are the cacti, of which there are hundreds of species in the southwestern United States, the largest rising as great fluted columns thirty or forty feet above the desert floor. Other cacti are in the shape of great barrels, full of water; these the desert Indians often cut open and by crushing the soft pulp inside, extract its precious fluid. In every case the cactus exposes as little of its surface as possible to the burning sun and parching winds, and this surface is protected with a thick, waxy coat through which little or no water can evaporate.

Other desert plants curl or fold up their leaves or drop them altogether during dry weather and remain dormant until the rare shower or rainstorm does come. Then they open up, spread out their leaves, produce buds and flowers, and in a few days carry on enough life and growth to maintain them for another long period of inactivity. The smaller desert plants do even better than this. During the vast majority of the time they remain as seeds underground, containing practically no moisture and protected by a hard, tough seed coat. When the rain comes, the seeds germinate, grow to mature plants, produce flowers and new seeds in a week or two, and wither away, leaving their offspring to remain dormant for another four or five years.

The slow-growing plants of the desert, although they have comparatively few living enemies, must nevertheless be well protected against those that they have, since any damage done to them could be repaired only at a very slow rate. For this reason, a large majority of them possess spines or thorns, making the "thorny wilderness" an actuality in dry countries. Spines and thorns are found, of course, in plants of damper climates also and are modifications of various parts of the plant. In some cases, as in the holly, they are simply very sharp teeth on the sides of the leaf. In others, as in the cacti, each spine is the modified remnant of a whole leaf. The green part of the cactus is really a much thickened and sometimes broadened stem, and the groups of spines are tufts of modified leaves. Still other spines and thorns, as in the hawthorn, are modified, reduced branches.

The animals of the desert are likewise equipped to stand long periods of drought, and can get along with extremely little food. Most of them are fleet and agile, since they must roam far and wide for their sustenance. A number of them, like plants, can store up water within themselves. The camel has, leading from his stomach, a number of water cavities which may be closed up when full by means of a sphincter muscle which acts as a draw string. When the camel drinks, he fills not only his stomach, but the bags as well, and during a long dry march draws on this extra supply. A camel can march for five or six days without water but is much weakened by such a journey. Many smaller desert animals, such as frogs, store water under their skins. Of the Australian desert frog, one observer writes: "If you put a lean, dry, herring-gutted *Chiroleptes* into a beaker with two inches of water, in two minutes your frog resembles a somewhat knobby tennis ball."

Many desert animals keep alive over the long periods of drought by building huge burrows underground, in which they lay up great stores of food. The ant, to whose habits Solomon referred the sluggard, was one of these desert dwellers; if Solomon had lived in the American southwest he might well have chosen an even more industrious animal and made the proverb, "Go to the kangaroo rat, thou sluggard." For this agile jumping creature may amass as much as a bushel of seeds and other forage in his burrow.

Life in the Arctic Regions.—The other parts of the earth in which conditions of life are particularly unfavorable are the arctic and antarctic regions. North of the arctic circle in both the Old World and the New are vast treeless stretches of barren land known as the *tundra.* The tundra covers all of the northern parts of Russia, Siberia, Alaska north of the Yukon, and the shores of and islands in the Arctic Ocean, while patches of tundra extend down the coast of Labrador and Newfoundland, recurring on the higher mountains of eastern Quebec and New England, such as the White Mountains. The higher summits of the Rocky Mountains, the Cascades, and the Sierra Nevada in the western part of our country as well as the mountains of Eurasia also contain large areas of tundra. In these regions organisms must face not only extremes of cold, but for nine or ten months of the year a scarcity of available moisture, since all of the moisture on the ground is during that time locked up as snow and ice, and the air, on account of its coldness, is physiologically dry. Furthermore, fierce winds often sweep the tundra, drying and freezing still more the living things exposed to them, and beating down any plant or animal which is not strong enough to withstand them. Under these conditions both animals and plants must be equipped with every possible adaptation against wind and drought. The animals possess, in addition to their heavy coats of fur, thick layers of fat inside of their skin, which serve not only as protection against the cold, but also as a reserve supply of food for times of food scarcity. Although many of the mammals of the temperate zone hibernate and remain dormant during the winter, this is impossible for arctic mammals, since the winter is too long and the summer too short for them to store up reserves of energy. The vegetarians, therefore, must all be able to feed the year round. The larger animals, like the reindeer and caribou, feed entirely on the evergreen lichens and mosses, which they obtain during the winter by shoveling away the snow with their broad, fan-shaped antlers. The most common of the smaller mammals are the mouse-like animals known as lemmings, which during most of the year live in tunnels burrowed under the snow, feeding on the mosses, lichens, and grasses underneath. The carnivorous mammals, such as the ermine and the arctic fox, are barely able to survive, although the former can maintain itself by pursuing the lemmings through their burrows under the snow, while the latter often stores up caches of meat during the summer which lie well preserved in the cold storage of a snow bank for months. Scarcely any birds exist through the arctic winter, and the insects all remain in their pupal cases.

The plants must all have extreme adaptations for protection against cold and drought, and in many ways they resemble desert plants. The evergreen shrubby types all have small leaves, which are generally hard and needle-like, or which have their edges rolled in and their surfaces protected by heavy coats of wool. Other woody plants shed their leaves, and are green for only a few weeks during the summer. The smaller plants, or herbs, die down each season, and remain alive during the winter only in the form of roots and underground stems. Furthermore, most of them protect themselves from vegetarian animals as do the desert plants. They are all hard and tough, and many are filled with acrid or bitter substances as well.

Although life in the arctic is for nine months of the year a grim, slow struggle against the elements, the time comes in June when the sun shines for three-fourths or all of the time, the snow and ice melt, and for several weeks all conditions are favorable for life. Then comes a mad rush on the part of both animals and plants to take advantage of these favorable conditions, and the struggle for existence between organisms becomes as keen as it is in the tropics. Butterflies, bees, and mosquitoes burst from their pupae and fill the air with their humming. Plants send up new shoots and flowers, some of them even pushing their buds through the snow so as to be the first to be pollinated by the bees. Tender leaves appear on the willows and grasses, affording ample new food for half-starved lemmings and hares, which must bear and raise their young while this abundant supply is available. Their appearance from under the snow banks brings new life to the famished foxes and wolves which capture so many of the smaller mammals that the lemmings and hares must bear unusually large litters if their kind is to survive at all. Birds arrive from the south, to nest where there is continuous daylight for building their nests and feeding their young, and where competition from other birds is less severe. Cooperation for mutual welfare exists in the arctic summer as it does in the tropics, and is exemplified by the arctic birds, which nest in great flocks, fly to each other's aid against intruders, and, in the case of some aquatic birds, join together in overturning large stones in order to pick up the small animals hidden underneath them.

For a few weeks the moister and warmer parts of the ground are covered with a garden of wild flowers larger and brighter than any of their relatives farther south. The insects are so abundant that they swarm over all of the animals that live there, and drive the reindeer to drier feeding grounds. The flowers produce their seed, the young birds grow up and get ready to migrate southward, the insects lay their eggs and die, their larvae feeding and growing rapidly on the profusion of vegetation, getting ready for their long winter's rest. Finally, in early September, the winter storms begin again, and all life resumes its passive struggle against the elements.

Some Features of Life in Temperate Regions.—When we look about us at the animal and plant life in the temperate regions of the earth, we find that the enemies of an organism are about equally divided between the unfavorable elements of its inanimate environment and the other organisms which are competing with it. As a result, both the adaptations highly developed in tropical organisms and those most characteristic of the arctic regions are found here, though in less extreme forms.

For instance, if we go to a moist swampy woodland in June, we find tall trees shutting out the light from the forest floor, their branches crowding together to form a veritable platform of foliage above, while the Virginia creeper and clematis vines often twine about their trunks like lianas. Competition between birds, insects, and mammals is very keen, and all must be equipped with weapons for defense or aggression. The birds are mostly of a duller hue than those of the tropics, since there is not the same brilliance of sunlight and foliage, and to be protected they must blend with the dull browns and greens of their environment. Nevertheless, many birds, such as the goldfinch, bluebird, and scarlet tanager, are nearly as brightly colored as their tropical cousins. There are many protectively colored insects, and some have shapes that imitate objects of their surroundings in almost as striking a fashion as do the tropical insects. There is a whole series of butterflies which, when their wings are folded, bear a striking resemblance to dried oak leaves, and there is one common insect which resembles a stick so closely that it is not often noticed by amateur naturalists, and is sent every once in a while to our museums as a rare curiosity.

Warning coloration is also present among our animals. The skunk is as conspicuous as possible in his pattern of black and white, and the rattlesnake has perhaps the best-known warning signal of any animal. Mimicry is found among our insects. The most famous case of mimicry is that of two familiar butterflies, the monarch and the viceroy. The monarch is a large, bright orange butterfly, conspicuously marked with a network of black lines, and notorious for its bad odor and taste. Another somewhat smaller butterfly, belonging to a totally different family and not at all ill-smelling or distasteful, has exactly the same color pattern; this is the viceroy. Birds, which have learned from experience to avoid the monarch, leave the viceroy alone.

Associations of all sorts are also found among organisms. Cases of parasitism and symbiosis have been mentioned in an earlier chapter, and the social insects, the ants and bees, are familiar to all of us, though they are not so abundant and dominant as in the tropics.

There are many spots even in our temperate climate in which conditions are something like those in the desert and the arctic tundra. The seashore has many of the features of the desert. Where the shore is sandy, the soil is so porous that the rain percolates through it in a few hours after each storm, making the sand between rains almost as dry as that of the desert; the great heat reflected by it on hot sunny days is familiar to all who seek their summer tan on the beach. Sand beach plants, therefore, are either succulent like the "sea rocket" or, as in the beach grass, hard and tough, with their narrow leaves curled up like those of desert plants. Where the shore is marshy, water is plentiful, but it is so salty that plants have difficulty in assimilating it. Hence most salt marsh plants are very fleshy and equipped for storing water. The samphire or glasswort has a jointed, fleshy, leafless stem like that of a miniature cactus, while its associates, the orache and sea blight, are not only similar to but actually close relatives of the salt bushes and the greasewood of our western deserts.

A habitat that in many respects resembles the arctic tundra is the peat bog. Such bogs are frequently found in northeastern America, within the region once covered by the great ice sheet, and were formed by the gradual filling in of ponds by the growth of sphagnum or peat moss. In fact, many of them still have small ponds in their centers. The floor of these bogs is a mass of soft peat which extends down scores or even hundreds of feet. The great masses of decaying peat fill the water with carbonic acid, which makes it difficult for plants to assimilate and use the water, while there is no soil at all to provide the necessary mineral matter. Furthermore, peat moss is a poor conductor of heat, so that even in June the water is very cold or actually frozen a few feet below the surface. The plants growing under these conditions are equipped to resist cold and drought as are those of the tundra, and many of them are the same species as, or close relatives of, arctic plants, which reach their southern limits in these cold, physiologically dry places. On the other hand, some of them obtain mineral salts by means of adaptations similar to those found in the tropical epiphytes. The pitcher plant, a common denizen of peat bogs, gathers water in its pitchers, in which it traps and

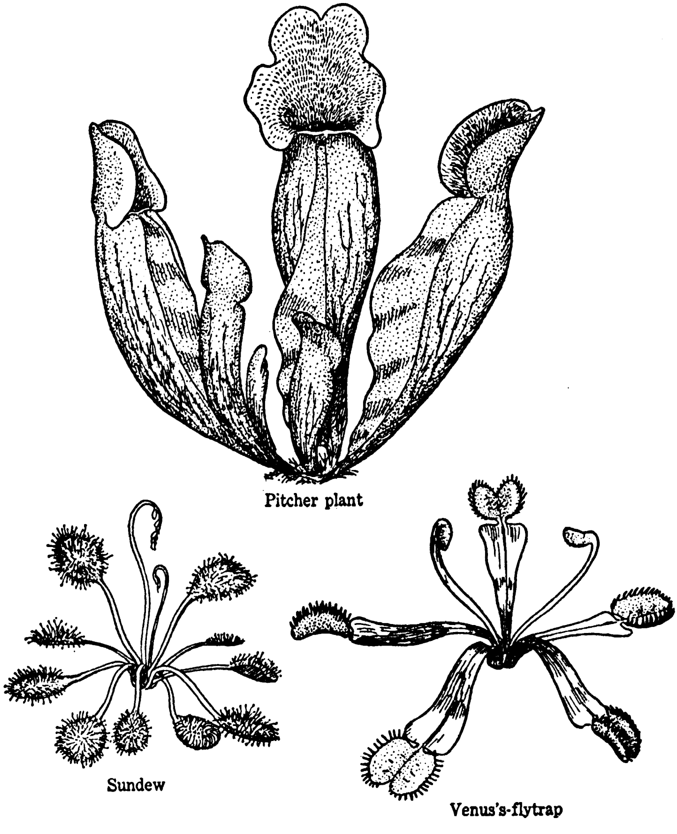


FIG. 84.—Insectivorous plants.

digests insects, as do the tropical pineapples and their relatives. Furthermore, the water of these pitchers is, as is the similar environment in the tropics, occupied by its particular set of animals. Microscopic examination of the water in the bottom of any one of these pitchers will reveal the presence of Protozoa, wheel animalcules or rotifers, insect larvae, and a species of water mite. These small animals are apparently adapted to resist the digestive secretions of the pitcher plant, and in return for this adaptation are able to feed on the victims that fall into the water. Another insect-eating plant of peat bogs is the sundew, which captures flies on its leaves by means of a surface of sticky glands. The leaves of the Venus's-flytrap, a rare bog plant of the coast of North Carolina, are transformed into traps. When stimulated by flies which brush against the long bristles lining their edges, these traps fold over their prey in a few seconds. All of these adaptations for insect-catching are of value to plants of peat bogs, since the animal proteins, when digested, supply the mineral elements necessary for their growth.

The Seasonal Changes of Life.—The most severe change which occurs in all of the habitats of temperate regions is the onset of winter, and for this change many remarkable adaptations exist. None of these are necessary in the moist parts of the tropics, some of them are characteristic of deserts and the arctic regions, and some are not found in either place. For instance, there are plants which, like the cacti, carry on a slow, steady activity all the time, and others which practically suspend their life during the winter. The evergreens, such as pines, spruces and cedars, have leaves that are quite thick for their breadth, which store a good deal of water and are covered with a thick, protective layer of wax. Most other trees, like the desert shrubs, shed their leaves during the dry, cold and windy winter, when most of the moisture is locked up in snow, ice, and the frozen ground. The bare twig of a tree in winter is as well equipped to stand extreme drought and changes of temperature as is a desert plant. It is covered with a thick, corky bark which insulates it, and effectively keeps water from evaporating from the tissues inside. This bark is, nevertheless, perforated with little openings which show on the twig as dark excrescences. These admit the oxygen which the tissues must have if they are to carry on oxidation and keep alive. At the tip and along the sides, in what were the notches above the leaves, are the buds. These are covered by several thick, leathery scales, and often coated with a shining layer of varnish-like substance. Within, often wrapped in a heavy layer of wool, are small leaves and often flowers, already formed, and needing only the warmth and moisture of spring to expand and burst through the protecting scales.

Non-woody plants, known as herbs, must in this climate die down each autumn. They have two different ways of surviving the winter. In some, the *perennial* herbs, the parts underground remain alive and often store within them enough food to maintain themselves throughout the winter and start the growth of a new shoot the following spring. These underground storage organs may be either thickened roots, as in the dandelion; short

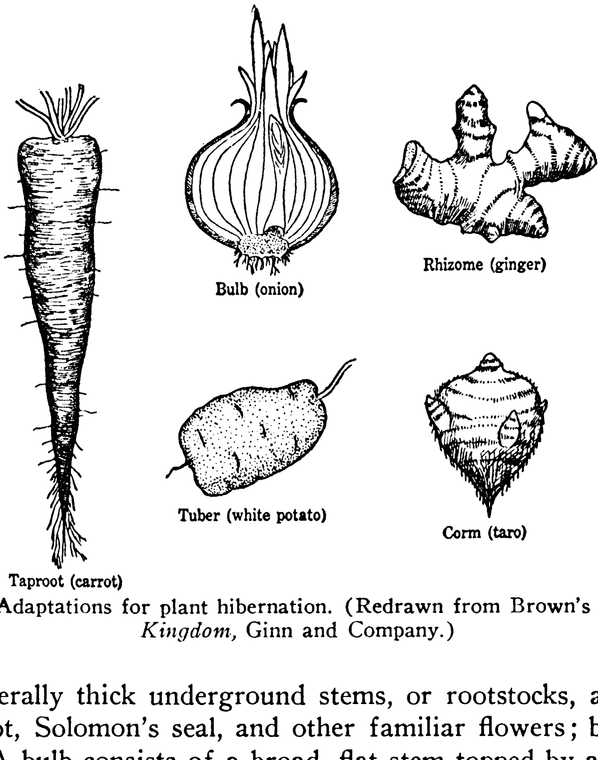


FIG. 85.—Adaptations for plant hibernation. (Redrawn from Brown's *The Plant Kingdom*, Ginn and Company.)

and generally thick underground stems, or rootstocks, as in the bloodroot, Solomon's seal, and other familiar flowers; bulbs; or corms. A bulb consists of a broad, flat stem topped by a number of thick, fleshy modified leaves; and a corm, as in the crocus and trillium, is simply a much swollen, rounded base of the stem. Bulbs and corms, with their large supply of stored food, allow the new shoot to grow up and flower quickly, and hence are most common in spring flowers. They, and generally rootstocks as well, bear buds, within which are small leaves and often flower buds. Some perennials keep a few leaves at their base alive and green throughout the winter. Perennials almost always spend the first years of their lives storing up food in their underground parts and hence do not flower until they are two, three, or more years old.

Annual herbs flower, produce seed, and die away in a single season, leaving their seeds as the only parts which survive the winter. They generally produce a very large amount of seed for the weight of the plant, and hence most of our seed crops, such as grains, peas, and beans, are annuals.

The animals of the woods in these regions either maintain themselves on a scant supply of food as do the deer and rabbits, or else they hibernate in some way or another. The woodchuck, like the kangaroo rat, builds burrows; bears lie in caves; and frogs bury themselves in the muddy bottoms of ponds. These long periods of suspended animation are most characteristic of the animals of temperate regions.

In some animals that are active throughout the year in temperate regions, concealing coloration has taken the form of changes of color with the seasons. The varying hare of our northern forests is brown in summer, but in winter develops a coat of white which matches the snow over which it must wander. The ptarmigan, quail-like birds of northern regions, have similar changes of color.

Animal Migrations.—Some animals have adapted themselves to changing environments by means of migrations. These are of three types, *seasonal, cyclical,* and *irregular* or *dispersal.*

The *seasonal* migrations of birds are from winter quarters in the south, where food is abundant, to breeding places in the north, where the simultaneous appearance of numerous flowers and insects provides a greater abundance of food and the increased length of the days in summer gives the parents more time to gather food for their young. Migrations are manifestations of some of the most marvelously complex instincts in the animal kingdom. Sometimes the distances covered are almost incredible, as, for instance, in the case of the arctic tern, which breeds chiefly in Greenland and Labrador and winters in southern South America, traveling 10,000 miles, nearly from pole to pole, twice a year.

Cyclical migrations are those taken by an animal once or twice in its lifetime. The most interesting are those of some species of fish. The king salmon of the Pacific, for instance, travel up the great rivers of western North America to spawn, combating swift currents and leaping over falls and rapids until they reach the quiet pools of the headwaters, in one case two thousand miles from the sea, quite exhausted and wasted away. The young spend their first winter in the fresh-water streams, and in the following spring make the long journey to the sea. After two to seven years in the ocean, they have the urge to spawn, and travel back upstream, following exactly the same river and tributary route as they took on their downward journey, until they spawn in practically the same spot as that in which they were hatched. Eels migrate in exactly the reverse direction. They spend most of their lives in fresh-water streams and pools, but when they have the urge to spawn, they travel down to the ocean and across to an area south of Bermuda, both the European and the American species of eels spawning in nearly the same spot. The young eels, as soon as they can swim, head back across the ocean. Those of European parentage always return to Europe before reaching maturity; the American eels head northwest, until they reach the rivers of our coast, up which they swim, often making short journeys overland to reach the ponds and streams where they spend their lives. The extraordinary ability of the young eels, which are a fraction of an inch long, to find the continent inhabited by their ancestors is not quite so unbelievable as it seems at first. The breeding grounds are much nearer to the American coast than to the European coast; and the European eels are prepared for their longer journey by taking three years to mature, whereas their American cousins mature in one. Hence if the young of an American eel starts toward Europe, it reaches the stage in its development when it must transform itself into a fresh-water fish while it is still in mid ocean, and therefore it perishes. The young of the European eel, although they come within 150 miles of our coast, are immature at this time, and do not enter the shallower waters near the coast until they reach Europe.

Irregular or *dispersal* migrations are due to the temporary overpopulation of some region with a particular species of animal, and are best known in the insects and mammals. The grasshopper or locust is an animal normally solitary in its habits; but some species, under pressure of overpopulation and scarcity of food in their breeding grounds, develop gregarious tendencies and swarm across the country in droves of millions, darkening the sun and devouring all of the vegetation in their path. These plagues of locusts occur in open prairie regions all over the world. They have been quite frequent in the central and western United States, but have diminished in recent years as a result of the destruction of the breeding grounds of the insects. Even more spectacular are the migrations of the lemmings. These small mammals make dispersal migrations at irregular intervals in all parts of their range, but they are best known in the Scandinavian peninsula, where the high plateaus on which the animals breed are surrounded on all sides by narrow valleys down which the lemmings must migrate. When overpopulation becomes extreme, and the food scarce, armies of lemmings rush blindly down the valleys. They are accompanied by crowds of birds and beasts of prey which constantly devour them, but which have no effect on the persistence of the survivors. They never end their migration, however, since all the lowland regions are inhospitable to lemmings. Most of them are eventually killed by animals or by man, but some of them, in attempting to swim across the narrow fjords, are swept out to sea and drowned. Although thousands of them have been seen swimming together through these arms of the sea, there is no evidence that their instinct compels them to do this; and the frequently made statement that they head directly from the shore toward the open sea, swimming straight ahead until they perish, is not supported by the careful studies of biologists.

Life in the Ocean.—As we learned from the last chapter, life existed in the ocean long before it did on the land, and even today there is a greater wealth of animal life in the sea than there is on any of the continents. Life has pervaded the sea as it has the land, and has penetrated to its utmost depths. There are, in the main, three types of environment that it has occupied: first, the shore and the shallow waters, i.e., the *littoral* and *sublittoral* region; second, the surface of the open ocean, or *pelagic* region; and, finally, the depths of the ocean, or *abyssal* region.

The seashore and the shallow seas, down to a depth of two or three hundred feet, are in many ways among the most favorable habitats for life on the earth. Here are in abundance the four necessities for plant life—light, water, carbon dioxide, and mineral salts. As a result, this part of the ocean is as densely overgrown with vegetation as is the rain forest. The plants, however, are of fewer species, and practically all of them belong to one group of plants, the algae. All of the four types of algae mentioned in Chapter VI are found along the seashore, and each occupies a more or less definite region. The blue-green algae form a thin scum over the surface of rocks, seaweeds, or animal shells. The green type occurs in the shallow waters, mostly between tide levels. The massive brown algae are the dominant vegetation along seacoasts of temperate regions down to depths of 100-200 feet. The red algae are more common in the tropics and in deeper waters, where they take advantage of the deeply penetrating violet rays. There are, in addition, many different species of microscopic algae floating in the water. These are in general similar to those of the open ocean, as described below.

Wherever a dense growth of plant life affords abundant food, a myriad of animals will be found competing for it, and the seashore is no exception to this rule. Here only are all of the main divisions (phyla) of the animal kingdom represented. In addition to such relatively familiar animals as worms, mollusks, crabs, and fishes, there is a whole host of animals that always seems weird and strange to us land dwellers—lace-like sponges, flowery sea anemones and corals, starfish and spiny sea urchins, squids and octopi, as well as numerous others that resemble nothing but themselves. All are living in, upon, or about each other, hiding under rocks for protection or camouflaging themselves with incrustations of rocks, seaweed, or other animals.

Concealing coloration, as well as weapons and lures of many kinds, is the rule. In tropical waters, the fish are vividly colored to match the brilliance of the sunlit coral reefs and the masses of red, green, and brown seaweeds. In temperate waters, as in temperate forests, browns and grays prevail among both animal and plant life. Here, however, some very striking examples of concealing coloration can be found. The flounder and its relatives, for instance—broad flat fish which most of the time lie quietly on the ocean bottom—imitate perfectly their surroundings. In fact, they are most efficient in changing their pattern of coloration to suit the particular type of bottom on which they are resting. When lying on a sandy bottom, flounders have a fine-grained pattern, with a tawny yellow the predominant color, and are almost indistinguishable from the sand. If, however, a flounder swims over to a bottom that is pebbly or rocky, its back quickly becomes blotched with dark brown, yellow, and cream color, so that it is again almost exactly like the surrounding ocean floor.

Powerful vises for crunching or squeezing their prey are found not only in the well-known claws of crabs and lobsters, but in the tentacles of sea anemones, octopi, and squids, and the slow-moving but very powerful legs of the starfish. Some shellfish have a "tooth ribbon" which resembles sandpaper, and is used to bore holes in the shells of crabs or other shellfish, while still others have a boring organ equipped with acid which dissolves the shells of their victims. These shellfish then insert a long proboscis and suck out the insides of their prey.

Among the most remarkable fish is the angler fish, found not uncommonly along the Atlantic coast. This fish, lying flat on the sandy or muddy bottom a few rods from shore, is well camouflaged in its colors of sandy or dull brown, and bears on its dorsal fin a long, thread-like spine, tipped with a soft and flesh-like flattened cap. When the fish is hungry, it lifts this spine up directly over its huge mouth and waves the writhing tip back and forth. Small fish, mistaking this lure for a wriggling worm, make for it, only to be snapped up by a sudden movement of the large and powerful jaws of the angler half hidden in the mud below.

Poison darts have been adopted as a weapon of offense and defense by a whole division of the animals of the seashore—that including the sea anemones, corals and their relatives. These "stinging cells" are scattered over the entire surface of the animal, but are particularly numerous on its tentacles. The darts shoot out like an uncoiling spring whenever the cells are stimulated, carrying with them poison from the small sacs at their base, which serves to paralyze the animal's prey or to ward off its enemies.

Although many conditions at the seashore are favorable for life, there are other adverse elements against which the animals and plants must be thoroughly protected. One is the regular rise and fall of the tide, depriving much of the shore of the essential necessities of life twice daily. To guard against this, seaweeds are covered with a jelly-like substance capable of storing great quantities of water; and animals either remain in the tide pools, hide under rocks and seaweed during low tide, or, as is true of some crabs and fish, are capable of breathing both air and water. Most remarkable in this respect is the "walking goby" of the tropics, which actually climbs the lower limbs of trees. It breathes air though a lung-like extension of the gill chamber, and drowns if kept constantly under water.

The other most inimical condition which seashore organisms must face is the ceaseless battering of the waves. To guard against this, the algae are pliable but exceedingly tough, so that they can be tossed hither and thither without being broken. They are also firmly fastened to the rocks by means of vacuum cups or "holdfasts" which are so powerful that the plants cannot be torn loose without destroying either the seaweed or the rock. The animals are either leathery and pliable, like the fishes, octopi, and—among the smaller animals—the sea anemones, sea slugs, and sea cucumbers, or they are encased in thick, limy shells that are resistant to the force of the waves. Most of the latter animals are stationary or very slow moving, using their muscles chiefly for closing up their shells or for squeezing and crunching their prey; while some, such as the barnacles and sponges, engulf microscopic organisms by means of a vortex of current set up by myriads of beating cilia.

The floating animals of the shallow seas, the jellyfish and the microscopic organisms, form the transition from the life of this region to that of the next, the *pelagic* region. The organisms that live there must be either floaters or swimmers, respectively termed *plankton* and *nekton.* They must be either small or very large. The larger plants cannot grow here, since they have no anchorage, and plant life is confined to unicellular, microscopic algae. The most numerous of these in northern waters are the diatoms, which are encased in pill-box-shaped shells, often armed with horns or prongs or ornamented with intricate and beautiful designs. They can be caught in great quantities along the coast of New England simply by dragging a cheesecloth net behind a rowboat. The other group of organisms with autotrophic metabolism is a group of flagellates, known as the dinoflagellates. These "plant-animals" are usually equipped with brownish or yellowish plastids, and are

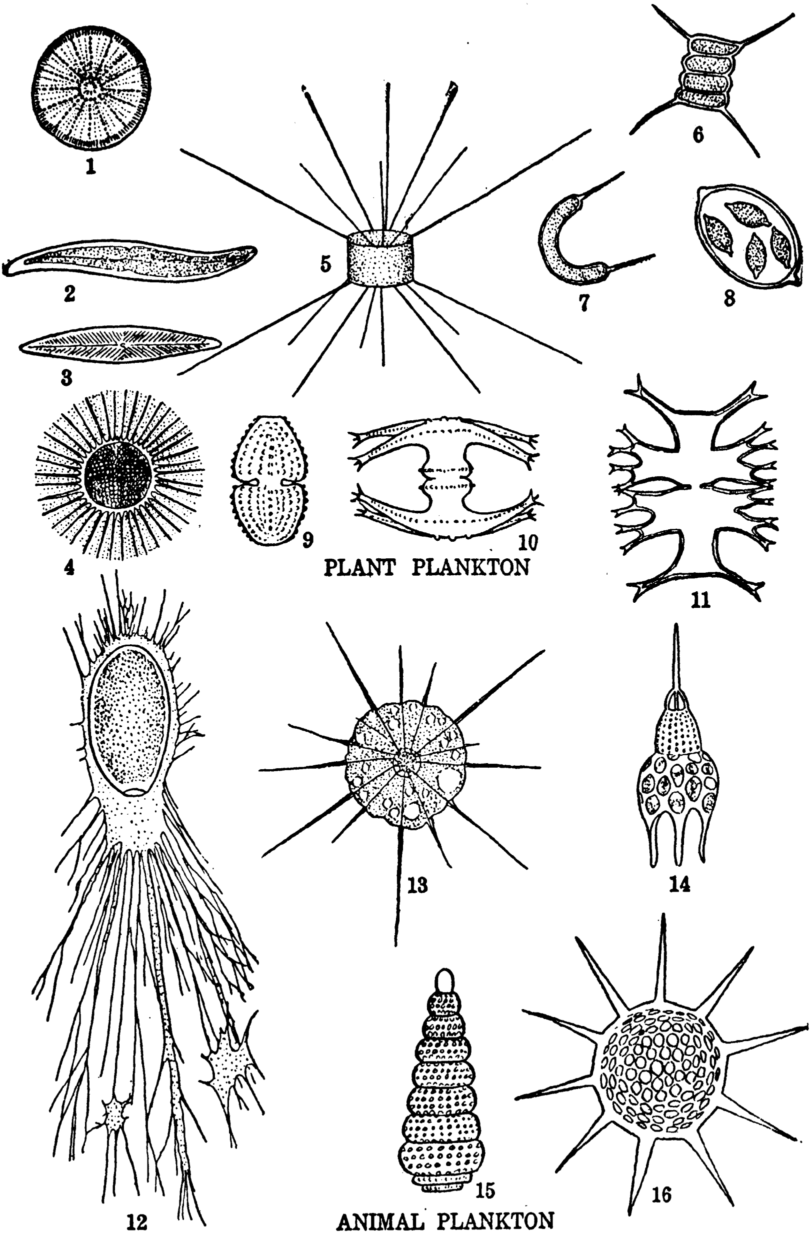


FIG. 86.—Plankton life: 1-5, diatoms; 6-8, unicellular and colonial green algae; 9-11, desmids; 12, foraminifer (protozoan); 13, heliozoan (protozoan); 14-16, radiolarians (protozoan).

encased in vase-like shells of a most elaborate design. They are most common in tropical waters. Subsisting directly or indirectly on the diatoms and flagellates or their remains is a whole host of animals, small and large. There are groups of Protozoa known as Foraminifera and Radiolaria, with elaborately carved and sculptured shells; delicate jellyfish of many types; minute shrimp-like animals known as copepods; "winged" snails, or pteropods; as well as the larvae of most marine animals, including worms, starfish, crabs, oysters, and fishes. Most of these animals have modifications of structure which make them particularly buoyant. In tropical waters there is a striking type of jellyfish, known as the Portuguese man-of-war, whose boat-shaped body contains air sacs to enable it to float better, while from this body there extend downward long, violently poisonous streamers. In the copepods, the feet are not claw-like as in their cousins, the shrimps, crabs, and crayfish, but are delicate fringed appendages, often brilliantly colored; and in the "winged" snails the muscle corresponding to that used by their terrestrial and shore-dwelling relatives for crawling is modified into flat, wing-like structures that spread out above the top of the shell.

This vast array of floating life known as plankton is of great importance as food for fishes. Sometimes myriads of the microscopic organisms are packed together so densely that they color the sea a reddish brown. At night most of the plankton organisms give off a tiny phosphorescent light, making the ocean sparkle and glow.

Besides the plankton, the open ocean supports chiefly three forms of animal life: squids and cuttlefish, some fishes, and the whales and their relatives, the porpoises and dolphins. The fishes are much less numerous than they are near the shore, and consist mostly of small types quite unfamiliar to those who know only shore fish. They are mostly bluish or silvery in color to match their surroundings, and since the open ocean affords them little protection, they must be agile, fast swimmers. Among them are the delicate flying fish, which use their enlarged fins to skim over the surface of the water. The squids and cuttlefish are soft-bodied animals with long tentacles equipped with disk-like suckers. They range from small forms an inch or so long to giant monsters which have tentacles twenty feet long, and may inflict great damage in combat with the whales which prey on them. Whales, which are perhaps the best-known animals of the open ocean, are not fish, but mammals. They have warm blood and suckle their young; and under their thick coating of hide and blubber they have a skeleton which can be matched, bone for bone, with that of land mammals. Whales are of two main types. Some, such as the sperm whale and the killer whale, have their jaws packed with sharp teeth with which they kill and eat fish and seals, and even such monsters as the giant squid and other whales. The second group, the whalebone whales, have their teeth replaced by long, thin, fringed plates which act as strainers. These whales feed by gulping in huge mouthfuls of water, and by straining it out through their whalebone plates, they extract its plankton. Here we have the phenomenon of the largest animals in the world feeding on millions and millions of the smallest.

Frequently the open ocean contains what may be termed "islands" of shallow water life, formed by the drifting out of masses of algae that have broken away from their anchorage on the rocks of the shore. The commonest type of seaweed thus found is the yellow-brown Sargassum, which has slender stems bearing leaf-like plates of tissue and grape-like clusters of air bladders which serve to float it. Under the shelter of the Sargassum live shellfish, small shrimps and crabs, and many types of brightly colored and strangely shaped fish. The Sargassum is carried far out to sea by ocean currents, but does not form a true element of the pelagic life since it lives only about two years after it is torn from its rocks and, although it retains the power of growth, does not reproduce during that time. The famous "Sargasso Sea" is formed by a great eddy of the Gulf Stream and other large ocean currents which send load after load of Sargassum into this part of the north Atlantic. It is not, however, as is sometimes thought, a solid mass of seaweed, and ships have little difficulty in sailing through any part of it.

As we descend from the surface of the open ocean toward the third realm, the *abyssal* region, conditions for life become more and more severe. Adequate light for plants is not found below 1,000-1,500 feet, and the greater depths are inhabited only by animals. These must either subsist on the dead bodies of animals and plants constantly raining down from above, or devour each

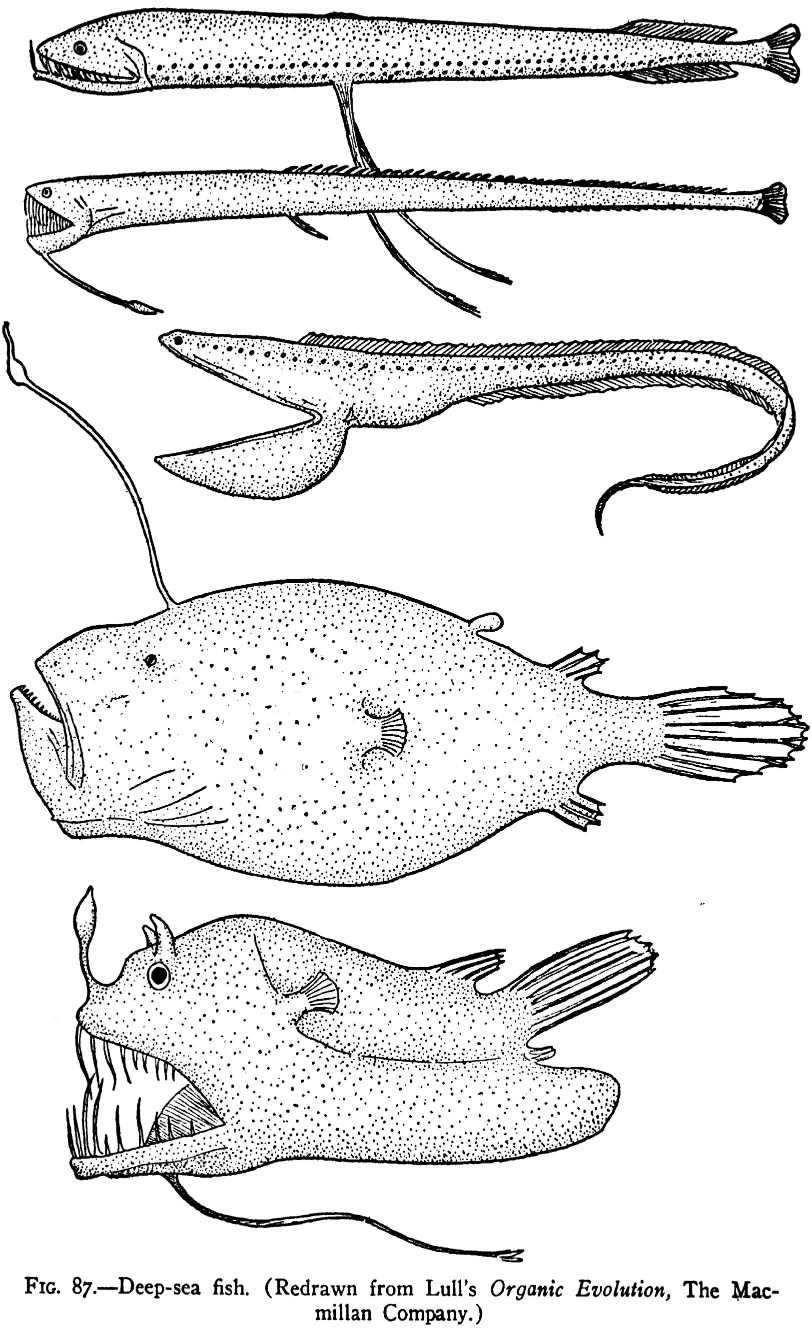


FIG. 87.—Deep-sea fish. (Redrawn from Lull's *Organic Evolution,* The Macmillan Company.)

other. Furthermore, they must withstand tremendous pressure amounting to several tons.

The animals living under these conditions are of the same groups as those of the upper regions, but their shapes often seem strange and weird to us. The plankton animals are found to depths of 15,000 feet, and form the most abundant life of the abyssal as well as the pelagic regions. Fishes of various types are very abundant down to 4,000 feet, but below that are less common. Most of them are small, from a few inches to a foot or two long, and are of extraordinary shapes. The scarcity of the food supply means that many of them consist of little besides an enormous mouth and a thin ribbon of a body. There are many different kinds of angler fish, whose lures are like those already described in the shore form, except that they attract the smaller animals by means of their glowing, phosphorescent tips. These fish, which have all of the vast, dimly lighted ocean depths in which to roam, must rarely meet a member of the opposite sex; to overcome this difficulty the male of some species of angler fish attaches itself to a female when it is less than an inch long, and soon becomes completely fused to its mate, spending its entire life as a small appendage on the head of the female. It nevertheless becomes an adult, and, when the female on which it lives lays her eggs, is ready to fertilize them.

Phosphorescence is the rule among most types of animals of the medium depths, but in the deepest waters, below five or six thousand feet, few animals have luminescent organs, and everything is pitch black. In the intermediate depths many of the fish have much enlarged eyes, but others are nearly sightless.

The bottom of the deep ocean is a soft ooze, consisting entirely of the shells of the minute plankton organisms which have fallen upon it in a steady rain for millions of years. Living on this bottom are a number of different kinds of animals related to those of the shore. There are spreading, fan-like corals, strange types of thin-shelled, colorless shellfish, long-stalked "sea lilies" related to the starfishes and sea urchins, and great spreading crabs, composed almost entirely of legs which may spread over an area as much as eleven feet in diameter. Because of the soft nature of the ooze, these animals must have a large surface for their size. They subsist chiefly upon the remains of plankton animals that rain down on them continuously, and some are equipped for burrowing through the ooze and extracting from it whatever scant nourishment is left. One of the most striking examples of the persistence of life is its penetration to these ultimate depths of the sea where, at depths of from 12,000 to 18,000 feet, all is inky blackness for thousands of feet above, and the pressure is two or three tons per square inch.

Adaptations to Changing Environments.—Up to now we have spoken of the various environments of the earth as they are at present—apparently static entities. We know, however, that conditions in most parts of the earth are anything but static. In the geologically very recent time of 25,000 years ago most of New England, New York, and the North Central States were covered by ice or by tundra, and even in historical times much of the United States has been transformed from deep primeval forest into cultivated fields and patches of scrub pine or scrub oak. Obviously no organism will survive long on this earth, no matter how well it is adapted to a particular environment, unless it can either move to follow the changing position of its own environments or change to adapt itself to new environments. The former course is of no difficulty for terrestrial and oceanic animals; but for many fresh-water animals and for plants it is not so easy, and these organisms must have special adaptations for moving. In such fresh-water animals as Protozoa, wheel animalcules (rotifers), and the water fleas and shrimps this is accomplished by the formation of resistant spores which may be blown from one pond to another by the wind.

The Dispersal of Plants.—Plants change their location, some of them with considerable rapidity, by means of efficient methods of scattering their seeds over large areas. Excellent examples of this are given by two families of angiosperms which are widespread and common in the north temperate regions, the aster or composite family, and the rose family. Most of the former, such as the asters, goldenrods, thistles, dandelions, and hawkweeds, have seeds with light, feathery plumes which may be borne long distances by the wind. Others of them, such as the beggar's ticks or sticktight, the burdock, and the clotbur, have seeds bearing barbed or hooked spines which cling easily to the hair of animals and the clothing of man, and may thus be transported long distances. The members of the rose family, which includes besides the rose, the apple, cherry, peach and plum, as well as such berries as the strawberry, raspberry, and blackberry, and many other familiar plants, have most of them fleshy fruits which are avidly eaten by animals, particularly birds. The flesh of the fruits is digested, but the seeds are surrounded by a coat which resists digestive enzymes, and hence are excreted whole and unimpaired with the feces. Since the bird may fly many miles while it is digesting the fruit, it spreads the plant quite effectively. These three methods, hairs or plumes for dispersal by wind, and hooks or barbs and fleshy fruits for dispersal by animals, are the most common methods of seed dispersal in land plants.

That these methods of seed dispersal actually help the plant to invade new regions is shown by the change of vegetation in North America in the last few centuries. With the coming of civilized man, the woods of this region have been largely cut down and made into fields, pastures, or waste lots near cities. The native woodland plants have been driven out and largely replaced by a host of weeds which have been brought in from Europe and other places. There has thus been a complete change of environment accompanied by a corresponding change in vegetation. Of the European invaders of this new, changed environment, among the most successful and widespread have been members of the aster family. Dandelions, coltsfoot, hawkweeds, and thistles are all widespread and familiar members of this invading host of European weeds. Similarly, our native members of this family have been among the most successful to survive the change in conditions and occupy the new environment. Goldenrods and asters have been increasing while woodland flowers have gradually become rarer and rarer. Our native members of the rose family have also increased with the changing environment. Hawthorns have spread all over our pastures, while blackberries and raspberries line thickets and fencerows, becoming ever more abundant as the woods are cut down.

The Value of Sexual Reproduction in the Struggle for Existence.—The alternative of migration, variation to suit a new environment, is largely responsible for evolutionary change. Although the mechanism of this change will be discussed in the next chapter, one important factor in it has already been de-

:ribed, namely, sexual reproduction. That an infinite variety of ›mbinations may be obtained by this process has been shown in hapter XIII on heredity. Furthermore, variation is probably the ıly advantage of sexual reproduction. We have learned that in ants there are many methods of asexual reproduction which are ›th faster and more certain than the sexual process, and that ants may be reproduced indefinitely by these methods without ›preciably lowering their vitality. Animals, on account of their fferent method of growth, do not as a rule possess these ethods. Some, however, reproduce entirely by parthenogenesis, ıd these are not in any way inferior in appearance or activity › their sexual relatives. We must conclude, then, that the primary ırpose of the often long and arduous cycle of sexual reproduc- on is to help the organism to vary so that it may become lapted to changing environments. Along with changes in the :rm plasm, which will be discussed in a later chapter, the varia- lity produced by the segregation and recombination of genes ırough sexual reproduction has been, in a changing environment, ıe prime moving factor in evolution.

Non-adaptive Differences Between Organisms.—Although e have shown that a large proportion of the species of animals ıd plants owe their individuality to their adaptation to one of ıe thousands of different environments on the earth, naturalists l know that the differences between species often have nothing › do with their adaptation to different environments. For in- ance, there are many different species of warblers living in the ›rests of the eastern United States, each of them with its own :culiar pattern of markings. Although most of them are adapted › slightly different habitats, these adaptations can only in a small ay account for their differences in color pattern, song, and other ıaracteristics. The same thing is even more generally true of ants. The student of trees learns to distinguish between various ›ecies of pine by observing whether the needles are in bundles f two, three or five, the size and shape of the cones, and whether : not the cone scales have prickles at their tips. None of these ıaracteristics help the pines to become adapted to the particular ıvironments which they occupy, and yet if such differences did ›t exist the pines would probably all belong to the same species.

The same may be said of oaks, maples, hickories, goldenrods, asters, and practically every other group of plants.

For this reason our understanding of evolution depends on our knowing not only how organisms can become adapted to all sorts of new environments, but in addition how they can evolve and successfully maintain all sorts of variations that have little or nothing to do with adaptation to the environment. The essentials of our knowledge and theories on these subjects are set forth in the next chapter.

Chapter Summary

The world of living organisms consists of a vast number of species, which are the end products of evolution. The chief aim of the study of evolution is to understand how these species came into being, and what is the cause of their close adaptation to their environment. The adaptation of organisms to many diverse environments is partly responsible for the large number of species that exists. This adaptation is essential to the existence of any organism. The tendency for all organisms to reproduce their kind at a rapid rate results in a potential overpopulation of every environment on the earth, and a consequent *struggle for existence* between organisms to see which will survive. This struggle is equally keen in all parts of the earth, but varies in its nature with the environment.

In the tropical rain forest, where conditions are most favorable for life, the struggle is chiefly between the multitude of organisms present. Hence all organisms are equipped with devices for protection or aggression, many of them very elaborate. Most animals possess concealing coloration, either for protection or for aggression, and many also imitate objects of their surroundings in shape. Poisonous or noxious animals often possess warning coloration, which consists of a great contrast in color with their surroundings. These animals are sometimes mimicked by harmless animals or by other harmful ones, by which device the mimic gains added protection. Parasitism, saprophytism, and symbiosis are strongly developed in the tropics; and the social insects, the termites and ants, are most highly developed there. Unfavorable conditions against which organisms must be protected are, in the case of aquatic animals, the drying up of rain pools, and, in the case of the smaller plants, the necessity of living high up in the branches of the trees, where a constant supply of water and mineral salts is difficult to obtain. The development by some plants of "reservoirs" at the bases of their leaves is an adaptation to this condition of their environment.

In the deserts, life must be adapted to protect itself against drought, cold, and windstorms, rather than for a struggle of organism against organism. Plants, like the cactus, have special structures for the storage of water, expose a minimum of surface to the air, and have a thick, waxy covering over the surface parts. They are also covered with spines and thorns to protect them from foraging animals. Smaller plants remain as seeds underground, germinating and flowering only during the brief rainy seasons. Animals of the desert are fleet and agile, and many of them, like the camel, are able to store water in their bodies. Some build huge burrows underground and store up large quantities of food during the wet seasons when the seed plants are growing in abundance.

In the arctic regions, the herbivorous animals must be equipped for feeding on the sparse evergreen vegetation under the snow, while the carnivorous animals must live on short rations for much of the time. Birds migrate southward and insects remain dormant for all but a few months of the year. Plants must be equipped to resist extreme cold and drought for most of the year, but must be able to grow and flower rapidly during the summer months. Animals usually raise larger broods of young than their relatives in temperate climates.

In temperate regions, adaptations are found similar to those of tropical organisms, as well as those most characteristic of the deserts and the arctic regions. Concealing coloration is well developed, and warning coloration and mimicry also occur. Plants of sandy beaches and salt marshes resemble desert plants, while many of those found in peat bogs are similar to arctic species. The lack of available mineral salts in peat bogs has been overcome by some insectivorous plants in the same manner that a similar deficiency has been overcome by the epiphytic plants of the tropics. The most important adaptations characteristic of temperate regions are those which fit organisms for seasonal changes of climate.

One type of adaptation of animals to meet changing conditions is migration. Migrations are of three types: (1) seasonal, (2) cyclical, (3) irregular or dispersal. Seasonal migrations are best exemplified by birds; cyclical, by fish, such as the salmon and the eel; dispersal migrations are found in insects such as the grasshopper and in mammals as exemplified by the lemming.

The habitats of life in the ocean are in three general regions: (1) the littoral and sublittoral, (2) the pelagic, and (3) the abyssal. Conditions in the littoral and sublittoral regions are unusually favorable for life; hence the struggle for existence between the numerous organisms inhabiting this region is unusually keen. Striking adaptations for protection or offense are those of the flounder, some shellfish, and the angler fish. Unfavorable conditions against which organisms in this region must contend are the rise and fall of the tide and the battering of the waves. For protection against the latter, plants and animals are either very tough and flexible, or are encased in hard shells.

The majority of the organisms of the pelagic region are minute floating forms known collectively as plankton. The most frequent components of plankton are diatoms, flagellates, Protozoa, jellyfish, and various types of crustaceans, chiefly copepods. The most important swimming animals of the pelagic region are small fish, squids and cuttlefish, and whales and porpoises.

In the abyssal region only animals can survive. They are of the same groups as the littoral, sublittoral, and pelagic animals, but are often of unusual shapes. Those inhabiting the ocean floor must cover a large surface so as not to sink through the soft ooze, but must have slender limbs so as to resist more easily the great pressure.

There are two means of adaptation to a changing environment, moving away or varying.

In addition to those variations which enable organisms to become adapted to their environment, a large number of non-adaptive variations have resulted from evolution.

QUESTIONS

1. Briefly characterize the species, giving original examples.
2. Compare the tropical rain forest, the desert, and the arctic regions

as to the factors which favor or are inimical to life and as to the nature of the struggle for existence in the different regions.

3. Describe, with examples, concealing coloration, warning coloration, and mimicry.
4. Give some ways in which conditions for life and the adaptations of organisms in the temperate regions compare with those in the tropics, the desert, and the arctic regions.
5. Discuss the different types of adaptations to changing seasons.
6. Describe the different types of migrations, giving examples.
7. Compare the three different regions of the ocean as habitats for life, and briefly describe some of the adaptations possessed by organisms in each of these regions.
8. Discuss the nature and significance of plankton to life in general and man in particular.
9. What are the ways in which animals and plants can become adapted to a changing environment?

GLOSSARY

abyssal (a-bis′al) Pertaining to the depths (of the ocean).

bulb An underground structure for storage in plants, consisting of a modified stem and many modified, fleshy leaves.

concealing coloration Coloration possessed by animals which blends with their surroundings.

corm An underground structure for storage in plants, consisting of a modified, very short, thick, and fleshy stem.

epiphyte (ep′i-fīt) A plant which lives on top of, but is not parasitic on, another plant.

littoral (lit′o-ral) Pertaining to the shore.

mimicry The imitation in color and form of a harmful species by a totally unrelated harmless or harmful one.

nekton The swimming life of the open ocean.

pelagic (pē-laj′ik) Pertaining to the open ocean.

plankton The floating life of the open ocean.

rootstock A somewhat thickened, jointed underground stem in plants, used largely for storage.

species (spē′shēz) The unit of classification of organisms, consisting of individuals which have certain characteristics in common in which they differ in a discontinuous fashion from other related species.

tundra The treeless areas of the high arctic and high mountain regions.

warning coloration The coloration of poisonous or otherwise noxious animals which makes them conspicuous and therefore unmolested.

CHAPTER XVI

WHAT CAUSES EVOLUTION?

The Problem of How Evolution Takes Place.—Since the publication of Darwin's epoch-making theory, scientists have become agreed that evolution has taken place. They are agreed also that, taking it as a whole, it has been a gradual, steady process, and has resulted in a wonderfully precise adaptation of a tremendous host of species to a great variety of environments. The great problem at present for students of evolution is to determine just what are its causes and what factors have guided it in the many directions which it has taken. Much evidence from different directions has already been brought to bear on this problem, and at the present time discoveries which may lead toward its solution are being made at such a rate that this field of research has become one of the most active in all biology. There are two ways of attacking the problem. One is the historical and comparative method, which involves the comparison of different organisms, living and fossil, to determine just what directions evolution has taken and how fast it has progressed. The other is the experimental method, which consists of studying the variation and evolution that are occurring at the present time. The first has the advantage of covering the whole history of evolution in one broad field, while the second is the more direct and gives more certain results. It is the aim of this chapter to present the chief facts and theories that have arisen from both of these lines of investigation and the relative importance of each according to present-day opinion.

The Lamarckian Theory.—Half a century before the publication of Darwin's *Origin of Species*, Jean Baptiste Lamarck set forth an evolutionary theory with a clear-cut suggestion as to how evolution had taken place. Lamarck included in his somewhat philosophical rather than scientific theory the statement that organisms adapt themselves to new environments by struggling to overcome handicaps, and that these adaptations are transmitted to their offspring. He used the example of the giraffe, an animal with a very long neck which enables it to crop the leaves of trees. The ancestor of the giraffe, according to Lamarck, took to reaching up at the leaves of trees. In doing so it developed the muscles and bones of its neck more than did its fellow animals which were content to browse on grass. This ancestor then transmitted its slightly longer and better-developed neck to its offspring who, continuing to reach as high as possible for tender, juicy tree leaves, developed still longer necks. Their offspring, in turn, inherited this added development, until finally, after generations of neck straining, the modern giraffe was evolved.

This theory seemed to fit very well the fact of exact and complete adaptation to environment that we see everywhere in the world of life. The great difficulty with it, however, is that as yet there is no good evidence that characteristics acquired in such a way as Lamarck postulated can be inherited, and there is much evidence that they cannot. Many experiments have been performed to test out Lamarck's hypothesis, and practically all have gone against the theory of the inheritance of acquired characters. For instance, one zealous experimenter tried cutting off the tails of rats for many generations; the descendants of the mutilated rats all had just as long tails as their ancestors. A similar operation, that of circumcision, has been performed by the Jews for centuries, yet no Jewish boy has ever been born in whom it was not necessary. That such *mutilations* are not inherited is, however, not strange; more important is the fact that, in animals at least, we have little or no evidence that more subtle, adaptive acquired variations are inherited. Many experiments have purported to show such inheritance, but in every case the results are either doubtful or actually discredited.

The case of the inheritance of acquired mental characteristics has been more difficult to decide, but here also the evidence is mainly against such inheritance. One well-known experimenter recently seemed to prove that the ability of rats to learn mazes may be increased in successive generations by careful training, but this experiment has been repeated in the same manner by two other workers, with entirely negative results. Furthermore, the latter have found, by keeping careful pedigrees of the rats trained by them, that the different qualities which help a rat to learn a maze are numerous, and each is inherited independently in a rather complex fashion. The experience of the human race, after all, corresponds to that of the latter set of experiments in showing that acquired knowledge or skill is not inherited. For instance, English and American children have for centuries been taught to speak English, and French children French; but if an English child is born and brought up in France, he learns to speak French as easily as a French child, and finds it equally difficult to learn English.

Can Environment Influence Our Inheritance?—It is possible to look at this problem of the inheritance of acquired characteristics from the point of view of what we already know about the mechanism of heredity. In a previous chapter it was pointed out that the hereditary characteristics of any individual are given him through the gametes which formed the zygote that was the start of his existence, and, in fact, are carried chiefly in the chromosomes of those gametes. Our problem narrows down to whether these gametes or the cells that produce them can be changed by the environment.

If, for instance, a white man goes to live in the tropics and his skin is constantly exposed to the burning sun, it becomes, in a few years, as brown as that of many mulattoes. The cells of the skin have produced brown pigment like that of Negroes, and it is possible that changes have taken place in the chromosomes and genes of their nuclei. But you will readily see that such changes could not affect the hereditary nature of the race, since the skin cells do not hand their chromosomes on to the gametes and thence to the zygotes. The only cells from which the genes and chromosomes of the zygotes are derived are the germ cells in the gonads. These germ cells, together with the gametes and zygotes, are frequently spoken of as the *germ plasm*, to distinguish them from the cells of the body, or *somatoplasm*. The germ plasm is handed down in a continuous line from generation to generation. It is set off at an early stage in embryonic development from the somatoplasm, which produces only cells that go to form a particular individual, all of which eventually die. Hence, any changes which take place in the cells of the somatoplasm last only as long as the life of the individual that they form, and the only changes which can affect the hereditary nature of the race are changes in the germ cells. The question at issue, then, is whether the environment can change the germ plasm of a race.

The answer is that it can in certain ways, and in other ways it cannot. It can change the germ plasm of a race by the selection of those individuals most fitted to it, as well as by producing mutations, which will be discussed further on. The environment cannot, so far as we know, produce adaptive variations which would tend directly to make an organism more fitted to it, nor can the germ plasm be influenced to change in the direction of changes which have been produced in the body cells. Hence we may conclude that the inheritance of acquired characteristics is, at least in animals, theoretically impossible. That this argument does not hold for plants is obvious, since new germ cells are differentiated from the cells of the growing region each season; but the fact remains that evidence for the inheritance of acquired characteristics is as scanty in plants as it is in the animal kingdom.

Darwin's Theory of Natural Selection.—Lamarck's theory of evolution was disregarded by the scientific world because he failed to pile up sufficient evidence for the fact of evolution and because he failed to offer a sufficiently plausible theory of how it had occurred. When Darwin, through his observations in the Galápagos Islands and in South America, became convinced of the fact of evolution, he was still at a loss to explain how, generation after generation, animals and plants had gradually changed, *usually in a direction that would adapt them to their environment.* Lamarck's theory would account for such adaptive changes, but Lamarck's theory could not be proved true. Then, suddenly, one day, the true explanation dawned upon Darwin. It was suggested to him by the writings of Malthus, the famous authority on population. All forms of life are multipying at a rate that leads to a continual *struggle for survival.* In each generation there is a considerable *variation* in form, strength and habits among the members of a given species. Consequently, those which vary in such a way as to be *well adapted to the environment* will win out in the struggle for survival and *pass their traits on to their offspring.* Thus over several generations there will be a *natural selection* of types best adapted to the environment; and as environments gradually change, species will evolve to fit them.

This theory of natural selection is so plausible, once one has come to understand it, that it seems remarkable that Lamarck or some of the early evolutionists did not think of it. Without doubt it did much to bring about a favorable acceptance of Darwin's whole theory; and at present, while most biologists are intensely skeptical of the inheritance of acquired characters, few doubt that natural selection has played an important part in the evolutionary process.

Darwin's theory, as set forth in his *Origin of Species*, has, however, certain limitations. He considered that any variation, however slight, could be used by natural selection in developing a new type, and placed the most stress on fluctuations such as exist between brothers and sisters of the same family. We know now, however, that many of these slight variations are due to the effect of the environment and are therefore probably not inherited. Secondly, we know from experiments that selection of such slight variations as those which Darwin stressed often leads merely to the reassortment of existing gene factors until a pure line is reached, and that beyond this point selection has no effect. Other difficulties are, thirdly, that a slight, heritable difference, if it should appear in a single individual, would probably be swamped out by crossing with other individuals; and, fourthly, that many of the differences between closely related species of organisms are not all such as would adapt them better to different environments, or to any environment whatever. From all these facts we are now certain that not all variations can, by selection, result in evolution. Our principal task is, then, to find out what sort of heritable variations exist, how well they may be used by natural selection, and, finally, what are the causes of such variations.

Mutations.—Perhaps the most important step in the modern study of variations which are the basis of evolution was the discovery made by the Dutch biologist DeVries in 1900, at the same time as he was making known Mendel's laws of heredity. DeVries concluded, from studies of the evening primrose, a yellow flowered plant native to the United States which he found growing in the gardens and back yards of Holland, that sudden, rather than gradual and slight variations, are the material with which evolution works. He found all sorts of unusual forms of this plant; some had exceptionally broad leaves, others reddish leaves and stems, there were giant evening primroses, and stunted dwarfs, all springing occasionally from a stock which otherwise bred true to type. Such sudden changes he called *mutations*, and he considered that the new forms produced were new species which had appeared, full-fledged, before his eyes.

These sudden variations had, of course, long been recognized by animal and plant breeders under the name of "sports." Darwin referred to them but considered them of such rare occurrence that they could not be of use in evolution. Since the attention of scientists was called to them by DeVries, however, these sudden changes have been found literally by the hundreds in both animals and plants.

An interesting mutation recorded historically is the well-known Ancon sheep. One of the colonists of Massachusetts discovered among his flock a sheep with much shorter legs than the others, which appeared suddenly as the offspring of a normal, long-legged sheep. Since it could not jump over the stone fences of his pasture as easily as the rest of his flock, he decided to breed from it, and was able, as the characteristic was inherited, to create a new breed of short-legged sheep, known as the Ancon. Similar sudden changes are recorded from time to time in other domestic animals. A cat with seven toes, and a barnyard fowl with webbed feet, are both mutations that have been recorded. In animals bred experimentally in the laboratory, mutations appear with a striking frequency. The most familiar of these animals, the fruit fly, has produced more than five hundred mutations in the past twenty-five years. These mutations include such extraordinary forms as flies without wings, without eyes, with short, stumpy legs, and with every conceivable shade of brown and red in their eyes, and of gray, brown, and black in their bodies.

Types of Mutations.—At the time when DeVries published his mutation theory little or nothing was known of the relations between hereditary characteristics and the chromosomes. Since then, with the development of the chromosome theory of heredity, mutations have been shown to be associated with changes in the chromosomes, or in the genes which they contain. On this basis, we now can classify the sudden changes which DeVries called mutations, and show considerable differences between various types of them, both in the ways in which they are inherited and in the changes of the germ plasm which are their direct cause. The biggest distinction to be made is that between *gene* or *point mutations*, and *chromosome mutations* (often called chromosome aberrations). These two classes are very distinct, both in their causes and in the influence that they have on evolution.

Gene mutations consist of the change in composition of a single gene. They are much the best-known type of mutation, and, in fact, the term mutation is often applied to them only. They may involve a change in only one or in several characteristics, and may have only a slight effect on the germ plasm. They are, of course, inherited in Mendelian fashion, as described in a previous chapter. They may be either dominant or recessive to the original type, but as a matter of fact most of the mutations that have appeared in experiments are recessive.

At present there is considerable difference of opinion as to the actual importance of gene mutations in evolution. A large school of geneticists consider that they are the "building stones" from which nature selects to produce new and better-adapted forms. Other workers, chiefly those in different fields of biology, maintain either that these mutations are changes of minor importance, mostly abnormalities or actual defects which can be of little use in evolution, or that their occurrence reflects an abnormal state of the germ plasm caused by the hybrid ancestry of the mutating species, or resulting from adverse environmental conditions. In favor of these criticisms one must admit that most of the mutations that have appeared in the laboratory have been abnormalities and defects, and that few if any are such as would help the organism in the struggle for existence. On the other hand, we are now certain that the germ plasm consists of chromosomes with a highly complex but definite and regular chemical structure. Hence the most logical method of reasoning from our present knowledge is to assume that permanent changes of the germ plasm are brought about by changes in the chemical structure of a chromosome at some point along its length. Such changes would produce the visible effect now called a gene mutation.

Chromosome mutations involve changes either in the chromosome *number* or in the *gross structure* of the chromosomes. The former consist either of the addition or subtraction of a single chromosome, or the doubling of the entire set. For instance, the broad-leaved mutant of the evening primrose has fifteen chromosomes, one more than the wild type. It can be produced when, in the meiosis of the normal form, two adjacent chromosomes stick together and pass to the same pole of the spindle. By this means a gamete containing an extra chromosome is formed which, uniting with the normal gamete, produces the mutant. This type of mutant cannot breed true, since the extra chromosome cannot pair regularly at meiosis, and hence is of no importance in evolution. The doubling of the chromosome set, known as *polyploidy*, occurs frequently in plants, although it is rare in animals. Plants with this double number of chromosomes are usually larger and more robust than, but otherwise similar to, the plants from which they arose. The most important type of polyploidy, that accompanying hybridization, is discussed below.

Mutations which depend on changes in *chromosome structure* are of several different types. There are mutations due to the fragmentation of one or more chromosomes, to the translocation of a segment of one chromosome to another, to the interchange of the segments of two chromosomes, and many others. The great frequency of this type of change has been recently demonstrated most strikingly in two different ways. In the first place, these changes have been produced artificially in great quantities by the action of X-rays, sudden changes of temperature, the aging of seeds in plants, and various other agencies. Secondly, by means of hybridization experiments many changes in chromosome structure have been produced which correlate with changes in the appearance of the organisms. The fruit fly, the most important animal in modern genetic research, has proved a fine object for this type of study. Its larvae, in common with those of other flies, possess a number of giant cells in their salivary glands, in which the enormous chromosomes are over 100 times as long as those in normal cells. Furthermore, although these cells are in a permanent resting condition, the chromosomes in them are not only evident, but in addition are closely paired as at the beginning of meiosis. Hence each chromosome can be compared with its mate in every detail, and even the most minute structural differences between them are clearly seen under the microscope. Many kinds of changes in chromosome structure have been observed, and study of them has shown that the various species of fruit fly differ from one another as a result of structural changes in their chromosomes, and even within certain species there are many races differing from each other in this fashion.

The importance of chromosome changes in evolution cannot at present be estimated. There is now at least one undoubted instance of a visible change in the organism produced directly by the inversion of a piece of a chromosome, and in several instances gene mutations appear to have accompanied the breaking and rearrangement of chromosome segments. In addition, some of the well-known "gene" mutations are now known to consist actually of the rearrangement, the reduplication, or the absence, of a very small part of a chromosome. On the other hand, some races of the fruit fly that cannot be told apart by their external appearance have been found to differ in the arrangement of their chromosome parts, so that we know certainly that such rearrangements occur frequently without changing the appearance of the organism. One important result of these rearrangements, however, is that the accumulation of a large number of them makes the pairing of the chromosomes difficult, so that hybrids between two races differing in this fashion, even though their parents look much alike, are often more or less sterile. Hence two races may by this means become isolated from each other genetically, so that they can evolve independently even though they inhabit the same region. (See below for a discussion of genetic isolation.) There is no doubt, therefore, that chromosome mutations play a considerable rôle in the multiplication and diversification of the species of a genus, but whether they themselves can produce much that is actually new is not known.

The Rôle of Mutation in Evolution.—Although the production of hereditary changes in the organism has been observed innumerable times in the laboratory, evolutionists are not agreed that these observed changes are of the same order as those which have in nature produced new species and varieties. The skepticism of many scientists is based on two facts. First, the great majority of mutations observed in the laboratory are detrimental to the organism, and none of them have brought a species any nearer to one of its relatives, i.e., in no case has an experimenter reproduced by means of mutation even the first step of some path of evolution that has been followed in nature. Secondly, the genetic differences between any two natural species, although they are inherited in Mendelian fashion, are not quite the same as those between a normal and a mutated race of a laboratory organism. Most of the laboratory mutations have produced some marked change in a single step, while most differences between natural species and varieties are inherited according to the "multiple factor" principle, which points to their development by means of an accumulation of slight changes. Furthermore, the observed mutations have in most cases affected predominantly a single organ, whereas most of the genetic differences between species involve a number of organs almost equally. Typical laboratory mutations in animals are the loss of wings, reduction in size of the eye, shortening of the legs, and the like, while the differences between species are such things as the average size of the body as a whole, the proportional lengths of the various bones, and such general characteristics as the type of food required and the average intelligence.

This discrepancy between observed mutation and the known course of evolution is explained partly by the fact that the geneticist sees and breeds those changes that are most striking to the eye, i.e., marked changes of a particular organ. On the other hand, the slight mutations that by their accumulation would produce the known differences between species are almost impossible to detect, since just as great changes can be produced by the segregation of genetic factors already possessed by the organism. In some exceptionally pure genetic lines of plants, particularly snapdragons and tobacco, indications have been found that these small mutations affecting several characteristics at once actually occur more frequently than do the large, obvious changes, but this evidence is as yet not definite. At present, therefore, we can merely say that since the only known way of producing differences that are inherited in Mendelian fashion is by mutation, the differences between species and varieties were probably initiated in this manner, although the type of mutation responsible for evolutionary changes is not well understood.

Although a direct attack on the problem of the rôle of mutations in evolution is at present fraught with almost insurmountable difficulties, a new method of indirect attack on it is being rapidly developed with great success. This is the combining of genetics with a study of the development of the organism, in order to discover the relationship between genes and the characteristics for which they are responsible.

As a result of studies of this sort, many evolutionists are beginning to think of the organism as the end product of a long chain of chemical reactions, each of them highly complex, but all coordinated and following each other according to a well-defined pattern. The functions of the genes are connected with the regulation of these reactions and the production of the final pattern. Some of them affect only that part of the pattern that is concerned with the production of a single organ; others affect all of the reactions that are taking place at a particular time; but most, if not all, of them have their principal activity confined to some particular period in the development of the organism.

For instance, there is a mutation in fowl, known as the creeper, which results in a short-legged bird. A study of the development of this bird has shown that a sudden retardation of all of the metabolic processes controlling its growth occurs at one particular time, and this time is just when the leg buds are growing most actively. There is another case, a series of mutations of a certain gene of the fruit fly, all of which produce a greater or less degree of reduction in the size of the wings together with a distortion of their shape. These mutated genes stop the normal growth of the wings at some point in their development. Those that come into action early produce great degeneration of the wings, while others that do not act until later produce relatively little change from the normal fly. The effects of these various mutations have been exactly reproduced in genetically normal flies by subjecting them to sudden changes of temperature at particular times in their development. By this means the experimenter can produce a copy of any one of these mutations that he wishes, although this change is not of course inherited, since the germ cells are not affected.

We are now in a position to understand the underlying difference between the average laboratory mutation and most changes of evolutionary significance. The former acts by retarding or actually inhibiting one or more of the chemical reactions necessary for the production of the mature organism, while most evolutionary changes alter, apparently by gradual steps, the *pattern* of these reactions. Hence scientists are looking hopefully for a solution along these lines of the riddle of how evolution has taken place.

The Causes of Mutation.—These changes of the germ plasm occur naturally with great frequency, but what causes them is as yet little known. They can be produced in the laboratory by a number of agencies. The most notable of these is X-rays; but several other factors, such as extremes of heat, high concentrations of ultra-violet rays, aging of seeds in plants, and the growth of plants under unfavorable conditions of nutrition, can also produce mutations. In every one of these treatments, however, mutations are obtained only when the conditions are so severe that most of the organisms subjected to them die. Hence the production of mutations by these agencies under natural conditions is probably not an important factor in evolution, although the fact that the mutation rate as well as the amount of natural selection is increased by adverse conditions is probably of considerable significance. An interesting fact is that chromosomal mutations as well as gene mutations can be produced by these agencies. This suggests that the natural causes of these two different types of changes in the germ plasm are, if not actually the same, at least a good deal alike.

Perhaps the best explanation of natural mutation that can be given at present is that the chromosome has a complex molecular structure which, like many complex chemical compounds, is in a more or less unstable condition. Hence a change of its structure at any particular point can occur either spontaneously or under the influence of external agents, and this produces some particular change in one of the chemical reactions controlling the development of the organism. However, such postulates are at present little more than scientific guessing, and future discoveries may give us quite a different conception of evolutionary change.

The Importance of Isolation in Evolution.—Although mutations of the germ plasm, acting along with natural selection, are probably chiefly responsible for the adaptation of organisms to their surroundings, they do not explain the enormous diversity of the world of living organisms. Why should there be thousands of different species of flies or fishes in the world, and scores of them inhabiting the same small patch of land or sea?

The differentiation of a new species depends on the accumulation, within a group of individuals, of a number of differences by which the members of this group can be distinguished from all of their relatives.

Before this accumulation of differences can take place, an individual or a group of individuals must be prevented from sharing with any others outside their group the new characteristics that appear, either by mutations or by new combinations of genes, in their germ plasm. For this purpose another evolutionary factor must be postulated, namely, *isolation*. By isolation we indicate any influence which prevents free interbreeding between closely related organisms. There are several forms of isolation, but the two most important are *geographic* and *genetic* isolation.

It has already been noted in Chapter XIV that geographic isolation of certain animals on the various islands of the Galápagos Archipelago has apparently resulted in the evolution of species peculiar to each island. It is a notable fact, furthermore, that in mountainous regions there are always many more species of animals than in flat ones, and that such regions are generally the centers of distribution in which many species of organisms appear to have had their origin. The high mountain ranges effectually shut off the members of a species in one valley from those of another, with the result that they do not interbreed and hence are likely to undergo different courses of evolutionary change. For instance, many groups of animals and plants, such as the pheasants and other wild fowl, as well as wheat and oats, are believed to have originated in the mountainous country of Central Asia. The high Andes of South America are the center of distribution for many groups of plants, including that to which tobacco belongs and the wild ancestors of the potato, while many other groups center around the mountains of the western United States. There are about fifteen species or subspecies of squirrels and about eight of cottontail rabbits in the eastern United States, while in the west there are about thirty forms of squirrels and twenty-three of cottontails. In many instances valleys only a few miles apart and having almost identical climates, but separated by ranges and peaks where the climate is essentially arctic, have several species of plants and animals peculiar to them; and, similarly, isolated peaks and ranges will possess species characteristic of them alone.

Geographic isolation is seldom entirely permanent. Changes in climate and geography or exceptional migrations will usually bring two isolated groups into contact once more. Then they will interbreed and the differences between them will be wiped out unless genetic isolation, that is, sterility between the members of the two groups or in their hybrid offspring, has developed. The differences between the races of man are doubtless the product of geographic isolation; but since, during the course of this isolation, sterility has not developed between these racial groups, racial lines begin to disappear as soon as two human races come into contact with each other, although, in the human species, social barriers against intermarriage usually retard the amalgamation to a certain extent.

As a general thing, biologists do not consider that separate species have been formed until genetic isolation—that is, interspecific sterility—has developed.

Genetic isolation may develop after geographic isolation has produced marked differences between the two groups, or it may develop suddenly, by means of a single mutation, without greatly changing the other characteristics of the mutant group. For instance, two races of a certain species of fly are so alike in appearance that they cannot be distinguished at all on the basis of external signs; yet when they are crossed, the hybrids are not only sterile but have imperfectly developed ovaries and testes. In the future course of evolution, these two races may undergo entirely different courses of development, with the result that two entirely different species may be formed, even though they live in essentially the same environmental situations.

Genetic isolation resulting in sterility between two groups may lead to an almost immediate differentiation into two species. A single family may be genetically isolated from its relatives, thus practically forcing inbreeding among the members of this family. By this means recessive mutations which have occurred previously but have been "swamped" by mixture with normal strains can appear. If these are not harmful to the organism and therefore eliminated by natural selection, they will breed true and be perpetuated; hence a new species can be evolved without further mutations.

In some instances, isolation over a long period of years has failed to result in the formation of new species. The common

May apple, and various other plants as well, have been isolated on separate continents for millions of years, and yet have not evolved enough differences for botanists to be able to tell them apart. Isolation only sets the stage for evolutionary differentiation. The vicissitudes of mutation and natural selection must then enter into actually bringing about the differentiation.

The Theory of Preadaptation.—On the basis of the knowledge that mutations are rather frequent occurrences and that they modify the organism more or less at random, evolutionists are now considering more and more important a modification of Darwin's theory of natural selection. This is the theory of *preadaptation,* or, as one zoologist has very aptly put it, "the selection of the environment by the animal." This theory would explain evolutionary change by adaptation to a new environment somewhat as follows: Imagine a species of fish inhabiting a large lake with muddy shores in the days before the advent of land animals. These fish normally can escape from their enemies by their rapid swimming, and their swim bladder is relatively little developed, as is true of most fishes. Among the mutations occurring in this species of fish there appears by chance one which swims more slowly than its fellows, but which has a larger swim bladder, capable of holding a greater amount of air than those of its fellows. This fish would, on account of its slowness, be particularly open to attack by other carnivorous species of fish in the middle of the lake, but, on account of the greater air-holding capacity of its swim bladder, could gain protection by lying under the mud at the shore of the pond and occasionally breathing air. If it adopted this different mode of life, it would have little chance to breed with its fellows and so perpetuate its line; but in case two of the thousands of fish in the lake possessed similar mutations, they would be drawn together by their mode of life, and would very likely mate with each other, thus perpetuating their peculiarities. By this means a shore-inhabiting, partly air-breathing race of fish could be established which, if suitable gene or chromosome mutations occurred in it, could become sterile in crosses with the fish still inhabiting the center of the lake, and therefore would be a genetically isolated, distinct species. Suppose, then, that the climate of the region became drier and drier, and the lake gradually dried up. The newer shore-inhabiting species would increase at the expense of the older, purely aquatic one, and would become the dominant species of fish in that region. The way would then be open for a further conquest of the land in a similar manner.

This theory could be applied to plants as well as to animals. Imagine the same lake filled with a species of green algae. These plants are adapted for rapid growth, but cannot resist desiccation. Among the mutations occurring in the species, however, could be plants in which the cell walls became abnormally thick as the plant developed, thereby retarding growth, since much of the carbohydrate formed by photosynthesis would be built up into cellulose rather than used as energy to promote growth. Such a mutation is actually known to exist in the columbine, and could occur in any plant. The spores bearing this mutation would have no chance of developing in the middle of the lake, since the young plants produced by them would soon be overtaken and crowded out by the normal sporelings. However, if any spores bearing this mutation should germinate near the shore of the lake, where the sporelings were partly exposed to the air during dry weather, the thickening of the cell walls would enable the mutated plants to resist desiccation while the normal ones perished. Their subsequent history would be much the same as that of the mutated fish.

One great asset of the theory of preadaptation is that it explains one set of facts that are very difficult to understand from the point of view of simple natural selection, i.e., the presence of rudimentary and vestigial organs. For instance, the sightlessness of cave-inhabiting fishes could be explained as follows: Imagine a stream inhabited by a species of fish in which mutations producing blindness sometimes occurred. These blind fish would normally perish when still minnows, since they could not see to escape from their enemies. But suppose that a tributary of the stream flowed through a cave. This cave would not be inhabited by normal fish, because food in it would be difficult to see and capture. But if one of the blind mutants should chance to swim into the cave, it would be protected by its invisibility, and therefore would survive by remaining in the cave. Then, if during its lifetime another blind fish should similarly seek refuge in the cave, the two could mate, and a new race of blind fish would begin its existence. The theory of preadaptation is, of course, only a slight modification of natural selection as conceived by Darwin, but emphasis on it serves to answer many of the objections which have been raised to the Darwinian theory, and brings it into better accord with the findings of modern genetics.

The Rôle of Hybridization in Evolution.—Aside from spontaneous mutation, *hybridization,* or the crossing of different varieties and species, is undoubtedly the most important agent in causing the variations with which natural selection works. It can act in two different ways. In the first place, the crossing of closely related varieties and races, which are fertile when crossed but which differ in a number of gene factors, will produce new combinations of genes. If any of these combinations are particularly well adapted to the environment in which they are found, they may overcome their parent stocks in the struggle for existence and thus cause a new race to supersede an old one. In other words, the process of cross breeding and then selecting the best of the progeny, a process which man has found the best for improving his domestic animals and cultivated plants, has been used also by nature in making organisms better fitted to the environment. In fact, the whole sexual apparatus, with its carefully designed methods of securing cross fertilization, is valuable only in that it results in these new combinations without which a species or race becomes stagnant and can no longer adapt itself to a changing environment. Those organisms, such as the dandelion and some plant lice, which have given up sexual reproduction entirely, are flourishing at the present time, but they have come to the "end of their rope" from the evolutionary point of view, and if conditions should change very much in the regions where they are found, they would quickly succumb.

Hybridization is much more important in evolution, however, in that it is a cause of the abnormalities in meiosis which result in chromosome mutations. One way in which this happens has already been described in a previous chapter in the case of the mule. The chromosomes of the dissimilar parents cannot pair properly and so do not go to the equator of the spindle together, do not separate normally, and may be thrown out of the spindle completely. The resulting gametes are almost all sterile, but may occasionally function, even though they have not the normal chromosome number. By this means a second generation with a different chromosome number is produced.

The Formation of Polyploid Species.—The best-known chromosome change produced by hybridization is the production of a new species with two or three times the number of chromosomes that its parents have. Such a species is known as a *polyploid.* Polyploid species are very common in the higher plants, though rare in animals. Roses, chrysanthemums, and clovers are famous examples. For instance, there are roses with 14, 21, 28, 35, 42, and 56 chromosomes. All of the types with higher numbers are derived from those with fourteen, chiefly through crossing. While man has created hundreds of races by cross breeding and artificial selection, nature has produced an almost equal number of wild species by spontaneous crossing and natural selection.

The evidence that such polyploid species are produced chiefly by hybridization has gradually accumulated with the creation of one after another of new species of this type experimentally. About forty of these experimental species of plants have been produced, and there is one case in animals, i.e., butterflies. One of the most famous group is that which resulted from the crossing of the radish and the cabbage, since in this case the parents were of different genera. The first-generation rado-cabbage offspring had 18 chromosomes, as did their parents, but were almost completely sterile. They produced occasional viable gametes, many of which, on account of the complete failure of the reduction division, had the chromosome number of 18. From the union of two such gametes a plant with twice the normal number of chromosomes, or 36, resulted. This plant was quite fertile, since the radish chromosomes could pair with each other, as could also those derived from the cabbage. Although considerably more variable than its radish or cabbage grandparents, it bred true to a general intermediate character, and could be considered a new species, particularly since it could not be crossed easily with either the radish or the cabbage. By different combinations of gametes with 9 and those with 18 chromosomes a number of different intermediate, fertile types were produced, all of which, except for minor variations, bred true and could be considered distinct species. That this same process can take place in nature has been demonstrated by the artificial synthesis of a known wild species from two others.

One very interesting case in which this process is known to have taken place in nature is that of a marsh grass, known as *Spartina Townsendii.* This grass was first noticed in the harbor of Southampton, England, in 1870, where it grew alongside of the typical European species and one characteristic of the American coast, which had been introduced in that locality, presumably by transatlantic vessels. *S. Townsendii* soon demonstrated its vigor, however, by spreading rapidly along the shore and out into the harbor, where it formed clumps around which soil collected and thus actually built up new land. Its value as a soil holder and land former was quickly recognized, and it was carried to many parts of the world, particularly along the dikes of Holland. Botanists were at first puzzled by the sudden appearance and spread of such a vigorous species, and the fact that it possessed characteristics intermediate between the two species with which it was first found, led them to suspect a hybrid origin for it. Recently an examination of its chromosomes has shown that *Spartina Townsendii* has just as many as those of the European marsh grass and of the American one added together. Hence there is now no doubt that it is a polyploid form derived from the crossing of these two species. Here hybridization in nature has produced a vigorous, self-perpetuating species which has, moreover, actually changed the coast line of Europe and has been of great value to man.

Straight-line Evolution.—The types of variation which we have just described have all been found in experiments and, by those who approach evolution from the experimental point of view, are considered to be the only types of variation found in living things. Nevertheless, students of evolution who have obtained their evidence from fossils and from comparisons of different living forms which seem to show the course of evolution through the larger divisions of the animal and plant kingdoms, apparently see a different type of variation acting as the moving force of evolution. They are not satisfied with the *random* variations that the experimenters describe, but believe that each one of the main lines of evolution is guided by variations of the germ plasm in a definite direction which is determined by the nature of the germ plasm of that line. Such directed, progressive evolution is known as *orthogenesis*, or straight-line evolution.

The evidence for orthogenesis consists mostly of series of fossils which show a gradual, continuous progression toward a certain type. The best example of such a series is found in the evolution of the horse. As far as we know, the evolution of the horse from its diminutive ancestor has proceeded in a straight line with regard to every characteristic. No fossil horse yet discovered shows any features which are not intermediate between those of the earliest horse ancestor and the modern horse. Furthermore, horses appear to have evolved independently on both sides of the Atlantic and both the American and the European horses followed the same line of evolution.

A more convincing type of evidence for this mode of evolution lies in the apparent overdevelopment of many organisms, both fossil and living, in certain characteristics. The Irish deer evolved huge antlers which, as far as we can see, did it no good whatever and apparently were the cause of its extinction. Of the same nature were the huge tusks of the Columbian mammoth, and in the present-day animals the numerous curving tusks of some wild boars and the enormous horns of a few species of bighorn sheep.

These latter cases have, however, been interpreted from the point of view of random mutation and a type of natural selection. For instance, the fact that male deer fight for the possession of the does is well known. Therefore a mutation producing larger antlers would give a buck an advantage over his fellows, and a particularly good opportunity for passing on this mutation. By this means, random mutations for larger antlers could, over a large number of generations, accumulate until the antlers became so large that their owners could not escape from their natural enemies, and the extinction of the race could thus be effected. In fact, a prominent contemporary evolutionist has brought forth this argument to refute the statement, frequently made, that the struggle for existence is always a benefit to a race or species.

The concept of orthogenesis, if examined carefully, is not so directly opposed to that of mutation and natural selection as one might think. Mutation, as conceived at present, depends on the innate ability of the germ plasm to vary; orthogenesis, on the ability of a particular type of germ plasm to vary in a definite direction. The orthogenetic development of certain characteristics, such as the feet and teeth of the horse, could be accompanied by random mutations in other characteristics which, if they were valuable to the organism in its particular environment, would, of course, be selected. Hence the existence of random mutations does not preclude the possibility of other directed ones.

The great difficulty with the theory is, however, that as yet we have never observed a series of mutations progressing in a definite direction such as orthogenesis would call for. For that reason we cannot say that orthogenesis is more than an interesting possibility and, if we are bold enough, we can consider it as a working hypothesis on which to base future experiments. Random mutation followed by natural selection and hybridization gives us a much simpler explanation; and it is a well-known principle in science that one should apply the simplest explanation of any phenomenon that will fit the facts.

Actually, the recently developed concept of mutations as changes in the pattern of development has suggested an explanation for the facts produced by the supporters of orthogenesis which completely reconciles them with the hypothesis of random mutation. This is the fact that, although many changes in the developmental pattern of organisms are possible, most of these produce an "unworkable" system that results either in death, or in the production of an abnormal, weak, or degenerate organism. Most of the other changes are of no value to the organism, and therefore are very unlikely to be perpetuated. The changes most likely to lead to success in the struggle for existence are those which exaggerate or modify some special adaptive structure which the organism already has. Hence the "orthogenetic" evolution of some special structure may be merely the result of random mutation and natural selection acting along one of the few lines open to these processes.

Chapter Summary

The oldest theory of evolution, that of Lamarck, stated that evolution proceeds by the acquisition of new characteristics by organisms through the action of their environment and the inheritance of these characteristics. The theory is now largely discredited because of lack of evidence in favor of it. Experiments designed to demonstrate the inheritance of mutilations, adaptive acquired variations, and mental characteristics have been tried many times and have with a few uncertain exceptions resulted in failure. Furthermore, the separate condition of the germ cells in animals makes the inheritance of most acquired characteristics quite impossible.

Darwin's theory of natural selection is widely accepted at present, but modern biologists restrict the types of variations which may be the basis for natural selection. The variations accepted are chiefly of the type known as mutations, that is, sudden random variations that are inherited. These mutations were first brought to the attention of evolutionists by DeVries, who believed that species arise full-fledged in this manner.

Two types of mutations are now recognized, gene mutations and chromosome mutations. The former consist of changes in a single gene which are inherited in a Mendelian fashion. Most gene mutations which have been observed in the laboratory have produced abnormalities or defects; but as the only known method for producing a permanent change in the germ plasm, their importance is great.

Chromosome mutations or chromosomal aberrations consist of changes in either the number or the structure of the chromosomes. The most common changes in number are either the addition or subtraction of a single chromosome, or the doubling of the whole set. The various changes in chromosome structure—fragmentation, translocation, interchange, and reduplication—can be produced artificially in many ways, and are known to occur frequently in nature, being particularly evident in the salivary gland chromosomes of certain flies. They are of some importance in producing directly visible alterations of form, but are probably more important in producing genetic isolation.

The difference between the observed mutations of laboratory organisms and the genetic differences between natural species is that the former involve chiefly marked changes of one or two organs, while the latter are made up of many small differences involving several organs about equally. Expressed in terms of the pattern of chemical-physical reactions that bring about the development of the organism, the laboratory mutations retard or inhibit one particular process, while interspecific differences involve differences in the general pattern. Mutations may be produced in the laboratory by means of X-rays, extremes of temperature, and other agencies, but their natural causes are largely unknown.

In order to produce the accumulation of differences necessary for the formation of a new species, the isolation of a group of individuals from all related groups is necessary. The most effective types of isolation are geographic and genetic. The former is particularly effective in mountainous and insular regions, and partly explains the relatively large number of species present in such regions. It does not always result in the evolution of species, however. For this, genetic isolation, or the presence of sterility in the hybrids between two groups, is usually necessary.

A modification of the theory of natural selection is that of preadaptation. This theory states that the modification of an organism which would adapt it to a particular environment occurs before it enters that environment. This modified theory of natural selection is helpful in explaining such problems as the apparent reduction of structures through disuse, as exemplified by the blind animals of caves.

Hybridization is important in evolution, first, because it produces new combinations of genes which may be selected and perpetuated. Secondly, it may produce the abnormalities of the reduction division which result in chromosome mutation. The production of polyploids, or species with two or three times the normal number of chromosomes, has often been accomplished by hybridizing. A good example is the cross between the radish and the cabbage, from which three distinct fertile, true-breeding strains have been derived. Known wild species have also been produced in this manner from other wild species. The existence of many species and varieties with polyploid chromosome numbers in a large proportion of genera of plants is evidence of the importance of this process in plant evolution.

Students of fossils and of the larger groups of living organisms have developed a different concept of variation from that of random mutation, and hold that evolution is guided by variations of the germ plasm in a definite direction. This is the theory of orthogenesis. Evidence for it is the existence of fossils apparently demonstrating this process, such as the continuous series of ancestors of the horse and the apparent overspecialization of many fossil and living organisms. The theory, however, lacks the basis of definite experimental evidence for it, and, furthermore, is a complex explanation for phenomena which may eventually be explained in a simpler way.

QUESTIONS

1. Compare Lamarck's and Darwin's theories of evolution, stating the principal evidence for and against each and the importance of each in the modern concept of evolution.
2. Define mutation and distinguish between the two different types.
3. Using examples, describe gene mutations and give an estimate of their probable importance in evolution.
4. Describe briefly the various types of changes in the chromosome structure, and the method of identifying them in the fruit fly, and discuss their importance in evolution.
5. Tell what you know of the natural and artificial causes of mutations, and of their importance to evolution in general.
6. Discuss the two most important types of isolation and their importance in evolution.
7. In what way does the theory of preadaptation modify that of natural selection, and what is the value of this modification?
8. Using examples, explain two ways in which hybridization may further evolution.
9. Define orthogenesis, and give evidence for and against this theory of evolution.

GLOSSARY

chromosome mutation A sudden heritable change in an organism which is caused by a change in the number or structure of its chromosomes.

gene mutation A mutation caused by a change in the constitution of a single gene.

mutation The production of an offspring differing from its parents in characteristics which are heritable.

orthogenesis (or-thō-jen'e-sis) The variation of organisms progressively in a definite direction.

polyploid (pol'i-ploid) An organism possessing a multiple of the characteristic number of chromosomes for the group to which it belongs.

somatoplasm (sō-ma'tō-plaz'm) All the cells of the organism except those that develop into gametes.

CHAPTER XVII

HUMAN EVOLUTION

Man's Place in the Animal Kingdom.—As has been said before, the evolution of man from his ape-like ancestors is only a small part of evolution as a whole, but, to us, it is a very interesting part.

First let us orient ourselves as to man's position in the animal kingdom and learn something about his nearest living relatives. Man belongs to the subphylum of vertebrates, or backboned animals, and to the class of mammals, the evolution of which we have already discussed. The particular order of mammals to which man belongs is known as the primates. The members of this order do not possess any very marked characteristics which distinguish them as a whole, as do such orders as the carnivorous mammals, the ungulates, the bats, and the rodents. Instead, the primates have gone in for a rather unspecialized bodily form, which is probably one reason why a large, inventive brain, which could devise tools to supplement the disadvantages of an unspecialized body, was of particular value to them, and hence was strongly developed by natural selection. The following characteristics are, nevertheless, typical of them and taken together serve to distinguish them from other orders of mammals. In the first place, primates have paws, or rather hands fitted for grasping. Secondly, in most primates the finger and toe nails are flat, rather than claw- or hoof-like; and finally, most primates have just two breasts, situated on the upper, or thoracic, part of the body.

Man's Living Relatives.—Although the living primates are all the ends of their own particular lines of evolution, we have fossil evidence that our ancestors resembled some of them, and that these, as a whole, have diverged less from the common ancestor of primates than has man. The first primates were a group of squirrel-like tree climbers which appeared about fifty million years ago.[1] These animals, known as lemurs, developed from the rat-like tree shrew that was mentioned in Chapter XIV as being the ancestor of the primates, and resembled this animal more than they do man. A few of these lemurs have survived until modern times on the island of Madagascar, in parts of Africa, and in the East Indies. One, the aye-aye, is not very different from the fossil of the earliest known primate. It is quite hairy, about the size of a large squirrel, and walks along the branches of trees, rather than swinging its way, as do monkeys. Furthermore, its ears, rather than being flattened against the side of its head, as are those of monkeys and men, are large and stick out rather prominently, while its eyes are set more or less on the side of its head and do not look straight forward as do those of the higher primates. All of these characteristics show that the lemurs are a link between the true primates and the simple ancestor of all mammals.

The next group of primates, the monkeys, is rather far removed from our own ancestors, the modern monkeys being at the ends of several long lines of evolution which developed independently of that which led toward man. There are two main groups. The most primitive are the New World monkeys, mostly small animals with long prehensile tails, and characterized by a broad, flat nose which is closely pressed to the face. The capuchin monkey, the familiar organ-grinder's companion, is typical of this group. The Old World monkeys are larger, and never have a prehensile tail. Furthermore, their nose is narrower and more prominent, showing a closer relationship to the apes and man. The mandrill and the baboon are Old World monkeys that one often sees in zoos.

The Man-like Apes.—Man's closest living relatives are the man-like, or *anthropoid,* apes. The four living members of this family are all found in the tropics of the Old World and are fairly closely related to the Old World monkeys. The smallest and most primitive is the gibbon, found in southeastern Asia. This ape is comparatively unspecialized, and hence probably near the earlier common ancestor of apes and man. Its chief marks of distinction

[1] It should be understood that all references to the time at which various stages in the evolution of man and his ancestors took place are merely the estimates most widely agreed upon at the present time. We do not possess exact knowledge of prehistoric dates.

are its tremendously long arms, which, although the animal is only three feet high, have a spread of five feet or more. It is thus well equipped for swinging its way from tree to tree through the forest, and can easily clear spaces of twelve to fifteen feet. The orang-utan, native of the deep forests of Sumatra and Borneo, is likewise a tree dweller, but is much larger and stockier, with hair of a reddish color, and rather sluggish. It is quite intelligent, however, being exceeded among the anthropoid apes only by the chimpanzee. This third member of the family, found in central Africa, is perhaps the most familiar of all. Its black hair and its light face, a grotesque caricature of that of man, are quite distinctive. Chimpanzees flourish in captivity, and have been used for many experiments to test the mentality of apes in comparison with our own. The fourth and largest of the anthropoid apes is the gorilla, also a native of tropical Africa. The gorilla is over five feet high, and with its massive limbs and chest may weigh more than 400 pounds. With its powerful arms, massive jaws, sharp teeth, and sloping forehead, the gorilla is better equipped for fighting than for thinking.

If we compare man with these cousins of his, we find surprisingly little difference in bodily characteristics. The main differences are in the proportions of the various parts, which in man are better fitted to walking upright, and in the apes to tree climbing. For instance, man has proportionately longer legs and shorter arms; and his toes are shorter, and the joint of the large toe is changed, so that he cannot grasp with his foot as can apes. Other differences are in the head, which in man is balanced so that it can be carried erect and can contain his very large brain. The jaws of man are much smaller than those of apes, and the teeth less prominent; and the comparatively high forehead makes the facial angle, or angle formed by the profile of the face, practically vertical, while in apes it is around 45°.

The greatest difference between man and the apes is, of course, in the size of the brain and in intelligence. Man is usually considered in a class by himself as far as intelligence is concerned; and it was the picture of progressive, high-minded, forward-looking man having evolved from the brutish, unthinking apes that was particularly repugnant to the early opponents of evolution. Even here, however, recent experiments have shown that the anthropoid apes very definitely approach man, and that, in intelligence as in physical features, they are nearer to man than they are to the earliest primates. Apes, as do also monkeys, display the exploratory urge and that innate curiosity which in man has led to so many revolutionary discoveries. Furthermore, they show the beginnings of reasoning and insight. A chimpanzee can be taught to use simple tools quite adeptly.

In regard to the emotions, which are sometimes considered man's exclusive possessions, we may say the same thing. A chimpanzee can feel anger, grief, jealousy, joy, affection, and sympathy for his fellow chimpanzees. The social urges, on which our whole moral code is based, are well developed in apes. They readily give aid to injured companions, and are so ready to avenge the death of one of their number that it is dangerous to injure one of a large group of chimpanzees or gorillas.

The Evolutionary History of Man and the Apes.—Considering these resemblances between man and the other primates, we have no reason to doubt that they have a common ancestry. The important problems connected with this part of human evolution are, therefore, the closeness of this relationship and the manner in which the various characteristics peculiar to man were evolved. In this connection, the study of fossil evidence and of comparative anatomy has brought out the following opinions. Soon after the monkeys became differentiated from the primitive lemuroid stock, probably about thirty million years ago, a group of them became adapted to climbing trees in an upright position, using their arms for support and for swinging themselves from branch to branch, rather than walking along the branches on all fours. This differentiated the anthropoid stock from that of the monkeys and was the beginning of the evolution of man in upright posture. Other modifications, such as the loss of the tail, the narrowing of the nose, and the development of a vermiform appendix, were probably evolved about the same time. One group of these early small anthropoids developed their arms more and more, and evolved into the gibbon. The other went in for increased bodily size and brain capacity, becoming less adapted for tree climbing. Then, about fifteen million years ago, some of these large anthropoids began to develop a larger and larger brain. This enabled them to use tools and finally fire, and to develop a social organization, so that arboreal life was no longer necessary for defense. Life became possible for them in regions less bountifully supplied than the tropical forests with easily accessible food. What caused the evolution of man's superior brain is not known, but one suggestion seems very plausible. We know that at the time when this evolution occurred mountain ranges were being built up in many parts of the world, particularly in central Asia, and that the climate of the earth began to get cooler in anticipation of the Great Ice Age. The whole history of man's divergence from the anthropoids, therefore, is associated with conditions which favored the disappearance of tropical or subtropical forests. Under these conditions the struggle for existence among forest dwellers would obviously become excessively keen, and any of them which could become adapted to life in the open would have a greater and greater chance for survival. The anthropoids had undoubtedly the greatest intelligence of any animals then living, but no other characteristics which could be modified to enable them to live in the open; that is, they could not develop the strength, the sharp teeth, and claws of the tiger, the size of the elephant and rhinoceros, the fleetness of the deer and antelope, or the burrowing ability of rodents. Hence any mutations producing greater brain power gave their possessors an increasing advantage in the struggle for existence outside of the tropics. All apes which did not develop these mutations had either to migrate to the tropics, probably already crowded with anthropoids, or perish. This provides a good example of the effect of a changing climate on evolution, as mentioned in a previous chapter.

The Man Family.—The family of man, then, is, biologically speaking, fairly closely related to that of the apes. It consists of but one living species, as all of the various races of man are interfertile and have the vast majority of physical characteristics in common. In past ages, however, various other species of our own genus, Homo, existed, and there were a few other genera belonging to our family.

The First "Missing Link."—People often talk about the "missing link" which connects the apes and man, and suppose that the discovery of the remains of such an animal will clear up the mystery that shrouds our origin. As a matter of fact, man and the apes are not connected by a chain of known forms which will be complete when one or two gaps are filled in; what we actually have is the rusty remains of a few links of a chain that contained many thousand. Man-like and ape-like animals were being evolved side by side for millions of years before they developed into modern apes and modern man, and all that we know of these animals is what we can gather from a few fragmentary skeletons, and from the tools that man's ancestors made and discarded.

The reasons that fossil remains of man's ancestors are so rare are several. In the first place, these ancient primates were largely forest dwellers, living in places where the struggle for existence was so keen that any dead body would quickly be attacked by other animals, and finally be completely disintegrated by bacteria and molds. Man and his ancestors were too clever to be caught in the quicksands, tar pits, and quagmires that caught so many of his contemporaries in the animal kingdom and preserved their fossils for our study. Besides, there is evidence that burial customs developed early in the prehistory of man and that bodies were either burned or exposed in places where they easily became disintegrated. The only places where fossil remains of man or of apes are found are in river sands, in which unfortunate victims of drowning were soon buried, and in caves, which formed the dwelling places of some of the earliest men.

There is still considerable doubt as to where man first appeared. Some scientists believe that Africa is the "cradle of the human race," but there is more evidence pointing to Asia as the continent which produced the first men. In south central Asia, and in no other part of the world, are found the fossil prototypes of all four of the modern anthropoid apes. No fossil men have been found in just this region, but it has been comparatively little explored for fossils.

The species which has been considered the direct ancestor of man, the Peking man described below, lived in eastern Asia; and perhaps explorers in other parts of the same continent, particularly western China and Tibet, will discover remains which will tell us what his and our ape-like ancestors were like. The remains that we know are all of species that appear to have migrated outward from this center, and from time to time invaded various parts of the globe.

The earliest fossil remnant which has any human characteristics is the skull of a child discovered in Bechuanaland, southern Africa, and known as the Taungs skull. This Taungs child, who lived about ten million years ago, was certainly a mixture of anthropoid and human characteristics, and is called by some scientists an ape and by others a man. The brain was small, and when fully developed would have been hardly larger than that of modern anthropoids. The shape of the base of the skull, however, indicates that its possessor belonged to a tall, upright race; the forehead was relatively high, the jaw did not protrude as do those of the apes, and the eyeteeth for fighting, so characteristic of modern anthropoids, were absent. Although the evidence is as yet too scanty to give us a real picture of the Taungs being, the discovery of this skull provides evidence of the existence of ape-like forms which had started to evolve in the direction of man some fifteen million years ago.

The First True Men.—For the next nine million years, the fossil record of the evolution of man is a complete blank; but at a period which may be placed at about a million years ago, traces of the man family again appear, and there can be no doubt that they were left by beings that were truly men, although they were so primitive and ape-like in many of the features of their anatomy that they are not classed as belonging to our species. One piece of evidence that makes it certain that they were true men is that they possessed a *culture*. Culture is the thing that most definitely marks the human species off from all other animals. It may be defined as the sum total of all the traditional ways of behaving and thinking that have been handed down to us by our ancestors. These traditional ways of behaving and thinking include the making of tools; the carrying on of agriculture, industry, and commerce; the observance of religious rites and moral laws; and all the behavior and thought that are involved in art, science, and the maintenance of political and legal institutions.

Whatever an animal may learn during its lifetime about adjusting to its environment dies with it. The animal cannot pass its discoveries on to its descendants. But what an individual man learns may be imparted to others, and thus become a part of the traditional manner of getting along in the world that is followed by all the members of a human society. Language is the instrument that men use to pass cultural tradition on from generation to generation. It is the chief basis for the difference between human and animal life; and when we study the brains of apes and men, we find that the part that in man is specially concerned with speaking shows scarcely any development in the ape.

If our classification of man as an animal has seemed to be a derogation of man's true dignity, this feeling is to a certain extent justified. To be sure, any organism that ingests its food before digesting it is an animal, and therefore man belongs in that class of organisms. But man is a very unique animal, differing greatly from the "dumb" brutes, who have no language. For his language has enabled him to build up a cultural life which, as it has evolved, has become civilization. All the things that we feel most proud of, that seem to us to mark us off from the beasts, are aspects of culture.

We now believe that life has evolved from inorganic beginnings. But when life did come into being, something with entirely new properties arose. A definite boundary line was passed. Whenever something possessing entirely new qualities develops in the course of evolution, it is called an *emergent*. Just as life has *emerged* out of the inorganic world, culture has emerged out of the organic world, producing the human quality of living which differs radically from the sort of life that animals lead.

The first indications of true men that we find in the fossil record are the remains of their culture in the form of crude stone implements. At first these implements are so crude that we cannot be entirely certain that they were formed by men rather than the forces of nature. But in the rocks that were laid down approximately a million years ago, we find pieces of stone that show unmistakable evidence of having been formed into implements by human hands. And in four parts of the world, remains of the men who used these implements have been discovered. Three of these finds—one in Java, one in England, and one in east Africa—have revealed only a few skeletal fragments of creatures who were distinctly of the human type, but who were much more like the apes than are modern men. The human beings who left these remains are referred to as the Java Ape Man, the Piltdown Man, and the Kanam Man. The fourth of these earliest known human groups is by far the most important, since it may have been directly ancestral to present-day man.

This species, represented by parts of five skulls discovered in a cave thirty miles from the city of Peking, is known as the Chinese Man of Peking. Since the various skulls were found embedded at different levels in the sediments composing the floor of the cave, this type of man must have lived there for a long period of time, and the species of animals associated with him indicate that he lived about eight hundred thousand to a million years ago. The skulls show a brain capacity considerably lower than that of our species, but the relatively narrow, high brain case is strikingly suggestive of a line of development toward modern man. The lower jaw is definitely man-like, except that the chin is not well developed. The teeth, although very unequal in size, are like those of modern men in shape, and in fact have certain characteristics which have a definite relationship to the modern yellow, or Mongol, race. This, along with certain peculiarities of the jaw, has led certain scientists to the belief that the Peking Man was the direct ancestor of the present-day inhabitants of China.

The cultural remains in the cave show that the Peking Man knew the use of fire, and was able to chip crude ax heads and scrapers out of stones. Furthermore, the complete absence of any bones except those of the skull has shown that the actual inhabitants of the cave buried their dead outside. The skulls found in the cave are believed to be the spoils of head-hunters, indicating that even at the earliest known time of their evolution man's ancestors had learned to kill each other.

Neanderthal Man.—We often hear primitive men spoken of as "cave men." Actually, only the primitive men who left fossil remains were cave men, for human bodies left outside the protective shelter of a cave were almost certain to disintegrate rapidly. The men who lived for hundreds of thousands of years after the time of the Chinese Man of Peking were apparently not cave dwellers, for they are represented by only three fossil finds, a jawbone in Germany, a skull in Rhodesia, and eleven skulls in Java, found close to the spot where the Java Ape Man was discovered. Our chief evidences of human life during this time are stone implements, of which many specimens have been found. It was not until about a hundred and fifty thousand years ago that there appeared a race of cave men in western and southern Europe and eastern Asia to leave a fairly large collection of fossils for the enlightenment of the modern scientist. These forerunners of our

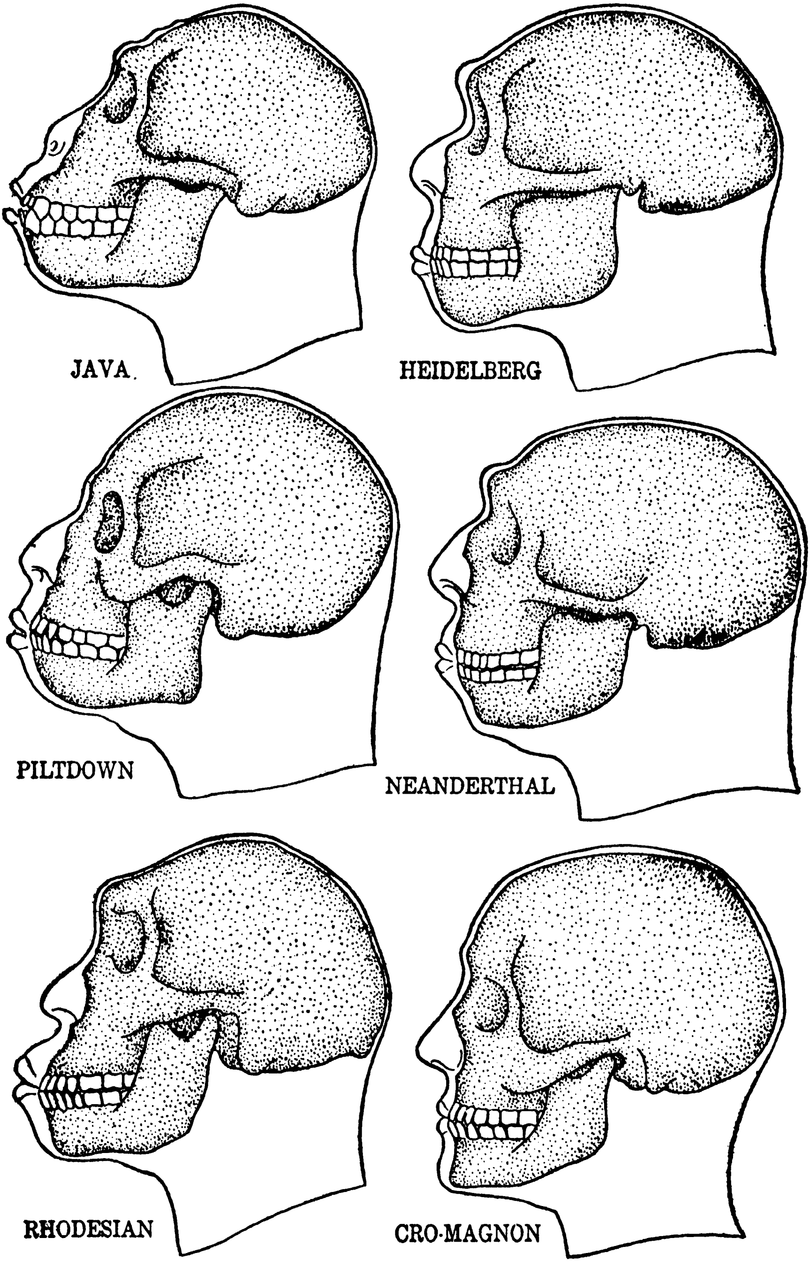


FIG. 88.—Fossil men. (Redrawn from Lull's *Organic Evolution,* The Macmillan Company.)

species are known as the Neanderthal men. They were dwarf-like in stature, but very strong and stocky, with stooped shoulders and receding chins and foreheads. Their brains were as large as those of modern man, but it is improbable that they were as highly developed in the direction of intellectual capacity. Their stone implements were considerably superior to those of their predecessors, and they were successful hunters of the large bison, cave bears, horses, reindeer, and mammoths that lived in Europe at that period. There is even some indication that they believed in an afterlife, for they buried their dead with implements and food at hand.

Cro-Magnon Man.—The Neanderthal men ruled Europe for a hundred thousand years, and then, apparently, they were driven out or exterminated by a new sort of human, tall, with a high forehead and prominent chin, armed with superior weapons and supported by a generally superior culture. This new cave dweller, known today as Cro-Magnon Man, was the first member of our species of whom we have any record. He appears to have lived in Europe up to about twenty thousand years ago, and it is highly probable that he is numbered among our own ancestors.

Not only did the Cro-Magnons have relatively fine weapons and tools; they seem to have been a people with a real love of beauty, for they dressed in furs, wore ornaments of shell and ivory, and painted the walls of their caves with colored pictures of the animals that they hunted. Their art is considered to be of high excellence. They were very tall, and from the physical standpoint they seem to have been one of the finest stocks the human race has ever produced.

Cultural Evolution.—The appearance of the Cro-Magnons marked the virtual end of the biological evolution of the human race. These prehistoric men differed no more from present-day men than the races of man differ among themselves, and these differences between human races are, biologically considered, so slight as to be negligible. Nor can any one of the human races be considered more advanced biologically than any other. For instance, the shape of the skull and jaw of the white man is less like that of the ape than are the skull and jaw proportions of the Negro. But the white man is more like the ape in that his legs are shorter, his lips thinner, and his body more profusely covered with hair. Nor, as we shall see in Chapter XXVI, has it ever been established that one human race is innately superior to any other in intelligence or capacity for developing a civilization.

To many people it may come as something of a shock to learn that, from the biological point of view, they are no whit superior to the Cro-Magnon cave man or the African barbarian. What of our civilization? Isn't that a product of evolution? Yes; but not of *biological evolution.*

The reader will recall that culture is the product of the discoveries made by individuals which become a part of the heritage of the entire race. Early men could not possess as high a culture as our own, since fewer inventions could have been made up to their time. In the course of human history, one discovery builds upon another, and thus a *cultural evolution* takes place that greatly improves the conditions of man's life. This is particularly true of the material aspects of human culture, the tools and machines, and the things which they produce. Not only is each invention built upon its predecessors, but the more inventions there are present at a given time, the greater is the opportunity for and stimulus to new inventions. Because of this, material progress becomes more and more rapid as time goes on.

A few thousand years after the time of the Cro-Magnons, man discovered the advantages of agriculture over hunting as a means of getting a living. The wealth produced through this new mode of life made possible the building of cities, which in turn facilitated intellectual stimulation between man and man, giving a new impulse to discovery and invention. The use of metals was discovered, making possible a vastly higher development of tools and machinery than could ever have been achieved with stone and wood. The art of thinking in mathematical terms gradually improved, the alphabet was developed, and thus it was made easier for man to think and to transmit his thoughts. Thus, with each important advance in invention, new advances were facilitated until, about five hundred years ago in western Europe, a tremendous acceleration of scientific discovery and invention began. Since that time, one invention has followed another with breathtaking speed relative to the rate at which culture developed in earlier years.

It is this rapidly accelerating cultural evolution, rather than any biological changes, such as modifications in our brains, that places us at a higher level of life than was attained by the Cro-Magnons. As for savage and barbarian tribes who have failed to attain our level of civilization, here again there is no reason to believe that biological evolution accounts for the difference between our society and theirs. Rather, failure to be provided with opportunity and stimulation for cultural development seems to account for their relative retardation. And culture has not only provided us with the material benefits which we enjoy. Our art and literature, our political and legal institutions, our religion, and our moral ideas are all a product of cultural development.

The Future of Evolution.—The study of evolution is bound to raise in our minds a final question. What is the future of our race and of the whole world of life? Of course, it is impossible to prophesy; we can only examine the possibilities and consider what might happen. For the next few thousand years at least, the biological future is bound up almost entirely with the future of human culture. The first possibility is that the human race is only sporadically capable of building up and maintaining a complex civilization such as the one we now live in. Many thoughtful persons see signs of decay in our present culture, and it is possible that we shall soon revert to a barbarism in which the great scientific tradition that has been built up in the past few hundred years will be totally destroyed. But if the scientific tradition does not die out, if it continues to maintain itself and grow as it has in the past, we may expect it to wield its great power over nature to speed up the processes of evolution in a thousand directions. New kinds of plants and animals may be brought into being by methods that we cannot even imagine. The human race, through scientific control of its own evolution, may utterly transform itself, producing a population of "men like gods," or, perhaps, a race that, from our present point of view, would appear freakish and monstrous. Evolution has been going on for hundreds of millions of years; the scientific movement has arisen only during the last five hundred years. What science may do to modify life in the millions of years to come, no one can imagine. Mother Nature gave birth to culture when the organism *Homo sapiens* was evolved, but human culture is becoming a very lusty infant, and may in the future shape the destinies of its parent in marvelous and unpredictable ways.

On the other hand, the human race may die out within a few thousand years; but biological evolution will continue, and perhaps some new organism will arise with sufficient intelligence and talent to produce a culture. Perhaps life, either through human or other agencies, will discover means of moving from one planet to another, or even to distant regions outside the solar system, so that it may become immortal, escaping the doom that threatens it when in the long course of stellar evolution our planet becomes cold, and the light of our sun fades into darkness.

Still another possibility exists that, while other forms of life are evolving or being brought into being by cultural interference with natural processes, the human race may persist relatively unchanged for hundreds of millions of years, as a few other forms have done after reaching what seems to be their final stage in evolution.

We can only guess at the future; for, while it may well be that all the events occurring in the great world of life are as subject to the laws of mechanical causation as are the revolutions of the planets, our science of today possesses no means of predicting the course of life processes. Of one thing we may be as certain as of the continuation of day and night. Life will change. In the millions or even billions of years which may remain for life upon this planet, new forms will shape themselves and vanish as living forms have done since life began. But what the nature of those transformations will be, no one can surmise; and having dimly glimpsed the strangely shifting spectacle of the past, we move toward a future full of exciting and unpredictable possibilities.

Chapter Summary

Man belongs to the class of mammals and the order of primates. The members of this order have few marked characteristics that distinguish them, the most important being hands fitted for grasping, a collar bone, flat finger and toe nails, and usually two breasts situated on the upper part of the body.

The chief groups of primates are the lemurs, primitive, squirrel-like animals that form a link between the primates and their ancestors; the New World monkeys, with flat noses and often a prehensile tail; the Old World monkeys, with narrower noses and a non-prehensile tail, the anthropoid apes, which lack tails, and approach man in intelligence; and man. There are four living types of the anthropoid apes: the gibbon, the orang-utan, the chimpanzee, and the gorilla. The physical differences between the anthropoid apes and man are chiefly in the proportions of the various parts. The greatest difference is the greater intelligence of man, although apes are nearer to man in this respect than they are to the most primitive primates.

The differentiation of the human family from the other primitive stocks is believed to have occurred at a time when the tropical forests were retreating; thus an exceptionally intelligent primate might be greatly favored in the sharp struggle for existence in the comparatively cold and treeless regions that were appearing. The first fossil link between man and the anthropoids is the Taungs skull, which apparently belonged to a child possessing such a mixture of human and anthropoid characteristics that its classification is uncertain.

True men are marked off from all other animals by the possession of a cultural tradition which may be considered an evolutionary emergent, since it imparts a quality to human life that is not found in other animals. Stone implements, the first indications of human culture, are found in rock laid down a million years ago or more. There are a few fossil human remains which are dated shortly after the appearance of the first implements, of which the most important are those of the Chinese Man of Peking.

The next important human remains are those of Neanderthal Man, which are found throughout western and southern Europe. While this race had developed a considerable culture, it was not sufficiently advanced to be accounted one of our species.

The first men belonging to our species were the Cro-Magnons. Since their time, there has been no significant biological change in the human race, and human advancement has been entirely a matter of cultural evolution.

If our scientific tradition does not disappear, it is probable that human culture will exert a greater and greater effect upon the course of evolution, bringing about changes, not only in other species, but in the human race itself. It seems probable that we are transitory as most other forms of life have been, and that in the long course of evolution we will either disappear or develop into some form of life quite unlike ourselves.

On the other hand, our race may remain stationary, from the evolutionary standpoint, for millions of years to come. The only prediction we can make concerning the future of evolution is that the process of living transformation will continue as long as life continues.

QUESTIONS

1. Describe the order of primates.
2. What factors led to the evolution of man from the primate stock?
3. What emergent came into being with the evolution of man?
4. Describe several of the fossil species that link man with the apes.
5. Outline the course of evolution which differentiates us from Cro-Magnon man.
6. Discuss the future of evolution.

GLOSSARY

anthropoid ape (an'thrō-poid) A man-like ape. Applied to the four groups of primates most similar to man.

Cro-Magnon (crō-man'yon) Earliest known race of men belonging to our species.

culture The sum total of the traditional ways of behaving and thinking. Also applied to a particular tradition, as "the Cro-Magnon culture," "American culture," "the culture of the western European peoples," etc.

Neanderthal (nē-an'der-tal) The most advanced race of man not belonging to our species.

PART III

BEHAVIOR AND MENTAL ACTIVITY

CHAPTER XVIII

THE RESPONSE SYSTEM: THE EFFECTORS

The most remarkable things that happen in this world are the everyday occurrences which we accept as a matter of course. To most people there is something of a fascinating mystery about the manner of digestion of our food or the passage of blood through the arteries and veins of the body, since these things are hidden from view. But when all about us we see people busily engaged in various activities and pastimes, walking, running, carrying on conversations, writing, using tools, and performing the most remarkably delicate operations, it never occurs to us to inquire what goes on in the human body to make such truly amazing phenomena possible. If we should observe a machine capable of walking, talking, manipulating instruments, and directing its activities entirely without outside assistance we should immediately want to inquire into how it was made to work that way. But we are so accustomed to human behavior that we take it as a matter of course and seldom feel the least curiosity concerning the mechanism that makes it possible.

The next few chapters are devoted to describing, as well as possible in our present state of knowledge, what happens in the human body to produce what we call human behavior. Already we have seen that the living part of the human organism is essentially a highly complex system of protein colloids, organized into cells which themselves are organized to form organs and tissues that are fitted into an intricate pattern which constitutes the organism as a whole. It is this patterned protoplasmic system that must carry on the activities that we call behavior; and it carries them on because of a fundamental property of protoplasmic colloids—their ability to *respond* to *stimulation.*

Let us take a simple illustration of human behavior. A squad of soldiers is lined up on a parade ground. The corporal in command of the squad shouts, "Forward, march!" The soldiers walk forward and, keeping perfect step and alignment, continue down the field until the order to halt is given.

Now, to give a simple explanation of what has happened, we may say that the soldiers are organisms that are "wound up" to perform certain activities. All that is needed to get one of those activities into progress is something to "pull the string" that sets them off. The thing that pulls the string and sets the soldiers marching is a pattern of sound waves which passes through the air from the lips of the corporal and finally sets into vibration certain small sensitive cells in the ears of the soldiers. Just the small disturbance produced by these sound waves is sufficient to set the soldiers into vigorous activity. We call the sound waves a *stimulus* and the marching a *response.*

A stimulus, therefore, may be defined as a small physical or chemical disturbance which touches an organism in a sensitive spot and causes it to begin some particular activity. A response, on the other hand, is an activity which is set into progress by a stimulus.

The things that human beings do are in all cases responses to stimuli; and the way to an explanation of human behavior lies in discovering what stimuli are acting upon a human being and in what manner they produce the responses which are observed.

Ability to respond is one of the fundamental characteristics of protoplasm, and we find responses taking place throughout the living world. The antibody reactions which were described in Chapter VIII are responses which the cells of the body make to stimuli offered by the presence of bacteria or toxins. When a man chops wood, the skin of his hands responds to the rubbing of the ax upon it by growing thick and hard.

The most important responses of plants are growth responses. The roots of a tree respond to the force of gravity by growing downward, the branches by growing upward. The roots also respond to moisture and rich soil by growing toward them. The stems of the leaves respond to sunlight by growing in such a fashion as to give the leaf a maximum amount of light.

The most important responses which animals make are responses of movement. This is because most animals have to move around to get food. Movement responses may be observed in the simplest animals, such as the small, one-celled creature, Paramecium, which may be found in a drop of water from the scum around the edge of a pond. If, while swimming about, it chances to bump into an obstruction, it will back away, turn slightly to the side, and swim forward again. Thus it responds to the obstruction by swimming around it.

You may have noticed a certain peculiar thing about all the organismic responses that we have described: they usually are of advantage to the organism in its task of maintaining and protecting itself. They help it to survive. We say that by means of responses an organism *adjusts to its environment.*

But at this point an interesting question arises; how does it happen that the right response—that is, a response that adjusts an organism to its environment—is usually the response that is made to the stimuli which that environment affords? Why should the soldiers go forward when the corporal calls "March" and stop when he calls "Halt," rather than doing something entirely different? Why should a tree be stimulated by sunlight to grow toward the light, rather than away from it or off to the side? Why should the Paramecium be stimulated by an obstruction to do just the thing that is necessary to get it around the obstruction? One answer that might be given is that only those organisms that are "wound up" to make adaptive responses have survived in the struggle for existence and are alive to be studied by the scientist. But this is something like explaining how an automobile runs by saying that an automobile that didn't run wouldn't be used to carry people about. Actually, we know that the running of an automobile can be explained by describing its various parts and how they are put together—in short, by describing the pattern of its structure. Everything that we know about organisms leads us to believe that the specific direction their behavior takes in response to stimulation is accounted for in a similar way—by the pattern of their protoplasmic structure. The Paramecium, the tree, the skin on a man's hands, the marching soldiers, all possess a protoplasmic pattern which causes them to respond to definite stimuli in definite ways. Our science has not yet advanced to the stage where it is possible to point out the exact nature of these patterns or to show just why they result in the particular behavior that they do produce. Probably only very slight changes in the protoplasmic pattern of the outer tissue of their brains would lead the soldiers to go forward at the cry "Halt" and to stop when the sound waves of "March" vibrate in their ears. But that the nature of a response is dependent upon some protoplasmic pattern in the brain is something that every scientific student of human nature believes. And although we cannot trace these patterns in detail, we can show that, in a general way, organisms are "hooked up" to produce just the sort of behavior that we can observe in them.

Receptors, Conductors, and Effectors.—Just as we have a digestive system to prepare our food for assimilation, a circulatory system to carry materials from one part of the body to another, and various other systems for the performance of particular organismic functions, so we possess a system which underlies our behavior, one which enables us to adjust to the environment through response to stimulation. It is called the *response system* and is divided into three types of structures, classified according to the functions they perform: the *receptors*, or sense organs; the *conductors*, or nervous tissues, comprised of the brain, spinal cord, and the nerve trunks which branch from them; and the *effectors*, or muscles and glands.

The receptors are organs which contain cells that specialize in sensitivity. Each receptor is sensitive to some particular form of energy. Certain cells in the eyes are stimulated by the energy of light waves; other cells in the ears specialize in sensitivity to those mechanical vibrations known as sound waves; and the sensitive cells for taste and smell are stimulated by the presence of certain chemical substances.

When any receptor cell is stimulated, its response is to stimulate a conductor cell. Every receptor cell is in contact with one or more of these nerve cells and is able to stimulate them. A nerve cell is a long, thin structure, stretching through the body for a considerable distance. The response that such a cell makes to the stimulation coming from a receptor cell is to conduct a *nervous impulse*. The impulse in the first nerve cell thereupon stimulates the other cells to conduct impulses. These impulses are carried through the nervous system to still other cells which pass them along. Finally, the impulses are carried by the last of the long chain of nerve cells to the cells of one or more muscles or glands, whereupon they stimulate these muscle and gland cells to respond by contracting or secreting. It is the responses of the muscles and glands which finally adjust the organism to its environment, and those structures, therefore, are called the effectors. But the total response of the organism begins in the sense organ, continues through the nervous system, and is merely completed in the muscles and glands. Of course, this whole process of the passage of a nervous impulse from a receptor to an effector and the contraction or secretion on the part of the effector may occupy only a small fraction of a second.

The usefulness of this arrangement of the response system is obvious. First, it makes for specialization. One set of cells concentrates on responding to light, another on responding to sound. The nerve cells have nothing to do but to conduct stimulation, while the muscle cells can be made as efficient for the business of contraction as it is possible for a cell to be, since contraction is their sole duty. Second, it enables muscles and glands in one part of the body to adjust the organism to stimuli falling on an entirely different part. And, finally, it binds the organism together, enabling it to respond as a unit to its environment, rather than as a mere aggregate of cells, with each cell responding in its own independent way. This last advantage is probably the most important of all. Just how the organization of the response system produces this advantage may not appear obvious at first, but it will be made clearer as we go along.

The remainder of this chapter will be devoted to a description of the effectors, and the arrangement of the conductors and receptors will be described in the next two chapters.

The Effectors.—In human beings and in most animals, there are two kinds of effectors, the muscles and the glands. Already the reader has become acquainted with a number of glands: the sweat glands, the glands which secrete digestive juices, and a few of the endocrine glands. Since most glands are set into action by the stimulation they receive from the nerves, they form an integral part of the whole response system. Frequently glands are activated by hormones as well as by nerves. Indeed, nerves and hormones may cooperate in activating not only our glands but our muscles as well.

Of the muscle effectors, there are three kinds—the ***skeletal muscles***, the ***heart muscles***, and the ***smooth muscles***.

Skeletal Muscles.—The skeletal muscles are those which are attached to the bones of our skeleton and which serve by their contraction to move our bodies about. They are large, powerful and quick-acting. They are made up of long, thin cells which, when viewed under the microscope, appear to have tiny transverse stripes running across them. For this reason the skeletal muscles are often spoken of as *striped muscles.*

Fig. 89 shows the extreme tip of three skeletal muscle cells. On the scale shown in the drawing, these cells would reach something like twenty-five feet from tip to tip. In actuality, they are about an inch long. Compared to other cells they are very large, and, because they are so large, each cell contains many nuclei.

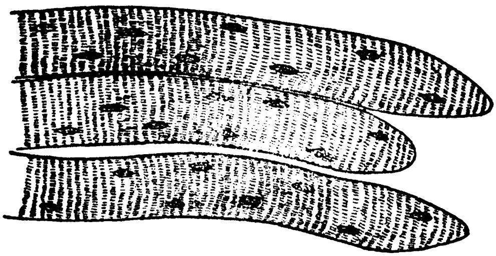


FIG. 89.—Terminal portions of skeletal muscle cells. (Redrawn from Martin's *The Human Body,* Henry Holt & Company, Inc.)

Skeletal muscle cells are packed close together and are bound by sheaths of connective tissue into small bundles. These bundles are bound into larger bundles which are themselves bound together to form the muscle as a whole. The sheaths of connective tissue in which the muscle cells are enmeshed come together at the ends to form the tendons which attach the muscles to the bones.

Fig. 90 shows a typical striped muscle, the biceps muscle of the arm. It has a thick, soft central part, called the *belly,* which is composed of muscle cells held within the meshwork of connective tissue, and it tapers at either end to pass into the tough, cord-like tendons which attach it to the bones. The biceps, as the figure shows, is attached by a single tendon to a bone in the forearm[1] and by two tendons to the shoulder bones. When the muscle thickens

[1] There is also a thin extension of this tendon, not shown in the drawing, which holds the lower end of the muscle close to the elbow.

and shortens in contraction, it pulls on the forearm bone, causing it to move upward toward the shoulder.

Anyone at all acquainted with the physical laws of the lever can see that the forearm bone acts as a lever with its fulcrum at the elbow and the force applied at the point of insertion of the muscle. The muscle, therefore, works at a considerable mechanical disadvantage and must contract very powerfully to lift a heavy weight held in the hand. At the same time, it is thus enabled to move the forearm rapidly and to carry the hand through a wide-sweeping arc while the muscle itself is shortening by only a few inches.

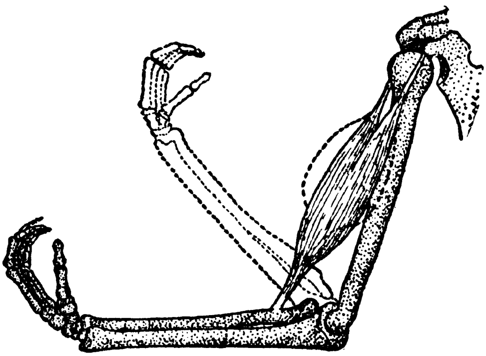


FIG. 90.—Biceps muscle and arm bones.

Nearly all our skeletal muscles are thus attached to the bones so that a short contraction of the muscle can produce a wide and rapid movement of limbs or trunk. Although the elbow and knee joints are arranged to bend in only one direction, many of the bones of the body, such as those of the upper arm and thigh, have joint and muscle arrangements that enable them to be moved in all directions. Thus provision is made for the rapid, vigorous, and versatile system of movements which is so essential to animal organisms for securing prey, escaping enemies, and quickly adjusting to all the emergencies in their rapidly shifting environments.

Heart Muscles and Smooth Muscles.—The skeletal muscles take care of our adjustments to the external environment, and heart and smooth muscles take care of those movements which must take place inside our bodies. Muscle cells with transverse stripes are capable of contracting rapidly; those without them are slow in their action. Since the heart must beat rapidly, while other internal movements may take a more leisurely pace, heart muscle is the only internal muscle that displays these stripes. (See Fig. 92.) Heart muscle cells are smaller than those of the skeletal muscles.

The heart muscles differ from those of the skeleton largely by virtue of the fact that they will continue to contract rhythmically without any nervous stimulation. Every contraction of the skeletal muscles is brought about by stimulation from the nerves which run to them, and they can be kept in contraction only by continual volleys of such stimulation, without which they immediately relax.

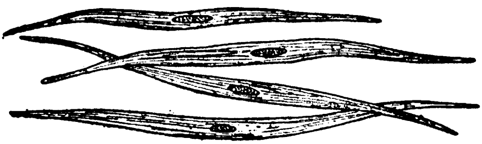


FIG. 91.—Smooth muscle cells.

But the heart may be taken from the body and completely severed from all nervous connections and yet continue to beat for several hours. Indeed, the heart of a cold-blooded animal, such as a turtle, if put into a proper sort of solution, may continue to beat for several weeks. Nervous impulses may, however, speed up or *facilitate* the heart beat or else slow it down or *inhibit* it; and to provide for both effects the heart is controlled by two sets of nerves, one of which facilitates and one of which inhibits its action.

The smooth muscles are so called because they do not show the stripes that are characteristic of the skeletal and heart muscles. In Fig. 91 it can be seen that their cells are simple in structure; and, while they vary greatly in size, the largest types are scarcely one-hundredth the length of an average skeletal muscle cell. They are bound closely together, usually in flat sheaths, to form layers of tissue in the walls of the alimentary canal, the arterioles, the bladder, and various other internal organs. Contractions of the smooth muscles run in waves down the walls of the stomach and along the long intestinal tubes, churning the food, mixing it with digestive enzymes, and pushing it slowly through the digestive tract. In this fashion, and in many other ways, they help to carry on the vital functions of the body.

The characteristic slow action of the smooth muscles can seldom be observed, since they are located inside the body. But those in the iris of the eye which contract and expand the pupil are located within a transparent tissue. If you stand before a mirror in the dark and then suddenly turn on the light, you can watch the relatively slow, steady movement of the iris as it contracts to make the pupil smaller.

Glands.—Glands are usually formed from epithelial tissue. Fig. 5 D in Chapter I shows the simplest form of gland structure, namely, a few secreting cells interspersed among the other cells of an epithelial lining. Glandular cells of this sort merely serve the purpose of keeping the lining moist. When a copious secretion is required, the lining folds inward to produce a considerable area of secreting cells, just as the many folds of the lung surface produce a large area for exchange of gases. The simplest sort of glandular folding is shown in Fig. 93 A. There is a single tube, surrounded by capillaries in which the cells lining the tube manufacture the secretion and pour it into the tube, whence it makes its way to the surface. Sweat glands are of this type, except that they are long and coiled. Another simple type of gland, a small sac, is shown in Fig. 93 B. The more important glands of the body are usually of a more complex type than this. They are composed either of branching tubules or of branching ducts which lead to chambers surrounded by sacs (Fig. 93 C and D). The latter construction reminds us very much of the lungs, and emphasizes the fact that both types of structure have the same function, the securing of a considerable surface for physiological activity. In both cases the structure has probably developed from a smooth epithelial surface in the course of evolution.

FIG. 92.—Heart muscle. (Redrawn from Martin's *The Human Body*, Henry Holt & Company, Inc.)

A thick capillary network usually surrounds the cells which line the tubules or sacs, and these cells have the power to absorb materials from the blood and manufacture them into secretory substances. Many of them are connected with the nerve cells; and when the nervous impulses stimulate them, they pour these substances into the sacs or tubules, whence they are carried to the point at which the main duct of the gland empties itself.

In the endocrine, or ductless, glands, the secretory cells are usually embedded in a thick capillary meshwork. They absorb sub-

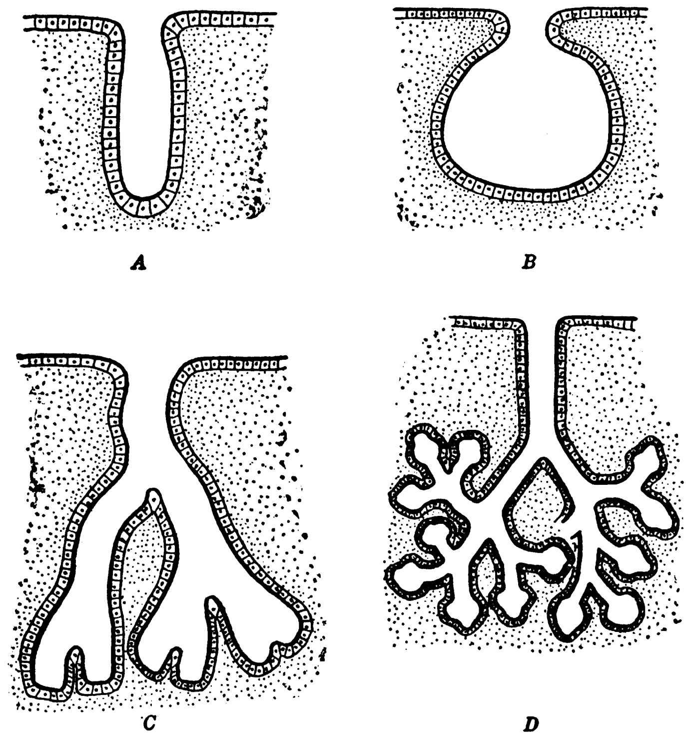


FIG. 93.—Four types of glands. *A,* simple tubular; *B,* simple sac (racemose); *C,* compound tubular; *D,* compound sac.

stances from the blood, manufacture their secretions, and, when properly stimulated, simply pour them into the tissue fluid, whence they dialyze into the blood and are carried to all parts of the body. Sometimes the secretory cells of the endocrines are arranged around small sacs into which they empty their secretions, but these sacs have no ducts which lead the secretion away, and hence the only place it can go is into the blood stream.

Chapter Summary

The things human beings do are in all cases responses to stimuli. A stimulus is a small physical or chemical disturbance which touches an organism in a sensitive spot and causes it to begin some particular activity. A response is an activity which is set into progress by a stimulus.

Ability to respond is a fundamental characteristic of protoplasm, and responses take place in all organisms. Growth responses are especially characteristic of plants, and movement responses of animals, although both types of response occur in all forms of life. Through response to stimulation, organisms adjust to their environments.

In human beings there is a highly developed response system composed of three parts:

1. The receptors, or sense organs, which specialize in sensitivity to stimulation.

2. The conductors, or nerves, which specialize in conducting stimulation from sense organs to effectors.

3. The effectors, or muscles and glands, which carry out the responses of the organism.

This arrangement of the response system has the following advantages:

1. It makes for specialization of function.

2. It enables responses to take place in a different part of the organism from the part that is stimulated.

3. It makes for organization of response, so that the organism acts as a unit.

There are four kinds of effectors:

1. Skeletal muscle, composed of long, thin, striped cells, quick acting. This type of muscle is attached to the bones of the skeleton and is used for movements of the trunk, limbs, head and face.

2. Heart muscle, composed of striped, quick-acting cells which will contract automatically without nervous stimulation.

3. Smooth muscle, found in internal organs and blood vessels, composed of small, simple cells, slow acting.

4. Glands, which are modified epithelial tissues.

QUESTIONS

1. What is meant by stimulus and response? Discuss response as a general attribute of all organisms. What responses are especially characteristic of plants? Of animals?
2. Describe the human response system. What are the functions of each division? What are the advantages of such a system?
3. Classify and describe the effectors.

GLOSSARY

conductor A structure (usually nervous) which carries stimulation from receptors to effectors in an organism.

effector A structure (usually a muscle or gland) which actually performs the activities involved in an organic response.

receptor A structure (usually a sense organ) which is specialized for sensitivity to some particular form of stimulation.

response An activity in an organism set into progress by a stimulus.

skeletal (skel'ē-tal) Pertaining to the skeleton. Applied to muscles that attach to the skeleton.

stimulus A small physical or chemical disturbance which touches an organism in a sensitive spot and causes it to begin some particular activity.

CHAPTER XIX

THE NERVOUS SYSTEM

Conduction and Integration.—The nervous system has two major functions. The first of these is to carry nervous impulses from the receptors to the effectors. The exact nature of the nervous impulse is not known, but it may be described as an electro-physical disturbance which travels from one end to the other of the very long, thin cells which make up the nervous system. The rate at which the nervous impulse travels varies, but a representative figure is 120 yards per second. The conduction of a nervous impulse is the way a nerve cell has of responding to stimulation received from either a sense organ or another nerve cell, and it is by the relaying of nervous impulses from one nerve cell to another that stimulation is carried from the sense organs to the muscles and glands.

But the nervous system does more than simply to conduct these impulses. It *arranges* them so that a definite *pattern of stimulation* is sent out to the effectors, and, consequently, our response to the environment is not a haphazard, unorganized affair, but one in which each muscle and gland responds in relation to a unified plan of action. Even when a man carries on as simple an act as walking, every muscle in the body falls in line with the general course of his activity. Not only does each leg muscle contract and relax at just the right moment, but the muscles of the trunk tip him from side to side in such a way as to maintain balance, and his arms swing backward and forward in the rhythm of his stride. The responses involved in walking are made by the entire organism acting as a unit, not simply by certain parts responding without any relation to the whole. This organization of our responses into a unified plan of action is called *integration,* and it constitutes the second function of the nervous system.

The General Contours of the Nervous System.—In order to understand how these all-important functions of conduction and integration are carried on, it is necessary to know something of how the nervous system is put together. It is generally considered to be composed of two divisions: *the central nervous system,* which includes the brain and the spinal cord; and the *peripheral nervous system,* composed chiefly of *nerve trunks,* which branch from the brain and spinal cord to all parts of the body. (See Fig. 94.)

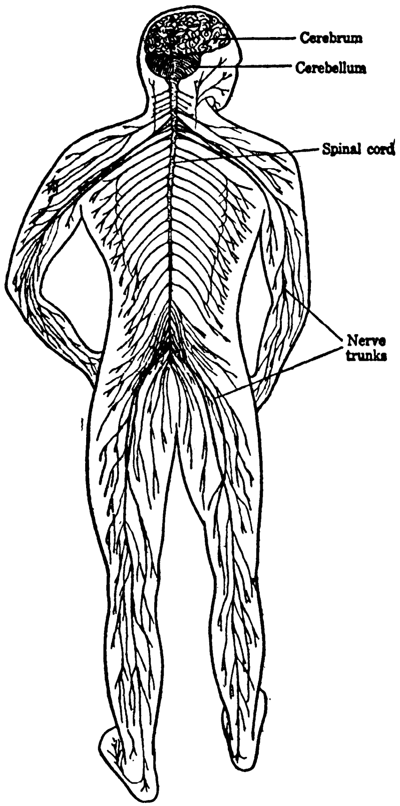


Fig. 94.—General diagram of the nervous system.

Fig. 95 A shows a view of the brain from the side, and Fig. 95 B is a similar view of the surface formed when the brain is cut longitudinally in half. It will be seen that there are three chief regions: the *brain stem,* which is located at the base; the *cerebrum,* which fills the greater part of the skull cavity; and the *cerebellum,* which is located at the back, above the brain stem, but covered over almost completely by the cerebrum. The functions of these three regions will be pointed out as we go along.

The spinal cord is simply a continuation of the brain stem which passes through an opening at the base of the brain case and continues down inside the "back bone" or *vertebral column* to a point about two-thirds of the way down the back. The vertebral column is made up of a series of ring-like bones, called *vertebrae,* placed one on top of the other; and each one of the rings encircles the spinal cord; thus it makes its way down the back completely encased within them. (See Fig. 96.)

As the long, thin nerve trunks pass outward from the spinal cord and also from the brain stem, they branch so profusely that they finally make contact with nearly every receptor or effector cell in the body. They leave the brain stem and spinal cord in pairs, one member of the pair going to the left, the other to the right.

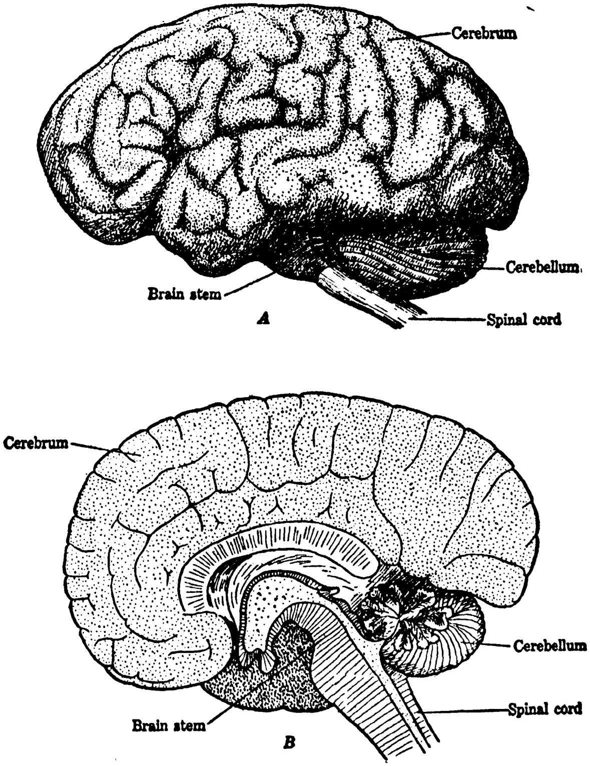


FIG. 95.—The brain. *A*, side view; *B*, longitudinal section view. (*A* redrawn from Martin's *The Human Body*, Henry Holt & Company, Inc.)

There are twelve pairs running from the brain stem and thirty-one pairs that branch out from the spinal cord, making a total of eighty-six nerve trunks in all.

The function of the nerve trunks is to conduct stimulation from the sense organs to the central nervous system and from the central system to the effectors. The chief function of the central nervous system is integration. It organizes the stimulation coming in over the nerve trunks from the sense organs into a definite pattern to be carried by the nerve trunks out to the muscles and glands.

Neurons.—Nerve cells are generally called *neurons.* Since their function is to carry nervous impulses from place to place, they are usually long, thin structures which reach tremendous distances—considering that they are single cells—from one part of the nervous system to another. The nerve cells which carry impulses from the sense organs over the nerve trunks to the central nervous system are called *sensory neurons.* Those which transmit impulses from one point to another within the central nervous system are called *connector neurons,* and those which carry impulses over the nerve trunks from the central nervous system to the effectors are called *motor neurons.*

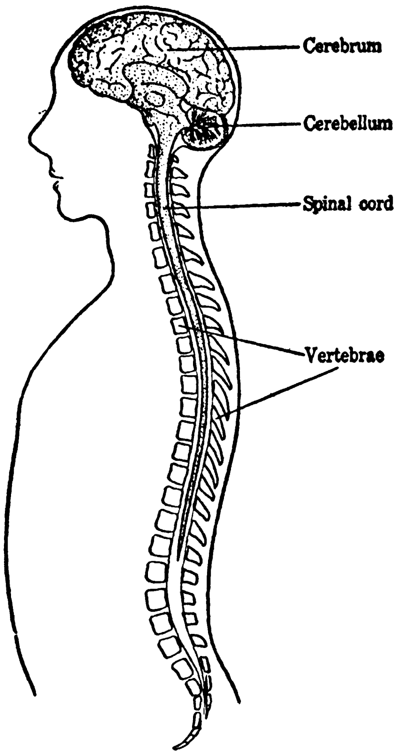
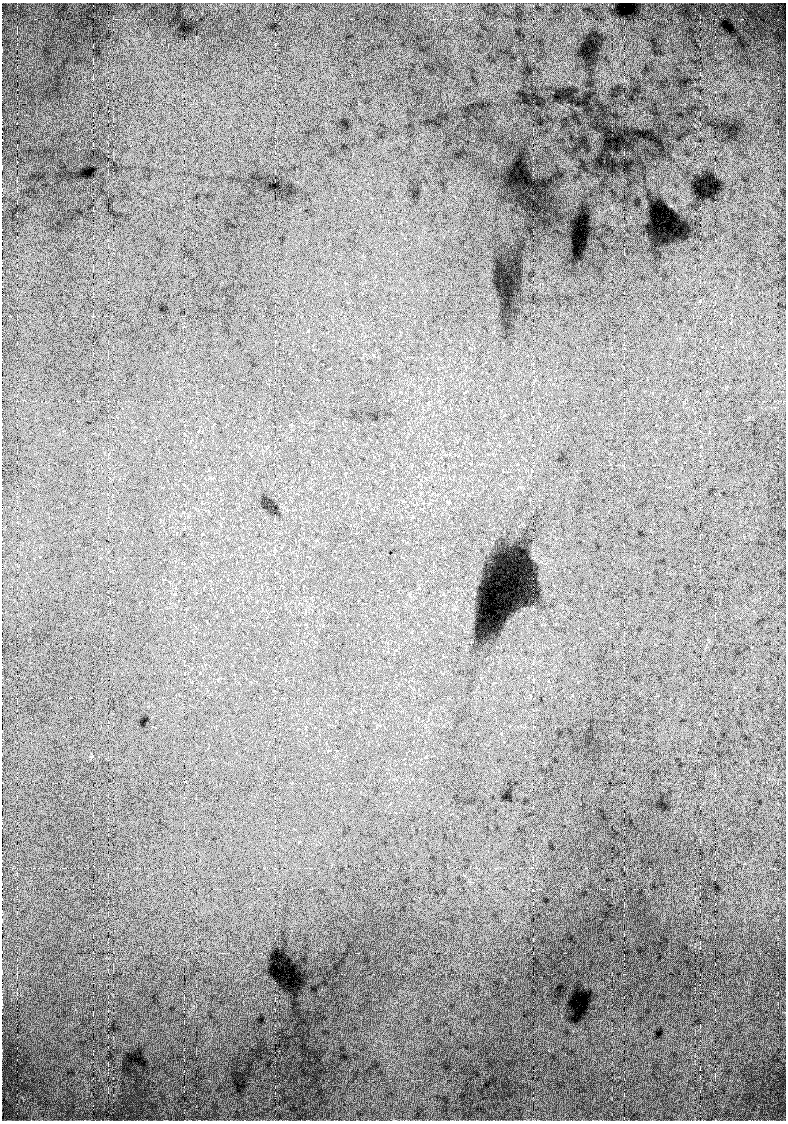


FIG. 96.—Central nervous system. (Redrawn from Woodruff's *Foundations of Biology,* The Macmillan Company.)

Every neuron is made up of three parts, a *cell body,* a *dendrite* (or dendrites), and an *axon.* Nervous impulses always enter a neuron over the dendrites, run along them to the cell body, and then pass out over the axon, leaving the cell at the tips (or end brushes) of the axon. The cell body plays only a minor part in the conduction of nervous impulses. It is, however, the part of the neuron which contains the nucleus, and it carries on the nutritional activities which keep the cell alive.

While the shapes and sizes of neurons in various regions of the nervous system differ considerably, there are only two fundamental structural plans, one characterizing the sensory neurons, and



Motor neurons from spinal cord of ox. The large, dark structures are the cell bodies. The dendrite and axon processes branching from them show rather dimly.

the other the connector and motor neurons. (See Fig. 97.) In the latter, the dendrites form a bush of thin protoplasmic strands, branching out from the cell body on all sides; the axon is an extremely long, thin strand which leaves the cell body and may

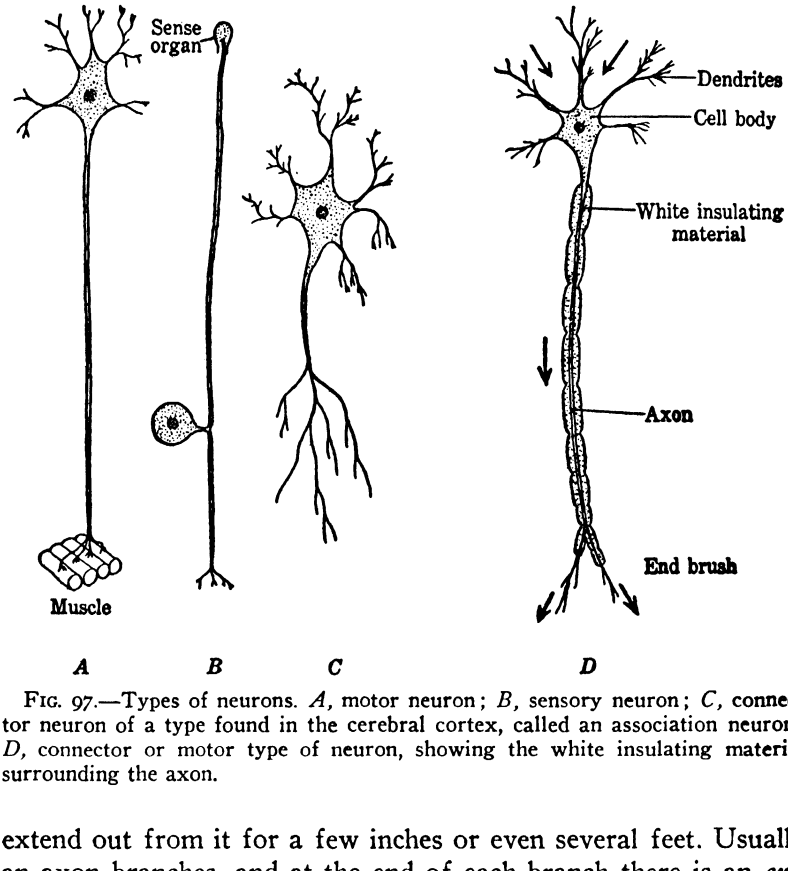


FIG. 97.—Types of neurons. *A,* motor neuron; *B,* sensory neuron; *C,* connector neuron of a type found in the cerebral cortex, called an association neuron; *D,* connector or motor type of neuron, showing the white insulating material surrounding the axon.

extend out from it for a few inches or even several feet. Usually an axon branches, and at the end of each branch there is an *end brush,* where the strand divides in several directions at once. When one considers that a neuron is a cell, microscopic in size, the length of these axons relative to their thickness is nothing short of astonishing.

Sensory neurons do not have a thick bush of dendrites surrounding the cell body. Instead, they have a single long dendrite, similar in structure to the motor and connector axons. The cell body is located a little to the side of the dendrite and axon, being connected to them by a short strand of protoplasm at the point where the dendrite ends and the axon begins. Hence, nervous impulses coming in over the dendrite probably do not pass through the cell body at all, but are simply carried along the axon, the structure of which is not very different from that of the dendrite or of the central and motor axons.

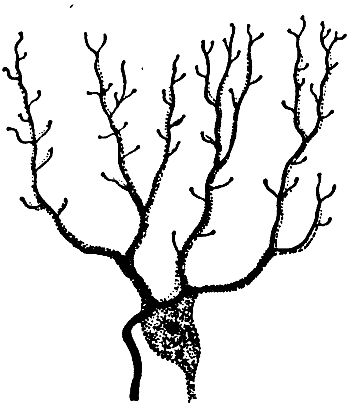


FIG. 98.—Diagram of a synapse. Solid black: End brush of axon of first neuron. Stippled: Dendrites and cell body of second neuron. The synapse is the surface of contact between the end brush and dendrites. (Redrawn from Herrick's *An Introduction to Neurology,* W. B. Saunders Company.)

The Synapse.—An impulse will first enter the nervous system over the dendrite of a sensory neuron, pass on into the axon of that neuron, and then be relayed along to the dendrites of a connector neuron. It passes through the dendrites of the connector neuron and along its axon and on to a second connector neuron, or perhaps a motor neuron, until it finally reaches an effector. At the point where the impulse passes from one neuron to another, the strands which form the end brush of the axon in the first neuron run parallel with the dendrite strands of the second neuron, coming into close contact with them; and it is across this surface of contact, called the *synapse,* that the impulse passes from axon to dendrite. (See Fig. 98.) What actually happens is that the nervous impulse in the axon of the first neuron stimulates the second neuron to conduct an impulse of its own, but it is common parlance to say that the impulse *crosses the synapse.*

It is important to realize that most axons branch and make synaptic contact with more than one neuron. Furthermore, an impulse may either pass a synapse or fail to pass it, depending on the conditions that hold at the time it reaches the synapse. Hence, the course that an impulse takes through the nervous system depends upon which of the synaptic contacts made by the axon along which it is passing are actually crossed.

Neural Connections in the Spinal Cord.—Fig. 99 shows a very simple series of connections between neurons occurring in the spinal cord. The cord is shown in cross section, with a nerve trunk entering on either side. As each nerve trunk approaches the cord, at a point immediately outside the vertebrae, it thickens to form a small mass of nervous tissue, called a *sensory ganglion.* These sensory ganglia of the nerve trunks contain the cell bodies of the sensory neurons. Just beyond the sensory ganglion, the nerve trunk branches to form the *dorsal root* entering the cord toward the back, and the *ventral root* entering it toward the front.

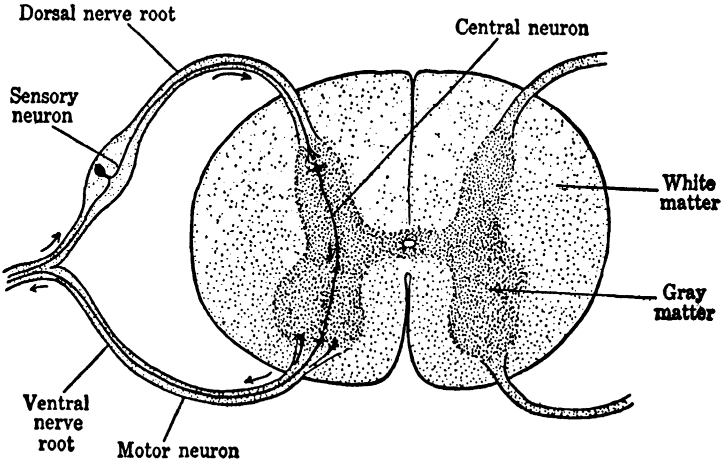


FIG. 99.—Diagram of a simple reflex arc in the spinal cord.

The axons of the sensory neurons enter the cord over the dorsal branch, and those of the motor neurons leave it over the ventral branch. Each dendrite of each sensory neuron runs all the way from a sense organ to a sensory ganglion, where its cell body is located. Its axon continues from the ganglion on into the spinal cord. All motor neurons have their cell bodies in the spinal cord or brain stem, and—with certain exceptions to be mentioned later—their axons pass from the cell bodies all the way out to the muscles. The connector neurons are always located entirely within the central nervous system.

As is shown in Fig. 99, the spinal cord is divided into two types of tissue, white matter on the outside and a butterfly-shaped core of gray matter on the inside. The axon of the sensory neuron entering the cord passes into the gray matter, where it makes synaptic contact with the dendrites of the connector neuron. The axon of the connector neuron passes into the gray matter in the ventral side of the cord, and makes a synaptic contact with the motor neuron.

When you unwittingly touch something painful—a hot stove, for example—your arm jerks the hand away from it automatically, even before you become conscious of the pain. Such a response is called a spinal *reflex*, and it is brought about by a set of neural connections similar to that in Fig. 99. The sensory neuron carries the nervous impulse from a pain receptor in the hand into the spinal cord, where the connector neuron passes it on to a motor neuron, which conducts it out to a muscle in the arm, setting the muscle into action. Such a neural hook-up is called a simple spinal reflex arc. Actually, of course, a whole group of neurons would be necessary to set an entire muscle into action. Furthermore, the sensory axon would probably branch, making several synaptic contacts, while the motor neuron would also be in contact with more axons than the one coming from the connector neuron. A more realistic picture of the relationships between connector neurons and the sensory and motor neurons in the cord is shown in Fig. 102.

Incomplete as our picture of a simple reflex arc may be, it nevertheless represents relationships between neurons which hold for every response we make. Sensory neurons carry impulses in over the nerve trunks from the sense organs to the central nervous system. Connector neurons relay them through the central nervous system to the motor neurons which carry them out to the effectors. Furthermore, synapses between neurons are in all cases located in the gray matter of the nervous system.

White and Gray Matter.—When the tissues of the central nervous system are studied, they are found to be partly whitish in color and partly gray. We have already shown how, in the spinal cord, the white matter is on the outside, while the gray matter forms a butterfly-shaped core within. This relationship holds throughout the entire length of the cord. In the brain stem, the gray matter does not form a single core, as in the cord, but is embedded throughout the white matter in masses of varying shapes and sizes. In the cerebrum and cerebellum, however, the white matter is on the inside, and the gray matter forms a rather

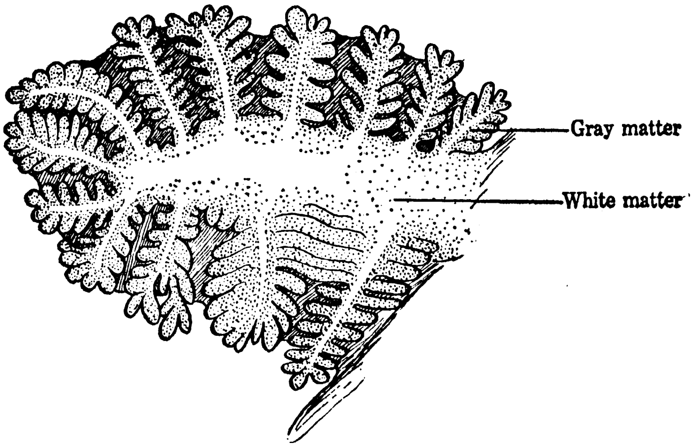


FIG. 100.—Longitudinal section through cerebellum.

thin covering all over the outside. These coverings of gray matter are called the cerebral and cerebellar cortexes, respectively. Fig.

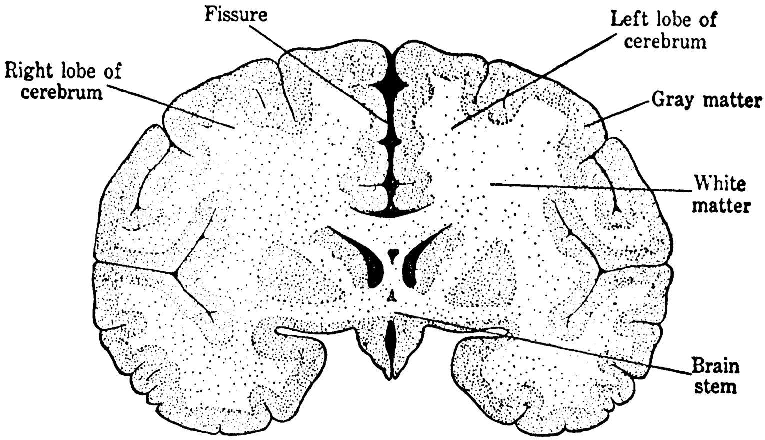


FIG. 101.—Diagram of transverse section of brain.

100 shows the cerebellum cut in half to show the relation between the white matter and the gray matter. Fig. 101 shows the brain

cut in half along a line that would run approximately from ear to ear. The cerebrum is divided by a deep fissure into two lobes and the gray matter almost completely covers each lobe. In addition, there are bunches of gray matter located in the inner part of each lobe of the cerebrum.

The surface of the cerebrum is thrown into a number of folds or *convolutions* which greatly increase the area of the cortex and hence the amount of gray matter. In human brains these convolutions are deeper and more numerous than in any other animal, and we therefore have more gray matter in proportion to the size of our brains than any other organism.

The white-matter regions are made up of the axons of the connector neurons running in closely packed bundles from one gray-matter region to another. Each axon has an insulating layer of white fatty material wrapped around it which causes the entire tissue to appear white. The term "white matter" applies to the tissue as a whole, not to the insulating substance. Since both the motor axons and the sensory dendrites are wrapped with this substance, the nerve trunks may also be said to be composed of white matter.

The gray-matter regions are places where the cell bodies and dendrites of neurons are bunched together. The tips of the axons enter these regions to make synaptic contact with the dendrites, and consequently all the synapses are located there. Since the cell bodies and dendrites of the connector and motor neurons are not wrapped with the white insulating material, these regions appear gray.

From the standpoint of the two major functions of the nervous system, the white-matter regions are devoted to conduction, carrying impulses from one gray-matter region to another, and the gray-matter regions perform the function of integration. Just how this integration is effected will be made clearer as we progress.

Possible Courses of a Nervous Impulse.—An impulse coming in over a sensory neuron may be carried to almost any part of the central nervous system. The sensory axons branch when they enter the spinal cord and make synaptic contact with several connector neurons. The axons of the connector neurons also branch, making it possible for the impulse to spread to more and more neurons as it passes through the central nervous system. It may go directly from the points where it enters the spinal cord to almost any other gray-matter region of the cord and there be passed on to motor neurons running to almost any part of the body. Or it may be carried up through the white matter of the cord to some of the little bunches of gray matter in the brain stem, where it may activate still other motor neurons, or else be relayed through the white matter of the cerebrum to the cerebral cortex. Once it enters

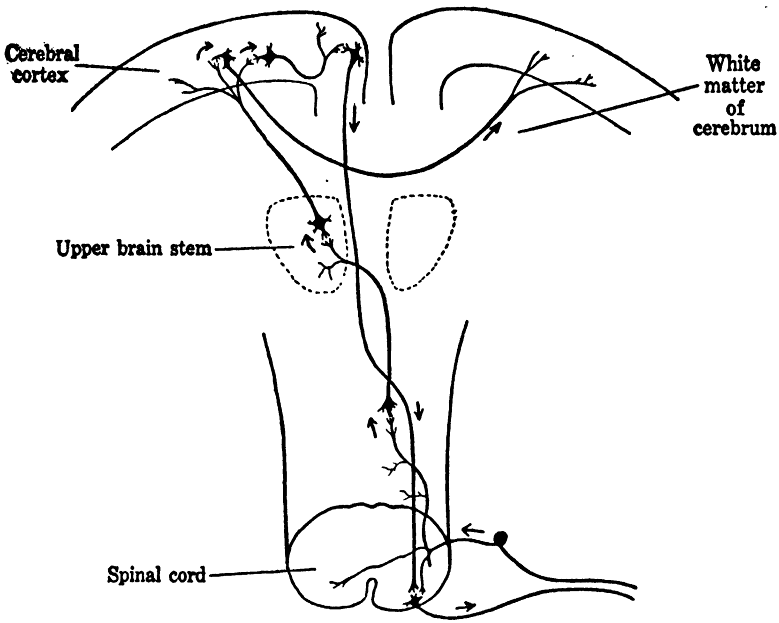


FIG. 102.—Diagram of nervous connections between spinal cord and cerebrum.

the cortex, there is no limit to the directions in which the impulse may spread. The cortex is a perfect network of billions of synapses, and each cell over which the impulse travels may carry it to dozens of other cells, with the result that it can be carried back from the various regions of the cerebral cortex through the brain stem and spinal cord to practically every motor neuron in the body.

Fig. 102 attempts to portray in simple diagrammatic fashion the various possible pathways that an impulse can take. The synapses made by most of the branches of the connector axons are not indicated, since if all these branches were followed out, practically every one of the billions of neurons in the nervous system would have to be shown.

An illustration will serve to suggest more clearly the multitude of paths which a nervous impulse can take in passing through the spinal cord and brain. Let us take the case of a man who is enjoying his vacation in his cabin in the woods and is engaged in the unfamiliar task of frying his morning flapjacks on the hot camp stove. In the act of turning one of the flapjacks, he awkwardly allows his little finger to touch the top of the stove. Instantly, nervous impulses flash from the receptors in his finger up his arm and into certain connector neurons which relay them across the spinal cord to the motor neurons which run to the muscles of the man's arm. Certain of these muscles are stimulated to contract vigorously, and the arm leaps upward, drawing the finger away from the stove. This, the *retraction reflex*, is the first complete response made to the stimulus, but it is far from being the only one. The various branches of the sensory neurons coming from the finger make contact with connector neurons, along which the impulses speed up and down to motor neurons in every part of the cord and brain stem. Passing out over these motor neurons, these impulses produce a "start of pain and surprise," that is, a sudden muscular rigidity all over the body. Meanwhile, other branchings of the sensory or connector neurons direct impulses up to the cerebral cortex, and the response which we call "feeling the pain" is made. We do not know just what the nature of this response is in terms of nervous and muscular activity, but it is known that neurons in the cortex are necessary to carry it out. Now the stimulation from the finger has started pouring through the cortex, and it produces a great variety of responses. The man shakes his hand up and down and puts it in his mouth. The muscles of his lungs, throat, lips, and tongue combine to produce sounds that any pious person would shudder to hear. The man writhes and groans and curses, and finally goes to the medicine kit, picks out a soothing salve, puts it on the burn, and wraps his finger with gauze. Before he has finished, practically every muscle in his body has responded to nervous impulses that had their start in his burned finger, and in addition the secretions of the digestive glands and of certain of the endocrine glands have been affected. To be sure, stimulation from other receptors combined or cooperated with the stimulation from the pain receptors in the finger to produce many of these responses, but impulses from the finger played a part in the stimulation of every muscle and gland that was set into activity. Hence, we may lay it down as a general principle which is true with only a few exceptions: *An impulse starting in any receptor can make its way through the central nervous system to every effector in the body.*

Inhibition, Reinforcement and Integration.—But if it can, why doesn't it? Our sense organs are being stimulated every minute of the day and night. If the stimulation of a single sensory neuron has within it the possibility of setting every effector in our bodies into action, why are our muscles not in a continuous state of rigid contraction? Why doesn't every gland secrete as copiously as possible without ever stopping to rest?

The answer is found in the fact that *one nervous impulse is capable of canceling out the effect of another so that an impulse does not cross every synapse it comes to.* The canceling-out effect is called *inhibition,* and it is one of the fundamental processes whereby integration is effected.

As nearly everyone knows, the biceps muscle, which lifts the forearm up toward the shoulder, is opposed in its action by the triceps muscle in the back of the arm, which straightens the arm out. When one stands with his arm hanging normally at his side, both the biceps and triceps muscles are slightly contracted. This slight contraction, characteristic of all muscles in the resting position, is called *muscle tonus*; and if we did not have it, we would be as limp and formless as jellyfishes. Now when an individual whose arm is hanging at his side wishes to lift the forearm, the slight contraction of the biceps muscle must be greatly increased and the muscle must contract vigorously. At the same time, something else must happen: the *triceps must relax.* If it did not, the slight tonus contraction would pull against the biceps, and the movement would be greatly impeded.

The manner in which this happens is as follows: While the muscles are maintaining a normal tonus, small volleys of nervous impulses are continually passing from certain connector neurons in the spinal cord into motor neurons running to the two muscles. When the arm is about to be contracted, a strong volley of nervous impulses starts down from the cerebral cortex. When it reaches the spinal cord, it ***reinforces*** the impulses that are going to the biceps muscle, making them stronger or more numerous. At the same time just the opposite effect is exerted on the impulses running to the triceps muscle. They fail to cross the synapses into the motor neurons; that is, they are *inhibited.*

The principles involved in the performance of this simple act hold good throughout the nervous system and for every act of our lives. Mutually compatible responses reinforce one another and mutually incompatible responses inhibit one another, with the result that a unitary pattern of response is formed for the organism as a whole. The various part responses of this pattern reinforce one another, while all responses incompatible with the general pattern are inhibited. Consequently, the organism responds as an organized unit to the multitude of stimuli falling in haphazard fashion upon its sense organs; and thus we see that inhibition and reinforcement are fundamentally responsible for what we call integration.

Inhibition and reinforcement can take place only at the synapses. Once a nervous impulse starts along a neuron, nothing can either stop it or help it along; but whether or not an impulse crosses a synapse depends upon whether or not it is inhibited or reinforced by the action of other impulses. For this reason, integration can go on only in the gray matter where the synapses are located.

Integration in the Spinal Cord and Brain Stem: Reflexes.—The gray matter in the spinal cord and brain stem is responsible for only the simpler forms of integration. If the spinal cord of a dog is cut in the neck region, so that there is no connection between the brain and the dog's legs, the legs can still carry out a considerable amount of integrated movement. If, for example, pressure is exerted against the left paw, the paw is pushed downward while the right paw is lifted upward. This is obviously a pattern of response that is used in walking. It is integrated in that each part fits usefully into the total response; the lifting of one leg and the pushing downward of the other are responses which *go together* for the performance of a useful act, just as the relaxation of the triceps goes together with the contraction of the biceps in lifting the arm.

But only the more mechanical part of the walking response is integrated in the spinal cord. The dog whose cord has been severed from the brain never walks *toward* anything, because the movements of its legs cannot be influenced by stimulation coming from its nose and eyes.

The legs of this dog can perform various other mechanical movements, such as scratching the flank or withdrawing from a prick, a burn, or an electric shock. Simple responses of this sort which can be integrated in the brain stem or spinal cord are called *reflexes*. The winking of the eyelid when something suddenly approaches the eye, the sneeze, the "knee jerk," the movements of breathing are other examples of reflexes. They can be performed without any activity on the part of the cerebrum.

Integration in the Cerebellar Cortex.—The cortex of the cerebellum has a very special integrative function. In order for us to make even the simplest movements, the activities of many muscles must be delicately coordinated. Each must contract and relax at just the proper instant of time. Furthermore, nearly every movement we make throws us off balance, so that if we did not automatically "catch ourselves" we would fall over. The cerebellum acts as a center for the coordination of muscular movements and for producing the slight compensatory movements which are continually necessary to keep us balanced and "on our feet." We might sum it up by saying that the cerebellar cortex has nothing to say about what we shall do, but simply sees to it that the performance runs off smoothly.

Integration in the Cerebral Cortex.—The cerebral cortex integrates those responses which adjust the organism as a whole to the environment as a whole. Working, playing, reading, talking—such are the activities which depend upon the cerebral cortex for their organization.

The neurons which lead to the cortex bring to it nervous impulses from every sense organ in the body. And in passing through the cortex, these impulses mutually reinforce and inhibit one another, until they become organized into a complex pattern which is sent down through the brain stem and spinal cord and out to all parts of the body, producing a complicated but well-organized response which is appropriate to the situation at hand. Thus by the action of his cerebral cortex a man faced with a difficult situation is able to take everything into consideration and act intelligently.

And that is why having a great deal of gray matter in the cerebral cortex is a synonym for intelligence.

There are stories told of soldiers who were so thoroughly disciplined that an officer had only to give the word of command to march a whole company over a high cliff. If such a thing ever happened—and we seriously doubt it—it would mean that the nervous impulses from the ears of the soldiers somehow managed to inhibit the effects of the impulses from their eyes, so that they responded to the "Forward, march!" in total disregard of their future health and happiness. In most cases, we are sure it would be the other way round. The sight of the cliff would inhibit the usual effect of hearing the command to march, and the response of the company would be really adequate to the entire situation, rather than to a single auditory stimulus.

The entire science of psychology is given over to the study of the responses which are integrated by the cerebral cortex, and until we progress to the study of that science it will be possible only to hint at the complex nature of its activities. It is sometimes said that the cortex is the "seat of consciousness." Whether this is true or not is a matter for debate. At any rate, when a blow on the head puts the cortex out of commission, we immediately lose any consciousness that we may have; hence it seems fair to say that we become conscious by making certain responses that are integrated by the cortex.

It is also said that we think with the cortex, or, more popularly, that we think with our brains. As a matter of fact, we probably think with our entire receptor, conductor, effector apparatus, for, as we shall point out later, thinking is just a special form of response. But the cortex is the place where thinking responses are integrated, and it is the structure which makes thinking possible. When we think, we adjust not only to the situation at hand, but to the past, the future, and to objects far out of the range of our sense organs; and we may therefore say that the cortex enables us to adjust not only to the immediate environment as a whole. but to the entire universe in which we live.

There is a story of an old Roman who was sent as an emissary to foes who were attacking his city. In the course of negotiations it became necessary to impress the enemy with the courage and valor of the Romans. The old Roman stepped up to a torch that was burning nearby, thrust his hand into the flame, and held it there until it burned off.

In describing this act in terms of the nervous system, we should say that the activity of the cerebral cortex inhibited the retraction reflex. The retraction reflex could respond only to the stimulation of pain receptors in the hand. The cortex was adjusting to the complex political situation with which the old hero was faced, to the danger that threatened the city he loved, to the enemies who might be defeated if they could be made afraid of the Romans, and to the fact that he was the only Roman there to make them afraid.

Thus, the cortex dominates human behavior, because it integrates those responses which enable us as unified beings to cope with the intricacies of the world about us.

Chapter Summary

The nervous system has two functions: (1) the conduction of nervous impulses from receptors to effectors, and (2) the integration of those impulses into patterns which enable the organism to respond according to a unified plan of action.

The system is composed of the following general divisions:

A. The central nervous system, which includes:

1. The spinal cord
2. The brain, which includes:
   a. The brain stem
   b. The cerebellum
   c. The cerebrum

B. The nerve trunks, which branch from the spinal cord and brain stem and run to all parts of the body.

The central nervous system contains the regions where neurons come into synaptic contact, and it is therefore the place where nervous impulses are integrated. The nerve trunks contain the dendrites of sensory neurons, carrying impulses from the sense organs to the central nervous system, and the axons of motor neurons, carrying impulses from the central nervous system to the effectors.

Nerve cells are called neurons. They are composed of three parts: (1) the dendrite or dendrites, through which nervous impulses enter the neuron; (2) the cell body, which is the center for nutrition; and (3) the axon, over which the impulses travel to the point where they leave the neuron. The end brushes of the axons of the sensory and connector neurons make contact with the dendrites of the connector or motor neurons. The surfaces of contact are called synapses, and nervous impulses make their way across them from one neuron to another.

There are three kinds of neurons, as follows:

1. Motor neurons, which have thick, bushy dendrites clustering around their cell bodies, which are located in the brain stem or spinal cord, and long axons which run from the central nervous system out over the nerve trunks to the effectors. The dendrites of a motor neuron are in synaptic contact with the end brushes of several connector neurons.

2. Connector neurons, whose general structure is similar to that of the motor neurons. They are located wholly within the central nervous system and carry impulses from one part of the central system to other parts. The dendrites of a connector neuron are in synaptic contact with several sensory or connector neurons, while the axon makes contact with several connector or motor neurons.

3. Sensory neurons, each of which has a single long, thin dendrite that carries nervous impulses from a sense organ to a point just outside the spinal cord where the cell body is located. From this point the impulses continue into the spinal cord over the axon, which branches to form a synaptic contact with several connector neurons.

In the central nervous system are found two different kinds of regions: (1) the white-matter regions of conduction, which are composed of axons bundled tightly together, carrying impulses from one gray-matter region to another, and (2) the gray-matter regions of integration, composed of cell bodies with their surrounding dendrites plus the synapses between the dendrites and the end brushes of the axons. Gray matter is found in the following regions:

1. In an H-shaped core running up through the spinal cord.

2. In little spherical bundles, called nuclei, located in the brain stem.

3. In the cortexes of the cerebrum and the cerebellum.

White matter is found in all other regions of the central nervous system.

Because of the fact that nearly every neuron makes synaptic contacts with several other neurons, it is possible for nervous impulses to spread from almost any receptor to almost every effector in the body. The directions in which impulses actually do pass are determined by the mutual inhibiting and reinforcing influences they exert upon each other.

Because of this mutual inhibition and reinforcement, responses become organized into unitary patterns, with the various part responses reinforcing one another and inhibiting all responses not compatible with the pattern. In other words, through the reinforcing and inhibiting influences which they exert upon each other, nervous impulses become integrated and produce integrated responses. Since inhibition and reinforcement take place at the synapses, the gray-matter regions are the centers for integration.

The gray matter of the spinal cord and brain stem integrates the simple response patterns known as reflexes.

The gray matter of the cerebellar cortex is the center for the coordination of muscular movement and for producing the compensatory movements which enable us to keep our balance.

The gray matter of the cerebral cortex integrates those activities through which the organism as a whole adjusts to the environment as a whole. These activities include our conscious responses and frequently involve thought and the exercise of intelligence.

QUESTIONS

1. What are the two primary functions of the nervous system?
2. Describe the general contours of the nervous system. What are the functions of the nerve trunks and of the central nervous system?
3. Describe the structure, location and functioning of the three different kinds of neurons.
4. What is a synapse? What part do synapses play in integration?
5. What are white matter and gray matter? In what parts of the central nervous system is each located?
6. Discuss and illustrate the possible course of a nervous impulse through the central nervous system.
7. What is meant by (a) reinforcement, (b) inhibition, (c) integration?

8. What sort of responses are integrated in (a) the spinal cord, (b) the brain stem, (c) the cerebellum, (d) the cerebrum?

GLOSSARY

axon (ak′son) Long, thin part of a neuron which carries nervous impulses from the cell body to points of synaptic contact with other neurons.

brain stem Lower part of the brain, lying under the cerebrum and cerebellum and continuing directly into the spinal cord.

cell body Roughly spherical part of a neuron, lying between the dendrites and the axon. It carries on the nutritive functions of the cell.

cerebellar cortex (ser-e-bel′ar) The layer of gray matter which extends over the entire surface of the cerebellum.

cerebellum (ser-e-bel′um) Portion of the brain lying at the back below the cerebrum and above the brain stem.

cerebral cortex (ser′e-bral) The layer of gray matter which extends over the entire surface of the cerebrum.

cerebrum (ser′e-brum) The largest part of the brain, filling the entire upper portion of the skull.

connector neuron Neuron located entirely within the central nervous system, carrying impulses from one part of the central nervous system to another.

convolutions (con-vō-lū′shuns) Folds such as those on the surface of the cerebrum and cerebellum.

dendrites (den′drīts) The bushy processes extending out from the cell body of a neuron over which impulses enter the neuron. (Sensory neurons, however, have a single long, thin dendrite, resembling the axons of other neurons, except that stimulation enters through it as it does through the dendrites of other neurons.)

end brush A group of thickly branching processes at the end of an axon which make synaptic contact with the dendrites of another neuron.

ganglion (gan′gli-on) pl. *ganglia* Any small clump of gray matter.

gray matter Name applied to those grayish-colored portions of the nervous system which contain cell bodies, dendrites and synapses. They are the portions where integration takes place.

inhibition (in-hi-bish′un) Process whereby the nervous impulses underlying one response check or prevent the occurrence of another response that is incompatible with it.

integration (in-te-grā′shun) Process whereby the responses of an organism are organized into unitary patterns, so that the whole organism responds as a unit to the many stimuli falling upon its sense organs. Inhibition and reinforcement are the processes whereby integration is achieved.

motor neuron Neuron with cell body and dendrites located in spinal cord or brain stem and an axon which carries impulses out over the nerve trunks to the effectors.

muscle tonus (tō′nus) A continuous contraction of the muscles.

nerve trunks Bundles of motor axons and sensory dendrites which branch in pairs from the spinal cord and brain stem and run to all parts of the body.

nervous impulse An electrophysical disturbance running from one end of a neuron to the other, where it usually crosses one or more synapses and continues through other neurons.

neuron (nū′ron) A nerve cell.

peripheral nervous system (pe-rif′er-al) The part of the nervous system outside the brain and spinal cord. Composed chiefly of the nerve trunks.

reflex (rē′fleks) A simple response which can be integrated in the spinal cord or brain stem.

reinforcement (rē-in-fôrs′ment) Process whereby nervous impulses producing the same response or compatible responses combine to strengthen one another.

sensory neuron Neuron which carries impulses from a sense organ into the gray matter of the spinal cord and brain stem.

synapse (sin′aps) Surface of contact between the end brush of one neuron and the dendrites of another across which nervous impulses pass from the first neuron into the second.

white matter Name applied to white-colored portions of the nervous system which are composed of bundles of axons and sensory dendrites. They are the portions in which conduction takes place.

CHAPTER XX

THE SENSE ORGANS

Specialized Irritability.—The receptors or sense organs of any organism are cells or arrangements of cells that specialize in the protoplasmic attribute of *irritability.* Primitive protoplasm, such as that found in one-celled organisms, is sensitive to all sorts of stimulation, but the specialized sense organs are usually sensitive to only a very limited range of stimuli. Our eyes are sensitive to light waves, our ears to sound waves, the sense organs in our skin to mechanical pressures and to changes in temperature, the sense organs of taste to certain chemicals that are dissolved in the saliva of the mouth, and the sense organs of smell to chemicals dissolved in the mucous membrane of the nose.

A highly developed sense organ usually is composed of two sets of tissues, the *sensitive tissues,* which are the actual receptors since they are the ones which really respond to stimulation, and the *auxiliary tissues,* which are not especially irritable but which are arranged to bring the stimuli into proper contact with the sensitive tissues.

These outstanding characteristics of sense organs—first, limitation in the range of stimuli which act upon them and, second, the possession of auxiliary as well as sensitive tissues—are well illustrated in our most highly developed sense organs, the eyes.

The Structure of the Eye.—The eyeball is composed chiefly of certain jelly-like substances held within a tough membranous sheath known as the *sclerotic coat.* It is constructed on the same principle as a camera. Inside the eye at the back is a membrane, called the *retina,* which contains the cells that are sensitive to light. It corresponds to the sensitive plate of the camera; and just as in the camera chemical changes taking place in the sensitive plate result in producing a record of the image that was thrown on the plate, so in the eye chemical changes produced by light in the sensitive cells of the retina result in the sending of nervous impulses to the brain that enable the organism to react to the situation that is represented by the image on the retina. Like a camera, also, the interior of the eye is darkened by a coat of black

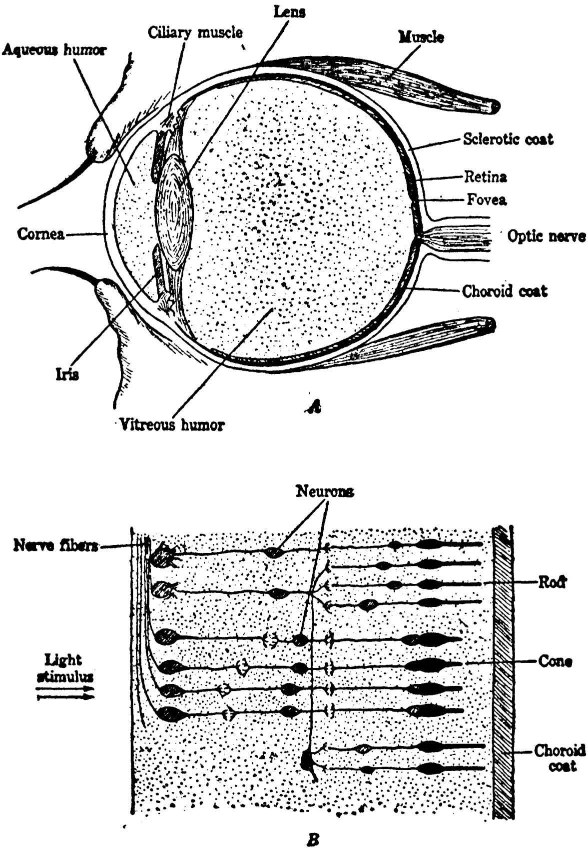


FIG. 103.—Diagram of visual structures. *A*, eye; *B*, retina.

pigment, the *choroid coat*, placed between the retina and the sclerotic coat, so that no light rays can be reflected from its sides.

In the front part of the eye is a lens system which throws an image of the world outside upon the retina. The first element in the system is the *cornea*, a hard, transparent sheath that is a continuation of the outer coat. It is placed in front of the pupil and iris and bulges forward in such a way as to bend the light rays which pass through it. The *iris* (the colored part of the eye) is a membrane that is open in the center to form the *pupil*, which is the peep hole that lets light through to the lens. The *lens* is a tough, transparent body, shaped like an ordinary magnifying glass. It completes the work of bending the light rays so that they will form an image on the retina. The large inner cavity of the eye, between the lens and the retina, is filled with a soft jelly called the *vitreous humor*. The space between the cornea and the iris contains a liquid, the *aqueous humor*.

The eye shows further resemblance to a good camera in that it can be adjusted for the distance of the object that is being brought to focus and also for the brightness of the light entering it. Surrounding the lens is the *ciliary muscle*, the contraction of which causes the lens to thicken and thus shortens its focus. In addition, the iris, which surrounds the pupil, may contract when the light is bright to produce a very small pupil, or open wide when the light is dim to let in as much light as possible. These adjustments are simple reflex responses. When a great deal of light enters the eye, neural impulses are carried to the muscles of the iris, stimulating them to contract. When the light becomes dim, the muscles are stimulated to relax. Similar reflexes serve to bring the lens into focus whenever the objects of regard change from near to far or far to near.

It will be seen that all the structures of the eye except the sensitive cells of the retina are merely auxiliary. Their purpose is to make it possible to throw an image of the outside world upon the retina. The light makes a pattern on the retina which clearly represents the objects that are in the environment. Organisms such as worms that do not possess a lens system to throw definite patterns of light on their visually sensitive cells cannot react to objects, but merely to degrees of brightness or darkness. The only difference for such an organism between a printed and a blank page would be that the blank page would appear a little brighter than the printed one. The forms of the letters could never be discriminated.

The Retina.—The retina is a membrane about one six-thousandth of an inch in thickness. It is made up of connective tissue cells in which sensitive cells and nerve cells are thickly embedded.

The sensitive structures are actually modified dendrites of sensory neurons. They are of two kinds, known as rods and cones because of their characteristic shape as shown under the microscope, and they are located in the back layer of the retina. (See Fig. 103 B.)

There are millions of these rods and cones in the retina. Around the edges the rods are most numerous, and at the very center there is a slight depression, called the *fovea,* which is composed entirely of cones. (See Fig. 103 A.) Any object that we look at directly is focused by the lens on the fovea. The rods are sensitive only to light and darkness, while the cones are sensitive to color. If we had only rods for sensitive cells, the world would be quite colorless to us, with only whites, grays and blacks, as in a photograph. The rods, however, have one advantage over the cones in that they can increase their sensitivity when the intensity of light decreases. As night falls, the cones become quite blind, being incapable of stimulation from the dim light; and the rods, which have greatly increased their sensitiveness, take over the job of seeing almost completely. That is why we do not see colors at night. When one is looking for a rather dim star, it fades if looked at directly, but as soon as the eyes are shifted a little to the side it reappears. The reason is that the fovea, which is the center of vision, is nearly blind at night, since it contains no rods.

The Stimulus for Vision.—It is well known that light is due to certain waves in the ether. But many people fail to realize that these waves are identical in kind with radio waves, heat radiations, utra-violet rays, and certain radium rays. All these ether waves are called electromagnetic waves. They are all alike in that they travel through the ether at the rate of 186,000 miles per second; in fact, they differ from one another only in wave length and rate of vibration.

The longest waves, naturally, have the lowest rates of vibration. Certain radio waves which are about twelve miles long vibrate about 15,000 times per second, while certain radium emanations, about one-millionth of a centimeter in length, vibrate three hundred million trillion times per second. Between these two extremes are all gradations of length and vibration rate. Light rays are simply those electromagnetic waves to which the rods and cones happen to be sensitive. They range in vibration frequency from 380 trillion to 800 trillion vibrations per second.

The *hue* or color of any visual sensation is dependent upon the *frequencies of the light waves.* Red has the lowest frequency, violet the highest. A typical frequency for red is 460 trillion vibrations per second, for yellow 520 trillion, for blue 630 trillion. A frequency halfway between red and yellow gives orange, but mixture of yellow and red waves also gives orange.

The *brightness* of light depends upon the energy of the vibrations. The more energetic the vibrations, the greater is their *amplitude.* But brightness also depends upon the sensitiveness of the retina to particular wave frequencies. It is most sensitive to yellow light; and hence, in the daytime, the yellows look bright and the reds and blues dark in proportion to their wave amplitude.

The Structure of the Ear.—The auxiliary tissues of the ear are arranged to transmit sound waves from the air outside to the sensory cells buried in the skull on either side of the head. By following the diagram in Fig. 104 A, the course of these waves may be made out. They enter through the passage that opens to the outside, travel down it and set into vibration the membrane known as the *eardrum* which is stretched across the end of the tube. Beyond the eardrum is a chamber, known as the *middle ear,* which opens into the throat by way of the *Eustachian tube.* The vibrations on the eardrum are carried across the middle-ear chamber by three minute bones or *ossicles,* the hammer, anvil, and stirrup. The hammer is attached to the eardrum, and the stirrup to another membrane that covers an opening to a second chamber, the inner ear. The anvil is located between the hammer and stirrup and joins them. The three bones together act like a rod which is pushed back and forth with the vibrations of the eardrum and which in turn pushes the membrane over the inner ear back and forth, thus transmitting the vibrations from one membrane to the other.

The *inner ear* is a very small cavity in the bone, filled with a watery fluid. It resembles a miniature limestone cavern, with a number of winding passages leading off from the main chamber which is called the *vestibule.* Three of these passages make half-circle turns out of the chamber and back into it; they are called the *semicircular canals.* A fourth passage, called the *cochlea,* leaves

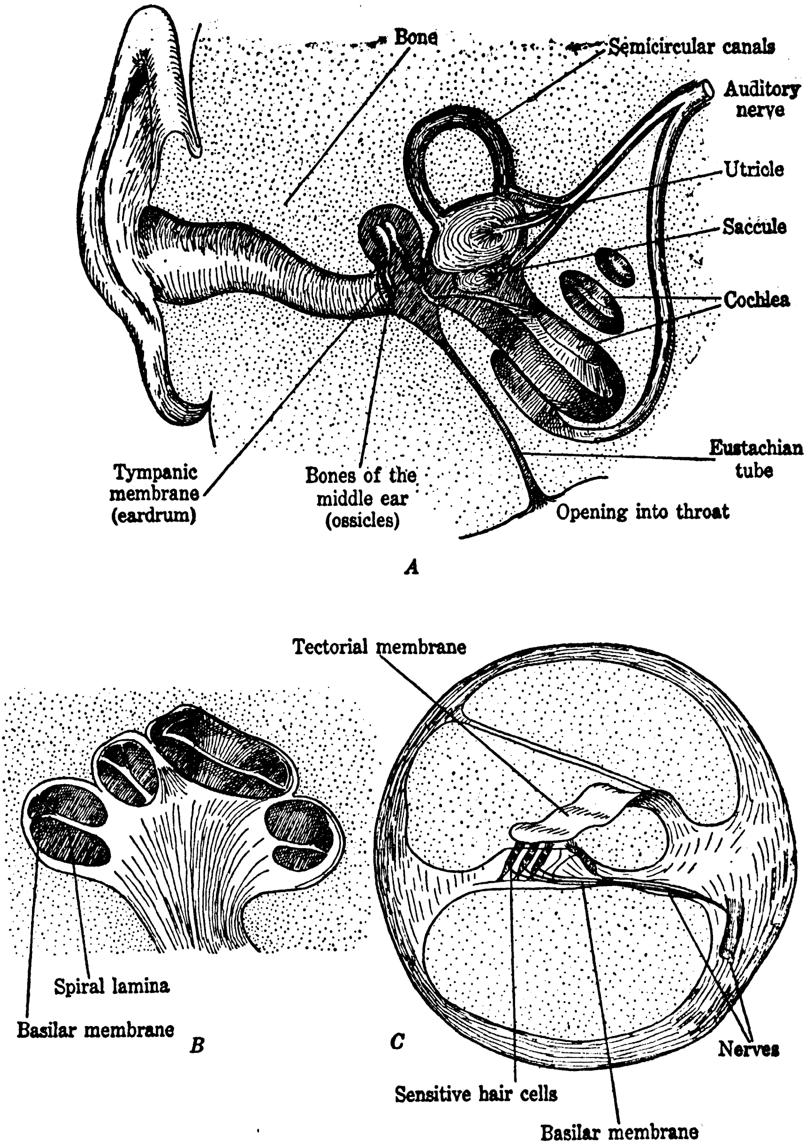


FIG. 104.—Diagram of auditory structures. *A,* diagrammatic section view through right ear; *B,* longitudinal section through the entire cochlea; *C,* cross section of the cochlear passage. (*A* and *B* redrawn from Martin's *The Human Body,* Henry Holt & Company, Inc. *C,* after Gray.)

the lower part of the vestibule from a single opening and winds about in a spiral course, taking about three complete turns to a blind ending in its tip. If the bone were whittled down around the cochlea until it was a mere fraction of an inch thick on all sides of the passage, the structure formed would resemble nothing so much as a tiny snail shell.

The semicircular canals and the vestibule contain receptor cells that have to do with maintaining the balance of the body. The sensitive cells for hearing are located in the cochlea. They stand upright on a spiral membrane known as the *basilar membrane*, which is stretched across the cochlear passage. The liquid which fills the inner ear is set into vibration by the movement of the stirrup against the membrane which separates the inner ear from the middle ear. The vibrations of the liquid set the basilar membrane into vibration. This vibration causes the sensory cells to rub against the *tectorial membrane*, which hangs over them from above, and in this way they are stimulated. The lower ends of the sensory cells are in direct contact with nerve dendrites which carry the stimulation from them to the brain. (See Fig. 104 C.)

The Stimulus for Sound.—Sound waves are mechanical vibrations which may pass through almost any sort of body, but which are usually brought to our ears through the air. The pitch of a sound depends upon the rate of vibration of sound waves, just as color depends upon the rate of vibration of light waves in the ether. The lower the tone, the slower the rate of vibration. The lowest tones that can be heard by human beings vibrate about 20 times per second; the highest, about 20,000 times. Middle C on the piano vibrates 256 times per second. Going up an octave doubles the rate of vibration; coming down an octave divides it in half.

The loudness of sound depends upon the amplitude of sound waves, just as brightness of light depends upon the amplitude of the ether vibrations; but here again the relationship is not perfect, because of the fact that the ear is more sensitive to certain vibration rates than to others. The region of greatest sensitivity lies between 500 and 5,000 vibrations per second.

The Chemical Senses.—Smell and taste differ from the other senses by virtue of the fact that the stimuli which arouse them are chemicals in solution.

In the tongue are numerous small cavities, each of which contains a few sensitive cells for taste. (See Fig. 105 A.) Each sensitive cell is in contact with the dendrite of a senory neuron which transmits stimulation from it to the brain. The sensitive cells themselves are stimulated by various chemical substances in solution in the saliva.

In spite of the fact that we attribute a different taste to nearly every different substance we take into our mouths, there are really only four basic taste sensations. They are *sweet, sour, salt,* and

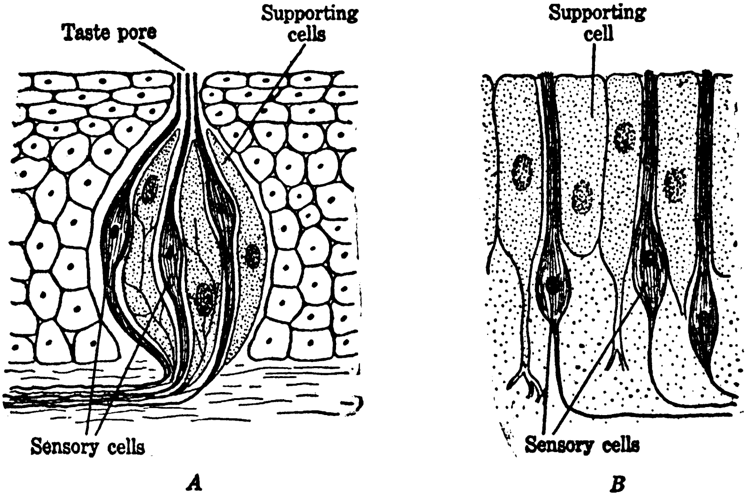


FIG. 105.—Diagram of the chemical sense organs. *A,* taste; *B,* smell.

bitter. What we ordinarily call the taste of a substance is really a combination of its true taste with touch and temperature sensations aroused by its contact against the tongue and the sides of the mouth and, most important of all, the sensations of smell that are aroused by the vapors which pass into the nose through the place where the nasal passages enter the back of the mouth. Things taste so flat when one has a cold because the cold cuts off the smell sensations that are the most important part of the taste. If our food is spicy or peppery, there is usually a component of pain added to its taste.

The sensitive cells of smell are squeezed in between epithelial cells in the lining of the upper part of the nasal passages. Chemical substances which enter the nostrils as gases are dissolved in the mucus which covers the lining of the passages and are thus made capable of stimulating the sensory cells. (See Fig. 105 B.)

The sense of smell can be aroused by astoundingly small amounts of an odoriferous substance. In the case of some substances, one part in thirty billion parts of air is sufficient for a man to detect it. And as everyone knows, smell is vastly more

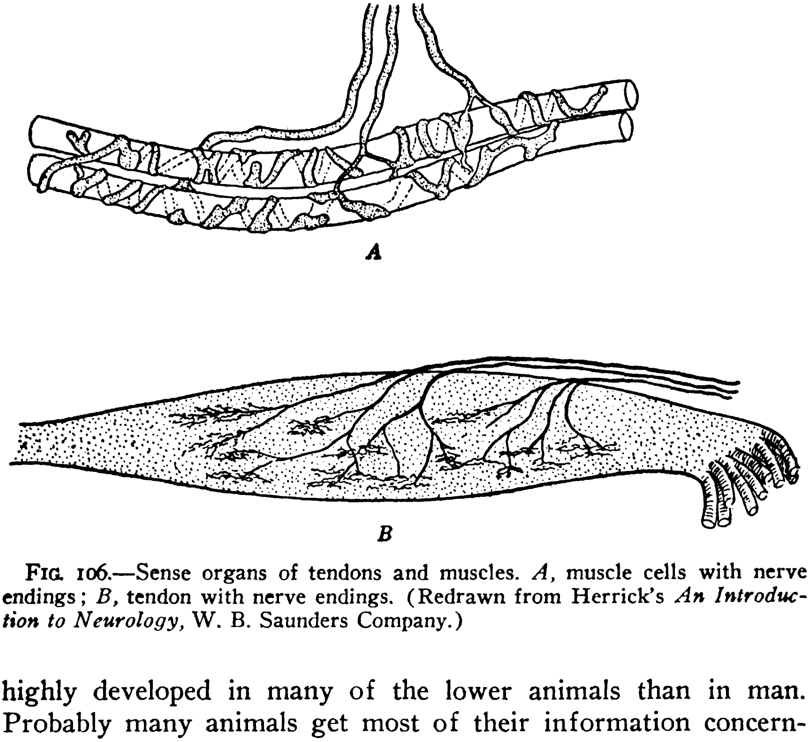


FIG. 106.—Sense organs of tendons and muscles. *A*, muscle cells with nerve endings; *B*, tendon with nerve endings. (Redrawn from Herrick's *An Introduction to Neurology*, W. B. Saunders Company.)

highly developed in many of the lower animals than in man. Probably many animals get most of their information concerning the outside world by means of the sense of smell, just as we get our most valuable information through sight. But although smell may not serve us to any great extent as a bringer of information, it probably plays a more important rôle than is ordinarily suspected in the life of feeling and emotion. Nearly everyone has experienced the manner in which an odor will bring back a forgotten scene and with it a very vivid sense of the feelings he had at the time it was enacted. And it is probable that we do not realize to what extent our reactions to people or things are favorable or unfavorable because of the presence of pleasant or unpleasant odors.

The Somesthetic Organs.—Scattered throughout the body, in the skin, the smooth muscles, the skeletal muscles, the tendons, joints, and elsewhere, are numerous very simple sense organs. Some are merely free endings of dendrites, without any special sensitive or auxiliary structures connected with them. In others,

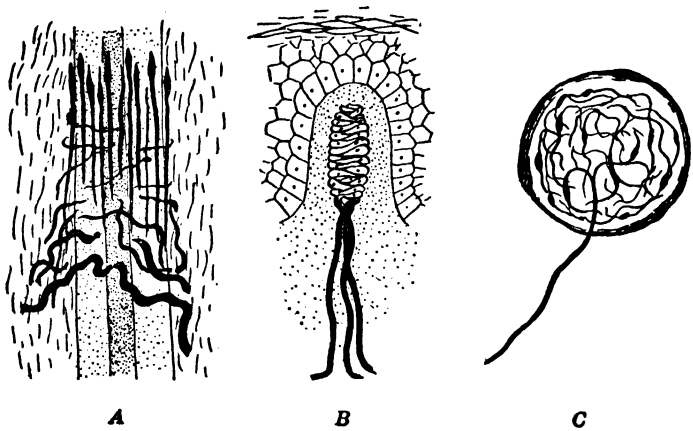


FIG. 107.—Sense organs of the skin. *A,* sensory dendrite wrapped around the base of a hair; *B,* Meissner corpuscle in a papillus of the finger; *C,* end bulb of Krause, from the conjunction of the eye. (Redrawn from Herrick's *An Introduction to Neurology,* W. B. Saunders Company.)

the dendrite endings are enclosed in small capsules of tissue which are auxiliary and possibly sensitive in function. Figs. 106 and 107 show a number of these receptors. The free nerve endings are believed to be the sense organs for pain. The receptors at the roots of the hairs are sensitive to pressure. The functions of some of the others are indicated below, but in the case of many of these organs little is known about the nature of their sensitivity.

At any rate, the functions of all these receptors are so completely interlocked that it seems best to treat them as a single sense-organ group, calling them the organs of bodily sensation, or *somesthetic* sense organs. In spite of their interlocking function, we find that these organs enable us to respond and adjust to three different types of facts: *organic,* having to do with the condition of our bodies; ***kinesthetic,*** having to do with the position and movement of the limbs and trunk and the weight of objects being lifted; and *tactual,* having to do with the qualities of objects that are touched or handled or that in other ways come into contact with the surface of the body.

If one touches a thin, cold piece of wire to his wrist at a number of points, he will discover that the sensation of cold is aroused only at certain points in the skin. Now if the wire is heated, particular spots of sensitivity to warmth may also be located, and these spots are not found in the places where the cold spots are placed. By similar means, numerous spots that give a sensation of pain and less numerous spots that produce a feeling of pressure can be found.

These three sensations—pressure, pain, and temperature—seem to be the only kinds provided us by the somesthetic sense organs, although different types of pressure, pain, and temperature are produced by different kinds of stimulation. Thus, we find that a very warm wire will produce not only a feeling of warmth at the warm spots, but a feeling of cold at the cold spots, and that, to a lesser degree, the warm spots are stimulated by a very cold wire. Still greater heat or cold will stimulate the pain spots. We therefore have at least six kinds of temperature sensations: warmth, produced by stimulation of the warm spots; heat, by stimulation of the warm and cold spots; burning heat, by stimulation of the warm, cold, and pain spots; cool, by simple stimulation of the cold spots; cold, by stimulation of the cold and warm spots; and painful cold, by stimulation of the cold, warm, and pain spots. The difference between extreme heat and extreme cold is probably a difference in the balance between cold- and warm-spot stimulation. Those who have participated in the old trick of making some poor blindfolded victim believe he is being branded with a hot iron while touching him with a piece of ice will realize that the difference in feeling between hot and cold is not very great, after all.

Similarly, there are different kinds of pain. Itching is the result of slight stimulation of the pain receptors, pricking is produced by somewhat stronger stimulation, while what is called "clear pain" results from cutting the skin. The pain receptors in the muscles produce aching pains, and those under the finger nails yield a lively and most disagreeable sensation called "quick pain." Pressure sensations also are of all types, from a light tickle on the skin to the strain that is felt in our joints when we lift something heavy.

Organic Sensitivity.—We are made aware of the internal condition of our bodies chiefly by sense organs located in the smooth muscles of the digestive, circulatory, and excretory tracts, although feelings of bodily heat or cold are probably mediated by the temperature receptors in the skin, and feelings of fatigue result largely from stimulation of the sense organs in the striped muscles. Four kinds of organic feelings which are probably produced by complex patterns of pain and pressure stimulation may here be noted.

1. The feeling of *hunger* is apparently produced by stimulation of receptors in the walls of the stomach. It will be remembered that during the time we are digesting a meal, waves of peristaltic contraction move down the stomach. These contractions apparently arouse no sensations; but as soon as the stomach becomes fairly empty, certain stronger, slower contractions set in, which arouse the sensations that we call hunger. When we are hungry, the pangs become very intense for a few minutes and then fade away, only to return again; and it has been shown that the most intense pangs come just at the time that the stomach is contracting most vigorously.

2. The feeling of *thirst* is mediated by receptors in the mucous lining of the throat. Whenever the throat dries out, usually as a result of lack of water in the body, the thirst receptors are stimulated. If, for any reason, the flow of saliva is stopped, we feel thirsty even though our bodies contain sufficient moisture.

3. It is known that sensations of *nausea* are accompanied by waves of contraction that move up the alimentary canal, rather than down it as peristaltic waves do. It seems probable, therefore, though it is not known for certain, that these "antiperistaltic" contractions provide the stimuli for the sensations.

4. Whenever the mucous membranes are stretched, whether in certain regions of the alimentary canal or in the bladder, sensations of *strain* and *fullness* are produced which may become quite painful.

In addition, we experience many bodily sensations in connection with sexual activity, emotion, illness, and other conditions the stimulation for which is imperfectly understood.

Kinesthetic Sensitivity.—Embedded in our skeletal muscles and in the tendons which attach them to the bones, and occupying the surfaces between our joints are numerous somesthetic organs which secure information as to what is going on in our limbs and muscles. They are the sense organs for the *kinesthetic sense,* the sense of movement. It is a remarkable fact that, although this sense is probably the most essential one we possess, most people are not even aware of it, and it was not called to the attention of the scientific world until the middle of the last century.

Anyone who stops to notice it can sense a feeling of strain in his muscles when they are strongly contracted. Closer attention will reveal the fact that even the slightest movement produces some sense of strain in muscles and joints. Even though we habitually disregard our kinesthetic sensations, every movement we make is guided by kinesthetic nervous impulses. It would be impossible to perform any sort of skilled action without them, since these impulses coming into the central nervous system exert inhibiting and reinforcing influences which serve to coordinate the activity of the muscles concerned. As might be expected, most of the impulses entering the cerebellum come from kinesthetic receptors.

You may readily demonstrate how your own movements are guided by kinesthetic sensations. Close your eyes and hold out your left hand with the fingers spread apart. Then touch the tips of each finger with the index finger on your right hand. No matter how much you move the left hand about, you will have little difficulty in finding the tips of the fingers, although the kinesthetic sense is the only one that can guide you to them.

When, in the disorder known as locomotor ataxia, the nerve fibers of the spinal cord which carry kinesthetic impulses to the brain are destroyed by the spirochete of syphilis, it is no longer possible to control the movements of the legs properly, and the gait becomes jerky and irregular. The patient has to watch his legs when he walks to find out what they are doing!

Tactual Sensitivity.—Whenever anything touches our skin in almost any part of the body we can be made aware of it by the tactual organs located in the skin tissues. In addition to warning us of danger and preventing our coming into contact with noxious substances, the tactual sense gives us information about the smoothness, temperature, and other qualities of the objects we touch. In combination with the kinesthetic sense it enables us to adjust to the shape, size, and weight of objects. This combined action of skin and kinesthetic organs is so complete that it is impossible to draw a line between the point at which skin sensation leaves off and kinesthetic sensation begins.

The Maintenance of Equilibrium.—In addition to having the kinesthetic sense to guide our movements, we possess two sets of organs, the *otolith organs* and the *semicircular canals*, located in the inner ear, which help us to maintain our balance. The otolith organs are found in two small sacs, known as the *utricle* and *saccule*, located inside the vestibule. (See Fig. 104 A.) Each organ is composed of a clump of "hair cells," that is, cells with tiny hair-like strands extending from them. They are receptor cells and are in direct communication with sensory nerve fibers. Scattered among the hairs are small granules called *otoliths*; and as the head tips one way or another, the otoliths press from various directions against the hairs, stimulating the cells so that they respond to the relation between the force of gravity and the position of the head.

The semicircular canals are located so that they open into the utricle. There are three of them in each ear, and they lie in the three planes of space, that is, in positions that would be parallel to the back, side, and bottom of a cubical box.

At one of the openings of each canal into the utricle, there is a clump of hair cells similar to those in the otolith organs. These cells, however, are stimulated not by otoliths, but by the movement of the liquid which fills the canals. If one twirls a bucket full of water back and forth by means of quick turns of the wrist, the water may remain quite stationary while the sides of the bucket move rapidly over it. A similar thing occurs in the canals. When the head is moved, the liquid in the canals remains relatively stationary and as the hair cells move over it they are stimulated.

The location of the canals in the three planes of space is now readily understood. Let us, for the purpose of making the point clear, imagine that a man's head is square, or, rather, cubical in shape. If he wags his head from side to side, the hair cells in the canals parallel to the back and front surfaces of the head will be stimulated. If he nods his head forward and backward, the canals parallel to the right and left sides will go into action. And if he turns his head, the canals parallel to the top and bottom surfaces will be involved. *The receptors in the semicircular canals, therefore, are arranged to respond to motion of the head in any direction.*

We are never conscious of sensations from the otolith organs and the semicircular canals; but with their ability to respond to motion and to changes in position with respect to gravity, those organs act as receptors for a complex group of reflexes of equilibrium, or *righting reflexes*. The nervous impulses for these reflexes pass through the cerebellum and brain stem, and it is largely as a center for righting reflexes that the cerebellum acts to coordinate the movements of an organism. When the individual is standing still, he always sways slightly, but the instant he begins to tip too far in one direction there is a reflex contraction of the muscles that will pull him back into position. As one writer has put it: "The act of standing is a continual process of falling and righting oneself." The minute one begins to walk or move about, the reflexes of equilibrium are called upon to an even greater extent. Walking is essentially a tipping from side to side from one leg to another while the legs are swung back and forth. Practically every movement we make—of arms, trunk or legs—throws us off balance and makes necessary some righting reflex to keep us from tipping over completely.

Although the otolith organs and the semicircular canals are specialized receptors for the righting reflexes, they are, fortunately, not the only receptors that can be used. Both our eyes and the kinesthetic receptors can and do cooperate in stimulating the righting reflexes. In certain deaf persons all the receptors of the inner ear have been destroyed, yet such individuals successfully maintain their equilibrium on the basis of reflexes from other receptors. It is said, however, that when they dive into water they are as likely to swim downward as not, since when they are under water neither their eyes nor their kinesthetic receptors can tell them "which way is up."

When the semicircular canals are overstimulated, they produce dizziness. The tendency to fall down is due to exaggeration or improper direction of the righting reflexes. The impression that the world is spinning about one is caused by reflexes from the canals that make the eyes jerk back and forth, and the nausea which accompanies dizziness is due to other reflexes that affect the muscles of the alimentary tract.

Chapter Summary

The most highly developed receptors or sense organs are composed of auxiliary tissues which serve to bring stimuli in contact with sensitive tissues. In each of our sense organs the receptor cells specialize in being sensitive to certain types of stimuli.

The auxiliary tissues of the eye serve as a camera to focus a pattern of light coming from the world outside on to the rods and cones (the sensitive cells) of the retina. The rods are sensitive to white, gray and black and are capable of adapting to dim light. The cones are sensitive to colors as well as brightnesses, but they cannot adapt to dim light.

The stimuli for vision are light waves, that is, electromagnetic vibrations in the ether. The hue of a visual sensation depends upon the frequency of the light waves, red having the lowest frequency and violet the highest. Brightness is dependent on the energy or amplitude of the waves and also upon the degree of sensitivity of the rods and cones for certain hues.

The auxiliary tissues of the ears exist for the purpose of conducting sound waves to where they can cause the sensitive hair cells of the basilar membrane in the cochlea to vibrate.

The stimuli for hearing are sound waves, that is, mechanical vibrations that usually come to us through the air. The pitch of a sound depends upon the frequency of the sound waves; the loudness, upon the energy or amplitude of the waves and upon the special sensitivity of the ear to certain wave frequencies.

The receptors for taste are found in little pits in the tongue. There are four basic taste sensations: sweet, sour, salt and bitter. What we call the taste of foods depends also on smell, temperatures, pressure and pain.

The receptors for smell are in the mucous lining of the nose. They are sensitive to extremely minute amounts of chemical substances which become dissolved in the mucus.

In the skin, muscles, and mucous linings of the body are simple sense organs of different types, known as somesthetic receptors. Their stimulation results in various types of pressure, pain, and temperature sensations. Their functions overlap considerably, but they furnish us three types of sensitivity: (1) Organic sensitivity to physiological changes in the body, which produces feelings of thirst, hunger, nausea, feelings of strain and fullness, and many other bodily sensations; (2) kinesthetic sensitivity to muscular movements and to the movement and position of the limbs; (3) tactual sensitivity to objects touching the skin.

In the otolith organs and semicircular canals of the ear there are receptors that never produce sensations. Their stimulation results in certain righting reflexes which help the body to maintain its equilibrium. The kinesthetic receptors and the eyes cooperate with them in producing righting reflexes.

QUESTIONS

1. What are the functions of the sensitive and auxiliary sense organ tissues?
2. Describe the eye, comparing it to a camera.
3. What are the rods and cones? What is the function of each?
4. Describe the relations between the auxiliary and the sensitive structures for hearing.
5. Compare the stimuli for vision and hearing (a) as to their nature and (b) as to the effects they produce.
6. Discuss the chemical senses.
7. Discuss somesthetic sensitivity from the following points of view: (a) the receptors, (b) the kinds of sensation, (c) the kinds of facts to which it adjusts us.
8. Describe all the factors of sensitivity which enable us to keep our balance and integrate our movements.

GLOSSARY

aqueous humor (ā'kwē-us) The liquid substance between the cornea and lens of the eye.

auxiliary tissues Parts of a sense organ which serve to bring stimuli into proper contact with the sensitive tissues.

basilar membrane (bās'i-lar) Spiral membrane in the cochlea on which the sensitive cells for hearing are placed.

choroid coat (kôr'oid) A black pigmented membrane located between the sclerotic coat and the retina of the eyeball.

ciliary muscle (sil'i-a-ri) A smooth muscle surrounding the lens of the eye which contracts to thicken the lens and relaxes to allow the lens to flatten.

cochlea (kok′lē-a) A spiral passage which winds out from the vestibule in the inner ear and across which the basilar membrane is stretched.

cones Modified sensory dendrites in the retina which act as sensitive cells for vision. They are sensitive to hues as well as brightnesses.

cornea (kôr′nē-a) The transparent part of the coat of the eyeball, covering the iris and pupil.

electromagnetic waves Vibrations in the ether. Light waves are the electromagnetic waves that range from 380 trillion to 800 trillion vibrations per second. Other electromagnetic waves are radio waves, heat rays, ultra-violet rays, and X-rays.

Eustachian tube (ū-stā′ki-an) Tube running from the middle ear to the throat.

fovea (fō′vē-a) Slight depression in the retina which is the center of focus in the eye. It contains only cones.

iris (ī′ris) A contractile membrane, perforated by the pupil. It is the colored part of the eye.

kinesthetic sensitivity (kin′es-thet′ik) Sensitivity to movements of the muscles and changes in position of the muscles and trunk.

organic sensitivity Sensitivity to internal physiological states and changes, such as sensitivity to hunger, thirst, and nausea.

ossicles (os′i-k′ls) Three small bones in the middle ear (the hammer, anvil and stirrup) which transmit sound vibrations from the eardrum to the membrane covering the inner ear.

otolith organs (ō′to-lith) Small clumps of hair cells, located in the utricle and saccule, which have small hard granules, called *otoliths*, scattered among them. They are receptors for the righting reflexes.

retina (ret′i-na) Sensitive membrane in the eye upon which an image of the outside world is focused. It contains the rods and cones.

rods Modified sensory dendrites in the retina which act as sensitive cells for vision. They are not sensitive to colors.

saccule (sak′ūl) Small sac in the vestibule of the inner ear which contains an otolith organ.

sclerotic coat (sklē-rot′ik) The tough external membrane of the eyeball.

semicircular canals Semicircular passages running out of and back to the vestibule of the inner ear. They act as receptor organs for the righting reflexes.

sensitive tissues The tissues in the sense organs which possess special sensitivity to definite types of stimuli.

somesthetic sensitivity (sō'mes-thet'ik) Sensitivity to stimulation of the skin and internal bodily tissues.

tactual sensitivity (tak'tū-al) Sensitivity to stimulation of the skin. The sense of touch.

tectorial membrane (tek-tō'ri-al) The membrane lying over the sensitive cells on the basilar membrane. Vibrations of the basilar membrane cause the cells to be stimulated by rubbing against the tectorial membrane.

utricle (ū'tri-k'l) Small sac in the vestibule of the inner ear at the base of the semicircular canals. It contains an otolith organ.

vestibule (ves'ti-būl) Cavity of the inner ear out of which the cochlea and semicircular canals run.

vitreous humor (vit'rē-us) A jelly-like substance which fills the eyeball and through which light waves pass from the lens to the retina.

CHAPTER XXI

INTERNAL ADJUSTMENTS

The Vital Reflexes.—It is usually said that the function of the response system is to adjust the organism to its environment. This it does by causing the organism to move about in a manner that, as a rule, protects it from harm and secures for it the necessities of life. But there are other movements that go on within the body that may or may not have to do with its relationship to its environment, but that are quite as essential to its existence as its external behavior. These internal movements are also functions of the response system, although, as we shall see, some of them are to a certain degree independent of nervous control. They are usually integrated in certain specific gray-matter regions in the brain stem, known as the *vital centers*, and they are spoken of as the *vital reflexes*. For the most part, they are not under voluntary control, or are only incompletely so; which means that impulses from the cerebral cortex—the center for the integration of our so-called voluntary responses—are not always able to inhibit or reinforce them.

The Nervous Control of Breathing.—There is no known instance of a man's committing suicide by the simple expedient of holding his breath. Nor does one have to keep his attention on breathing in order to insure its progress. This is because there is a center in the brain stem which insures the sending out of impulses to the muscles of the chest and diaphragm, whether the cerebral cortex enters into the picture or not. To be sure, cortical action upon this center can cause the movements of breathing to be hastened or retarded. But if one attempts to hold his breath for more than a minute or two, sooner or later the cortical inhibition will be overcome, and breathing will recommence. What happens is that, as carbon dioxide piles up in the blood, the breathing center becomes more and more acid—since carbon dioxide combines with water to make carbonic acid—and this acidity acts as a strong stimulus to the neurons that innervate the breathing muscles. The acid stimulus finally becomes too strong for the cortical inhibition.

The vigor of our breathing depends upon the amount of acid in the breathing center. When we exercise severely and the blood's acidity increases steeply, breathing becomes deeper and more rapid, until that acidity is reduced. On the other hand, if one forces oneself to breathe deeply and rapidly for a minute or two, carbon dioxide is washed out of the blood so completely that, for a short time, breathing may come almost to a standstill.

The regular rhythm of breathing is dependent not upon the direct stimulation of the center by acid, but upon reflexes from the receptors located in the lung tissue. There are two sets of these receptors, one stimulating inspiration as the lungs collapse, and the other stimulating expiration as they become filled. Thus a regular inflow and outflow of air is automatically maintained. At the same time, the center may receive reflex stimulation from many other sources. A sudden dash of cold water on the skin will cause us to catch our breath, and various emotional states may produce rapid breathing, deep breathing, holding the breath, or sighing. Among the most delicate indications of emotional disturbance are changes in the ratio between the time taken for inspiration and the time for expiration. A successful card shark once boasted that he could always tell when his opponent was bluffing by watching his breathing movements.

All this means that neurons from many regions of the nervous system must make synaptic contact with the neurons of the breathing center, making possible all sorts of reflex or intentional control of this most important vital function, and thus integrating it with the other activities of the organism.

The Autonomic Nervous System.—Although breathing movements themselves do not take place inside the body where they cannot be seen, they belong properly among the responses of internal adjustment, since the important change which they effect is in the internal condition of the body, not in the relation of the body to its environment. Breathing differs from most of our internal adjustments, however, in being carried out by skeletal muscles. Ordinarily the effectors for internal adjustment are either heart muscles, smooth muscles, or glands, all of them buried in the tissues where their activities are seldom noticed. The motor neurons which run to these three groups of effectors are different from those that have so far been described, in that the axons leaving the spinal cord do not run all the way to the effectors, but relay their impulses to a second set of neurons which carry them to their destination. This double set of motor neurons is generally referred to as the *autonomic nerve fibers.*

Scattered throughout the body cavity are found small bunches of nervous tissue called *autonomic ganglia.* The autonomic nerve fibers which leave the spinal cord run out to these ganglia, where

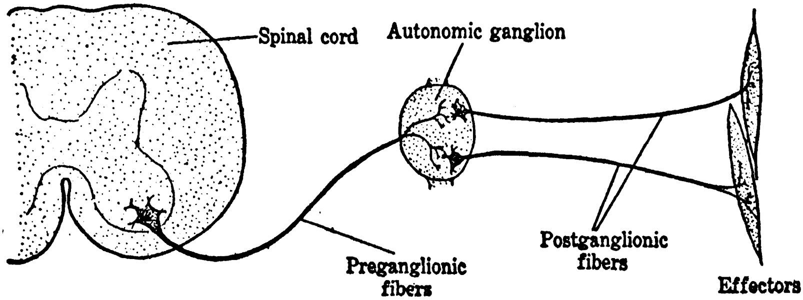


FIG. 108.—Diagram of preganglionic and postganglionic neurons.

each one makes synaptic contact with several neurons whose cell bodies are located in the ganglia. The axons of these latter neurons carry the impulses to the effectors. (See Fig. 108.) The neurons which run from the spinal cord to the ganglia are spoken of as *preganglionic fibers*; those which run from the ganglia to the effectors are called *postganglionic fibers.* The arrangement permits a nervous impulse starting from the central nervous system over a single preganglionic fiber to be carried to several different effectors by the postganglionic fibers with which the preganglionic fibers make contact.

The autonomic ganglia and the pre- and post-ganglionic nerve fibers constitute what is known as the *autonomic nervous system.* It is sometimes mistakenly supposed that this system is quite independent of the nervous system as a whole, but that is untrue. It is simply that particular part of the system which carries motor impulses to the smooth muscles, heart muscle and glands, rather than to the skeletal muscles.[1]

The autonomic nervous system is divided into three parts. The first division is called the *cranial* because its preganglionic fibers leave the central nervous system from the brain stem. The preganglionic fibers of the second division, the *sympathetic*, arise in the spinal cord in the region back of the chest cavity and stomach; while in the third division, the *sacral*, the preganglionic fibers come from the lowermost region of the spinal cord. The cranial and sacral divisions are sometimes classified together as the *parasympathetic* system, because their activity is always opposed to that of the sympathetic system.

Heart muscle, smooth muscles and glands are usually governed by two sets of nerves, one of which sets them into action and one of which causes the muscles to relax and the glands to stop their work of secreting. In other words, one set of nerves is excitatory and the other inhibitory. In all cases of this double innervation, one set of nerves comes from the sympathetic system and the other from the parasympathetic. Sometimes the sympathetic system has the exciting influence and the parasympathetic is the inhibitor. At other times these relations are reversed. For example, stimulation from sympathetic neurons speeds up the heart beat, while that from certain cranial fibers slows it down. On the other hand, activity of the cranial system causes muscles in the iris of the eye to contract, thus narrowing the pupil, while sympathetic stimulation causes the iris to relax, thus dilating the pupil.

The activities of the sympathetic system are especially interesting in that this system employs the services of a hormone to back up its action on the body. Sympathetic nerve fibers run to the medullary part of the adrenal glands, and whenever the sympathetic system goes into action, they stimulate the glands to secrete their hormone, adrenin. Whatever responses are stimulated by the sympathetic system are also stimulated by the adrenin, and whatever responses are inhibited by the action of the sympathetic system are also inhibited by adrenin. The sympathetic nervous

[1] Some authorities classify the sensory neurons to the blood vessels, digestive organs, heart, lungs, etc., as parts of the autonomic system. Here we include only the pre- and post-ganglionic motor neurons.

system and the adrenal glands work together in such harmony that they are now looked upon as a single system for the regula-

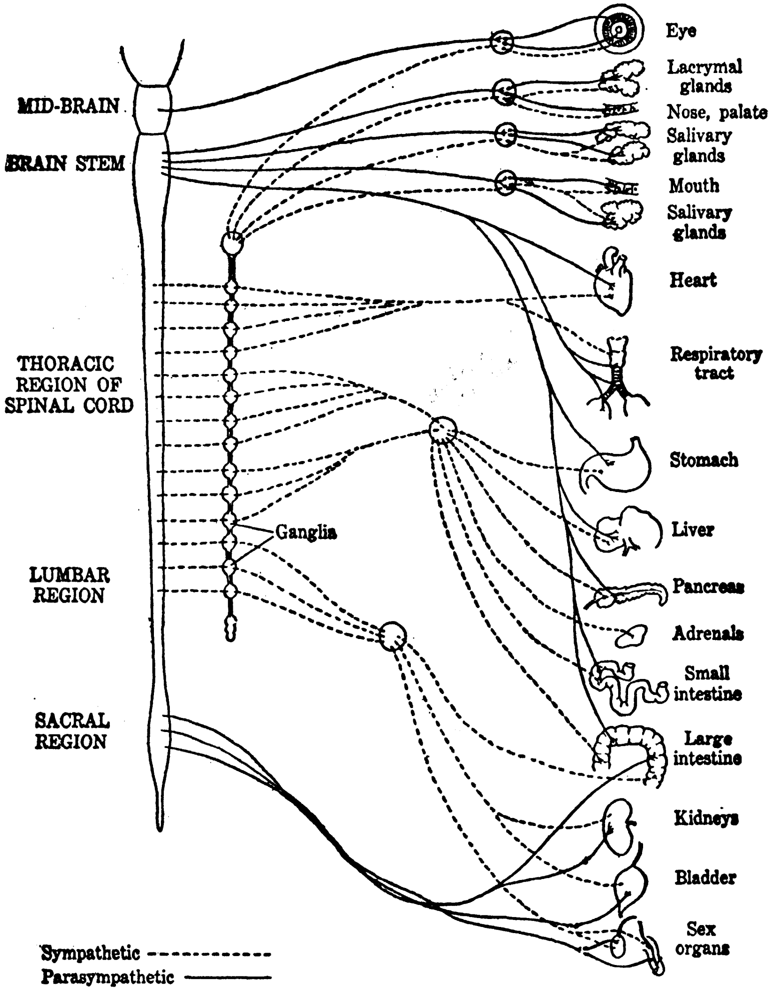


FIG. 109.—Diagram of the autonomic system. (Modified from Meyer and Gottlieb's *Experimental Pharmacology*, Urban and Schwarzenberg and J. B. Lippincott Company; by permission of the publishers.)

tion of internal responses, and are referred to as the *sympathico-adrenal* system.

Adrenin is not the only chemical mediator of autonomic responses. When impulses are sent out over sympathetic fibers to the various effectors which they innervate, certain adrenin-like substances, known as *sympathins*, are formed at the junctions between the nerve fibers and the effectors. It is thought that the sympathetic nerves stimulate or inhibit the effectors through the mediation of these chemical substances. Like adrenin, sympathins may be carried by the blood stream to all parts of the body, where they have the same effect on the muscles and glands that is produced by adrenin or sympathetic stimulation.

Parasympathetic stimulation or inhibition of the effectors results in the formation of another sort of chemical, *acetylcholine,* which, however, is not carried through the circulatory system, since there is an enzyme in the blood which causes its disintegration almost as soon as it enters the blood stream. Acetylcholine is formed in both the sympathetic and parasympathetic ganglia whenever impulses are passed from the preganglionic to the postganglionic neurons, and there is evidence that it is also formed in the stimulation of skeletal muscles. It is possible that chemicals play an important part in the passage of impulses across synapses in the central nervous system, and it may be that further study of these chemical mediators of nervous and muscular response will throw much light on the nature of inhibition, facilitation, and learning.

The Regulation of Circulation.—We have already seen how, when the muscles of the body become active, the rate of breathing is automatically increased to take care of the rapid rate of cell respiration. It is just as important that blood be carried to the muscles at a rapid rate to bring large amounts of oxygen to each muscle cell.

When a muscle is at rest, only a few of its capillaries are open at a given moment. This can be demonstrated by making the skin semi-transparent by rubbing oil on it. Then, if a powerful light is focused upon a certain spot, the capillaries in the underlying muscles can be seen by means of a microscope. Only a few of them are visible at a time, but there is a continual closing and disappearance of the visible capillaries and opening of others. Now, if the muscle is contracted, nearly all the capillaries will open out and remain open as long as the muscle cells are at work.

The number of open capillaries may be a hundred times greater than the number in the resting muscle.

It is believed that the opening and closing of the capillaries is regulated by the presence or absence of certain products of metabolism which cause the muscle fibers in their walls to relax, with the result that they open up. As soon as the blood carries these products away, the capillaries close. In the resting muscle these products are formed so slowly that most of the capillaries remain closed; but when the muscle is active they form rapidly enough to keep nearly every capillary open continously, and the muscle actually swells and grows larger with the added volume of blood. Not only is there more blood in the muscle, but it flows through at a more rapid pace. Obviously, changes must take place in the entire circulatory system if enough blood is to be brought to the muscles during periods of activity. The following is an outline of the nervous connections which serve to bring about these changes:

1. A center in the brain stem for inhibiting the heart beat, sending out parasympathetic fibers to the heart.

2. A center in the brain stem for augmenting the heart beat, sending out sympathetic fibers to the heart.

3. A *vasoconstrictor center* in the brain stem, sending sympathetic fibers out to the arterioles and capillaries in the skin and abdominal organs. Impulses from this center cause the muscles in the walls of the arterioles to contract, thus causing less blood to flow through them to the tissues of those regions.

4. Certain *vasodilator fibers,* running to the arterioles and capillaries of the skeletal muscles and causing these vessels to dilate through relaxation of their muscular walls. The nature of these fibers and their reflex connections is not well understood at present.

5. Fibers running to the large veins. Presumably they are sympathetic fibers which cause the veins to contract.

During the waking hours of the day, at times when the body is not very active, all these fibers constantly carry a small amount of stimulation to their effectors, just enough to keep the heart beating regularly and to maintain a certain degree of tonus in the blood vessels. Such would be the condition of a man working at his desk in the office. Now suppose a sudden stimulus, such as a fire alarm, causes him to jump to his feet and run for his life. The first thing that happens is that the flow of nervous impulses going from the cerebrum to the muscles inhibits the action of the center for slowing the heart beat, resulting in an immediate acceleration of the beat. An instant later, the sympathetic fibers go into action. The heart begins to beat even more rapidly, and as the veins contract, forcing more blood into it, its contractions become stronger and stronger. The arterioles and capillaries in the skin and abdominal regions contract, greatly reducing the amount of blood flowing to those parts; and, with the expansion of the capillaries and arterioles of the muscles through stimulation by metabolic products as well as by the vasodilator fibers, nearly all the blood in the body is forced to flow rapidly through these latter vessels. Finally, there is a stimulation of the adrenal gland by other sympathetic fibers, and the added secretion of adrenin reinforces all the sympathetic responses that are being made.

In brief, when the muscles are active, the inhibition of parasympathetic impulses running to the heart, together with a wide range of activity on the part of the sympathico-adrenal system, results in an increase in the rate of blood flow and a shunting of the major volume of blood from the skin and abdominal organs into the muscles.

The Regulation of Digestion.—There are three typical kinds of effector stimulation that serve to bring about our internal adjustments. The first is local stimulation, as illustrated by the self stimulation of the heart referred to in Chapter XVIII, and the stimulation of the capillaries by metabolic products. The second is stimulation from autonomic nerve fibers, and the third is stimulation from hormones, as instanced by the action of adrenin. In the control of digestive responses, all three play a part.

Digestive responses are of two kinds: the movements of the digestive tract, of which the peristaltic movements are the chief type, and the secretion of digestive juices. The peristaltic movements can go on quite automatically, being controlled by a net of nerves located in the walls of the stomach and intestines and having no connection with the central nervous system. But the vigor of these movements is controlled by autonomic nerve fibers. The parasympathetic group stimulates the contractions; the sympathetic, with the adrenal gland cooperating, inhibits them.

Similarly, the secretion of saliva and of the gastric and pancreatic juices is effected by the parasympathetic nervous system, while the sympathico-adrenal system inhibits their secretion. The sight, taste, or smell of food stimulates reflexes through the cranial autonomic neurons which cause the digestive glands to secrete. Once the food begins to be digested in the stomach, however, hormones are formed in the partially digested food which stimulate both the gastric and the pancreatic secretions. Indeed, secretion of the pancreatic and intestinal juices is almost entirely dependent upon the formation of a hormone which is made by the action of acid from the gastric juice upon certain substances in the walls of the small intestine. Nevertheless, stimulation from the parasympathetic nervous system is necessary to start the digestive secretions; and without this start, the formation of the hormones is impossible. Hence, the sympathico-adrenal system, by inhibiting both the movements and the secretions that are essential to digestion, may put a stop to the entire process.

The General Function of the Sympathico-adrenal System.—But why should the digestive organs be subject to the stimulation of a nerve-gland system whose whole function is to ruin digestion? The answer is found if we consider how this action cooperates with the sympathico-adrenal control of circulation. Since the blood supply to these organs is shut off, they are deprived of the materials needed for active metabolism, and it is therefore essential for contraction and secretion to stop.

The general function of the sympathico-adrenal system is to prepare the body for strong muscular effort. It not only causes the blood to run more rapidly through the skeletal muscles but increases the amount of sugar in the blood by stimulating the liver to secrete sugar from its glycogen stores. It goes into action not only when the muscles are actually busy, but whenever we experience fright, anger, worry, or any other exciting emotion. Normally such emotions occur when we face emergencies, and the sympathico-adrenal system is getting us ready to fight or run for our lives. In civilized life, of course, fear and anger are not always followed by extreme muscular activity, and the internal adjustments which prepare us for activity may have no result other than to spoil our digestion.

It is characteristic for every part of the sympathetic system to go into action at once, whereas parasympathetic reflexes usually occur in only one part of the body at a time to meet special local conditions. An anatomical difference between the two systems underlies this difference in manner of functioning. (See fig. 109.) The sympathetic ganglia form two long chains on either side of the spinal cord plus three ganglia located in front of the cord. Any sympathetic impulse leaving the spinal cord is likely to spread through all these ganglia, setting the whole system into activity. Furthermore, the transportation of adrenin and sympathins through the blood stream tends to produce characteristic sympathetic activities throughout the body whenever any part of the sympathetic system is active. The parasympathetic ganglia, on the other hand, are placed close to the particular organs to which they relay stimulation—the eye, the heart, and so on—and are not interconnected. We therefore find the parasympathetic system regulating the everyday work of each organ of the body, while the sympathetic, with its ally, the adrenal gland, sounds the alarm at the approach of an emergency, and prepares each organ to play its part in the total plan for adapting to this external situation.

Heat Control.—As you will recall, most animals are cold-blooded, while birds and mammals are warm-blooded. "Cold-blooded" and "warm-blooded" are not the best terms to use, since the real difference between the two groups is that the warm-blooded animals maintain an approximately constant temperature throughout the year, whereas the body temperature of a cold-blooded animal is usually only a few degrees above the temperature of its environment. On a hot summer day, the temperature of a "cold-blooded" animal may be even higher than that of a "warm-blooded" one. Since the rate of oxidation automatically decreases when temperature falls, the movements of cold-blooded animals slow down in cold weather, and these organisms usually die or become dormant with the approach of winter. You have doubtless noticed how sluggish house flies become on cold days. Respiration in frogs is so slow during the winter that if their lungs are removed they can still secure enough oxygen through the skin to keep alive. In warm weather, however, they are quickly asphyxiated upon removal of the lungs.

The heat which maintains the temperature of warm-blooded animals above that of their environment is derived from the oxidative reactions in the cells. We become warm with exercise because so much oxidation is taking place in the muscle cells. Since the rate of oxidation does not necessarily follow fluctuations in external temperature, the rate at which heat is lost from the body must be controlled by certain vital reflexes. There is a heat center in the brain stem which is connected with sympathetic nerve fibers running to the sweat glands, and parasympathetic fibers running to the arterioles and capillaries of the skin. When the temperature in this center is increased because of the flow of warm blood through it, it sends out impulses over both these sets of fibers, with the result that the capillaries in the skin dilate and sweat breaks out. The evaporation of the sweat helps to cool the skin; the blood flowing just below this cool surface is itself cooled and, passing to all parts of the body, cools all the tissues.

This is the main device for heat regulation. In addition, we lose heat through all the excretory processes and especially through breathing. In animals with thick fur or hair, the latter may be the chief avenue of heat loss, which explains the constant panting of dogs on hot days.

In cold weather, the first sign that heat is being lost too rapidly is the formation of "goose-pimples" on the skin. This is really a vestige of a method of resisting cold that was employed by our animal ancestors. The goose-pimples are formed by the contraction of smooth muscles at the base of the hairs. In animals with long hair this causes the coat to become fluffier and hence a poor conductor of heat. A second warmth-conserving reflex is the tensing of the skeletal muscles which we speak of as "resisting the cold." Finally, the muscles begin the rapid alternate tension and relaxation that we call shivering. This reflex muscular activity warms the body by increasing the rate of oxidation in the muscle cells. If the shivering reflex fails to warm us sufficiently, we may begin to run around and stamp our feet to warm up.

So efficient are the temperature-regulating mechanisms of the body—especially the flushing and sweating reflexes—that, unless the heat center is affected by the toxins of disease, causing us to have chills or fever, our temperature seldom varies much from the normal 98.6 degrees Fahrenheit. When, however, the air surrounding us is warm and at the same time so humid that evaporation of sweat cannot take place, we may develop a slight fever and actually begin to feel ill. It used to be thought that the ill effects of poor ventilation were due to the accumulation of carbon dioxide in the air. It is now known that carbon dioxide has nothing whatever to do with the matter. In a hot, crowded room, the evaporation of sweat fills the air with moisture, while the heat escaping from the bodies of the crowd increases the temperature. Soon it is no longer possible for heat loss to take place, and every person in the room begins to run a temperature. For good ventilation, the air in the room need not be changed as long as it is kept cool and set slightly in motion to facilitate evaporation.

The human body, when it is covered by an ordinary amount of clothing, seems to thrive best in an environment where the temperature is between 65 and 70 degrees Fahrenheit and there is a slow current of moderately humid air to allow for some evaporation of sweat and yet prevent the drying out of mucous membranes in the respiratory tract; and modern air-conditioning systems ordinarily aim to provide an environment of this sort. At the same time, health seems to be best maintained when there are occasional changes in temperature and humidity, possibly because these changes afford needed exercise to the temperature-regulating mechanisms.

Chapter Summary

Physiological equilibrium within the body is maintained by muscular and glandular responses produced by certain vital reflexes integrated in certain vital centers within the brain stem. The breathing movements are caused by stimulation of the breathing center by the acid formed in the blood when it is carrying carbon dioxide. The rhythm of the breathing movements, however, is produced by reflexes that are stimulated by the movements of inspiration and expiration.

Unlike the breathing movements, most responses of internal adjustment are performed by the heart muscle, smooth muscles and glands, which are innervated by the autonomic nervous system. This system is composed of a special group of motor neurons which run to the heart muscle, smooth muscles and glands. There are two groups of neurons, the preganglionic and the postganglionic. The preganglionic neurons run from the spinal cord to the autonomic ganglia, which are small bunches of nervous tissue scattered throughout the body cavity. Here they make synaptic contact with one or more postganglionic neurons which carry the stimuli to the effectors.

The autonomic nervous system is made up of three divisions:

1. The cranial division, in which the preganglionic fibers leave the brain stem.

2. The sympathetic division, in which the preganglionic fibers leave the middle region of the spinal cord.

3. The sacral division, in which the preganglionic fibers leave the lower region of the spinal cord.

The sympathetic system sets the medullary portion of the adrenal glands into action; and since the hormone, adrenin, which is thus produced has the same effect on the muscles and glands as the sympathetic nervous stimulation, the nerves and the glands together are called the sympathico-adrenal system. The cranial and sacral systems combined constitute the parasympathetic system, which is opposed to the sympathico-adrenal system in its action on the effectors.

Adjustment of the blood flow during muscular activity is brought about by (1) dilation of the capillaries in the muscles through direct response to certain katabolic products in the blood stream, (2) inhibition of the parasympathetic innervation of the heart, resulting in a speeding up of the heart beat, (3) a wide range of activity on the part of the sympathico-adrenal system which results in acceleration of the heart beat, relaxation of the arterioles in the skeletal muscles, contraction of the arterioles in the skin and digestive tract, and contraction of the large veins. In this way the amount of blood carried through the muscles greatly increases.

Digestive activities are facilitated by (1) local reflexes brought about by the nerve net in the digestive tract, (2) parasympathetic stimulation which reinforces the activity of the muscles of the digestive tract and starts the flow of saliva and gastric juice, (3) stimulation by hormones formed in the food that is being digested which reinforces the flow of gastric juice and is chiefly responsible for the pancreatic and intestinal secretions. The sympathico-adrenal system inhibits all the digestive activities which are stimulated by the parasympathetic system. In so doing, it conserves the energies that might go into digestion for the work of the skeletal muscles. The general function of this system is to prepare the body for muscular activity, and it goes into action not only when we are really active, but also whenever we experience emotional excitement.

The vital reflexes having to do with heat control are as follows: *Cooling reflexes:* Expansion of the blood vessels in the skin, sweating, and (chiefly in furry animals) panting. *Warming reflexes:* Constriction of blood vessels in the skin, fluffing out of the hair (represented by "goose-pimples" in man), tensing of the muscles, shivering.

QUESTIONS

1. Explain in physiological terms why deep-sea divers take a few deep, rapid breaths before diving.
2. Why aren't the breathing movements set in action by stimulation from the autonomic fibers?
3. What is the difference between the arrangement of the autonomic fibers and ordinary motor neurons?
4. What happens within the body when we become emotionally excited or active? Describe in detail.
5. Describe the responses whereby digestion is carried on.
6. What is the importance of heat regulation in the body, and how is it maintained?

GLOSSARY

acetylcholine (as'ē-til-kō'lēn) Chemical formed when parasympathetic fibers act upon their effectors.

adrenin (ad-ren'in) Hormone secreted by the medullary part of the adrenal glands. It reinforces the activity of the sympathetic nervous system.

autonomic ganglia (o-to-nom'ik gan'gli-a) Small bunches of nervous tissue scattered throughout the body cavity where preganglionic neurons make synaptic contact with postganglionic neurons.

cranial (krā'ni-al) Pertaining to the cranium or brain case. Applied to the division of the autonomic nervous system whose fibers arise in the brain stem.

parasympathetic system (par'a-sim-pa-thet'ik) A system for internal adjustment composed of the cranial and sacral divisions of the autonomic nervous system, which carries on the life-sustaining vital functions. Its action is opposed to that of the sympathico-adrenal system.

peristaltic waves (per-i-stăl′tik) Ring-like contractions of the walls of the alimentary canal which move down the canal, pushing the food along ahead of them.

postganglionic fibers (post′gan-gli-on′ik) The neurons which run from the autonomic ganglia to the heart muscle, smooth muscles, and glands.

preganglionic fibers (prē′gan-gli-on′ik) The neurons which run from the spinal cord to the autonomic ganglia.

sacral (sā′kral) Pertaining to the sacrum (a long bone near the base of the spine). Pertaining to the division of the autonomic nervous system whose fibers arise in the lower part of the spinal cord.

sympathetic Applied to the division of the autonomic nervous system whose fibers arise in the middle section of the spinal cord.

sympathico-adrenal system (sim-path′i-cō-ad-rēn′al) A system for internal adjustment composed of the sympathetic division of the autonomic nervous system and the adrenal glands, which prepares the body for activity. Its action is opposed to that of the parasympathetic system.

sympathin Chemical formed when sympathetic fibers act upon their effectors.

vasoconstrictor (vas′ō-con-strik′tôr) Applied to nervous structures which cause the arterioles and capillaries to constrict.

vasodilator (-dī′lā-tôr) Applied to nervous structures which cause the arterioles and capillaries to dilate.

vital centers Gray-matter regions in the brain stem that integrate the vital reflexes.

vital reflexes Reflexes which produce muscular and glandular responses that carry on the internal adjustments of the body.

CHAPTER XXII

BEHAVIOR AND MENTAL ACTIVITY

The Level of Cortical Integration.—The preceding chapter has described the responses going on within the body which enable the vital organs to do their work properly. The present one deals with those responses which adjust the organism as a whole to its environment. These are the functions of the organism which are from day to day of greatest concern to the average human being. In this class of adjustments fall all the activities of work and play, of companionship and achievement that a man thinks of when he speaks of "his life" or tells about when he writes his autobiography. They are the responses that are integrated in the brain—more specifically, in the cerebral cortex. Popularly, it is said that the brain is the organ with which we think. More accurately, it is the organ in which the thinking responses are integrated. But it is more than that. When a football player takes the ball and runs through the open field, dodging here and there, changing his course to suit every change in position of his interference and of the opposing tacklers, he must react far too rapidly to have time for anything that might properly be termed thought; yet a good open-field runner may display much cleverness in adjusting to the situation that presents itself to him. Such adjustments could not be made without integration in the cerebral cortex. Only the myriad of synapses present there could make possible the infinite variety of response that must be made to this constantly shifting situation. Indeed, the amount of integrative interplay that enables you to perform such a simple act as rising from your seat in the classroom and finding your way out through the door requires activity on the part of the cerebral cortex. In brief, the brain integrates immediate adjustments to the environment as well as thinking responses.

Now, when we begin to study responses at this level of integrative complexity, we discover that new phenomena appear which do not have to be taken into consideration when we are dealing with mere reflexes. Three things especially must be taken into consideration: consciousness, motivation, and thinking. This chapter will be devoted to a brief consideration of such phenomena, with emphasis on the fact that they are all aspects of the general process of response to stimulation.

Consciousness

Consciousness is one of the most remarkable properties that organisms possess. The problem of why an organism should be conscious is one that has puzzled philosophers from time immemorial. Some have come to the conclusion that consciousness is a fundamental property of matter which reaches its highest level in animal organisms. According to these thinkers, even atoms and molecules possess a dim sort of consciousness; and as matter becomes more and more highly organized in living things, consciousness becomes clearer and more definite, until it reaches its apex in man. Others have taken the view that matter could never become conscious at all and that an organism to be conscious must possess an immaterial soul which interacts with its response system in some fashion. Still others hold consciousness to be an emergent—in the sense that life and culture are emergents—which suddenly appears when the response system in a species reaches a certain level of complexity. The psychological scientist finds that these problems are quite insoluble. What he does discover is that whatever it may be that we refer to when we speak of consciousness, it is certainly something that is correlated with the activity of the response system. By arranging definite stimulus situations and getting his human subjects to respond to them by saying "I see this" or "I hear that" he can learn what they become conscious of from moment to moment and how their consciousness varies with each stimulating situation, with their past history, and with the responses that they are capable of making in a given situation. This sort of verbal response to situations arranged by the psychologist is called *introspection.* Note that its meaning is different from the ordinary meaning of the term. Ordinarily it means mulling over your thoughts and feelings, thinking about yourself, about the things you want and why you want them. Here it means simply telling a psychologist what you see, hear, taste, smell, feel or in other ways become conscious of in a given situation.

Because of the philosophical controversies that have raged around the term "consciousness" some psychologists have thought it best to drop the term entirely and speak only about what we actually observe, namely, verbal responses; while others have employed the word "experience" to indicate the thing they are studying when they get introspective verbal reports. But "experience" also has its philosophical difficulties. Here we shall use both "consciousness" and "experience" interchangeably, and, disregarding philosophical problems, will mean by them "whatever it is that we study when we get introspective verbal responses."

The Analysis of Consciousness: *Sensory Consciousness.*—Consciousness may be analyzed into three types: sensory, imaginal, and emotional, although, as we shall see, the latter may actually be a form of sensory consciousness. Sensory consciousness is the experience of things that stimulate our sense organs, either by directly touching them or by sending stimuli to them. When I touch a polished table top, for example, I have a sensory consciousness of its smoothness and hardness. When I look at a red lantern, the light waves coming from it give me a sensory consciousness of its redness and brightness. Each of our sense organs provides us with a form of consciousness that is entirely different from that of any other sense organ. We express this fact by saying that there is a *modality* of consciousness which corresponds to each of our senses. Conscious modalities may be classified as follows:

1. *Vision,* or the *visual modality,* referring to sights.
2. *Audition,* or the *auditory modality,* referring to sounds.
3. *Olfaction,* or the *olfactory modality,* referring to odors.
4. *Gustation,* or the *gustatory modality,* referring to tastes.
5. *Somesthesis,* or the *somesthetic modality,* referring to the feelings evoked by the sense organs in our bodily tissues.
   a. The *tactual submodality,* referring to the feelings evoked by substances touching the skin.
   b. The *kinesthetic submodality,* referring to feelings of po-

sition, movement, or strain in the muscles, tendons, and joints.

c. The *organic submodality*, referring to internal feelings other than the kinesthetic.

In the primitive organisms from which we evolved, there was little or no specialization of the senses. Somesthesis probably represents the general modality out of which the senses have been specialized. The three submodalities under somesthesis may be thought of as not sufficiently specialized to merit a rating as independent modalities in their own right. We have seen that their sense organs show only a low degree of specialization with respect to both structure and position. They are all pretty much alike and are scattered throughout the body. We speak of the senses or modalities that are more specialized as "higher." In the above table, the modalities and submodalities are arranged in order of their "height."

Imaginal Consciousness.—We are not conscious merely of objects that are immediately present to our sense organs. We can be conscious of the sound of a bell when no bell is ringing, and of the visual appearance of a hat when no hat is in the room. We are said to imagine these things, and this type of consciousness is called imaginal. Imaginal consciousness exists in exactly the same modalities as sensory consciousness. One can have a visual image of a house, an auditory image of the sound of a friend's voice, an olfactory image of the smell of ham and eggs, a gustatory image of the taste of salt or sugar, a tactual image of the footsteps of a fly walking across the cheek, a kinesthetic image of the movement and strain in one's legs in climbing a flight of stairs, or an organic image of the distress of nausea. Some readers may doubt this, since most people pay little attention to their images. They are merely aware of the fact that they are "thinking of" certain objects and they never realize that they "think of" them in terms of images belonging to one or more of the sensory modalities. When reading, nearly everyone experiences a series of auditory images of the words, yet few are aware of this fact until their attention is called to it. Then they can easily introspect the auditory imagery, usually upon the first trial.

Individuals differ greatly in the types of images that they experience. In some, imaginal consciousness is almost entirely auditory; in others, it is visual; while with a few people, both auditory and visual imagery is almost completely absent, and kinesthetic-tactual imagery takes its place. The writer was once acquainted with a girl who said she could imagine neither the sight nor the sound of a church bell, but could picture how it felt to touch it and the vibrations set up by its ringing. This, of course, is the only way a blind and deaf person could become aware of a bell; but this girl was not blind or deaf, she was merely curiously lacking in visual and auditory imagery. As a rule, the higher sense modalities furnish the clearest and most easily introspected images. Kinesthetic imagery is probably the hardest to introspect, which is not surprising when we recall that most people do not distinguish even their kinesthetic sensations.

Imaginal consciousness is seldom as definite, clear, and strong as sensory consciousness. Picture the visual appearance of a printed word of about three syllables. You may believe that you have a rather clear image of the word, but now try to read the letters backward! If you can read them with anywhere near the same fluency with which you read the letters of a word that is actually present to your senses, your visual imagery is exceptionally clear. To be sure, some people have this very clear imagery. They are able to look for a moment or two at the silhouette of an animal and later project the image of this silhouette so clearly on a piece of paper as to be able to draw an outline of it. Such people are said to have *eidetic imagery*. Imagery of this degree of definiteness occurs rather frequently in children, but usually disappears by the time they are grown up. Actually, it seems to be of little practical value.

The Sensory Areas in the Cortex.—The mere stimulation of a sense organ is not enough to awaken sensory consciousness. Certain regions of the cortex must also be active. Nervous impulses may pass from the ear through the brain stem and out to an effector without producing any consciousness of sound. In order for sounds to be heard, the impulses must at least reach certain parts of the cerebral cortex located on either side of the brain, and known as the *auditory areas*. At the back of the brain there are similar areas for vision; at the top, for somesthesis; and at the base of the brain, between the two halves of the cerebrum, are areas for olfaction and possibly gustation. Each half of the cerebrum has one of each of these areas in the same location as the other half. (See Fig. 110.)

There are fairly direct neural pathways from each sense organ to its appropriate sensory areas, and impulses from the sense organs make their way into these regions of the cortex before being

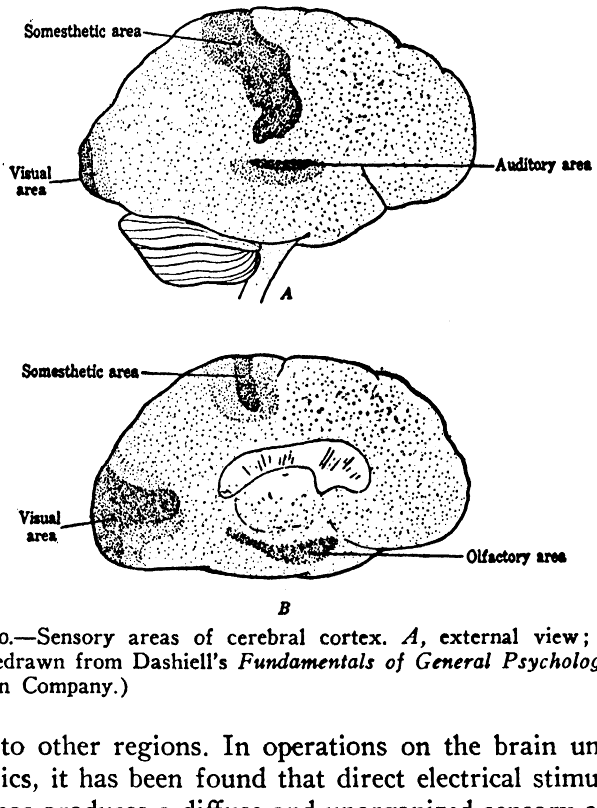


FIG. 110.—Sensory areas of cerebral cortex. *A*, external view; *B*, section view. (Redrawn from Dashiell's *Fundamentals of General Psychology*, Houghton Mifflin Company.)

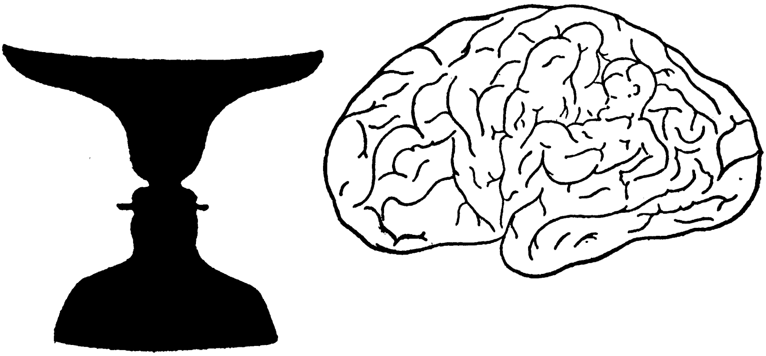
carried to other regions. In operations on the brain under local anesthetics, it has been found that direct electrical stimulation of these areas produces a diffuse and unorganized sensory consciousness without any stimulation of the sense organs. When the auditory area is stimulated, the individual hears a mass of tones and noises. Stimulation of the visual area produces flashes of light and color that may have scarcely any localization in space.

It has been thought by some that the functioning of the neurons in these regions is what produces sensory and imaginal consciousness. Others hold that the impulses must not only enter these regions but must pass through them and undergo further integration in other parts of the cortex, finally being carried out to the effectors before consciousness occurs. We have no final proof of the correctness of either of these theories, but it may safely be assumed that for sensory or imaginal consciousness to arise, impulses must pass through these regions. In the case of sensory consciousness, the impulses come from the appropriate sense organ, while the impulses which produce imaginal consciousness may originate in other sense organs and make their way less directly into the sensory area corresponding with their modality.

Emotional Consciousness.—At the present time there is a debate as to whether emotional consciousness is only a special form of sensory consciousness or whether it is something unique. When we are angry, the sympathetic nervous system goes into action, producing smooth muscle responses that stimulate the organic receptors in those muscles; we flush or pale, thus stimulating temperature receptors in the skin. At the same time, we tremble with rage and set our muscles for combat, so that various kinesthetic receptors are stimulated. Some students of the subject believe that our emotional consciousness, that is, the "angry feeling" that we have, is produced by all this sensory stimulation sending impulses to the somesthetic area, while in other emotions other combinations of organic and kinesthetic sensations constitute the emotional consciousness. This is the famous James-Lange theory of emotion, first promulgated by the renowned American psychologist, William James, and the Danish physiologist, Carl Lange. According to these men and their followers, the only difference between emotional consciousness and other forms of sensory consciousness is that emotional sensations are not analyzed and localized as visual and auditory sensations are, but come to us as a shapeless, spaceless mass of somesthetic feeling. Some individuals, indeed, seem to localize their emotional sensations more accurately than others. When they are afraid, they have a "sinking feeling" in the pit of the stomach; when they are thrilled, they feel shivers down the spine; hot anger rages in their breasts; and they are made sick with disgust.

There is no doubt that sensations produced by the responses of our smooth and skeletal muscles are present at times of emotion, but many who have investigated the question doubt that they are the central thing in emotional consciousness. It has been found that a certain region in the upper part of the brain stem, the *thalamus*, is the center of integration of emotional responses, and some investigators believe that impulses passing from the thalamus to the cortex are responsible for emotional feelings.

Perception.—When we possess sensory consciousness of a thing, we are said to *perceive* it. We distinguish it from other parts of the environment and have some knowledge of its position, size, shape or other qualities. Practically all clear sensory consciousness is perceptual, which means that it gives us some knowledge of our bodies or of the world about us. But what is meant by "having knowledge"? A little thought on the subject will lead us to realize that when we know about things we are thereby made capable of responding appropriately to them. This is clear enough when we make mistakes in perception. Nearly everyone has experienced the embarrassment of having acted inappropriately in cordially greeting a stranger whom he has mistakenly perceived to be a friend.



A *B*

FIG. 111.—How much can you see?

Usually our perceptions are accurate enough for us to "get by," but nearly all perceiving is slightly inaccurate. Sometimes a given stimulus situation may be perceived in more than one way, yet the various ways seem equally correct. Is Fig. 111A a picture of a goblet or of two identical twins gazing into each other's eyes?

Probably the most important error in our perceptions is the failure to see everything that is present in a situation. Some things we do not immediately distinguish, and there are usually many aspects of a situation that we never distinguish. In Fig. 111B you doubtless recognize the brain immediately, but probably a little time will elapse before you distinguish the brain child. Going back to Fig. 111A, you probably saw the goblet and the twins, but did you notice the little square-headed man with the under-sized hat? One of the best illustrations of this failure on the part of our perceptual processes to get everything present in a situation is the difference between what the musically untrained person and the one with training in music can hear when a complex musical selection is rendered. The writer once attended a concert at which a pianist played one tune with his left hand and a complementary tune with his right, in the manner of a fugue. Then he asked the audience what tune he had played with the left hand. Only a half-dozen out of the two hundred or so present had recognized it. It was "Yankee Doodle."

We have emphasized this incompleteness of perceptual response and its occasional ambiguity in order to make clear the fact that what we see, hear, or perceive in other ways does not depend simply on what is there, but on *how we respond to what is there.* Different people may respond differently, or the same person may respond differently at different times, and thus we get different perceptions of the same situation.

Implicit Responses

Perceiving is as much a matter of responding to stimulation as moving an arm or leg. Perceptual responses belong to a class which we call *implicit responses.* An implicit response is one which involves the activity of the nervous system and in some cases—if not all—of the muscles. But the muscles do not contract strongly enough for any movement to be readily observed; hence the response is not *overt,* but hidden, or *implicit.* To demonstrate, suppose you say in a loud, firm tone of voice, "Implicit responses cannot be observed, overt responses can be observed." In doing so you will have performed an overt verbal response, one that anyone present could have observed, either by hearing the sound or watching the movements of your mouth, throat, and chest. Now suppose you make the same response, but make it less vigorously.

You repeat the statement in a lower voice, which means that you use fewer muscle cells in making the response, that the activity of certain muscle cells has been inhibited.—Now try it again, but still less vigorously.—You whisper.—Still less vigorously!—Your lips scarcely move, and no sound comes out of them.—Make it less vigorous than that.—And this time it is impossible to see any movement, although you are conscious of saying the sentence to yourself. The response has become implicit. Yet you will notice that its becoming implicit is merely a matter of the gradual inhibition of more and more of the muscular activity involved, until it becomes so slight as to be unobservable. The response is reduced to a mere vestige of its former self. Whether in these vestigial responses there is ever a complete elimination of muscular activity or not is a question that remains undecided. By using a radio amplifier to pick up minute electrical disturbances in the muscles, it has been shown that when we form an image of lifting our arms, there is a slight activity in the arm muscles, even when no movement can be observed. In this particular implicit response, therefore, unobservable muscular activity still remains; but it is not impossible that in some implicit responses, muscular activity may be completely inhibited and the response may take place entirely in the brain.

But what is the good of making motionless responses that fail to effect any adjustment to the environment? The function of implicit responses is to act as stimuli to inhibit or reinforce overt responses. A small child starts toward the cupboard to get candy when she thinks, "Mother spanked me last time." And this implicit response inhibits the overt one of reaching for the candy. Or you are asked to multiply 46 by 59 mentally. You cannot immediately respond with the answer, but by going through a series of implicit responses, you finally say to yourself "2714," whereupon your implicit response may stimulate the overt response of saying the answer aloud.

At about this point, you are doubtless saying to yourself, "But what this writer is calling 'implicit response' is just what I call thinking or mental activity." Precisely. Perceiving, thinking, imagining, remembering are the things which the mind does. But they are also implicit responses. "The mind" is simply the everyday term for "the process of implicit response."

The Nature of Perceptual Responses.—The function of these implicit, "mental" responses is to prepare the organism for overt activity. Instead of a simple, direct conduction of nervous impulses from receptor to effector, there are intermediate processes which adjust the organism to the environment by getting it ready to make adequate overt responses.

These preparatory adjustments are not always completely implicit. Perceptual responses involve two types of preparation: first, turning the attention toward some specific part of the environment; second, getting ready to make a great variety of responses to the objects to which attention is given. A part of the former preparation is the turning of the sense organs toward the object, and this is an overt response. However, we can look at a thing without attending to it, or attend to something that we see out of the corner of the eye; hence the implicit part of attending is quite as important as the overt adjustment of the sense organs.

The second aspect of the perceptual response is somewhat more difficult to understand. How can this implicit response get us ready to make all the responses we might possibly make toward an object? One theory is that the perceptual response is composed of the implicit vestiges of the responses the individual has been accustomed to make with respect to the object or to similar objects. An apple, for example, belongs to a class of objects that have been eaten. Perceiving the apple involves making a vestigial response of eating. Now, if we happen to be hungry, that response will be reinforced strongly enough for it to become overt. But the vestigial eating response will not be the only one involved in the perception of the apple. A multitude of other responses that we have habitually made to objects similar to the apple will also be vestigially present. For instance, the apple belongs to a class of small, round objects of the sort that we often throw, and in perceiving it, we may make a vestigial throwing response. The sight of a suitable target might reinforce this implicit throwing response, so that we might respond in that manner to the apple.

Whether or not this theory of vestigial response in perception is correct, the function of the perceptual adjustment is to make us ready to respond to a situation in whatever manner is appropriate relative to what the organism is motivated to do.

Conceptual Adjustments.—In everday language, we say that, through perceptual responses, we *know* how to respond to the situation in which we are placed. Such knowing responses are called *cognitive*, from the Latin verb *cognosco*, to know. The term perception is confined to cognitions of the environment immediately present to the senses. But we may know about many things that we can never see or hear, and we may at any time be planning action with respect to objects that are far outside our range of perception. These cognitions of things absent are implicit preparatory adjustments, just as perceptions are. They are generally referred to as *ideas*, or *concepts*. As you have doubtless guessed, they involve imaginal consciousness of the absent situation. More important, however, than imagery in making us aware of absent environments is *symbolism*. Words are the most important symbols. The perception of a sentence, written or spoken, and referring to something outside the range of a man's immediate environment, makes him ready to act relative to the situation described. You want to find a friend. "Where's John?" you ask. "He's over in George's room." With this brief exchange, you are prepared to find John much more easily than you could if you could not respond to the words as symbols.

By the use of word symbols, we can come to know about things we have never perceived, even things which no one has ever perceived. In this book we have talked about molecules and atoms, yet no one has ever seen them; about things that happened on the earth hundreds of millions of years before any man was present to view their occurrence. Man is distinguished from his animal relatives by the tremendous range of his cognitive adjustments. Even for the higher apes, cognition of anything outside the immediate range of the sense organs must be a very dim and fleeting affair. The difference between man and the apes in this respect is not so much a difference in inborn intelligence as it is in the possession by man of that incomparable tool of knowledge, spoken and written language.

Motivation

In summary, we may say that the implicit responses called cognitions make us ready to respond appropriately to an object or situation and that this readiness is what we ordinarily term "knowing" about the object or situation. But though we are thus prepared to respond in an almost infinite number of ways, only a few of the responses for which we are made ready actually occur at a given time. We usually respond according to some definite plan of action, selecting from the great variety of possible responses only those which fit in with the plan. We say that we are *motivated* to respond in one way or another. But what does motivation mean in terms of stimulus and response? An example of motivated behavior may help to make this clear.

A man is sitting in his study late at night, reading a detective story. For hours he reads steadily, hardly moving, but at about eleven o'clock he begins to show signs of restlessness; he crosses and uncrosses his legs, wriggles about in his chair, pulls at his collar, unbuttons and buttons his vest. Once he even gets up and, reading his book all the while, walks over to the mantel, leans against it, reads and returns to his chair, still reading. The restless movements cease for a few minutes, but soon begin again. The man gnaws at the back of his thumb. Finally, he throws his book down, goes to the door of his study and opens it, switches on the light in the next room, crosses this room and then another and makes his way into the kitchen, fumbles about for several minutes to find the cord to the kitchen light, finally gets the light on, goes to the icebox, opens it and takes out a bottle of milk, goes to the dish cupboard and gets a glass, pours the milk into the glass, sets glass and bottle on the table, goes to another cupboard and gets a piece of pie, draws a chair up to the table, and, holding the pie in one hand and the milk in the other, begins to enjoy a midnight supper.

Here is a whole series of responses that fit together into a pattern of activity which finally ends with the arrival at a definite *goal,* namely, the filling of the man's stomach with food. Out of all the possible responses to the situations in which the man found himself, all the way from the study out to the kitchen table, only those were selected that would be of some service in bringing him to his goal. Furthermore, this line of activity had to put an end to or inhibit another line of activity which the man had been engaged in up to the moment he began to search for food. We could even see a sort of struggle between the reading activity and the food-getting activity in the man's restlessness just before he finally began his search. In ordinary terms, we would say that the man behaved in this way because he was hungry.—But what does "being hungry" mean in terms of stimulus and response?

Let us suppose that before he started to read that night we had persuaded the man to swallow a small rubber balloon with a long tube attached to it. We would keep hold of one end of the tube, so that after the balloon had reached his stomach we could blow it up to make it fit tightly against the stomach walls. We would then attach the tube to a little rubber bulb, or tambour, which would be slighly expanded every time the muscular walls of the stomach squeezed against the balloon. By attaching a recording device to the bulb, we could make a record of every movement of the man's stomach. At first there would be only the steady little ripples caused by the peristaltic movements. Hours would pass by as the man's supper left his stomach, and the peristaltic contractions would gradually die down. Suddenly certain stronger, slower contractions would set in. Simultaneously, the man's restlessness would begin. The stomach movements would cease for a few moments, and the man would become less restless; then they would begin again, stronger than ever. Finally, as if in response to certain especially strong stomach movements, the man would rise and start for the kitchen; whereupon, no doubt, we would neatly and considerately remove the balloon to give him a chance to enjoy his meal.

But we would have discovered the stimulation which caused him to seek and eat food. We know that the receptors in the walls of the man's stomach would be stimulated by the stomach movements and that they would initiate nervous impulses passing into the central nervous system. These impulses would, then, exercise inhibiting and reinforcing influences over the responses which the man's cognitive adjustments had prepared him to make. They would also affect the *direction* of these cognitive adjustments. In other words, they would determine to what he would pay attention. Before the hunger stimulus, his cognitive adjustments were directed toward the book. He was probably scarcely conscious of the room in which he was sitting. Then his attention began to be distracted, he began to look around the room, then to think of the kitchen and the icebox. And then these newly adjusted cognitive preparations were integrated with the hunger stimuli in such a manner as to produce movements in the direction of food.

Such interactions as this between cognitive and motivating factors account for the greater part of our behavior. Very little of our activity—in fact, only the reflex part of it—is simple, direct response to a single stimulus. Most of it is organized into long chains of responses leading up to more or less definite goals in which both cognitive and motivating factors play a part.

We may call any stimulus which causes us to move toward a definite goal a *motivator.* When we are responding to a motivator, we are said to have a *motive*, a *desire*, a *want*, a *need*, a *wish*, an *aim*, an *objective*, an *urge*, or a *drive.* All these words are used to designate goal-directed activity; and whenever they are employed, the fact that they signify activity under the stimulus of a motivator should be kept in mind.

Physiological Motivators.—The hunger stimulus belongs to a class which we may term the *physiological motivators.* Any condition which produces a need on the part of our tissues that can be provided for only by some adjustment to the environment may produce a stimulus of this sort. Thus, lack of water in the tissues will stimulate the thirst receptors and cause us to seek water. Excessive heat and cold which cannot be relieved by the internal warming and cooling mechanisms will produce movements toward cooler or warmer places, or, in the case of cold, considerable muscular activity. Tension in the bladder or rectum may produce activities leading toward urination and defecation. The changes that the body undergoes during puberty produce physiological conditions that direct the organism toward sexual activity. Finally, certain bodily conditions, as yet incompletely understood, produce the stimuli which cause us to become fatigued and to seek rest or sleep.

These internal changes which act as physiological motivators may either stimulate the somesthetic sense organs, as in the case of the hunger contractions, or, like the chemical changes that stimulate the respiratory reflexes, they may act directly on the nervous system.

External Motivators.—Internal stimuli, however, are not the only ones that have a directive effect on our activities. Tactual stimuli, such as those that produce itches and other uncomfortable sensations, will cause us to behave in various ways in order to remove them. A child will work and struggle to reach and handle some brightly colored toy or other outstanding object that causes his eyes to be stimulated. Fearsome objects may produce a series of movements that are integrated in the direction of escape from them. In short, the external world may be as motivating as the internal condition of the body.

Sets.—It is characteristic of a motivating stimulus that it persists until the goal toward which it directs the organism is reached. Frequently there is no persistent stimulus, of either the physiological or the external group, to account for a persistent line of behavior. For example, if I tell a child that I have hidden a piece of candy in a certain room and that if he finds it he can have it, he may search persistently for several minutes until he reaches his goal, even though he has had a good meal and hunger can in no way account for his behavior.

To explain this persistence, we must assume that an implicit response has taken place which maintains itself over a period of time until the goal is reached. Such implicit adjustments are called *sets*. Because of their persistence, they are believed to be related to overt postures. Overtly a man may set his muscles to run, as when a starter in a race says, "Ready, get set!" or his muscular posture may prepare him to fight, or to greet a companion. According to what we may call the vestigial theory of implicit response, motivating sets are implicit postural responses.

The most remarkable thing about sets is the way they persist until the goal is reached. An incompleted task may produce a sense of restlessness and frustration lasting for days, because the set to complete the task keeps driving us back to it. In one experiment, subjects were given a number of tasks to perform. Some they were allowed to complete, while in others they were interrupted before the completion. The next day the subjects were asked to describe all the tasks that they remembered. The ones they remembered best were those which were not completed. Apparently the persistence of the sets to complete these tasks aided in their recall.

Another characteristic of a set toward the completion of a task is that it may grow stronger as the work on the task proceeds. When a student first sits down to his work, his attention is easily distracted, since the set toward that line of activity is not strong enough to keep his cognitive adjustments channeled along the line of study. In a quarter of an hour or so, if he is a good student, his concentration will be much improved. If he is distracted for a few minutes, however, he may find it difficult to get back to work again. Many students who spend much time on their work to little avail probably have never learned to develop this deeper concentration. They allow themselves to be so continually interrupted by small distractions or by daydreams that they never really get warmed up to the task. These individuals need to set out consciously to learn the habit of becoming absorbed in their work.

Cognitive Sets.—Some sets function more nearly like cognitive adjustments than motivating stimuli. They do not aim toward any goal, but merely prepare us to respond in certain ways. For instance, after a baseball batter has watched several fast ones go by, the pitcher can often fool him by throwing a slow curve, because the batter has become set to hit a fast ball. This set is not a determination to reach some goal, but an assumption concerning the nature of the environment to which he must adjust. Its function is cognitive rather than motivational; but unlike the cognitive adjustments that we have already become acquainted with, namely, perceptions and ideas, it is not correlated with any form of sensory or imaginal consciousness. The batter does not see a fast ball coming, he does not have an image of a fast ball, nor does he say to himself, "This will probably be another fast one." He is merely ready for that kind of ball. His muscles and brain are set for it. But this set *functions* in exactly the way that a perception or an idea would function.

Unclassifiable Sets.—Our implicit responses may be classified under two headings: *motivating sets* and *cognitive adjustments*, with perceptions, ideas, and cognitive sets all fitting into the latter category. The classification is based on the way the implicit responses function as stimuli. If they cause us to persist in attempts to reach a goal, we call them motivational; if their function is to guide us toward the attainment of the goal, we call them cognitive. But anyone who has ever had a job that involved the filing of papers has probably discovered that, with the best of classificatory systems, he is continually being confronted with papers that seem to fit as well into one pigeonhole as another.

Similarly, there is no sharply drawn line between a desire and an idea, or, in general, between cognition and motivation. We would be hard put to say whether some sets are cognitive or motivating. For instance, if an experimenter says to a subject, "I am going to read you a list of words, and I want you to respond to each word by giving its opposite," the individual will respond to these instructions by developing a set to say the word whose meaning is opposite to that of each word he hears. Now, if we thought of this set as a *desire* to answer with the opposite, we would be classifying it as a motivational set. If we thought of it as *knowing* what the experimenter wanted, we would be putting it in the cognitive class. Actually, the set seems to function in both ways. It is on the border line between cognition and motivation.

Indeed, we separate the implicit activities of the response system into individual motivating and cognitive responses chiefly for convenience in thinking about them. If we could actually study all such activities by means of some super-X-ray-microscopic device, it is very unlikely that we should discover a number of individual implicit responses, each separate from the other and each performing some definite motivational or cognitive task. Rather we should observe a single continuous flux of implicit preparation for external activity, which, as a unified whole, would be performing both cognitive and motivational functions. Our separation of certain aspects of all this fluctuating implicit activity into individual cognitive and motivating responses or adjustments helps us to grasp the nature of mental processes and to understand them in terms of stimulus and response. But if we find at times that it is difficult to fit everything into our neat but artificial system of classification, there is no reason to feel surprised.

THINKING

Often a man is placed in a situation where he is motivated toward a certain goal but lacks the cognitive preparation to reach it. Under such circumstances, he may either move around at random, trying one response after another until he reaches the goal almost by accident, or he may hunt around, implicitly, for the proper cognitive adjustment. The former activity we call *trial and error*; the latter, *thinking*. But thinking of this sort is essentially implicit cognitive trial and error.

Here is an illustration. The superintendent of a large public school discovered one night that in order to be prepared for a conference that he was to have the following morning he must get some papers that were on his desk in the office. He got into his car and drove three miles to the school, only to find that the building was locked and he had forgotten his keys. Not wishing to return all the way home, he went around to the side of the building where his office was; its window was about twelve feet above the ground. First he tried to climb up to the window by holding on to projecting surfaces, but found this impossible. Then he went around to the back of the building and found an ash can. He carried it over and placed it under his window, but found that standing on it didn't enable him to reach the window sill. Then he noticed a rather small slide on which the younger children played during recess. He found that it was light enough to drag up to the window and that by climbing up it he could reach the sill. But all his efforts were of no avail; the window was locked.

Up to this time he had been trying to solve his problem by overt trial and error. Now, after putting things to rights, he went around and sat down in his car and tried to think of a solution to the problem. First he analyzed the situation. There were only two keys to the building and two to his office. He had one set and the janitor the other. The janitor lived in the school building, but the window to his room faced on an inner court. The superintendent knew that at this time of night he would probably be in his room playing solitaire. He thought of getting as close to the room as possible and shouting, but decided that it would be impossible to make the janitor hear, and anyhow it might disturb others and place him in an undignified light. "Darn it," he meditated, "there ought to be a doorbell connected with his room.—If he only had a telephone, I could call him up from the corner drug store.—Ah, but wait a minute, the junior high school principal has a phone in his office and that's just below the janitor's room. If it keeps ringing long enough, he might go down to find out what it's all about." . . . Five minutes later, the superintendent was on his way home with the papers.

In overt trial and error, the superintendent moved about in his environment physically. In thinking, he explored it mentally, trying one idea after another until he finally hit upon one that would work. *Thinking is a course of implicit cognitive response, where one implicit response serves as a stimulus to another, under the direction of some motivating factor.* It often involves going through some course of action in an anticipatory fashion, so that full preparation is made for overt action. Trial and error in thinking appears only when the thinker cannot immediately see what series of actions would lead him to his goal. Much of our everyday thinking does not involve trial and error at all but merely implicit anticipation of the course of action. For instance, the following situation offers no problem at all to a person with a fair degree of intelligence:

Jones and Smith have an eight-gallon cask of wine which they want to divide between them with absolute equality. They have an empty two-gallon and an empty five-gallon cask, but nothing else to measure with. How will they go about dividing the wine into two four-gallon lots?

The anticipation of action is so easy that the whole course of thought occurs in a fraction of a second. A somewhat more complex situation, however, will require trial and error for its solution. Try yourself on this one:

Jones and Smith have an eight-gallon cask of wine and also an empty three-gallon and an empty five-gallon cask. How would they go about dividing the wine into two equal lots?

Here you will find yourself trying out one plan of action, finding that it doesn't work, attempting another and another, and so on until you manage to hit on the right one. Or, if you happen to be clever or lucky enough to solve the above problem without trial and error, here is one for which a direct solution is well-nigh impossible:

Jones, Smith, and Robinson had two nine-gallon casks of wine and also an empty two-gallon and an empty five-gallon cask. How could they divide the wine into three equal lots?

If you introspect at all carefully on your method of solving these problems, you will find that you do it by talking to yourself. You think in terms of verbal symbols, accompanied, perhaps, by some visual imagery of the situation; but the symbols are the essential part of the thought process, and the visual imagery is hardly more than an accompaniment. Most thinking goes on in this symbolic form, especially thinking that must be exact, since symbols represent a situation more conveniently and exactly than images do. Often we find it convenient, when thinking through a complex situation, to jot our symbols down on paper, where they remain fixed, so that we can go back and check over the entire course of mental exploration to make sure there is no flaw in it. The first great advance in thinking was made when language was developed; the second, when written verbal and mathematical symbols began to be employed.

Thinking and Investigation.—More often than not in practical life, thinking alone will not solve our problems. A business man, faced with the problem of selling his goods, can seldom solve it by sitting down and cogitating. He must discover where his potential customers are, what their wants are, and their habits of buying. When he has his information, he can begin to think out a plan. Even then, he may find that, as his thinking proceeds, he must investigate further to make sure that his conclusions are correct. Modern science is based on this combination of thinking and investigation. On the basis of facts that are already known, thought leads to certain conclusions, which are never certain, since other facts must be ascertained before they can be fully established. Investigation ensues, and the conclusions must be modified somewhat. New ideas are suggested, and they must be checked on by further investigation. This investigation leads to a new train of thought, and so science advances. An interesting thing about this scientific advance is that it never seems to lead to final conclusions. It is not that the conclusions already arrived at are false, but that they are incomplete. They fail to tell the whole story. What the layman is interested in as far as science is concerned is the vast body of knowledge that has already been built up, but the mind of the scientist is occupied with the problems that yet remain to be solved. For him, science is not so much a body of knowledge as a process of acquiring knowledge. And the fundamental secret of this process is the combination of thinking with investigation.

Working out the solution of practical problems and scientific activity both belong to the type of thinking which we call *realistic*. They commonly combine thinking with investigation, and their purpose is to discover what the world is really like. The result is knowledge which enables one to make successful overt adjustments to the real world. The difference between scientific and practical thinking is that in the latter we always have some specific problem of overt adjustment confronting us, and we are simply trying to learn enough to solve it. Scientists, on the other hand, think and investigate simply for the sake of discovering truth, regardless of any practical problem with which they happen to be faced. But since scientists think realistically, as practical men do, their conclusions frequently have important practical applications. In fact, their practical results may, in the end, be much greater than the results of purely practical investigation and thinking, because specialization in the business of searching for truth leads to a more complete picture of the real world than that attained by the man who stops to apply his knowledge as soon as he gains a little.

Wishful Thinking.—There is another type of thinking which is quite different in its aims from scientific or practical thinking. Its goal is not knowledge which will enable us to arrive at other goals through overt behavior, but the direct satisfaction of desire through thinking alone. It is called *wishful thinking.* In spite of all our search for truth, we seldom learn enough to reach many of our goals. Our real environment is one in which urges are thwarted and hopes blasted. But by means of thought responses we can picture to ourselves worlds much nearer to the heart's desire than the one which stimulates our sense organs. And so our urges, avid for satisfactions that are denied them, spur us on to build up these unreal worlds or to form distorted pictures of the one in which we live. The following little jingle portrays fairly accurately the general trend of most daydreams:

If I were an Angel Bright,
If I were a Child of Light,
Resplendent, borne
On wings of the morn
I'd soar to heaven's height,
And the gaping throng on the earth below
Would wonder at the sight!
Alone, in the splendid night,
Like a flashing meteorite,
Toward the bright maroon

Of the rising moon
Would I direct my flight.
Where the Mystic Mountains of the moon,
Majestic in their might,
Surround the vale where the moon maids croon
An eerie, winsome, wilesome tune
In the Land of Pure Delight!

Although he puts it all quite ornamentally, one can plainly see what sort of a world this young fellow wants. He wants one in which he secures distinction, admiration, power, and sexual satisfaction, and all without too much effort; let the wings of the morn do the work! Furthermore, he wants to be an angel bright and he wants his delight to be pure; in other words, he doesn't want to feel that he has done wrong in getting what he wants, nor does he want to be criticized for it. Such is the burden of most wishful thinking, for the urges to secure admiration, approval, mastery, sexual satisfaction and rest are the ones that are most often thwarted in our civilization. As a general rule, we are sufficiently well fed so that we seldom daydream of food; but let a man go on a diet or fast, and he will find images of things to eat literally forcing themselves on his mind.

When our wishful thinking does not take the form of daydreaming, it distorts the real world, causing us to believe untruths about it. Some people, for instance, thoroughly enjoy believing that others bear an unjust grudge against them, for that explains why they don't get better pay, higher grades, or more commendatory smiles. Children occasionally convince themselves they have been adopted and that their ostensible parents are not really theirs. There is no other way of accounting for the fact that such exceptional persons as themselves should be brought up in such mediocre home surroundings. Flat-chested Phi Beta Kappas believe that all football players are morons, and the mediocre student is certain that all Phi Beta Kappas are flat-chested.

Occasionally an individual is carried away by his daydreams to the point where his beliefs become so utterly outlandish and ridiculous that we call them *delusions* and send him to a hospital for the insane. Such people are not very different from the rest of us; they have only gone a little farther than we all do in protecting our egos from the pitiless light of reality by shrouding them in a rosy haze of wishful believing.

Wishful Perceiving.—Our urges can even come to dominate our picture of the world so fully that we do not perceive what is present to our senses, but what we want to perceive. The writer has noticed that when he becomes thirsty while hiking in a forest it is quite impossible for him not to interpret the sound of the wind in the trees as running water.

Sometimes the thing which conditions an illusion is not so much a wish as an expectant set. A superstitious individual in a reputedly haunted house will see a ghost in every fluttering rag and hear a shriek in every gust of wind. People who tell you they have seen miraculous phenomena with their own eyes may very well be telling the truth, but what they saw was an *illusion* or *hallucination*. The term "hallucination" is popularly used to mean a false belief, although the proper term, of course, is "delusion." Both illusions and hallucinations are false perceptions, the difference between them being that there are no perceptible sensory stimuli for an hallucination, while an illusion is a misinterpretation of stimuli that are actually present. Thus, if a patient on the ward looks at the doctor's hat and sees a black cat, he is experiencing an illusion; but if, when there is nothing whatever on the floor of his room, he shrieks and runs away from what he describes as a large green alligator, he is subject to an hallucination.

Illusions and hallucinations are very characteristic of the insane. Usually they serve to confirm their delusions. The man who has a delusion of persecution will hear voices deriding and threatening him or feel sharp pains shooting through his body which he says are caused by the poisons that are put in his food. Or the patient who believes he is God—as many do—will see the other patients as angels, while the doctor, like as not, will be seen wearing a pair of horns and a forked tail.

Dreaming.—Hallucinations are much like images, the chief differences between them being that the hallucinated objects are much more vivid, and the individual feels that they are actually present. In dreams we experience a train of thought which is made up of a long series of hallucinations. Stimuli falling on the sense organs may act as cues for these hallucinations, as when an individual who is covered too warmly dreams that he is being cooked in an oven. But the manner in which the cues are interpreted depends upon the urges and sets of the individual; in other words, dreaming is a form of wishful thinking.

Many people will protest that they do not dream of the sort of world that they desire; quite the contrary, they have the most horrid nightmares. It is possible that both our sleeping dreams and our daydreams may be controlled to some extent by fearful and apprehensive sets, as well as by our wishes. According to the great Viennese doctor, Sigmund Freud, however, a dream always signifies a wish, although the wish may be somewhat disguised. According to him, we refuse to recognize some of our wishes because they would make us feel too ashamed of ourselves. But in our dreams, these wishes secure a certain amount of satisfaction by expressing themselves in a disguised and symbolical form. Thus, a daughter who has an unrecognized desire to have her mother out of the way will dream of her mother's death. Although she may feel the greatest sorrow and loss in the dream, thus disguising the fact that she really wants to be rid of her mother, still the dream is a form of wishful thinking, for the unrecognized desire receives a certain amount of satisfaction.

Chapter Summary

At the level of cortical integration of response the phenomenon of consciousness appears. Philosophers have been unable to decide what consciousness is or why it should be correlated with highly integrated nervous activity. As psychologists, we go no further than to say that it is the thing that we study when we get introspective verbal reports from our subjects.

Consciousness may be analyzed into sensory, imaginal and emotional consciousness. Sensory consciousness occurs when the sense organs are stimulated, and may be divided into the following modalities or sense departments: vision, audition, olfaction, gustation, and somesthesis. The last is divided into three submodalities, the tactual, the kinesthetic, and the organic. Imaginal consciousness is similar to sensory consciousness except that it occurs when the object of which we are conscious does not stimulate the sense organs. It may occur in any of the modalities, although it is most easily introspected in the visual and auditory modalities. It is seldom as clear and definite as sensory consciousness, although it approaches the clarity of sensation in eidetic imagery. Each of the sense modalities is correlated with an area or areas in the cerebral cortex which must be activated if sensation or imagery in that modality is to be experienced.

According to the James-Lange theory, emotional consciousness is merely the mass of somesthetic sensation aroused when we make an emotional response, but others believe that it is a special type of consciousness aroused by impulses passing from the thalamus in the upper brain stem up to the cortex.

What we ordinarily call "mental activity" is actually implicit response, that is, response which cannot be observed since it involves little if any muscular activity, but which can function in our behavior by stimulating overt (observable) responses.

An important type of implicit response is the cognitive response, or cognition. In making such responses, we come to know about objects or situations, which is to say that we are prepared to respond overtly to them in a variety of ways. The actual overt response depends upon how we are motivated. Two types of cognitive response may be distinguished: the perceptual response, whereby we come to know about things actually present to the sense organs, and the ideational or conceptual response, whereby we come to know about things not present to the sense organs. In perceiving, we actually see, hear, smell, taste, or feel an object. In conceiving, we experience an image of an object or see, hear, or "say to ourselves" a word or other symbol of the object.

Motivation is produced by stimuli known as motivators which cause us to make responses that carry us toward a goal. The motivating stimuli are integrated with our cognitive responses acting as stimuli in such a fashion as to cause us to move in a direction that is likely to bring us to the goal.

Motivators may be physiological conditions, external situations, or implicit responses, known as sets. Sets may also be of a cognitive nature, or they may display the characteristics of both motivation and cognition.

Thinking is a series of cognitive responses in which one response acts as a stimulus for the next one. Realistic thinking is a trial-and-error attempt to arrive at a new cognitive adjustment to a situation. It aims at the discovery of truth.

Wishful thinking is a course of thought aimed toward the picturing of a more desirable world than the real one. Sometimes it leads to wishful believing that this more desirable world actually exists. This is called delusion. Delusions are sometimes accompanied by wishfully motivated perceptions, called illusions and hallucinations. Dreaming is essentially a series of wishfully motivated thoughts or hallucinations.

QUESTIONS

1. Into what departments is consciousness analyzed? What is the relation of emotional to sensory consciousness, according to the James-Lange theory?
2. What is an implicit response?
3. Discuss cognition and motivation in terms of stimulus and response.
4. Criticize: "If I can see and feel a thing, I know it actually exists."
5. Describe thought and tell what its functions are in terms of stimulus and response.
6. What is an hallucination? An illusion? A delusion?

GLOSSARY

audition The sense of hearing.

cognition The act of coming to know about objects or situations. Cognition is effected by cognitive responses, which are for the most part implicit.

concept A cognitive adjustment to objects or situations not present to the senses. A thought or idea.

delusion A false belief.

eidetic imagery (ī-dē′tik) Very clear and sharply defined imagery, closely approaching the clarity of perception.

goal The end condition toward which an organism's activity is directed when it is acted upon by a motivator.

gustation The sense of taste.

hallucination (ha-lū′si-nā′shun) A false perception occurring when there are no apparent stimuli to be misinterpreted.

idea Approximately synonymous with concept. The term concept is sometimes reserved for the more abstract ideas.

illusion A false perception resulting from misinterpretation of stimuli.

implicit response A response that involves little or no muscular activity; hence it is unobservable.

modality (mō-dal′i-ti) A sense department, such as vision, audition, somesthesis, and the like.

motivator A stimulus or group of stimuli which causes an organism's activities to be directed toward a goal.

olfaction (ŏl-fak'shun) The sense of smell.

overt response (ō'vert) A response which can be readily observed.

perception Cognition of objects or situations through stimulation of the sense organs by those objects or situations.

sensory area A region of the cortex which is especially concerned with a certain modality of sensory or imaginal experience.

set An implicit or overt response which prepares an organism for action or produces a consistent course of action.

symbol Any object which stands for another object or situation. By experiencing symbols, we make conceptual adjustments to the objects for which they stand. Words are the most important types of symbols.

thalamus (thal'a-mus) Region in the upper part of the brain stem which integrates emotional responses.

trial and error A course of action in the pursuit of a goal which involves the attempting of many possible responses directed toward the goal until finally the successful responses occur. Trial and error occurs when an organism's cognitive adjustments are not adequate to bring it directly to the goal.

vision The sense of sight.

CHAPTER XXIII

GROWTH RESPONSES IN PLANTS AND ANIMALS

Why Organisms Must Respond.—About twenty years ago, during the difficult times of the World War, a certain wistful bit of verse seemed to catch the public fancy and was reprinted again and again in newspapers and magazines. It went something as follows:

I wish I was a little rock
A-settin' on a hill,
A-doin' nothin' all day long
But just a-settin' still.

I wouldn't work, I wouldn't eat,
I wouldn't even wash,
But just set still a thousand years
And rest myself, by gosh!

But the restful life of a little rock can never be the fate of any organism. The little rock just sits still, and hence needs no nourishment to supply energy for a restless round of activities. Through the thousand years of its life, it is slowly worn to dust by the ceaseless action of wind, water, and frost, yet it does nothing to prevent its gradual extermination. And when at last it has gone, it leaves no descendants to carry on for another long but indolent millennium. Time and change bring an end to all things. Rocks wear away, continents sink below the sea, stars grow dark and cold. But these inorganic objects do nothing to ward off their slow oblivion. What permanence they possess is entirely a result of a tough immunity to the onslaughts of their environment. The organism, on the other hand, is a delicate affair, and helplessly dependent on its environment for the maintenance of its existence. The slightest change in the relationship between itself and the world around it may mean its end, while at the same time it must continuously wrest from its surroundings the substances necessary for the carrying on of life. Hence, an organism must be able to change itself to meet each new problem that its environment presents. In other words, it must be able to respond. Through this capacity to respond, the organic world has resisted the all-pervading destructiveness of the universe and maintained its existence throughout millions of centuries.

Two Kinds of Responses.—If a young tree is tipped so that it lies horizontally, either by accident or through the act of an experimenting scientist, its tip soon turns and grows upward,

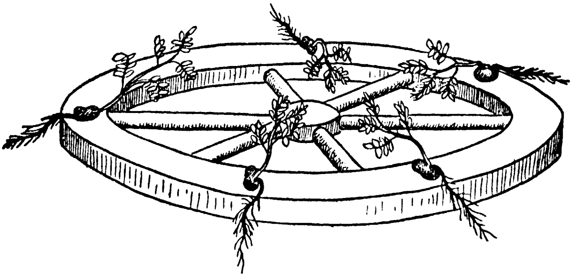


FIG. 112.—Centrifugal force and gravity as a stimulus. (Redrawn from Smith, Overton *et al.*, *Textbook of General Botany,* The Macmillan Company.)

carrying its leaves up into the light, while at the same time its main roots bend downward so that they grow into the ground, thus holding the tree firmly in place. This is a definite response to the force of gravity, as can be demonstrated by placing a seedling plant on the surface of a revolving wheel, whereupon the shoot no longer grows upward and the root downward, but the former slants inward and the latter outward in the direction of the resolution of the centrifugal force with that of gravity. (See Fig. 112.)

If a shoot or root, before being made to respond in the above manner, is marked with a series of horizontal, parallel lines placed close together, these lines can be seen to spread farther and farther apart on the outside of the bend produced by the response, while maintaining about the same distance from each other on the inside. This shows that the bending is produced by the faster *growth* of the shoot on the lower, and of the root on the upper side. Thus it is an entirely different sort of response from the movement responses of human beings with which we have dealt so far. Growth and movement constitute the most important types of organic response, although other types, including glandular responses and antibody reactions, exist; the implicit responses with which the last chapter dealt have developed out of movement responses. The most important type of response in the plant kingdom is the growth response, since it is by proper growth that the plant adjusts itself to the environment, whereas animals feature the movement response. To be sure, there are many plants that respond through movements, and growth response forms an important aspect of the development of all animals.

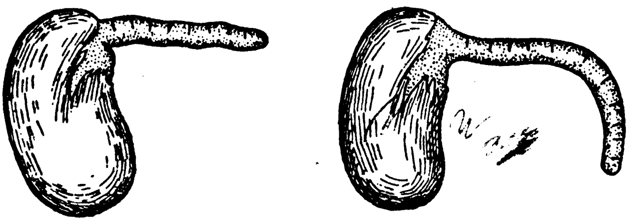


FIG. 113.—Diagram showing differential rates of growth in geotropism. (Redrawn from Smith, Overton, *et al.*, *Textbook of General Botany*, The Macmillan Company.)

The Mechanism of Plant Responses.—In addition to gravity, a number of other stimuli can produce growth responses in plants. Of these, light is one of the most important. Light in general inhibits the growth in length of plant shoots. If two pea seedlings of equal size are placed, one in strong light, and the other in a dark room for a few days, the latter will become very long and spindly, while the former will increase relatively little in length. On the other hand, light from a definite direction causes shoots to bend toward it, just as they bend away from the force of gravity. The adjustment of a plant part by bending to a stimulus from a definite direction is known as a *tropism*. Two of the best-known tropisms are those already described, *geotropism*, or the response to gravity, and *phototropism*, the response to light.

Extensive studies of these two tropisms have given us much information on the mechanism of growth response in plants. In both cases the response occurs in a different region from that which receives the stimulus. The bending always take place about halfway down the shoot of a grass seedling; but if the tip of a shoot is protected from the light by a cap of tinfoil, that shoot is prevented from bending, while removal of the tip destroys the response of the shoot to both gravity and light. The tip cells are therefore *receptors*, while the cells whose changes in rate of growth actually bring about the bending are *effectors*. Obviously, there must be some method of conducting the effect of the light stimulus from the point of reception to the effector cells located halfway

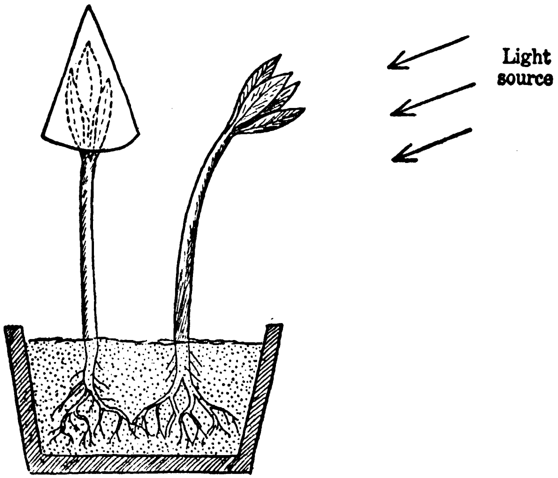


FIG. 114.—Diagram illustrating phototropism. When the tip of a plant is shielded from the light, the plant does not bend. (Redrawn from Smith, Overton, *et al., Textbook of General Botany,* The Macmillan Company.)

down the stem. A little experiment can be performed which demonstrates pretty clearly how this comes about.

An oat seedling is exposed to light for a short time and then the tip is cut off. The cut surface of the tip is then pressed against a small disk of gelatin and left there for some time. Now the tip is removed from a second seedling which has never been exposed to light and the gelatin disk is taken from the stimulated tip and placed against the cut surface of this unstimulated seedling. The seedling will proceed to bend in the usual manner, as if its own tip had been exposed to light. (See Fig. 115.)

This experiment demonstrates definitely that the response of the shoot is produced by the activity of a growth substance, similar in effect to the growth-regulating hormones produced by the endocrine glands of animals. Another experiment demonstrates that this growth substance is the same one that regulates normal growth in plants. Three seedlings are decapitated and placed in the dark. The substance from two of them is collected in agar disks, as in the previous experiment. One of the disks is replaced on the mid-

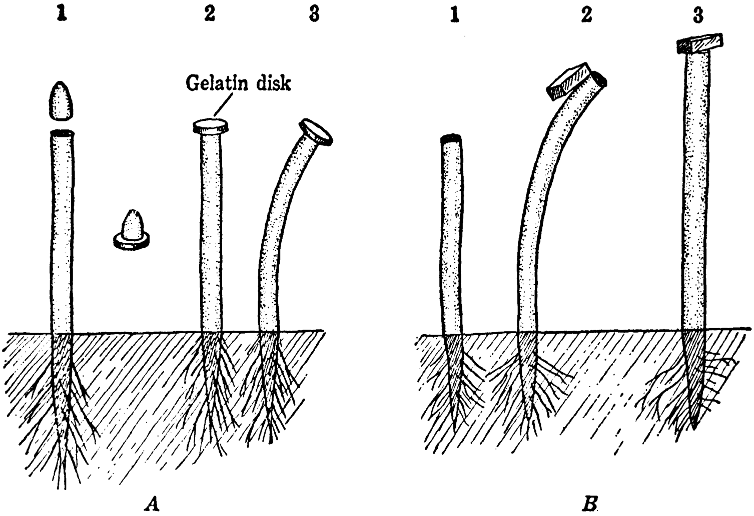


FIG. 115.—Experiments on hormone control of phototropism. *A* 1, Tip removed from stimulated seedling and placed on gelatin disk. *A* 2, Gelatin disk placed on cut end of unstimulated seedling. *A* 3, Unstimulated seedling bends as stimulated seedling would have bent if its tip had not been removed.

B 1, Tip in dark without auxin-containing gelatin fails to grow. *B* 2, Tip with gelatin on one side grows most rapidly on that side. *B* 3, Tip with gelatin on top grows straight upward.

dle of the cut surface and causes the shoot to grow upward normally; the second is placed on the side of the second shoot, causing this shoot to bend away from the treated side; while the third shoot is left decapitated, and ceases to grow.

By means of experiments such as these, the amounts of growth substance in different plant organs have been carefully measured, and the extracted substances have been isolated and studied chemically. Three slightly different chemical substances, known as *auxins*, have been found to be active as growth substances. These auxins can be extracted not only from the tips of roots and shoots.

but from many other plant parts as well, and from some animal substances, such as urine.

In the small concentrations in which they occur in the bending region of the shoot or root, these auxins produce only one type of growth, i.e., the elongation of the cells. This is brought about by the activity of the auxins in making the walls more elastic, thereby enabling the osmotic pressure within the cell to stretch them. On the other hand, the same substances when applied in high concentrations to the cut ends of stems or other plant parts produce an increased cell division, resulting in the formation either of a bump or callus, or of roots. Apparently the entire process of growth and differentiation, as well as response, is in part regulated by the activity of auxins or similar substances. The effect of light on growth is explained largely by the fact that, whereas light increases the production of growth substances by tissues, it inhibits the activity of these substances in producing cell elongation.

The method of conduction of the growth substance from where it is produced in the shoot or root tip to where the bending response takes place gives us an important insight into conduction in general in plants. If one looks through the microscope at the cells in the leaf of a type of water plant, *Elodea,* or in certain epidermal hairs of plants, one can see currents of protoplasm streaming rather rapidly around the cell. Similar currents of protoplasm exist in many types of plant tissues, and experiments have produced strong evidence that the growth substances are carried through the plants by means of these currents, diffusing from one cell to another through minute openings in the cell walls. Hence the method of transport is similar to that of animal hormones, except that in animals there is a special conducting system, the blood stream, while in plants the conduction is carried out by ordinary living cells.

Varieties of Tropisms.—Four other types of tropisms are those in response to the stimulation of chemical substances, water, temperature, and touch or pressure. The first, known as *chemotropism,* is most common in saprophytic plants such as fungi, enabling them to reach the substratum on which they feed. *Hydrotropism* is seen in the tendency of roots to bend toward a source of water, and *thermotropism* produces the bending of shoots away from an area of too high or too low temperature.

Thigmotropism, or the response to touch or pressure, is well exemplified by the growth of tendrils of vines. Sweet peas, wild cucumbers, and similar plants, as everyone at all familiar with them knows, attach themselves to their supports by means of tendrils that grow out from the stem and wind around the wires, strings, or twigs with which they come in contact. As the tendril begins to grow out from the stem it behaves very much as if it were groping about in search of something to which it might fasten itself. First the cells on one side of the tendril—say the left side—grow more rapidly than those on the right, thus causing the tip to bend toward the right. Then the cells at the top may begin to grow most rapidly, bending the little shoot downward. Next the tendril will be bent to the left by the rapid growth of the cells on the right side; and so it grows, bending back and forth and up and down until it finally comes in contact with a support around which it may twine. This contact acts as a stimulus to a new sort of activity. Growth becomes greatly accelerated, *particularly on the side opposite the point of contact,* so that the tendril bends toward the support and wraps itself around and around it in a tight spiral.

Another example of this type of response is the reaction of trees to the force of the wind. Anyone who has had an opportunity to observe trees growing along the seashore or in a high mountain pass in regions where winds are strong and where they almost always blow from the same direction, will have noticed that the limbs on the side which is buffeted by the prevailing wind are short and relatively leafless, while those on the opposite side are considerably longer, and the tree seems to lean over as if it had been pushed back by the wind. This impression of leaning is produced partly by the disproportionate length of the branches on the sheltered side of the tree. The fact is that the wind has not pushed the tree back; it has simply stimulated the branches to grow longer on the lee and to grow shorter on the side that faces the wind. The continual force of the wind acts just as would the pressure of a solid object; it inhibits the growth of the tree. Similarly the pull of the wind on the sheltered side facilitates the growth of these branches. It is a general law of plant growth that pressure against the tip of either a root or a stem retards or partially inhibits growth, while a *pull* or *strain* upon either a root or stem usually speeds it up or facilitates it.

It should be emphasized that it is not the force of the wind which pulls the branches of the tree out so that they become longer, as one may lengthen a mass of taffy by pulling at it. The force of the wind merely stimulates the branches on the lee side to grow rapidly. *The energy for that growth comes not from the wind but from the tree itself.*

Here we have an excellent example of the manner in which plants may *adjust* themselves to their surroundings by means of growth *responses.* In a normal situation these same trees would grow with their branches and roots approximately the same length on all sides. But where a hard wind blows almost constantly from one side, long, strong roots grow to grip the soil at just the place where they are most needed and the foliage and branches become "streamlined" and offer a minimum of resistance to the prevailing air currents.

The Developmental Reactions of Animals.—There are two ways in which the environment can affect the growth of an organism, whether plant or animal. First, it may furnish stimuli to growth responses; second, it may furnish or withhold certain nutritive elements essential for growth, such as organic foods, oxygen, water, or mineral salts. It is not always possible to say whether a given condition affecting growth is a stimulus to a growth response or an essential condition for nutrition. Thyroxin, for example, is frequently spoken of as a stimulus to growth in men and animals; but apparently the function of thyroxin is to enable cells to use a maximum amount of oxygen, and hence it is probably more correct to speak of thyroxin as a furnisher of the nutrition necessary for growth. Actually, it is hard to draw a hard-and-fast line between stimuli to growth and necessary conditions for growth; and this difficulty is especially marked in the study of the development of animals. We can get around the difficulty by speaking only of the environmental *conditions* which produce developmental *reactions* in the growing structures, remembering that some of these conditions refer merely to essential supplies of nutrition, while others refer to true stimuli for growth.

The development of an organism from the zygote up to the adult condition embodies three types of changes in the cells:

1. Growth in size of each individual cell, which may go on more

or less rapidly from the time the cell is formed until it divides or reaches an adult stage.

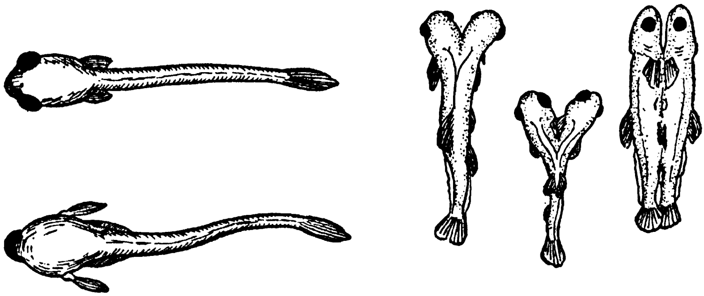
2. Division of cells, so that a vast multitude of them are formed from the single zygote in which the life of the organism has its beginning.

3. Differentiation of cells, so that each cell comes to possess a structure and function of its own, fitting into the structural and functional pattern of the entire organism.

The manner in which each cell will grow, divide, and differentiate depends upon two factors: first, what is in the cell, including the way its cytoplasm is organized and the equipment of genes in its nucleus; second, the conditions surrounding it. It is because the genes enter into the development of each cell that they exert control over the organism; and, since they are handed on intact with each cell division and are passed on from generation to generation, they influence the organism to develop its hereditary characteristics. But they are not the sole influence; for if they were, each cell would develop in the same fashion, and there would be no differentiation. The conditions surrounding the cells, however, especially their relationship to other cells of the growing organism, interact with the genes; and thus the developmental environment is as important as the genetic constitution in determining what the organism shall become. The formation of identical twins is a good illustration of this fact. If at a very early period, two halves of the growing organism become separated in some fashion, two organisms develop, one from each half. This means that the cells of the left half of the organism, which, if they were under the normal influence of the cells of the right half, would develop into only half an organism, now, being freed from that influence and developing entirely by themselves, react to this different environment by growing into an entire organism. In some animal organisms this capacity of cells to react to a different environment by undergoing a different course of development is so pronounced that even when the zygote has divided into sixteen cells, it is possible to separate the cells and have a complete—though rather small—adult develop from each one of them.

Another good example of how environmental conditions can change the development of an organism has been demonstrated in certain minnows. If, at a certain time in their development, magnesium chloride is added to the water in which they are growing, it changes the structures that are growing into eyes so as to produce a single eye in the middle of the head, rather than two eyes on either side. The chemical does not have to be present throughout the period of growth, but only at an early stage, whereupon certain cells are changed in such a fashion as to direct all the succeeding development toward the formation of the single eye.

Many of the "freaks" that we see in circus side shows are people in whom some slight change in their embryonic environment has resulted in a strange course of development comparable



A *B*

FIG. 116.—*A*, normal and one-eyed minnow, *B*, twinning in minnows.

to that of the one-eyed fish. Siamese twins are merely identical twins who became separated from each other at a later stage in development than is ordinarily the case, so that the separation was not as complete as usual. One investigator, by varying the environment at different stages of growth, has produced fish that show all degrees of "twinning," from complete identical twins to individuals with only slightly separated heads on the same body. The two-headed giants of our fairy tales are not biological impossibilities. Indeed, children are occasionally born with two heads, with single eyes, or with various other marked abnormalities brought about by accidents in embryological development; but in most cases they die soon after birth.

A striking characteristic of animal growth is the manner in which one part of the animal body may act as the condition which regulates the growth of other parts. An instance of this is the manner in which hormone secretions govern the growth of the body. We have seen how the appearance of secondary sexual characteristics is dependent upon the secretions of the gonads. The development of the gonads, in turn, is dependent upon one of the pituitary secretions, while the type of gonad developed, whether male or female, depends not only upon the organism's equipment of chromosomes, but also on environmental conditions in the earliest stages of life which govern the rate of metabolism in the embryo. Thus the development of the organism results from com-

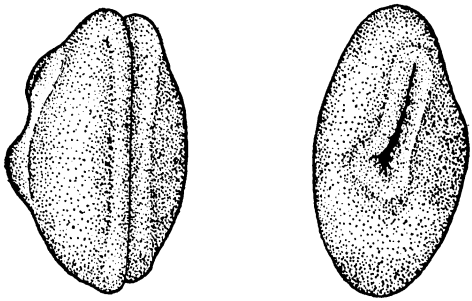


FIG. 117.—Effect of transplanted organizer on salamander embryo. Left: dorsal view, with changes produced by organizer shown on left side. Right: left side, showing how organizer produces a groove similar to the normal groove on the dorsal side.

plex interactions between the genes and the environment, and also from interactions among various parts of the growing body.

An important instance of the interaction of bodily parts is the development in the embryo of various groups of cells which in some manner control the growth and differentiation of the cells around them. Such a cell group is called an *organizer*. Early in the growth of vertebrate animals, a certain region in the unformed body of the organism becomes the organizer for the formation of the embryonic spinal cord, together with the regions surrounding it.

It is possible to take cells from this organizing region in an embryo salamander and transplant them on to the side of a salamander of an entirely different species in which the spinal cord has already started to form along the back, whereupon they will stimulate the cells along the side to begin the formation of a second embryonic spinal cord, together with various other structures, so that the embryo almost develops into two individuals, one attached to the side of the other. Without stimulation from this foreign organizer, the cells that develop into the second group of nervous structures would normally develop into the skin of the side. Similarly, the part of the eye that develops into the retina acts as the organizer for the entire eye. If the cells that would normally develop into the lens and other structures of the eye are removed, and other cells, say from the skin of the back, are put in their place, this second group of cells will form all the necessary eye structures under the stimulation coming from the organizer. On the other hand, if the organizer is removed, the rest of the eye may be very defective in its development.

Chapter Summary

The two most important types of response are *growth response* and *movement response.* Growth response in plants may involve merely a general rapidity or slowness of growth, as when plant stems grow more rapidly in the dark than in the light, or it may involve bending toward or away from stimuli coming from a definite direction. Such a response is called a *tropism.* Stimuli that can evoke tropisms are: gravity, light, water and other chemical substances, heat or cold, and pressure.

For many tropisms, definite receptor and effector cells can be found, as in a plant reacting to light, where the receptor cells are in the tip and the cells that elongate, causing the plant to bend, are slightly lower down on the stem. The impulses to grow are conducted from the receptors to the effectors by chemical substances known as auxins. Auxins are carried by means of streaming currents of protoplasm. By means of growth responses plants adjust themselves to special features of their environment, as when a tree becomes "streamlined" when a hard wind blows upon it always from one direction.

The growth of animals is essentially a reaction to the conditions of the environment, although it is not always possible to determine whether the condition affecting growth is to be considered a true stimulus or an essential condition for nutrition.

Changes in the environment in which an embryo develops may greatly change the course of development, as when one-eyed minnows are produced simply by adding magnesium chloride to their water. Furthermore, the tissues in the developing embryo affect one another's development, as when two individuals develop from a zygote that has been divided in half during the earliest stages of development, whereas each of them would have developed into half an individual if it had not been separated from the other half. During the course of development, certain groups of cells, known as organizers, act to control the growth of all the cells surrounding them, so that under experimental conditions they will cause certain structures to form out of cells that normally would have formed entirely different structures.

QUESTIONS

1. Show how it can be proved that chemical substances make their way from receptor to effector cells in producing plant responses.
2. Mention some of the ways in which growth responses adjust plants to their environments.
3. Criticize: "A man is bound to become whatever his hereditary nature determines that he shall become."
4. What similarity in principle is there between the formation of identical twins and the action of organizers?

GLOSSARY

auxins Chemical substances that stimulate growth in plants.
chemotropism (kem-ot'rō-piz'm) Tropistic response to chemicals.
geotropism (jē-ot'rō-piz'm) Tropistic response to gravity.
hydrotropism (hī-drot'rō-piz'm) Tropistic response to water.
organizer A group of embryonic cells which controls the development of the cells around it.
phototropism (fō-tot'rō-piz'm) Tropistic response to light.
thermotropism (ther-mot'rō-piz'm) Tropistic response to heat or cold.
thigmotropism (thig-mot'rō-piz'm) Tropistic response to pressure.
tropism (trō'piz'm) A response to stimulation in terms of the direction from which the stimulation comes. Tropisms in plants involve a bending of growing structures toward or away from a stimulus. Tropisms in animals are movements of the entire body toward or away from a source of stimulation.

CHAPTER XXIV

MOVEMENT RESPONSES IN PLANTS AND ANIMALS

Movement Responses in Plants.—Growth responses in animals differ significantly from those in plants in that they are not much concerned with adjusting the organism to its environment, but rather, with bringing about its completed development, and hence they involve chiefly the response of one part of the animal body to another. Plants, on the other hand, effect most of their adjustment to the environment through growth and find little need for movement responses. To be sure, swimming movements similar to those in the Protozoa are found among the flagellated algae and the sperm cells of all except the seed plants and the terrestrial fungi, but only a few of the higher plants display movement responses at all. What movement response does occur among the higher plants is exemplified by the folding of the leaves of various plants in response to light or to touch. The leaves of the common sorrel are spread out flat in moderate light, so as to expose the greatest possible surface to the activity of photosynthesis; but either in excessive light and heat or in darkness the leaflets are folded down closely against the leaf stalk, thereby reducing water loss from evaporation. In the "sensitive plant" of the tropics, a similar folding occurs whenever the plant is touched or shaken. In this case the leaves fold up so rapidly that their movement is easily watched, and strong stimulation of one leaflet will cause an impulse to travel through the plant in a few seconds, making the leaves fold up in succession.

The mechanism for this type of response consists in a group of large cells at the base of each leaflet, which normally are filled with water at high osmotic pressure, by means of which they hold the leaf up. Upon stimulation, they lose this water rapidly and collapse, causing the leaflet to drop. The mechanism by which the impulse is carried through the plant is not clearly understood.

Similar folding movements occur in insectivorous plants, as described in Chapter XV. The mechanism for these is apparently the same. In other plants, such movements are found in the stamens or the stigma, and help in pollination.

Movement Responses in Animals.—Although the fundamental distinction between the plant and the animal is that the

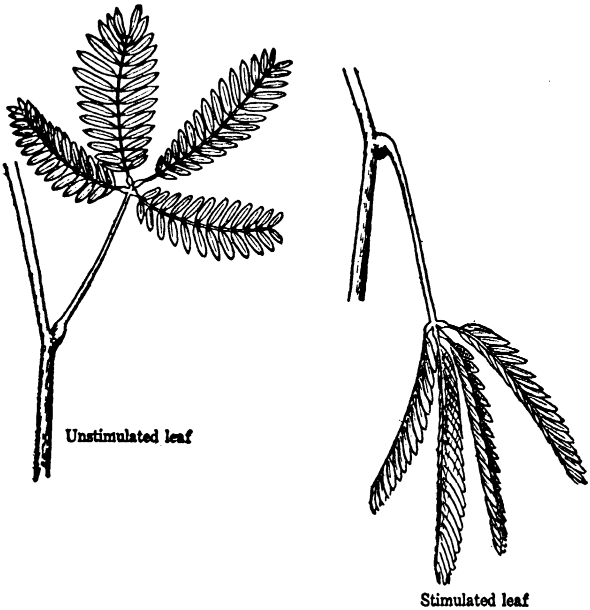


FIG. 118.—Movement response in sensitive plant. (Redrawn from Smith, Overton, *et al.*, *Textbook of General Botany*, The Macmillan Company.)

latter ingests its food, the most noticeable difference between the two kingdoms is the immobility of plants and the mobility that animals have developed in their constant search for material to ingest. No one who has looked through a microscope at the teeming, restless world of the Protozoa can doubt that, from its lowest forms upward, the animal world is a world of movement. We have already mentioned the major forms of animal movement—the rapid jerk of the striped muscles, the powerful, sluggish contraction of smooth muscles, the waving of minute cilia, the snapping of flagella, and the queer, formless flow of ameboid pseudopodia.

The most interesting aspect of animal movements is the manner in which the impulses which set them into action are carried from receptors to effectors, being integrated on the way so as to produce patterns of movement that result in the most delicate adjustments of the animal to its environment. In a few simple forms, such as Ameba, there are no ascertainable structures specialized for conduction and integration. But even in the lowly Paramecium, tiny, threadlike pathways of conduction exist, stretching from the anterior end of the organism, where the protoplasm is most sensitive, to the cilia in all parts of the body. These conductors are invisible in the living animal, but when the cell is stained, they appear in the form of minute fibrils. Near the fore end, these fibrils come together to form a network, known as the *motorium*; and it has been shown in Protozoa that are similar to Paramecium, that when the motorium is removed, the activities of the cilia lose coordination. Thus, even in this simple one-celled organism, there is an organ of coordination similar to our brain.

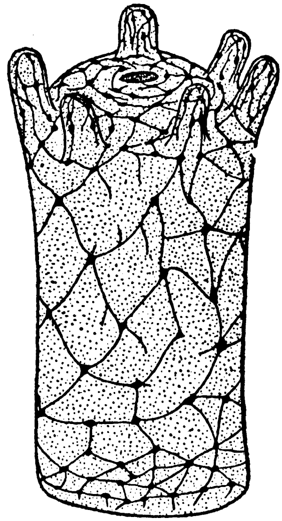


FIG. 119.—Nerve net in Hydra.

The Nerve Net of Hydra.—As the multicellular animal body evolved from its precursor, the protozoan colony, the development of conducting and integrating structures had to begin all over again; and it is not surprising to find that in the lowest form of multicellular animal, the sponges, there are no true nervous structures whatever. In Hydra and the other coelenterates, however, there is a complete network of nerves which extends throughout the entire body of the animal. (See Fig. 119.) There is no separation between cells in this nerve net. Thin fibers extend all the way from one cell body to another, and there are no synapses at which impulses may be held up or passed along, depending upon the dominant activity of the animal at the time.

But while the selective action of the synapses is absent in Hydra, a certain degree of coordination of response is effected simply by the fact that the nerve net stretches throughout its entire body. Thus, if the tentacles of the animal are touched by the point of a needle, sensitive nerve fibers in the ectoderm will be stimulated and will start impulses which move throughout the network to contracting cells in nearly every part of the body. The result is that both the tentacles and trunk contract, and the tiny animal draws itself up into a ball. The distance that a stimulus will travel through the network from the point of stimulation seems to depend upon the strength of the stimulus, so that a light touch upon one of the tentacles may result in the retraction of the tentacle only, rather than of the entire body.

In the human body, the impulses for the peristaltic movements of the digestive tract are carried down the tract by a nerve net unconnected with the central nervous system and spreading throughout the muscles of the walls, much as Hydra's nerve net spreads throughout its tissues. And these simple, unvarying peristaltic movements, together with the few other types of movements of the alimentary canal, suggest the simplicity of behavior that must characterize organisms possessing no synaptic nervous system. Hydra can wiggle and squirm about, take in food, contract its tentacles and its body to escape harm, and make a few other responses, but its repertoire of behavior is very limited.

The Nervous System in the Earthworm.—In the earthworm we discover a nervous system that in many fundamental ways is like that of man and of the other higher animals. Instead of a spinal cord running from head to tail on the dorsal side of the body, the worm has a nerve cord running the length of its body just inside the lower, or ventral surface. In each segment of the worm, the cord enlarges to form a ganglion which contains a number of synapses. At the anterior end of the body, the cord divides into two branches which pass on either side of the pharynx and come together in a ganglion which serves as a sort of brain. Nerve trunks, composed of the fibers of sensory and motor neurons, run out from each ganglion to the various parts of the body; and connector neurons run from ganglion to ganglion throughout the entire system.

The nervous system of the earthworm is like ours in that it is made up of neurons joined to one another by synapses, thus making complex integrations possible and allowing for considerable variety of responses. It differs from ours in that the nerve cord runs along the ventral rather than the dorsal side of the animal, and integration is carried out in a chain of ganglia, one in each segment of the worm's body, rather than being centered in a single great anterior ganglion, or brain. Hence, the activity of the organism as a whole is not as completely unified, nor can the organism respond appropriately to as complex an environmental situation. To a large extent, this is dependent upon the fact that the chief sensory regions of the worm are not as completely centered about the head as in the vertebrates. When we

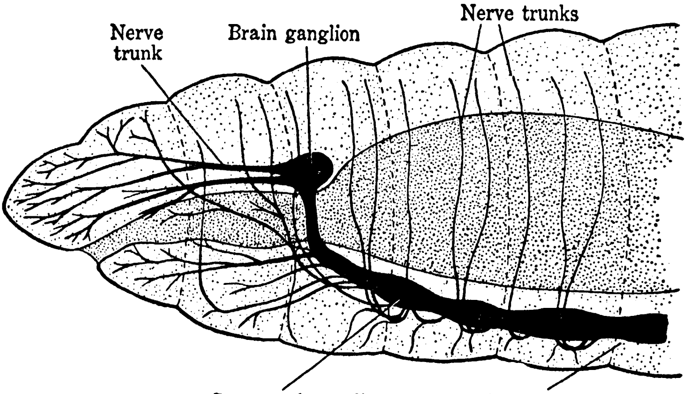


FIG. 120.—Anterior portion of nervous system of earthworm.

consider that sight, hearing, taste, and smelling in human beings are all located in the head region, we can realize why this region has become such an important center of integration in man. In the worm, sense organs are found in somewhat greater numbers in the head and tail regions, but there is no such tremendous concentration as occurs in human beings. The animal is sensitive to vibrations and pressures, to chemicals, and to light; but the entire surface of the body is sensitive to all these stimuli.

The Vertebrate Nervous System.—The nervous system of the earthworm contains all the fundamental features of the human nervous system. There are neurons with long axons or dendrites, each neuron joined to others by means of synapses. The synapses are located within a central nervous system in definite regions of integration (the ganglia) and these regions of integration are connected by regions of conduction through which the axons or

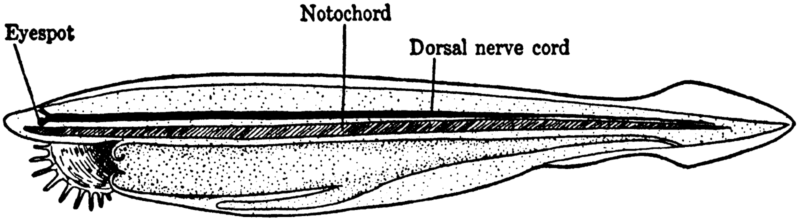
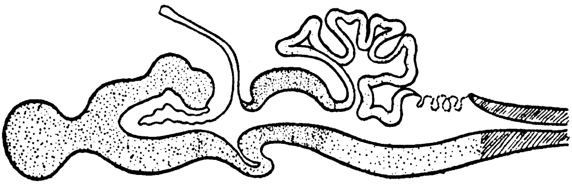
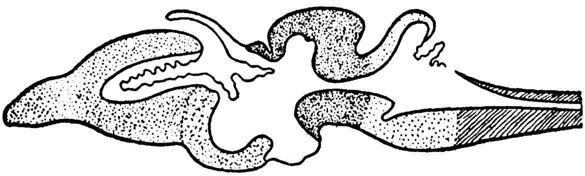


FIG. 121.—Amphioxus.

dendrites carry impulses from one part of the central nervous system to another or between the central system and the sense organs and muscles. But only in the vertebrates, or in their rela-



PRIMITIVE FISH

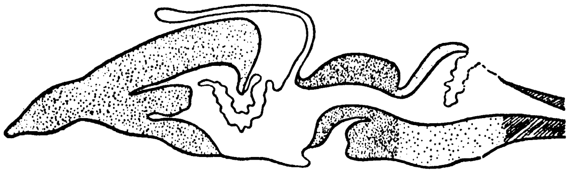


AMPHIBIAN

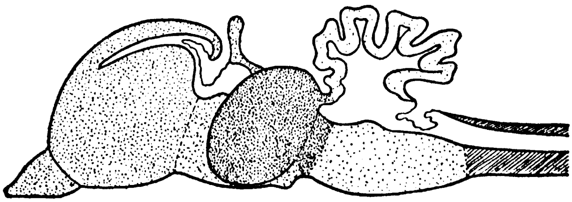
FIG. 122.—Vertebrate brains.

tives among the chordates, do we find a nervous system that is built upon the same general pattern that we find in human beings.

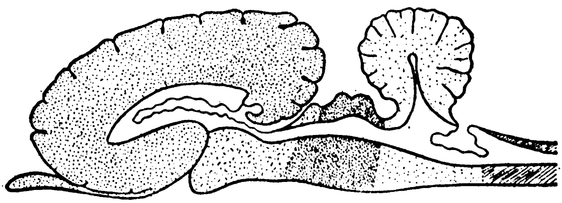
The basic features of this pattern are to be found in Amphioxus, a transparent, fish-like creature, about two inches in length, which swims about close to the shore and burrows in the sand at night. It is not itself a vertebrate, but it probably represents better than any other living form what the immediate ancestors of the vertebrates were like. Like the earthworm, its central nervous system is composed of a long cord of nervous tissue running



REPTILE



BIRD



MAMMAL

FIG. 123.—Vertebrate brains (continued).

from front to back, with nerve trunks branching from it. Unlike the earthworm, however, the cord runs along the dorsal side of the animal, above the alimentary canal rather than below it, and there are no segmental ganglia. The only appearance of anything like a ganglion is a slight enlargement of the cord at its anterior tip. This enlargement is the beginning of the vertebrate brain which, as one ascends the vertebrate series from the fishes up through the amphibians and reptiles to the birds and mammals, becomes larger and larger until, in the human species, it reaches its apex in size relative to the size of the animal and contains by far the greater portion of the nervous tissue in the body.

Figs. 122 and 123 show five types of vertebrate brains. The brain of the fish is little more than a brain stem with a cerebellum added. In each of the succeeding higher forms, the cerebrum increases in size relative to the brain stem, until in the mammals it is larger than all the rest of the brain put together.

The Evolution of Behavior.—When we leave the study of the nervous systems of animals and begin to consider their behavior, we find that they fall roughly into three groups, as follows:

1. *The lower organisms,* including Paramecium, Hydra, the earthworm, and many other forms. They are characterized by a relatively simple repertoire of responses to the stimuli which affect their sensitive structures, and they possess a limited capacity to vary these responses in case their first reactions to a situation fail to satisfy the motives which the situation, together with the internal conditions of their bodies, arouses in them. When Ameba, for example, is moving through a dimly illuminated region and comes upon a beam of strong light, it withdraws the first pseudopodium that enters the beam, but immediately puts forth another one, which, on entering the beam, is likewise withdrawn. After a few of these protrusions and withdrawals, it changes its behavior completely, begins to put forth pseudopodia on the side opposite the light, and thus moves away from the beam. Its first responses fail to adjust it to the situation, so it *modifies* or *varies* its behavior until it does become adjusted. Obviously, this is a simple form of trial and error activity. Another, more permanent way of modifying behavior is for an organism to *learn* to respond in a new way to a situation with which it has had previous experience. In the lower organisms learning, if it takes place at all, occurs very slowly, and probably quite infrequently. Nevertheless, the modifiability of behavior as seen in the lower organisms marks the evolutionary beginnings of human *intelligence.*

2. *The insects,* together with their relatives, such as the spiders, crabs, and other arthropods. They display a marked advance over

the lower organisms with respect to the complexity and variety of their behavior patterns, but their capacity for modifying these patterns is only a little further advanced than that of the lower forms. They adjust to the environment almost entirely by *instinct.*

3. *The vertebrates.* The vertebrates display a complexity of behavior as great as or greater than that of the insects, but, in

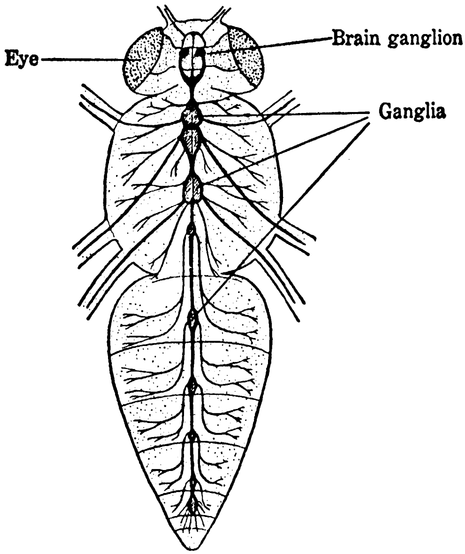


FIG. 124.—Nervous system of fly. (Redrawn from Herrick's *An Introduction to Neurology,* W. B. Saunders Company.)

addition, they show a marked capacity for modifying their responses which has increased tremendously throughout the course of vertebrate evolution, until it has reached its greatest development in the behavior of man.

The difference between vertebrates and insects in this respect seems to be related to a difference in the arrangement of gray matter in their nervous systems. The nervous system of the insect is arranged on the same basic pattern as that of the earthworm. There is a ventral nervous cord with a chain of ganglia, and a large brain ganglion located above the alimentary canal. The chief differences are that the ganglia are larger, there are not so many of them, and the brain ganglion forms a more important part of the nervous system. In such a nervous system as this, the synapses are located in little clumps within the ganglia. There is no widely spread *surface* of gray matter, as in the human cerebral cortex. Apparently clumps of gray matter are best for integrating unmodifiable, instinctive behavior, while sheets of gray matter are essential for modifiable, intelligent behavior. Thus, in our own bodies, the relatively unmodifiable reflexes are integrated in the spinal cord and brain stem, while the cortex is the seat of intelligence. Even among the higher vertebrates, we find that the cerebrum of the bird, although it is fairly large and contains a good deal of gray matter in solid clumps inside the white matter, has a very poorly developed cortex, relative to that of the mammal. Correlated with this is a very high development of bird instincts, as seen in the intricate architecture of their nests and their long seasonal migrations, together with a development of intelligence considerably inferior to that of the mammal, although, to be sure, it is much superior to that of the insects or even of the lower vertebrates.

The Unchangeability of Insect Behavior.—A good example of the complex but unmodifiable behavior of the insect is found in the nest-building activity which characterizes many kinds of wasps. The mason wasp of India builds a dome-shaped chamber of mud, leaving a hole at the summit of the dome. She then pushes her abdomen into the hole and fixes an egg near the top of the dome, whereupon she makes many flights through the surrounding countryside, capturing live caterpillars, one after another, and depositing them in the chamber. When it is full she closes the hole and flies off, soon to die. The wasp larva, after it has hatched from the egg, feeds on the live caterpillars which its mother has provided for it.

Here is a cycle of behavior which provides for the preservation of the species of the mason wasp with an exquisite neatness. Compared with the limited complexity of response in such an animal as Hydra, it is astonishingly elaborate. Each step in the process fits into the preceding and succeeding ones in such a way as to make the most complete preparation for the welfare of the offspring which the mother wasp herself will never see. From casual inspection it would appear that the wasp is anxiously looking forward to the birth of her child and leaving nothing undone to insure that it will be well cared for until it is able to shift for itself. Actually, the wasp knows nothing about what she is doing. She goes about her task quite blindly, and is unable to make the slightest change in her preordained cycle of behavior if some obstacle is raised in the path of its successful completion. A striking instance of this incapacity to modify behavior is related by Major Hingston, who has carefully studied the behavior of many insects.[1] He writes:

> I cut away the top of a cell before the wasp fixes her egg. The breach involves that spot in the dome to which the egg is always attached. What will happen now? The wasp will be unable to satisfy her instinct. For the one spot of attachment is gone. We wait until the time for egg-laying arrives. The wasp comes, puts her abdomen into the cell and brings it to the correct spot. She feels for the surface against which to lay. The surface is gone so she withdraws her abdomen. She gets very agitated. There is something amiss. Again she tries it. Again failure. She gets more and more impatient, evidently bursting with the impulse to lay. Now we see the unyielding rigidity of her forethought. There is plenty of space within the dome. She might fix her egg anywhere, to the sides, to the floor. Just the slightest deviation to the right or to the left and the wasp will find plenty of space. But she will not do this on any account. Her instinct permits of no such deviation. It has been ordained that the egg shall be anchored only at the very top of the cell. The wasp makes more efforts then more withdrawals. A time comes at last when she can wait no longer. She must get rid of her egg. Were does she lay it? Exactly in the place where it should be laid, that is, in the very top of the cell. But of course there is nothing to which she can fix it. Hence it is shot into the air and tumbles down to the bottom of the cell. Here we see instinctive foresight carried to its extreme degree. If the wasp would deviate a fraction she would find plenty of spots for anchorage. But she stubbornly refuses to make any deviation. Instinctive foresight demands one spot. No other spot is of any account.

The behavior of insects has always struck the human beings who have studied it as remarkable and almost uncanny. It is so different from our own. Our own activity, as described in Chapter XXII, is *goal-directed.* Consciously or unconsciously, we are

[1] Hingston, R. W. G., *Problems of Instinct and Intelligence,* chap. iii. By permission of The Macmillan Company, Publishers.

always aiming to attain certain ends; and if some unforeseen circumstance interrupts our progress toward a goal, we begin to try new ways of approaching our destination. We proceed by trial and error, either overt or implicit, until we succeed. Insect behavior *seems* to be directed toward certain goals; but when we study it, we discover that it is simply a chain of responses, one following another, without any real directedness toward the end results of the chain, and if a single link is broken, the entire chain falls to pieces as far as attaining results is concerned. Thus the spider, which, while it is not a true insect, is so closely related to insects in structure and behavior that it is usually mistaken for one, constructs a web of the most perfect geometrical design, simply by making one response after another. If a single thread in the net is cut, the spider can never go back to mend it, but must continue its chain of responses, although the result it then achieves is simply a formless tangle of threads.

But stupid as the behavior of insects may appear to be, it still arouses our wonder because the insect can do so much without ever learning how. No human being could create a net as perfect as the spider's web without much training, yet the spider builds its first net as perfectly as it does any other. The entire cycle of activity whereby the wasp provides for the future of its offspring occurs only once during its life, and, barring accidents, is carried on quite successfully that first and only time. Such complex, unlearned chains of behavior are called *instincts*. Human beings are very poorly endowed with instincts. It is doubtful that even such simple performances as the sucking response of the infant or the activity of walking are wholly instinctive in human beings. Even these universal human patterns of behavior may require a certain amount of learning to bring them to perfection.

How Learning Occurs.—Learning usually occurs as a result of motivated or goal-directed activity. This may be illustrated by what happens when a cat is placed in a cage from which it must learn to escape. Fig. 125 shows such a cage. In order to open the door, the cat must pull out one latch by stepping on a lever attached to a string; a second latch must be removed by clawing at the string to which it is attached, and, finally, one of the wooden bars in front of the door must be pushed upward. A hungry cat is placed in the cage, and a bit of fish is put outside.

Of course, the cat is not endowed with any instinct which enables it immediately to perform the three acts that permit it to get out of the box. But both the motive to escape from confinement and the motive to get the fish cause it to respond in a variety of ways that seem to be directed toward the goals of the motives. "It tries to squeeze through any opening; it claws and bites at the bars or wires, it thrusts its paws out through any opening and claws at everything it reaches; it continues its efforts when

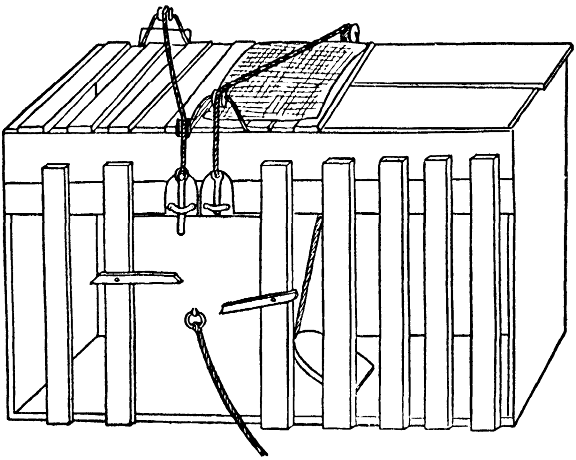


FIG. 125.—Animal puzzle box. (Redrawn from Thorndike's *Animal Intelligence*, The Macmillan Company.)

it strikes anything loose and shaky; it may claw at things in the box."[2]

Finally, almost by chance, it happens to perform all three of the acts that liberate it. The next time it is placed in the cage, the successful acts are likely to be performed sooner. Gradually the unsuccessful acts come to be inhibited, and the successful acts are reinforced whenever the cat is placed in the box, until finally it escapes almost immediately whenever it is placed in the situation.

Practically all learning is of this nature. An animal is subjected to a motive which it cannot immediately satisfy. It varies its behavior until it finally arrives at its goal. With repeated experiences in the situation, the responses which bring it to its goal

[2] Thorndike, E. L., *Animal Intelligence*, The Macmillan Company, New York, 1911, p. 35.

are strengthened and those which fail to bring it to its goal are weakened, until it learns to arrive at the goal directly.

Sometimes, when the situation is simple, the animal learns almost immediately to make the goal-directed responses. In one type of experiment, for instance, a hungry rat is put into a small box which contains a lever and a receptacle for food. If the rat depresses the lever, a small pellet of food drops into the receptacle and the rat's hunger drive is momentarily satisfied. When the rat is first put into the box, a considerable time may intervene before the lever is depressed. The rat responds to the situation by moving around restlessly, smelling of this and that, grooming its coat, and so forth. Then, in the course of these random activities, it strikes the lever and receives the food. A much shorter time will now usually intervene before the lever is pressed again, and soon the rat is pressing the lever almost as rapidly as it can eat the pellets. The fundamental principles governing this learning are the same as those which govern learning in the cat. *The responses which satisfy a motive are strengthened, those which fail to satisfy it are weakened, so that when the same motive is active in a similar situation, the responses which formerly satisfied the motive occur immediately, rather than at the end of a train of trial and error.*

Behavior Patterns.—Just as every species has its own special pattern of bodily structure, so each species displays a certain pattern of behavior which distinguishes it from others. In closely related species, to be sure, we find behavior patterns which show a general relationship to one another, but there is something unique in the form of behavior of each species. Thus, nearly all birds build nests, but each species has its own particular pattern of nest building. Reproduction in all species of placental mammals follows a single general pattern, involving copulation between male and female, carrying of the young in the mother's body, birth, suckling, and other care for the young; but each species mates and cares for its young in a manner of its own, which is correlated with the social life or the lack of it in that species. Wild horses, for example, live in groups known as harems, in which a single stallion is followed by several mares, and the young grow up under the protection of this group. Domesticated horses, turned loose upon the range, will revert to this form of family life.

Among certain wild cattle, on the other hand, males and females ordinarily live in separate herds which join each other only during the mating period, and the young grow up within the female herd. Among many species of mammals and birds, a monogamous family life develops; but, depending upon the species, this may last for only a few days, the female being charged with all the care of the young, or it may last for a season, with the male assisting in the care of the young, or it may last over a period of years.

In more specific ways behavior patterns vary from species to species. A horse rises to its feet fore legs first; a cow, hind legs first. A rabbit stands beside its food and nibbles; a rat may do this, or it may hold its food in its fore paws while eating. A chicken takes a sip of water and throws back its head to swallow; a dove dips its bill into the water and sucks it up, swallowing with its head down. This cataloguing of the behavior patterns of species could be endless. However, enough has been said to show that species are differentiated by their behavior as much as by their anatomy.

The Maturation of Behavior Patterns.—In the preceding chapter it has been pointed out that the development of animal structures takes place through a complex interaction between the organism and its environment. Part of this growth produces the structures which carry on our responses, namely, the muscles, glands, sense organs, and nerves. As the response system develops, certain capacities for response develop. For instance, the young bird cannot fly until its muscles and the nerves connected with them reach a certain stage of development; the young kitten shows no tendency to hunt for prey until a certain stage of physical growth is reached; and complete sexual behavior does not appear in most organisms until their bodies have grown almost to the adult stage. This development of behavior which parallels and is dependent upon the growth of the response system is called *maturation.*

When the capacity to make a response is dependent upon the development of the sense organs—as when young kittens must wait to respond to visual stimuli until their eyes are open—or upon the development of the muscles—as in the newborn child, whose muscular development is not sufficient to enable him to walk—the fact that the development of behavior depends upon physical growth is easily apparent. It is probable, however, that the most significant type of physical growth for maturation of behavior is the development of synaptic connections in the nervous system. The nervous system grows in size faster than any other part of the vertebrate embryo, and at a very early stage of development, all or nearly all the cells that will ever be formed will have appeared. But the complete growth of axons and dendrites to make synaptic contacts proceeds slowly, and probably is not completed until adulthood is reached.

This development of synaptic relationships is a difficult thing to observe, but through the study of the tadpoles of a certain salamander it has been shown that synaptic development exactly parallels the maturation of certain behavior patterns. When the tadpoles first begin to develop from the eggs, they lie motionless in the water, getting nourishment from the yolk of the egg, which remains attached to their bellies. Gradually, the yolk grows smaller and the tadpole larger, and soon the little animal must be able to swim around and secure its own food. The first sign of a swimming movement is a turning of the head to the right or left when the skin of the head is touched. The animal always moves its head away from the side on which it is stimulated. This movement appears quite suddenly. Before its appearance, you may stimulate the skin of the head as much as you please, but there is no response. An hour later, you may go back and touch the head, and the animal twists to the side. What has happened during that hour? Studies of the response system before and after the appearance of the turning movements show that previous to the movement both the sense organs and the muscles involved are completely developed. There are sensory neurons passing from the sense organs to the brain stem, and motor neurons from the brain stem out to the muscles. There are also connector neurons which are in synaptic contact with the motor neurons, but whose dendrites have not yet developed. Immediately after the twisting response occurs, it is discovered that the dendrites of these neurons have grown out and made contact with the sensory neurons from the skin, thus enabling impulses to pass from the skin on one side of the head across to the muscles in the fore part of the body on the other side. The result is that a response having a very definite pattern suddenly appears. (See Fig. 126.)

This twisting response is only the beginning of the total swimming response, which involves the waving back and forth of the head and tail, with the tail always moving toward the side opposite to the direction of movement of the head. Progress toward

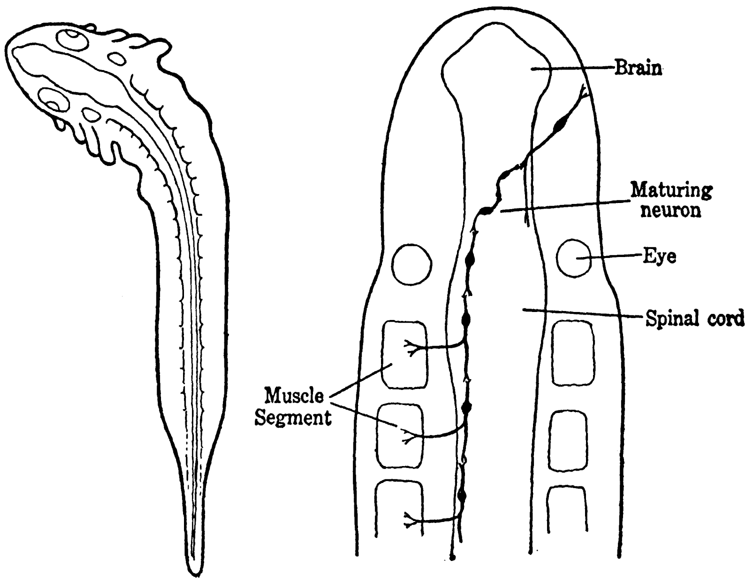


FIG. 126.—Maturation of response in salamander. The figure on the left shows the bending response that is made possible by the maturing neuron shown in the figure on the right. (Redrawn from Coghill's *Anatomy and the Problem of Behaviour,* Cambridge University Press.)

the complete swimming response occurs in stages, and each stage is marked by a definite new development of nervous connections. We can say that the swimming response pattern grows with the growth of the nervous system.

The Rôle of Learning in the Development of Behavior.— To the casual observer, the development of swimming behavior in the tadpole might not appear to be very different from the development of skill in a human being who is learning to swim. To begin with, the movements are very imperfect, and they gradually improve until the act can be carried on successfully. Experimental study has shown, however, that the two types of behavioral development are far different with respect to their causes. One is produced by maturation, the other by learning. Learning is always brought about by *exercise of the function of response*—what we commonly refer to as practice. The animal, or human being, usually strives to attain a certain goal, and sooner or later its behavior is modified so as to enable it to arrive at the goal more directly and easily. But the maturation of the swimming response in the tadpole occurs as readily without exercise of function as with it. This has been demonstrated by an experimenter who placed tadpoles in water containing a drug which rendered them completely incapable of movement throughout the period of maturation of the swimming response. All during this time they did not so much as wiggle the tips of their tails; but when they were placed in pure water and the effects of the narcotic had worn off, they began to swim just as well as tadpoles that had apparently been practicing all the time. Thus it was shown that learning has nothing to do with the establishment of the swimming pattern of response in tadpoles. It is dependent upon neural growth that has not been stimulated by exercise of function.

We find that among birds and mammals learning and maturation usually work together to produce the behavior of the organism. Maturation seems to provide the organism with certain necessary motor skills (swimming, walking, seizing food, etc.) and certain goal-directed motives. Learning may result in improvement of the skills, and determines the way in which the motives will be satisfied. Chicks, for example, begin to peck for food as soon as they are born. At first, however, they will peck at almost any small object on the floor. But soon they begin to avoid inedible objects—that is, objects which do not satisfy the hunger drive—and to direct their efforts entirely toward objects that are good to eat. This selection of means of satisfying the hunger motive results from learning. It is an illustration of how learning occurs through the dropping out of responses that fail to bring the organism to its goals and the firm establishment of responses that do bring the organism to its goals. Furthermore, research indicates that the accuracy and skill of the pecking response are improved by learning as well as by maturation. If the chick is kept from pecking for four or five days after birth and fed by forcing food into its mouth, it does not immediately begin to peck as accurately as chicks that have practiced throughout the five days. To be sure, maturation has progressed during this time, since the chick learns accurate pecking more rapidly at the end of the five days than do chicks who begin to practice at birth. But some practice is required in order to perfect this skilled act.

Instincts and Species Habits.—The behavior patterns of insects are doubtless almost entirely the product of maturation without the intervention of learning. In other words, they are true instincts. But it seems highly improbable that the behavior of mammals, their hunting, mating, and other activities which are frequently spoken of as instinctive, are truly so. The instinctive responses—that is, those resulting solely from maturation—probably appear as imperfect parts of the behavior patterns that are finally developed, and the perfecting of each pattern is dependent upon learning. For this reason, it is better to speak of the distinctive behavior patterns in animals as *species habits* rather than as instincts.

To be sure, they are not like the habits of a trained dog that has been intentionally taught to perform tricks, or of a human being whose whole scheme of behavior is determined by the intentional or unintentional education he receives from others. Species habits are not taught to an animal; it learns them naturally through its interaction with its natural environment. As a general thing, neither its parents nor other members of its species "show it how" to do things; it simply learns how by trial and error, as the cat learns to escape from its cage or the rat learns to get food by depressing a lever. Indeed, the learning of species habits may be looked upon as merely a continuation of the natural process of development which begins with the formation of the zygote, and continues always as an interaction between the organism and its environment. Learning is a developmental reaction to exercise of function under the spur of a motive, just as the growth of the eye is a developmental reaction to the organizing influence of the embryo retina within the type of environment that permits the growth to take place. For we must suppose that the change that takes place in the organism when it learns something is basically a change in the structural pattern of the neurons or of the protoplasm within the neurons. To be sure, no such changes have ever actually been observed. What we observe in learning is a change in the responses made to certain stimuli; but if such a change is to take place, there must be back of it an increase of resistance at certain synapses and a decrease at others, and such changes in synaptic resistance must be fundamentally dependent upon changes in the structure or chemistry of the neurons. Learning, then, is really a mere part of the total process of growth and differentiation in the organism.

In using the term species habit, rather than the older term instinct, to describe a type of behavior characteristic of a species, it is essential to guard against the underestimation of the great part that maturation plays in the production of most species habits. Studies of the rat show that both sexual behavior and nest building are carried out in practically the same way upon their first appearance as after practice. Of course, both these forms of behavior appear at a time of life when the animal has had an opportunity to practice most of the individual responses that go to make up the total pattern. The truth is that in many cases it is extremely difficult to discover whether a certain sort of behavior is the product of maturation alone or of maturation plus learning. For this reason it is desirable to use the term species habit for any characteristic form of behavior unless it has been definitely proved that it is not the result of learning, in which case the term instinct may properly be applied.

Do Animals Think?—Nearly everyone has at some time met the belligerent gentleman who proudly asserts that his dog "has got more sense than most humans." He is likely to give you the discouraging impression that he would have a great deal more respect for you if you could only manage to be as smart as his dog. As a matter of fact, it is usually impossible and quite unjust to compare one type of animal with another with respect to mental ability. It is highly improbable that any human being could equal the skill of the spider in constructing a web upon the first attempt. When it comes to making friends and influencing people—even to influencing their estimates of one's mental endowment—few men or women possess a talent equivalent to the cordial and flattering tail-wagging of the canine species. And psychologists have discovered that in the task of learning how to thread a maze of passageways, the lowly white rat is quite as capable as most human beings.

Each species seems to have its own special abilities which adequately adjust it to its environment, and, within the range of these abilities, it usually shows a great deal of "good sense." Nevertheless, there seems to be good reason for believing that the human species far transcends any group of animals in certain aspects of intelligence. The old philosophers called man "the reasoning animal"; and it is true that, in his ability to think, man differs tremendously from any of the lower animals. To be sure, many people will dispute this assertion and insist that animals are able to reason as well as human beings, but this point of view is the result of jumping to conclusions on the basis of an inadequate observation of animal behavior.

For instance, one close student of animal behavior came to the conclusion that cats could reason because he saw a cat open a door by jumping up and catching hold of the handle of the latch with one paw while depressing the button on the latch with the other, at the same time kicking and scratching with its hind paws against the door post so as to push the door open. This observer concluded that the cat must have sat down and looked the situation over and reasoned in advance that this method would open the door for it. But actual observations of cats in situations similar to this one show that in solving such a complex problem they learn by overt trial and error, rather than by the implicit trial and error that we call thought. The observer did not see how the cat learned to open the door, and hence jumped to the false conclusion that reasoning was responsible for it.

The cognitive adjustments of animals seem to be almost entirely of a perceptual nature. There is some evidence that they may have rather dim ideas of objects outside the range of their senses; but that they can manipulate these ideas in a trial-and-error fashion to develop new ideas, as we do in thinking, has never been proved. The nearest thing to thinking that has ever been observed in animals is the implicit problem-solving that is displayed by chimpanzees. For instance, a chimpanzee is placed in a cage with a banana or orange hanging from the roof. A box is also placed in the cage about eight feet from the point where the food hangs. The ape first tries to reach the fruit by jumping for it, but finds it impossible to do it. It paces up and down the cage, and then suddenly goes over to the box and, picking it up, places it near enough to the fruit to enable it to jump from the box and secure this food. It is clear that the animal does not at first perceive the box as something that may be used to get the fruit. At the same time, once it does so perceive the box, it uses it immediately, without any overt trial and error. Whatever trial and error has taken place must have been of an implicit sort. But even here the animal is only rearranging its *perceptual* adjustments. It is not required to use anything outside the immediate range of its senses. Animals may be clever enough on the instinctive level of adjustment. They may learn rather rapidly by means of overt trial and error, but careful study indicates that they show only the barest rudiments of ability to think.

Animals Have No Language.—Animals are not inferior to human beings in what is commonly called the "sense of direction," as indicated by the ability of rats to learn mazes and by the remarkable abilities shown by both birds and mammals in finding their way about to and from their homes. They are definitely inferior, however, in their capacity to appreciate spatial relationships and the possibilities of using tools. Most of all, they are incapable of learning a language and using that language as a tool of thought. Animals do have certain sounds which they make whereby they stimulate one another to various forms of activity. There are mating calls, growls and snarls which signify a readiness to attack, and cries of warning which, uttered by a single member, may send an entire herd of animals into a stampede. But they lack words that stand for or signify objects. They have only a system of signs, not a true language. Thus they can have only the haziest sort of concepts. Words can make ideas and concepts nearly as definite and as capable of being dealt with as objects that are placed before our eyes or in our hands; and human beings are able to think efficiently chiefly because they are able to talk to themselves, while animals, lacking this capacity for implicit verbal behavior, can make fine adjustments only to things that directly affect their sense organs.

Furthermore, words can stand for abstractions and generalizations. An animal may learn to respond differently to live animals than to dead ones, but only by the use of the words "life" and "death" can one have a clear-cut concept of the difference between the two classes of objects. And only by a gradual extension of the meaning of the word "life" to things which grow and reproduce as well as to things which move about, can the real differences between the organic and the inorganic world finally come to be recognized. Thus, by his tool of language, man can, as it were, "get a grip" on the world in which he lives. He is no longer condemned to adjust only to situations immediately present, nor to concrete objects and relationships. He can come to know the world in an entirely different way from that in which an animal knows it. Gradually, by adding one word to another, or by enlarging the meanings of the words he possesses, he builds up a body of knowledge and wisdom which can be passed on to his offspring. He is no longer a "dumb" brute but a "beast that reasons."

Chapter Summary

Movement responses in plants occur chiefly in the flagellates and the sperm cells of the higher plants, although a spreading or folding of the leaves occurs in a few of the higher plants in response to light or pressure.

In animals movement response is almost universal, and even in the Protozoa the structures are arranged so as to integrate movement responses. In Hydra and its relatives, the nervous system is in the form of a nerve net which extends throughout the body. In the earthworm, there is a ventral nerve cord running the length of the body. Integration takes place in ganglia which are located in each segment along the cord. In the vertebrates, the central nervous system is composed of a dorsal cord with a single ganglion at the anterior end, known as the brain. The size of the brain relative to the cord increases tremendously in the evolutionary series from fish to man. The cerebrum and especially the cerebral cortex increase out of all proportion to the increase in the rest of the system.

Instinct is the capacity to respond adaptively to a situation by a pattern of response that has not been modified by learning.

Intelligence is the ability to respond adaptively by varying responses to a given situation and by learning to perform the successful variations.

The lower animal organisms display slight complexity of instinctive response and a very low degree of intelligence.

The insects have very complex instinctive responses, but only a low degree of intelligence.

The vertebrates display a relatively high degree of intelligence which comes to preponderate more and more over their instinctive capacities with each advance in the evolutionary series from fish to man.

Learning usually occurs in connection with trial and error attempts to reach a goal. The trial responses that successfully bring the organism to its goal are strengthened so that they occur more readily the next time the organism is placed in a similar situation.

Instinctive patterns of behavior develop through growth of the response system—which, as pointed out in the preceding chapter, results from the interaction between the organism and its environment. The gradual development of these patterns is called maturation.

Subsequent to the development of a pattern through maturation, it may be improved or otherwise modified through exercise of the function of response, that is, through learning.

By the combination of maturation and learning, animals develop characteristic species habits which are the product of the interaction between the normal environment of the species and its inherent capacities for development. Since it is difficult to determine whether or not a given pattern of behavior results from maturation alone, it is better to apply the term species habit to a characteristic behavior pattern whether it is thought to be purely instinctive or not.

The capacity for thinking in animals—if it exists at all—is greatly inferior to man's, chiefly because cultural tradition supplies man with a language that enables him to work with precise conceptions of objects and situations that are not present to the senses.

QUESTIONS

1. Describe the movement responses that occur in plants.
2. Outline the evolutionary development of integrating structures in animals.

3. Illustrate the difference between purely instinctive and intelligent behavior.
4. Illustrate the difference between the development of a species habit by maturation alone and by maturation plus learning.
5. What evidence do we have as to whether animals can think? From what handicap do they suffer in thinking?

GLOSSARY

Amphioxus (am′fi-ok′sus) A small, fish-like animal resembling the supposed ancestors of the vertebrates.

instinct A pattern of response that has not been modified by learning. The capacity to make such responses.

intelligence The capacity to vary responses in the direction of arriving at a goal, together with the capacity to learn successful responses.

maturation The development of capacity for response that parallels the growth of the response system.

motorium Center for integration of responses in certain protozoans.

species habit A pattern or type of response characteristic of a species.

CHAPTER XXV

THE DEVELOPMENT OF HUMAN BEHAVIOR

Species Habits and Culture Habits.—Man, like other mammals, builds upon his maturated responses by learning. The sucking response, which, since it enables the child to sustain life, is without doubt one of the most important behavior patterns of our earliest days, is developed in this way. In a child born several weeks before its time, this response may be so incompletely maturated that the young infant must be artificially fed, as the Dionne quintuplets were fed by means of a medicine dropper. But usually, before the time that it would normally be born, it will have learned to carry out the response successfully. In the child born at the proper date, the response will be much more completely maturated; but even then, for the first few times that it is fed, there is likely to be a certain amount of trial and error before the response is carried out properly. And although maturation seems to be the chief factor at work in the development of this pattern of behavior, it reaches perfection only through learning.

The behavior of the child in picking up objects shows a beautiful series of changes as one pattern of activity develops into another in the course of maturation. At first it merely squeezes objects between the "heel" of its hand and its fingers; then it begins to place the thumb opposite the fingers, and gradually it ceases to use all its fingers, picking the object up between the thumb and two fingers. Then it ceases to put the flat of its hand against the object, but picks it up between the tip of the thumb and one or two opposed fingers.

It seems fairly certain that these changes in the patterns of manipulative behavior result from a gradual growth of nerves and muscles, with probably some degree of perfection being added through practice. Both the sucking response and the manipulative behavior of the infant are essentially species habits, which would probably develop in any child placed in almost any kind of environment. In this respect, they are unlike most of the habits which human beings acquire. For unlike animals, we do not grow up in a natural environment, but in one that is produced in large degree by the traditional ways of acting that characterize the culture of our group. Without that cultural tradition, our behavior would undergo an entirely different train of development from that which actually takes place. Most of the habits which we acquire are not species habits, but *culture habits*; and they vary from one culture to another, although some of them, such as speaking some sort of language, using fire, and possibly the habit of walking on the hind legs (it is not certain whether the latter should be classified as a species habit or a culture habit) are characteristic of all human cultures, are not found among the animals, and would in all probability fail to develop in human children brought up entirely out of contact with human culture.

The Development of Language.—The most fundamental of all culture habits is language. Language and culture must have grown up together, since language is the chief means by which culture is transmitted from one generation to another. The fact that human beings develop language and other mammals do not, seems to be due to the fact that human babies maturate a form of behavior which can only be described as "playing at making noises." They babble and crow from morning till night, and, to add to the sport, will produce more or less adequate imitations of the sounds they hear. Certain birds show this form of behavior, and doubtless it is their tendency to play with sounds and imitate them that enables such birds as parrots and crows to learn to croak a few creditable imitations of human words. Birds, however, are too lacking in intelligence to grasp the significance of words, and their speech is a mimicry which, to them, is entirely meaningless.

Among the higher mammals, on the other hand, some capacity to understand words seems to be present. A few years ago, the experiment was tried of rearing a young chimpanzee in the company of a human child, treating it in every respect like a true member of the family. The experiment extended over a period of nine months, from the time the little ape was eight months and the child eleven months of age. During this time, the ape learned the meanings of many words that were spoken to it. But it never learned to utter a single word. Unlike the little boy, the ape seldom made sounds just for the fun of it. It would make a special noise when it wanted something to eat, a sort of bark when it was angry, a screech or scream when it was afraid, and a whimpering "oo-oo" sound that seemed to take the place of the fretting of a human infant. Always the sounds seemed to be the result of special external or internal stimuli. The ape never vocalized just for the sake of hearing its own voice. Furthermore, while the child learned to make noises like the ape, the compliment of imitation was never returned. Strong efforts were made to get the ape to repeat words, but there was never any success. At the same time, in most activities requiring some degree of intelligence, the chimpanzee was approximately equal to the child, the difference in their ages being taken into account.

The babbling of articulated sounds, which begins in the average child at seven or eight months of age, seems to be the maturated behavior pattern on the basis of which language behavior develops. Imitation is probably acquired as a habit. The child happens by chance to make the same sound more than once, falls into the habit of imitating itself and then gradually into the habit of imitating others. Having learned to imitate, it can begin to learn to apply words to specific objects or situations. In learning to speak words, it may be motivated in three ways. First, the use of words may enable it to signal its wants to others or to attract their attention. Second, the child discovers that words go with things, and it may find naming things an entertaining pastime, just as it enjoys handling them and throwing them around. Finally, the use of words may secure the coveted approval of the child's parents.

From the very beginning of language development, children will use words as stimuli to themselves as well as to others. The writer has seen a little girl of eleven months, who, upon approaching a dangerous situation, would say "No-no," and then draw back, whether she was conscious of the presence of others or not. The two-year-old child will babble to himself as he plays with his toys, throwing down his engine with the remark, "Naughty train!" and in other ways dramatizing all his activities to himself. Three-and four-year-olds will talk aloud to themselves after being left alone in bed at night, sometimes continuing to do so for an hour or more. They are indulging in the "overt daydreams" of childhood. Gradually the child learns only to murmur the words, and then merely to "think them to himself." And at this point, the system of implicit self-stimulation which we call thought has completely developed.

The Development of Motives.—A few years ago it was the fashion among psychologists to ascribe the motives of men to so-called "hereditary instincts." The term instinct was used to describe not a maturated pattern of behavior, such as the swimming of tadpoles or the nest building of wasps, but an "inborn" desire to reach certain goals. Every desire or impulse on the part of the human being was attributed to the activity of one of these instincts.

There have been few careful experimental studies of the development of the major human motives. However, our knowledge of the way behavior develops in mammals, and in human beings especially, gives us good reason to believe that, aside from physiological drives, such as hunger, thirst, sexual desire, and the like, together with a general tendency to be active and to explore the world, and a few not very highly differentiated emotional tendencies, our motives do not maturate, but are developed by learning through the interaction between the environment in which we live and the few motives that are supplied by maturation.

There is little doubt that the most important of all motives in the social life of human beings is the desire to appear well in the eyes of others, to secure their approval and admiration. It is improbable that such a motive is truly instinctive. Rather, the infant is placed in a situation where, to satisfy his physical needs, to avoid punishments, to secure the emotional satisfactions that are derived from petting and other displays of affection, he must cause others to react favorably toward him. Day in and day out, situations wherein he is dependent upon the good will of others recur, until he comes to feel a reassurance whenever others approve of him and a sense of anxiety when they disapprove; and pleasing others comes to be an end in itself, rather than a means of securing other satisfactions.

A more easily observable motivational development is the growth of possessiveness in young children. One of the outstanding characteristics of young children is their tendency to play with a great variety of objects present in their environment. An eighteen-months-old child placed in a roomful of toys will pick up one toy after another, look at it, handle it, put it down, and go on to a new object of interest. If two such children are placed in the room together, an interesting development takes place. Without paying much attention to each other, they begin their process of exploration. Any toy picked up by one child, however, is thereby likely to be called to the attention of the other, who reaches for it, only to be thwarted in his attempt by the first child who is intent himself on exploring this object. Conflict ensues, and, for a while, that one toy becomes the chief center of interest. Let this go on for a few days, and a complete change in the behavior of the children can be noticed. They are no longer interested in playing with the toys, but only in monopolizing them, and they spend all their time trying to take toys away from each other. Possession, which was at first only a means to the end of enjoying the toy as a plaything, comes, in the course of learning, to be an end in itself.

Conditioned Emotions.—Without doubt, many human motives develop through this process of the transformation of a means of arriving at a goal into a goal in its own right. Another form of motivational learning, and one which has been demonstrated by carefully controlled experiments, is the *conditioning* of emotions. The classification of emotions, on the basis of either outside observation or personal introspection, is really an extremely difficult task. In an approximate fashion, however, it may be said that the emotions of fear, anger, and love are the ones that maturate in human beings. But the objects toward which we display these emotions depend to a great extent upon learning.

The emotion of fear, for example, is aroused, prior to learning, by unexpected, violent stimuli, such as a sudden loss of support, a loud noise, and the like. Believers in the existence of elaborate human instincts have claimed that children are instinctively afraid of furry animals. This has been attributed to the fact that animals constituted a real and ever-present danger to our primitive ancestors; hence we have inherited a fear of them. Actually, a child brought for the first time into the presence of an animal, whether furry or not, usually displays interest and even delight, rather than fear. It has been shown experimentally, however, that if a child is given a white rat to play with and at the same moment a sudden loud noise is made, causing the child to be startled and frightened, it soon learns to fear the animal. Here we probably have an explanation of the fact that a large number of children actually do show fear of animals. A child goes up to an animal and starts playing with it. The animal makes a sudden move, jumps against the child, barks, squeals, or frightens it in some other manner, and the child learns to be afraid of animals.

This type of learning is somewhat different from the type described in the foregoing chapter. In the first type there is a strengthening of responses that lead to goals and a weakening of responses that fail to lead to goals. In this second type—called *conditioning*—a stimulus, known as the *unconditioned* stimulus (the loud sound, for example), is capable of arousing a certain response (the fear response). The unconditioned stimulus is presented along with a second stimulus (the animal) in such a way as to secure the response. After one or more such presentations, the response is made to the second stimulus as well as to the unconditioned stimulus. The second stimulus is then referred to as the "conditioned stimulus," and the response as a "conditioned response."

Probably many of the emotional reactions and prejudices of human beings are attributable to emotional conditioning of this sort. A man of thirty-five was puzzled to understand why the name "Stella" aroused in him a feeling of aversion or disgust. Finally he managed to remember that when he was only four or five years of age, his family had engaged a servant girl of none too pleasing appearance who was discovered to be afflicted with lice. Her name was Stella.

Conditioning occurs in both animals and men. Simple reflexes, especially, seem to be particularly susceptible to it. If a bell is rung, for example, just before a dog is fed, he will soon begin to salivate at the sound of a bell. The food is the unconditioned stimulus for the secretion of saliva, the bell becomes the conditioned stimulus. Perhaps the reason emotions are conditioned so readily is that they are essentially reflex responses.

Because conditioning occurs in simple reflexes, many psychologists have come to believe that it is the basic unit of learning, that the most complex forms of learning are merely combinations of many conditioned reflexes. The assumption underlying this theory is that our more complex responses are actually combinations of many simple reflexes. This assumption is itself dubious, and the theory that the conditioned reflex is the unit of learning has never been established.

As a matter of fact, conditioning takes place under some circumstances and fails to take place under others, and we do not yet understand why. For instance, if a child is given blocks to play with, and a loud, frightening noise is made at the same time, the youngster develops no conditioned fear of the blocks. Indeed, it is perfectly obvious that conditioning cannot take place every time two stimuli are presented together, and hence the problem of the fundamental cause of learning remains as much a problem as ever.

The Cultural Determination of Motives.—Because of the possibility of modifying motives through learning, our motives are determined to a great extent by the culture in which we live. Let us consider, for example, the possessive or acquisitive motive as it develops in our culture. To go back to the two children who learn to monopolize rather than to play with their toys, it is unlikely that their monopolistic struggle would proceed very far before the cultural tradition would begin to interfere with it in the form of elders who would make such remarks as, "No, Freddy, you mustn't take the ball from Johnny, that's Johnny's ball," or older children who would shout, "You can't *either* of you have that, that's *mine*." Soon "mine" would come to be a magical word to both children. It would be a sign whereby they might expect to establish monopoly over an object by means of a simple vocalization, rather than a bitter struggle. Many children learn to say "mine" before they learn to say "mamma" and "dada," or any other word. In acquiring this verbal sign, they are developing a concept that has been handed down by generations of cultural habit, the concept of the right to personal monopoly of objects so that others can make use of them only upon the sufferance of the owner. Gradually the child learns that he is allowed to apply this magic sign only to certain objects; that he is expected to take good care of these objects, not to lose them or let them be destroyed; and that the more of such objects that he possesses, the greater is the respect and admiration that he may expect from others. He learns also that the key to the monopoly of all sorts of objects, together with the power to control the actions of others and to win their respect, is the right to say "mine" with reference to certain metal disks and pieces of paper—in short, that the possession of money is the open sesame to the satisfaction of nearly all his desires. No wonder that, under these circumstances, the acquisition of personal possessions and their display before the envying eyes of others become the chief preoccupation of a very large proportion of the individuals in our society, and that in a few, known as misers, the possession of money becomes such a monomania that they fail to seek any other satisfaction in life.

It is cultural tradition, not inborn nature, that provides people with the strong possessive motives that we observe in ourselves or in our friends. In other societies, the desire for ownership does not develop nearly as strongly as in ours. Property is in the hands of a family or tribe, and there are few things that the individual feels to be his own. Suppose that, as young Johnny and Freddy began to develop their habit of attempting to monopolize toys, no one had said to them "mine" or "yours." Or suppose these magic words had applied only to the *momentary* possession of a toy. It is yours as long as you are using it, then you have no more right to control what happens to it. The two boys would gradually learn not to quarrel over the possession of their toys, just as we learn to respect the property rights of others. But the whole idea of permanent ownership would be absent, and hence they would never develop the desire to own things that characterizes ourselves and our friends. Possessiveness, as it develops in our society, is neither an instinct nor a species habit; it is a culture habit or a *social attitude*. A social attitude may be defined as an habitual way of thinking and feeling about things, together with the motives that such thoughts and feelings imply, that is developed in human beings as a result of the traditional attitudes they find in their social environment. In brief, it is a socially determined motive.

Language constitutes an important tool in the development of social attitudes. The words "mine," "yours," "his" provide us with concrete symbols that define a certain way of feeling and thinking about objects; and by learning their meaning through experience with the way other people react toward them, we are provided with a set of motives, namely, to seek to add to our own property, to protect the things we do possess, and to respect the property rights of others. Our attitudes toward property constitute only a part, though it is an important part, of the great mass of socially conditioned attitudes that make life what it is. Our moral laws, our political institutions, our religious and our family life—in short, the entire pattern of human behavior—is determined by the attitudes that we develop in the course of contact with human society.

The behavior of a wild animal is pretty much a function of its genetic constitution. Given a certain assortment of genes, it is practically predestined to develop a certain set of behavior patterns, whether through maturation or learning. The behavior of a human being, on the other hand, is determined chiefly by the culture in which he is reared. Given exactly the same sort of hereditary materials to begin with, a human being reared among the Australian bushmen would develop an entirely different set of behavior patterns, and an entirely different set of attitudes, than one reared in a large city. And if there was ever a human society developed where the people crawled on all fours, spent most of the time in the water diving for fish, and lived in burrows along the banks of streams, the young human beings born into it would doubtless take to that life quite readily; standing on the hind legs would be viewed as an inexcusable breach of taste, and human nature would come to resemble the nature of the otter more closely than it resembles the nature of present-day human beings.

The Modifiability of Human Nature.—Of course, no nation or tribe of "otter men" has ever existed to anyone's knowledge, nor is such a society likely to develop. Men can find much more interesting and comfortable modes of life than that of the otter. But the contemplation of the possibility of such a society is worth while, since it emphasizes the tremendous extent to which culture can modify human behavior. A large number of people, when faced with a proposal for any social change more far-reaching than an increase in the tariff on cucumbers, will immediately assert that such a modification is impossible because "you can't change human nature." The belief that the motives and ways of behaving which characterize the group in which one lives are universal and eternal characteristics of human nature is a fallacy which seems to be very easy to develop.

The following are excerpts from a speech made by an Indian medicine man at a time when a missionary was attempting to persuade his people to abandon the custom of cannibalism:

> In all ages, as far back as the memory of the oldest man can reach, enemies killed in battle have been eaten and prisoners fattened into proper condition for killing. When a custom is so ancient, it is not dependent upon the will of men. It is not an accident of their history, but a law of their nature, instituted by the gods themselves. Hearts too tender may deplore it, but against natural fatalities it is vain and puerile to wish to fight. . . .
>
> Repudiate, then, Oyampis, these new ideas. Anticannibalism is a doctrine essentially chimerical. Men have always eaten one another; they will continue to do so in the future as they have in the past. . . .

Similarly, many people are convinced that, since war has always been the method of settling disputes among tribes and nations, it is contrary to human nature to settle them in any other fashion. But psychologists who have devoted their lives to the study of human nature are of a different opinion. A few years ago the following question was sent to all the members of the American Psychological Association: "Do you as a psychologist hold that there are present in human nature ineradicable instinctive factors that make war between nations inevitable?" Out of nearly four hundred answers there were only ten which assented to the proposition.

This does not mean that there are no instinctive factors at work in the production of human nature; it merely means that human culture builds upon those instinctive factors, so that the pattern of human behavior becomes something that is almost entirely a product of that culture. For good or ill, we become whatever our society makes of us; and when the cultural pattern of our society changes, as it surely will, the "human nature" of our descendants will change to fit it.

Maturation of Capacity to Learn.—Heretofore we have spoken of maturation as if it applied only to the development of specific instinctive patterns of behavior which might be improved upon by learning or used as a basis for other learning. But along with the development of the nervous system there goes a gradual maturation of capacity for learning without any apparent maturation of new behavior patterns. In learning things requiring both memorization and logical understanding, the capacity to learn increases rapidly up to about sixteen, when the rate of increase falls off gradually until about the age of thirty, at which time the capacity has reached its peak. There is then a gradual falling off up to the age of forty-five, when learning capacity is about equal to that of the sixteen-year-old. This is, of course, contrary to the old saw that "you can't teach an old dog new tricks" and the idea that children learn more rapidly than adults, although there is reason to believe that the curve of learning ability falls off rather rapidly from fifty onward. The causes for the changes in the curve after the years of adulthood are reached are not certain; but there can be little doubt that the rapid rise up to the age of sixteen is due to development of the neurons in the brain, and, hence, that it represents a true maturation.

Because of this factor of maturation, it is frequently useless to attempt to "push" children too rapidly in the acquisition of knowledge and skills. For instance, at a time when a certain pair of identical twins was about twenty months old, twin C was separated from the other and given an intensive vocabulary drill. Twin T was isolated from all contact with other children, and no words were spoken in her presence. Then at the end of five weeks twin T was given training exactly like that of twin C, but at this more advanced stage of maturation she learned much more rapidly. The same principle holds for the learning of motor skills. When the twins were forty-six months old, twin T was given an intensive six weeks' course in stair-climbing. At the end of that time the training of twin C was begun. Within two weeks C had learned more than T did in the entire previous six weeks.

There can be little doubt that much time and effort are wasted in our educational system in the attempt to teach children things which are too difficult for them, but which they could learn readily enough at a later stage in their development. Most children are very poor at writing during the first few grades of school. Recognizing that this is probably due not to lack of practice, but rather to incomplete maturation of the capacity to learn, many schools do not encourage children to write in script during the early years of schooling, but allow them to print their letters until they have developed to the stage where script writing is fairly easy for them to master.

The Learning of Skills.—Among the important things we gain from our social heritage is a considerable equipment of skills. The basic skill, of course, is the ability to speak and understand language. There are also *motor skills*, such as writing, handling tools, playing various games, typing, telegraphy, and the playing of musical instruments, together with such non-motor skills as reading, receiving telegraphic messages, and the like.

In addition to the maturation of the capacity for learning, an important factor in the mastery of skills is the presence of a strong motive to learn. It is utterly untrue that "practice makes perfect," unless practice is accompanied by a motive of some sort. For example, in order to graduate from a business school, a stenographer may be required to learn to typewrite sixty words per minute. In the course of six months' training, she may arrive at this level of skill. Now if she goes to work in an ordinary business office, she may continue to practice typing for several years without any increase in speed. In spite of continual practice, she learns nothing. But suppose at the end of all these years she becomes ambitious to secure a job which requires her to type at the rate of ninety words a minute. As she does her work she will continually try to increase her speed, and in a relatively short period she will have reached the goal of ninety words per minute, although the amount of time spent per day in typing may not have changed.

The type of motivation that is active here is different from that which produces learning in animals. The goal in animal learning is usually food or the satisfaction of some other physiological motive. In much of human learning, the immediate goal is simply *to learn*, although there is usually some motive back of this, whether it is to get a better job or simply to prove to oneself how capable one is at learning. Here again, the possession of language produces a difference between human and animal behavior. It is doubtful that animals ever realize that they are learning, since they have no word for it. And without a word for it, the concept of learning must be nebulous indeed. The obvious convenience of getting an organism to learn by simply telling it to do so, rather than being put to the necessity of arranging some external motive to persuade it to learn, doubtless helps to account for the fact that men are able to learn so much more during their lives than are animals.

When the goal of learning is simply to learn, information concerning progress helps considerably to speed the rate of learning; and if an individual who is engaged in acquiring an act of skill keeps close account of his progress, always striving to improve, his learning will proceed most efficiently.

Few human beings ever arrive at the level of skill of which they are capable, simply because they fail to note whether they are improving or not, have a comfortable feeling that "practice will make perfect," and do not struggle to improve, once they have attained a level of achievement that enables them to "get by." Most students could considerably increase their efficiency in reading and thus save themselves much wasted time, if they would maintain a continual effort to improve in this direction. When reading fairly easy material, read as rapidly as possible, keeping track of how many pages per hour you are able to read. Your progress may not be amazingly rapid, but if you keep a record of it, you will probably have the satisfaction of seeing your reading efficiency gradually increase to the point where you will be making a material saving in the time required for you to study a lesson assignment.

Acquiring skills of this sort is always a gradual procedure. Improvement takes place rather slowly, and there are many fluctuations, so that on one day an individual may be less skilled than he was the day before; hence progress can be noted only in terms of weeks or even months. Fig. 127 shows curves of progress in learning to send and receive telegraphic messages. These curves show that, even though records were kept in terms of weeks, there were some weeks in which achievement was lower than in the week preceding. If the record were kept in terms of days, the fluctuation would be even greater. This figure also shows that on the curve for receiving very little gain was made between the twelfth and the twenty-fourth week. Such a portion of a learning curve is known as a *plateau*. Plateaus have an uncomfortable way of appearing in learning curves. Weeks may pass while the individual makes little progress and usually feels very bored and discouraged. Then suddenly he begins to forge ahead again at a rapid rate. As the individual approaches his *physiological limit,* that is, the utmost of his capacity, in a certain skill, the rate of improvement gradually decreases, until finally he can improve no further. The sending curve in Fig. 127 apparently approaches the physiological limit of the subject. Actually he stopped

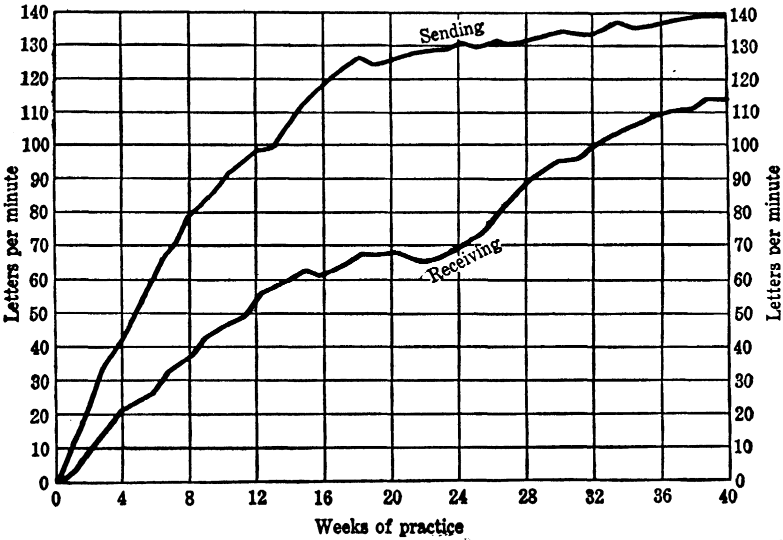


FIG. 127.—Learning curve for telegraph operating. (Redrawn from Ruch's *Psychology and Life,* Scott, Foresman and Company.)

his practice on a long plateau. An operator on a "fast wire" must send much more rapidly than this.

The Principles of Efficient Study.—A most important part of our cultural tradition is the body of knowledge which has been built up through man's age-long search for understanding of himself and of the world about him. Since the readers of this book are at present chiefly engaged in the task of acquiring some small part of this vast store of learning, we shall devote the remainder of this chapter to a practical consideration of how to study efficiently.

Study is the name we give to intentional learning on a conceptual level. Efficiency in study is dependent, first, upon applying the principles that hold good for all sorts of mental work, and, second, upon applying principles that are especially concerned with conceptual learning. Among the more important principles belonging to the first group are the following:

1. *Work according to a plan.* This principle involves more than simply having a schedule of hours for work and play. When you sit down to work, you should know as completely as possible just how long you are going to work and what you plan to accomplish in that time. Then you should do everything in your power to accomplish that amount during the time you have allotted for it. You should have a schedule of what is to be done each week, and allot ample time for doing it. Life is so constituted that the best of plans must be continually modified, but that does not alter the fact that people who work according to plan and struggle against having to alter their plans get the most done.

2. *Don't plan to work too many hours in a day or a week.* Most people when they plan their work get into a very heroic mood. Usually they have fallen behind in what they were doing and wish to catch up. A college student will plan to study ten or twelve hours a day, but the one who can actually stick to such a schedule is one in ten thousand. Even if he does, he would probably get more done if he worked only seven hours a day and really worked during those hours. It has been shown that, when the hours in a factory are reduced from twelve per day to eight or nine, more is actually produced in a week on the latter schedule than on the former. On the whole, concentrated effort over a short period of time is more efficient than work that is dragged out over so long a time that one has no leisure to enjoy life. Individuals differ greatly in the amount of time during which they can work effectively; but a college student who will schedule forty hours a week, including time spent in classes, and then actually works during those forty hours, is headed for Phi Beta Kappa if he has even a moderate amount of intelligence.

3. *Schedule study periods that are neither too long nor too short.* Studying is a task for which we "warm up" slowly. Most people probably do not reach their peak of efficiency for half an hour or so. Little is really known about it, but the writer's own experience suggests that fatigue from study begins to appear after

about three hours of concentrated effort. This applies only to those who really "warm up" to their work. If you continually feel that you would like to quit while you are studying, you are not warming up at all. Many students never warm up and never get to studying efficiently. A definite plan to get a certain amount of work done during a given period of time is of great assistance in warming up.

4. *Don't plan to study at times when you are fatigued.* The converse is to get enough rest so that you won't be fatigued when you study. In a group of college students, it was found that those who said they did not study when they were tired made better grades than those Spartans who studied in spite of fatigue.

5. *Study at times and places where you will be free from distraction.* This is of special importance in enabling you to warm up and stay warmed up. It also eliminates fatigue in study. Frequently a student finds it impossible to be free of distractions while studying in his own room, and it is necessary to find some other place. It is possible, however, to allow oneself to be too easily disturbed by distractions. One should form the habit of being able to concentrate when there is a certain amount of noise about, rather than using it as an excuse for failure to concentrate. The added effort required to shut out distracting noises, while it is doubtless somewhat fatiguing, may actually help you to maintain a vigorous, active attitude toward your work.

6. *Maintain an active, attentive attitude toward your work.* It is believed by many that the fatigue which accompanies mental work is almost entirely the product of the slight muscular tension which seems to be necessary if one is to maintain attention. Attention is essentially a *set* of the type described in Chapter XXII. It is an implicit posture, but, like other implicit postures, it is likely to become at least partly overt, and it may in all cases involve some muscular activity. Specifically, close attention seems to involve a rather general contraction of the muscles throughout the body. It has been shown experimentally that subjects given something to grip and hold tightly in their hands learn more rapidly than those whose hands are relaxed. Muscular tension seems to be essential to really active mental effort. You will study best if you sit up straight at your desk, with your whole body expressive of alertness and determination.

So much for the necessary conditions for studious work. Now for the principles of learning that should be applied.

1. *Distribute your learning over a considerable period of time.* Everyone knows that a thing that has been recently learned is remembered better than a thing that has been learned some time previous—in short, that we tend to forget things as time goes on. On the basis of this fact, many students jump to the conclusion that the most efficient method of studying for an examination is to do it all just before the examination is given. This assumption is absolutely false. There is no psychological principle better established than the fact that *distributed learning* is more effective than *massed learning.* This means, for example, that if you were given a poem to memorize, told to spend just five hours in learning it and to have it ready for recitation in three weeks, the most efficient method of going about it would *not* be to put in the entire five hours just before you were to be called on to recite, but to spend half an hour on it every two or three days, with perhaps a half hour of practice just before you started to recite. The amount of time required to learn a thing by distributed learning is frequently not more than half that required to learn it by massed learning. In the first extensive experimental study of memory that was ever made, it was found that a series of nonsense syllables could be learned as well in the course of 38 repetitions distributed over three days as in the course of 68 repetitions at a single sitting. One of the best methods for a college student to get good grades without working very much is to schedule a half-hour review period every other day for each one of his courses. Such a system will make a long period of cramming before examinations unnecessary, and yet will insure a better command of the subject matter of the course.

2. *Practice what you are expected to learn, and always study with the definite aim of learning that thing.* Many students seem to feel that if they read over an assignment, their brains will somehow absorb the knowledge that is contained therein. This is an utterly mistaken conception of the learning process. You are not being asked to learn to read, you are being asked to learn to tell about the subject matter with which an assignment deals. Therefore, you must practice telling about it. Most studying should be in the form of taking an imaginary examination, re-

citing to yourself what you have read about, then going back to the book or to your notes to see if you have succeeded in covering all the points which have been dealt with.

You should always have a definite picture in mind of what you are trying to learn. Things are seldom learned *incidentally*, but usually under the spur of a motivating factor; and the most reliable motivating factor for study is a definite *intention to learn.*

An illustration of the intention to learn is provided by the following experiment. The subject is instructed to read several times through a list of words, such as that given below, learning to respond to each word in the first column by saying the word opposite it in the second column.

Chicago	Philadelphia
London	Liverpool
Berlin	Munich
Paris	Bordeaux
Madrid	Barcelona
Rome	Naples
Calcutta	Delhi
Sydney	Melbourne

It will not take long for this learning task to be completed. But suppose, after testing the individual on his ability to say "Philadelphia" in response to "Chicago," we try to see if he can respond to "Philadelphia" with the word "London." Hardly any learning of this sort will have taken place, although the subject will have read "London" after "Philadelphia" just as often as he read "Philadelphia" after "Chicago."

3. *Learn in terms of general concepts; seek for the meaning of what you are learning.* Without doubt, this is the most important principle of all, since the real purpose of a college education is to acquire general concepts, not to memorize a battery of unintelligible facts. A single concept can be of tremendous help in remembering a great range of facts that are related to that concept. Thoughtless critics often conclude that, since an individual five years out of college will have forgotten most of the individual facts that he learned there, his education can have been of but little use to him. What they fail to notice is that in the course of a college education a man develops a series of con-

cepts about the world in which he lives which never leave him entirely. Five years from now, you will have forgotten most of the facts you have learned in the reading of this book; but, unless you are completely uneducable, you will remember the concept of the cell, of protoplasm, of the gene, of evolution, of stimulus and response, of implicit response as being equivalent to mental activity; and these concepts will be ready to function for you whenever you need to deal with the facts to which they apply. The reason for including many facts in a college course is that worth-while concepts are always related to facts. If you try to learn a concept without at the same time learning the facts which illustrate it, your concept will be so indefinite and inaccurate that it will be of no use to you.

A good illustration of the manner in which concepts can act to relate individual facts is found in the list of cities just above. The moment the individual realizes that all the words in the list are the names of cities, he possesses a concept which narrows down the range of possible responses, and thus facilitates thinking of the right response. If then he notices that both the cities in each pair are located in the same country, the problem of memorization will be greatly simplified, since he will know that neither Munich nor Philadelphia can follow London, and he will have only to remember that Liverpool was the other English city included in the list. Finally, if he were learning to recite the entire list, he might be helped by noticing that the countries are listed in the order of a possible trip around the world; and by developing a visual image of the itinerary in terms of a world map, he would be assisted in finding his way from country to country in the proper order.

An important example of the superior efficiency of learning that is subject to conceptual guidance is the fact that meaningful words—words about which one can have conceptions—are much more readily memorized than words that have no meaning. The following sentence has twenty-six syllables, but you will probably memorize it easily in a single reading:

"The quarterback tore around left end and made a beautiful run down the field for a gain of fifteen yards."

But see how many times you have to read this twenty-six syllable list in order to remember it:

"Lemon horse lawn brick till city hat forty water put gone blue never apple cry golf prime classic mint child."

And now count the number of times you have to go over these twenty-six syllables:

"Gos nof taf bek lal tef zaf dir nug kiz nar miz fod ref pog gif puz rak paf zik pel gep ror dop jur ket."

Memorize completely all three of these groups of twenty-six syllables; then, after two days during which you completely avoid thinking about them, try to repeat them again. The chances are that you will remember most about the first, although you will have spent a much shorter time in committing it to memory.

The use of this principle in carrying on efficient study is obvious. The big thing is to understand thoroughly the material that you are reading and to organize it, in so far as possible, into a logical, meaningful idea or set of ideas. There are many ways in which this can be done. One of them is to try to summarize each chapter you read in a single sentence, then to make sub-summaries, and so on down until you have covered the chief details of the chapter. Another way is to make a set of diagrams which express in terms of lines and drawings the outstanding ideas in the chapter, while a third method is the good old formal outline. Many very successful students do not bother with writing out their organization of a chapter, but you will nearly always find that they carry a good outline in their heads. An excellent habit for making sure that you are getting the meaning of a book is to attempt to think of illustrations of all the principles laid down, and, if the author gives illustrations, to think up others of your own. Another excellent idea is to talk your lesson assignments over with fellow students to compare your understanding with theirs. This practice also helps to motivate study and make it more interesting and somehow more "real."

A special application of the principle of learning things in a meaningful way is the advantage in learning a foreign language vocabulary in terms of sentences or phrases, rather than by memorizing the definition of isolated words. Everyone of course recognizes the value of a special vocabulary list which can be systematically reviewed. The best way to form such a list is to place each word to be remembered in a short sentence or phrase, with an English translation just below. Then in going over the list, repeat each sentence or phrase a few times. Thus you learn how the word fits into the language in a meaningful way, and you are much more likely to grasp its meaning when you see it in another sentence than you would be if you had simply memorized an English equivalent. An additional advantage in this method is that it hastens the process of learning to think in the new language, rather than having to translate into English in order to get the meaning.

Chapter Summary

Human behavior develops through learning on the basis of maturation, but since culture exerts a great influence on what we learn, most of our habits are culture habits rather than species habits. Speech is the most basic culture habit. It develops out of a maturated "playing with sounds." Words are learned because of the advantages their use brings to the child. Thinking is developed through the use of words to stimulate the self and through their gradually becoming implicit.

New motives are learned when a means to the attainment of a goal becomes a goal in itself. Emotions are sometimes conditioned when a stimulus originally incapable of arousing the emotion is presented along with a stimulus capable of arousing it, with the result that the emotion comes to be aroused by the former stimulus.

Motives are culturally determined through the development of social attitudes. The definition of situations through language is an important aspect of this development. So great is the influence of culture in producing motives that changes in culture may bring about very great changes in "human nature."

The capacity to learn, as well as definite behavior patterns, develops through maturation.

The goal involved in the acquisition of skills is frequently the conscious desire to learn. Unless this or some other motive for learning is present, mere practice of the skilled act may fail to result in improvement. Improvement in skills is usually gradual and fluctuating.

Efficiency in study—i.e., intentional learning of concepts—can be attained by intelligent planning of one's work, together with attention to the following rules which apply especially to the learning process:

1. Distribute learning over a considerable period of time, allowing intervals between practice sessions.

2. Practice the thing you wish to learn—not some other activity—and always study with the definite aim of learning that thing.

3. Learn in terms of general concepts; seek for the meaning of what you are learning.

QUESTIONS

1. Discuss as completely as possible the rôle of culture in determining the behavior patterns of a human being.
2. Discuss the problem of efficiency in learning.

GLOSSARY

conditioned response A response made to a conditioned stimulus.

conditioned stimulus A stimulus which comes to arouse a response through being presented along with an unconditioned stimulus for the response.

conditioning A form of learning in which a response comes to be elicited by a conditioned stimulus.

unconditioned stimulus A stimulus which arouses a response prior to conditioning.

CHAPTER XXVI

THE BEHAVIOR OF THE INDIVIDUAL

Emphasis upon the Individual.—In the last chapter, we have presented the picture of the great, impersonal force of cultural tradition seizing upon man's gradually maturating capacities for learning, to create the pattern of human behavior. In thus doing, we have overlooked the fact that, in reality, there is a special pattern of behavior for every human individual. Nor have we viewed the process of cultural acquisition from the point of view of the individual. The average man does not look upon his life as an arena for the interaction between two such abstract entities as maturated capacity and social tradition. Rather, he sees it as a struggle to make good, to attain to the standards that he has set up for himself, to please his friends and, if possible, his immediate family and his relatives. In this chapter, therefore, we shall deal with the differences between human beings, and with the problems that face the individual man in his attempts to lead a life that is interesting and satisfying.

The Mental Test.—Each human personality is such an amazingly unique affair that to study the differences between individuals would seem an almost hopeless task. Yet this is the task to which psychologists have been increasingly addressing themselves since the day in 1905 when the Frenchman, Alfred Binet, introduced the first intelligence test. To be sure, they have not as yet succeeded in seizing upon and subjecting to measurement all the myriad facets of human individuality. Nevertheless, by employing the device of the standardized mental test, they have made real progress in that direction.

The mental test is simply a systematic and carefully constructed device for sizing people up. Anyone called upon to make an estimate concerning a man's personality will attempt to put him to some sort of testing procedure. He will ask him questions and seek from his answers to make a guess as to what sort of man he has to deal with. The standardized test does this, but it does it systematically, on the basis of carefully recorded experience, and hence it arrives at a more dependable estimate of a man than can be secured in any other manner, except, perhaps, by the study of the individual's lifetime achievements.

Men have always felt a need for some method of arriving at an evaluation of the qualities of themselves and of others. So great has been this need that astrologers have come forward to satisfy it by reading men's fate in the stars, and phrenologists have attempted to estimate character by the contour of the skull. All sorts of magical means of diagnosing personality have been developed, and many cults of character-reading have attracted a wide following. Careful scientific investigation, however, has shown that a man cannot be judged by the stars under which he was born, or by the bumps on his head, or by his complexion or the shape of his nose. The only dependable device for measuring individual differences is a properly constructed mental test.

To be sure, a mental test is nowhere near as precise an instrument of measurement as a yardstick, a spring balance, or a thermometer. Practical decisions on the basis of mental measurement should always be made under the guidance of a psychologist who knows enough about the inaccuracy of the device to make the proper allowance for it. Yet, in spite of their imperfections, mental tests are being employed more and more widely because they have been found to be of definite use in practical situations.

For example, a few years ago a great electrical company called upon a psychologist to see if he could do anything to reduce accidents occurring in their switching stations. Errors in switching current loads from one line to another sometimes resulted in loss of life and frequently caused economic losses running into many thousands of dollars. The psychologist spent several months carefully constructing a test to measure proneness to accidents of the specific kind that were occurring in this company's substations. When the test was finally completed, all applicants for jobs who fell below a certain score were rejected, and low-scoring men already on the job were shifted to other types of work. As a result.

the incidence of accidents fell from about thirty per month to only three or four.

Such "tailor-made" tests as this, aimed at measuring fitness for a certain job, can be of widespread use throughout the world of business and industry. Other more general tests are of help in directing young people toward the types of occupations for which they are likely to be most fitted—although it should be emphasized that interpretation of the tests for this purpose should be in the hands of a trained and experienced vocational counselor who will always take other factors than a mere set of test scores into consideration in giving his advice. Psychological tests have come into widest use in the field of education, where they can be employed to help make decisions as to the proper educational program for the individual student, as well as being put to use for many other purposes.

There are scores of different kinds of mental tests: tests of mechanical, musical, and artistic abilities; tests of the individual's attitudes, interests, and feelings; and tests of traits of personality. But without doubt, the most widely used and successful of all have been the tests of intelligence. It is for this reason that the real beginning of the science of mental testing dates from Binet's first intelligence test, although many other tests had been introduced prior to that time. And because of the outstanding importance of the trait of intelligence, together with the fact that a fairly adequate means of measuring it has been worked out, we shall confine our discussion of individual differences to differences in intelligence.

What Intelligence Is.—In Chapter XXIV, intelligence has been described as the capacity to adjust to new situations and to learn. Among human beings this capacity shows itself most clearly in the ability to deal with symbolic situations, with words and with mathematical symbols, and the ability to perceive or conceive of spatial relationships. For instance, it takes a certain degree of intelligence to state adequately the difference between "justice" and "mercy"; here one is dealing with words. Or it takes intelligence to complete the following series of numbers, placing in the two blanks the numbers that would appropriately follow to complete the sequence:

4 16 8 64 12 144 ——— ———

Here one is dealing with mathematical symbols. A problem in spatial relationships is shown in Fig. 128.

The outstanding ability of a small proportion of the population to deal with complex symbolic situations has provided us with the achievements in literature, philosophy, and science which underlie the difference between our civilization and the primitive cultures of savage tribes. The average man could never have made these essential contributions, and it may be truly said that civilization depends upon the work of a small but highly intelligent minority of human beings.

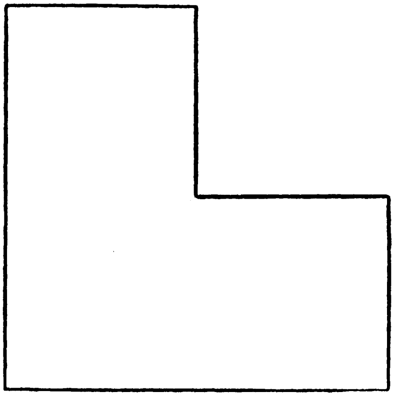


FIG. 128.—Show by drawing in lines how you would divide the given figure into four pieces of equal size and identical shape.

Furthermore, the degree of intelligence he possesses is of prime importance to the individual. The *idiot* is so lacking in intelligence that he is incapable of learning to speak a language and is condemned to live as a sort of animal parasite upon the society in which he is born. The *imbecile* must always be cared for like a child of six or eight. He can be taught to perform various simple tasks—washing dishes, pitching hay, and the like—but he can never be trusted to make decisions for himself or to find his way around in strange surroundings. The *moron* can learn an unskilled trade and may be able to take care of himself, though always in a rather inadequate fashion. But he is unable to plan for his future, and, unless he is very unadventurous, is likely to be continually getting into scrapes through his lack of intelligence and foresight. The person of average intelligence can carry on a small business, or succeed as a farmer, a clerk, a salesman, or a skilled mechanic; but those who fit into the leading rôles in our society, who enter such professions as law, medicine, or engineering, who run the large businesses or achieve the major political offices are for the most part considerably above the average in intelligence.

This doesn't mean that one can always judge a man's intelligence by his position in life, for the latter depends not only upon intelligence, but upon opportunity and upon the non-intellectual traits of the personality as well. Nevertheless, intelligence does set limits beyond which certain types of achievement are impossible.

How Intelligence Is Measured.—If you were asked to estimate the intelligence of a person you had never met before, you would probably begin by giving him problems to solve not unlike those described a few paragraphs above. If you knew the person, you would probably try to judge his intelligence by the range of information you knew him to possess, by the ability he had shown in understanding topics of conversation, or by the way he had solved various problems that you had presented to him. It is precisely in this common-sense fashion that the psychologist has gone about the business of measuring intelligence. The difference between an intelligence test and a shrewd person's estimate of intelligence is simply that the test eliminates certain tendencies toward error and standardizes the whole procedure. In estimating intelligence, we are likely to be led astray by the social effectiveness of an individual, by his ability to make a good impression. A cheerful, active, talkative person or one who is able to look very profound while agreeing with the opinions of his listeners usually receives credit for more intelligence than he possesses. Even with this error out of the way, it is impossible, without investigation, to know whether the performance of a given task is a sign of intelligence or not. Suppose a person is able to solve the problem in Fig. 128 within five minutes. Just how intelligent does that make him, relative to the rest of the population? Actually, you have no way of knowing. Psychologists have worked out exact ways of measuring intelligence simply by trying out a great many individual tests—known as *items* in an intelligence test—to discover just what percentage of individuals at a given age might be expected to pass them. They then pick the items that seem to work best and put them together in a standardized test. Each item is always presented to each person tested in exactly the same way, and all answers are scored according to the same plan.

Intelligence cannot be measured in such units as inches and pounds, starting from a definite zero point. In mental measurements it is only possible to compare one individual with another.

One way is to measure the intelligence of children in terms of the average intellectual capacity found at various ages. A child of six who can succeed on items that are just within the range of the average child of nine is obviously very intelligent. Only a fraction of one per cent of all children can do this. Another child of six who fails on all the items that are ordinarily passed by four-year-olds is obviously lacking in intelligence; in fact, he is definitely feeble-minded, and even when he is grown he will not be any brighter than the average child of seven or eight. He will always have to be taken care of in either a public institution or a private home.

Intelligence is a product of maturation and learning. It grows as the individual increases in age, and we express the degree of growth in terms of mental age. A child who can just pass the items that the average seven-year-old passes is said to have a mental age of seven, whether his age in years (chronological age) is fourteen or four. The *rate of growth*—which is a measure of how bright he is compared to other individuals—is called the *intelligence quotient*, or I.Q., and is measured by dividing the mental age by the chronological age and multiplying by 100. (Formula: I.Q. = M.A./C.A. × 100.) A six-year-old with a mental age of six has an I.Q. of 100; one with a mental age of seven years six months has an I.Q. of 125. One with a mental age of five has an I.Q. of 83. Unless some special factor enters in to change his rate of mental growth, an individual's I.Q. remains practically the same throughout the entire period of mental growth.

An I.Q. of 100 indicates average intelligence. According to the most recent findings, the distribution of I.Q.'s in the population as a whole is as follows:

Below I.Q. 68	2	per cent of the population
I.Q. 68 to 83	14	" " " " "
I.Q. 84 to 116	68	" " " " "
I.Q. 117 to 132	14	" " " " "
Above I.Q. 132	2	" " " " "

It will be seen that most individuals have I.Q.'s falling close to the average, and that very high and very low I.Q.'s are exceptional.

Most of the real leaders of society come from the upper 2 per cent, and most of the inmates of institutions for the feebleminded from the lower 2 per cent. Roughly speaking, idiots range below I.Q. 25; imbeciles, between 25 and 50; and morons, between 50 and 70. The highest I.Q.'s on record range between 180 and 210. At this level we find the true intellectual genius. A few cases are on record of children whose I.Q.'s measured 180 or above and who have now grown to adulthood. In every instance these individuals have been credited with outstanding creative or scholarly accomplishments during their late teens or early twenties.

Incidentally, there seems to be no reason for accepting the ancient superstition that "precocious" children are likely to come to no good end. Of course, if one means by precocity that the child's parents are forever urging it to display its intellectual gifts to the astonished gaze of the public or that the child is kept so busy acquiring inappropriate bits of knowledge and skill that it has no time for play and normal social intercourse with other children, then, to be sure, precocity may result in tragedy in later life, not because the child "burns himself out"—as if intelligence were a sort of fuel which could never be replaced when once it had been put to use—but because he fails to make a normal emotional adjustment to other people. If by precocity is meant nothing more than that a child is very bright for his age, then the outlook for his future not only is as good as that for the average child, it is better. Indeed, it has never been shown that intellectually brilliant children are, on the average, inferior to the run of the population in any respect. In the most extensive study of the question that has yet been made, a group of about 600 children whose I.Q.'s ranged between 135 and 175 were compared with a group of ordinary intelligence. The former group averaged somewhat taller, heavier, and stronger than the latter, and they showed themselves to be superior in tests of moral judgment and emotional stability.

Is Intelligence Inherited?—For thousands of years, argument has raged around the question as to whether a man's ability is fixed forever by his hereditary constitution or whether educational and other environmental factors are responsible for the differences between individuals. Believers in democracy have insisted that the deplorable intellectual incompetence displayed by the greater part of the human race is the result of lack of opportunity for mental development, and that, in so far as their innate capacity is concerned, the common people are the equal of their masters. Aristocrats, on the other hand, have retorted that the special privileges enjoyed by the upper classes are no more than right, since they are the people who are born with the ability to put these privileges to good use. It is clear that personal prejudice has entered into the points of view that have been expressed on this problem. But with the development of intelligence tests it has been possible to approach it in a more objective fashion, and more has been learned during the past fifteen years of scientific investigation than throughout the long centuries of philosophical debate.

In the first place, it is definitely certain that intelligence runs in families. While the offspring of any pair of parents may vary considerably in intelligence—as would be expected on the basis of our knowledge of Mendelian inheritance—and while intelligent parents may occasionally produce very stupid children and unintelligent parents very bright children, nevertheless, the children of intelligent parents are on the average more intelligent than those of unintelligent people. But this does *not* prove that intelligence is inherited in a biological fashion. The children of intelligent parents are brought up in homes where they receive more intellectual stimulation. Frequently they are accorded better educational facilities. And if we know no more than the mere fact that intelligence runs in families, we cannot be certain that the superior cultural environment provided by intelligent parents is not solely responsible for the intellectual superiority of their offspring.

In determining an individual's intelligence, there are three possible factors at work: (1) The *genetic factor*, the genes that the individual receives from his parents. (2) The *physiological factor*, the conditions of nutrition, hormone supply from the mother during embryonic development, and all other factors that affect the growth and physiological functioning of the nervous system. (3) The *cultural factor*, the degree of intellectual stimulus and opportunity for learning presented to the individual by his social environment. If we are to know anything about the inheritance of intelligence, we must isolate these factors.

One excellent way of securing this isolation is to compare the intelligence of identical and fraternal twins. Of course, twins, whether identical or fraternal, are reared in a very similar environment. Both the cultural and physiological factors will affect each twin to about the same degree. On the basis of these factors alone; we should expect both types of twins to resemble each other very closely. But with respect to the genetic factor, identical twins are exactly alike, while fraternal twins are different from each other genetically because, as was pointed out in Chapter XIII, no one zygote is at all likely to receive the same combination of genes that is found in any other zygote. If, therefore, pairs of identical twins are more nearly alike in intelligence than pairs of fraternal twins, we could explain this greater likeness only on the supposition that the genetic factor has produced it; hence we would know that the genetic factor does affect intelligence.

The fact is that identical twins are more nearly alike in intelligence than fraternal twins. They are so much alike that the differences in their I.Q.'s are almost entirely attributable to the inaccuracy of the tests. Even when identical twins are separated in infancy and reared in entirely different homes, they remain, on the average, as much like each other as fraternal twins. But they do not remain as much like each other as identical twins reared in the same family. The cultural factor, and possibly the physiological factor, have definitely affected their intellectual ability; and the more unlike their home environments are, the more unlike the twins become.

Other lines of investigation entirely support these results. All three factors—the genetic, the cultural, and the physiological—affect intelligence, although we do not know as much about the physiological factor as we do about the other two. Conditions of nutrition and hormone stimulation during the embryonic stage, accidents at the time of birth, and severe illnesses in early life can affect the individual adversely. On the other hand, the common opinion that defective tonsils and adenoids, or even the presence of hookworm may retard intellectual development in children has been found to be false. The intellectual standing of most people seems to be chiefly a product of the interaction of the genetic and the cultural factors.

Education appears to be the chief cultural factor affecting the I.Q. In England there is a group of people who spend their entire lives on canal boats, scarcely mixing at all with the populations on shore. Their children never attend school, with the result that between the ages of six and twelve the I.Q.'s of these children fall from 90 to 60.

It has been shown also that beginning one's education at an early age has a stimulating effect on mental growth. Children placed in pre-school at the age of two or three years sometimes undergo a considerable increase in I.Q. during the time they are in school. For some time it was doubted that these improved I.Q.'s would be maintained throughout life. It was thought that in later school years their I.Q.'s would fall to the level of those of other children with equally maturated capacities for learning. But the most recent information indicates that the stimulation received in pre-school leaves a permanent effect on intellectual ability.

The next most important cultural factor is the home environment. Children adopted into good homes show a definite increase in I.Q. and are brighter than might be expected on the basis of the intelligence of their true parents. It has also been shown that life in the city has a stimulating effect upon intelligence. Children whose parents take them from a rural to an urban environment experience an average increase in I.Q. of about five points.

Scientific investigation of the factors affecting intelligence fails to uphold the extreme views of either the environmentalists or the hereditarians. Although a stimulating environment will make for increased intelligence, individuals receiving equal environmental opportunities will display the most extreme differences in intellectual achievement. Children reared in orphan asylums, where opportunity is practically equal for all, are as different from one another in I.Q. as those in the general population. There can be no doubt that some are born gifted and others born handicapped, but that in a good social environment mental handicaps may be at least partially overcome, and gifts may receive adequate opportunities for expression.

Differences Between Races.—One of the most persistent of human ideas is the belief that one's own race is inherently superior to all others. Our own race has been especially prone to this point of view, and we have frequently used the argument of our own inherent superiority to justify our conquest and exploitation of darker peoples. A specific instance is the widespread belief in the inferiority of the black race. To a considerable extent, this is held to be an inferiority in intelligence. Even so strong an advocate of democracy as Thomas Jefferson believed that all Negroes are essentially uneducable, and the great southern statesman Calhoun said that they were so profoundly unintelligent that they should not be classed as human beings. Even today many people will confidently assert that no Negro could possibly be as intelligent as any but the most feeble-minded of the whites.

The development of intelligence tests has made it possible to secure definite information on this matter. On the basis of a large number of studies of Negro intelligence, it appears that the average I.Q. for American Negroes is somewhere between 75 and 85. At the same time these studies emphasize clearly that the *individual Negro* should not be judged according to the low average of his race. Approximately twenty-five per cent of Negroes possess an I.Q. higher than that of the average white man. In the Chicago schools a full-blooded Negro girl has been discovered with an I.Q. of 200, one of the highest ever measured. It is perfectly clear that belonging to the Negro race does not condemn an individual to inescapable feeble-mindedness.

A more difficult question concerns the extent to which the difference in intelligence between Negroes and whites in America is produced by the genetic factor or by the cultural or possibly the physiological factors. It cannot be doubted that the cultural factor is definitely responsible in part for the low average mentality of the Negro. The educational advantages offered him, especially in the southern states of this country, are so poor as definitely to handicap him. Even in the North, where Negroes usually attend the same schools as the white children, their entire life outside the school is spent with a group of people who have for centuries lacked even the most meager cultural advantages. In spite of the intellectually unstimulating home life of the average northern Negro, the test given to army recruits during the World War found the Negroes of Pennsylvania, New York, Illinois, and Ohio superior to the whites of Mississippi, Kentucky, Arkansas, and Georgia. The whites in the northern states, however, were superior to their Negro neighbors, and it is likely that the northern Negroes had received somewhat better schooling than the southern whites. A study of 500 Negro children in the schools of Los

Angeles showed them to have an average I.Q. of 104.7, somewhat higher than that of the white children with whom they were compared; and in New York City also, a group of Negroes has been found which tested as high as a comparable group of whites.

It may be that these children in New York and Los Angeles represent what the Negro race as a whole can do when it has freed itself of the cultural handicaps which centuries of slavery and deprivation of social and economic privileges have forced upon it. On the other hand, it may be that they constitute a specially selected group of Negroes inherently superior to the bulk of the Negro race. Many psychologists have held that the intellectual superiority of the northern Negro is the result of *selective migration,* that is, that the Negroes migrating to the North are on the average genetically superior to those that remain in the South. This assumption, however, has never been proved; and what little evidence we have indicates that the Negroes who remain in the cities of the South are equal in intelligence to those who move northward.

The above discussion has been able to provide merely a glimpse of the difficult problems that are encountered in any attempt to determine the inborn or genetically determined intellectual capacities of racial groups. On the basis of the entire mass of studies, it seems fair to draw the following conclusions:

1. It has never been proved that any race of people is inherently inferior in intelligence to any other great race.

2. The differences in intelligence between races as they exist today are due in large part, if not entirely, to differences in cultural opportunity.

3. Genetically conditioned differences between races, *if they exist,* are very slight relative to the difference between individuals within a single race; and all races are capable of producing men and women of genius.

Differences Between Social Classes.—Social status in America depends chiefly upon the occupation in which the family breadwinner is engaged. Many studies have shown that the children of men in occupations of high social status are more intelligent than the children of those in occupations of low social status.

The following table shows the approximate average I.Q.'s for offspring at various occupational levels:

Professional men and big business men	I.Q. 115
Clerical workers and small business men	I.Q. 105
Skilled laborers	I.Q. 100
Semi-skilled laborers	I.Q. 95
Unskilled laborers	I.Q. 90

It is impossible to determine to what extent these differences are due to the genetic or to the cultural factors. In a competitive society such as ours, which provides opportunity for men of outstanding ability to rise to the top, one would expect the genetic factor to be partially responsible for the differences. At the same time, it should be remembered that a large proportion of the unskilled and semi-skilled laborers in this country are recent immigrants who have not had the opportunity to rise to a social status commensurate with their inherent abilities, and that even in America, the mere fact that one is born into a laboring-class home deprives one of many opportunities for intellectual and social advancement. At any rate, we may conclude that the inherent capacities of the "lower classes" are not as far below those of the upper occupational levels as the actual differences in I.Q. might seem to indicate.

Eugenics and Euthenics.—As might be expected, the differential birth rate, described in Chapter X, applies to differences in intelligence as well as to differences in social standing. Children from large families average lower in intelligence than children from small families. There are two opposed schools of thought concerning the effect that this differential in the rate of reproduction is likely to have upon the human race. Believers in *eugenics* hold that the chief problem which the human race faces in its attempts to improve the quality of our civilization is to improve the genetic constitution of the race. What we need, they say, is not more hospitals, but fewer genes that produce susceptibility to disease; not bigger and better schools, but more genes for intelligence. Advocates of *euthenics* hold that better economic and cultural advantages for the entire population are essential to raise civilization above its present level.

Hence, the euthenists are inclined to scoff at the alarm with which the eugenists greet the differential birth rate for intelligence. They insist that if the same privileges were accorded the numerous offspring of the unskilled and semi-skilled laborer as are the birthright of the less numerous progeny of the professional man, the former would become quite as adept as the latter in satisfying the demands of the psychological tester. The radical advocate of eugenics, on the other hand, cries aloud that the biological heritage of the race is being destroyed by the dying out of the better racial strains and the multiplication of the poorer ones. He insists that giving social and economic advantages to these poorer strains merely encourages them to breed more rapidly and at the same time lowers the death rate among them, so that the increase in numbers of the inferior stocks is greatly accelerated.

A survey of the actual facts of the situation leads to the conclusion that both these schools of thought are right with respect to their positive programs of action, and wrong in criticizing the proposals of their opponents. The truth of the matter is probably fairly well summed up as follows:

1. Improvement in the social and economic status of the "lower classes" would doubtless lower the death rate among them. At the same time, however, it would *probably* result in a lowering of their birth rate, as a result of wider employment of birth control methods, so that their net rate of increase would be actually lowered. The higher the social, economic, and educational standing of a group of people, the more likely it is that they will practice contraception.

2. Improvement in social and economic status, together with improvement in educational opportunities, would actually increase the measurable intelligence of our population, regardless of any improvement through selection of genes for superior intelligence.

3. Decrease in the birth rate among members of the laboring class would enable them to make better provision for their offspring and thus raise their intellectual standing, regardless of any improvement in the genes.

4. The present differential birth rate probably does result in a more rapid increase among genetically inferior stocks than among genetically superior stocks, although this proposition has never been definitely proved.

5. Even if there is no genetic difference between the "upper" and "lower" classes, a reversal of the present differential birth

rate to produce a higher rate in the upper levels than in the lower levels would be desirable on purely euthenic grounds. If the professional man is able, simply through providing a better cultural environment for his offspring, to develop in them an I.Q. 25 points higher than the I.Q. of the day-laborer's children, it is most desirable that an increasing proportion of our population be reared in the type of home the professional man provides.

Thus, eugenics and euthenics are not really antagonistic programs for human betterment. On the contrary, a successful program of eugenics would improve the social environment, while improvement in the lot of the less fortunate classes would probably have a definite eugenic influence on the development of the race.

Intelligence Is Not All-important.—Because we have selected the trait of intelligence for special discussion in dealing with the differences between individuals, we may have given the impression that intelligence is the one important trait that an individual can possess, and that, lacking it, he is automatically doomed to failure and ignominious inferiority. No point of view could be more untrue. To be sure, a high degree of intelligence is requisite for the performance of certain important social functions. The work of the scientist, the doctor, the lawyer demands a degree of intelligence above the average. But as far as the individual is concerned, his success or failure should be judged in terms of the use to which he has put his mental gifts, rather than by the fortune he has enjoyed in receiving them. None but the most hopelessly feeble-minded are so lacking in intelligence that they cannot become happy and useful members of society. Indeed, there is no relationship at all between personal happiness and intelligence. Some of the most brilliant people are miserable failures in life, and many individuals of the most humble mental capacity are happily successful in the really essential aspects of living.

If we accept that rather crude standard of success, the capacity to make money, we find that intelligence is by no means the only important personal quality which makes for wealth. It has been found that the income of engineers is not closely related to intelligence, but is closely related to "personality." Another study has shown that among large business executives there is no apparent relationship between intelligence and success. This does not mean that intelligence is not necessary for the work of an engineer or business executive. Both groups are selected from the most intelligent elements of the population. But if one has enough intelligence to do the work at all, his money-making capacity in either field seems to depend more upon "personality" than upon his intellectual standing relative to others in the field.

But what is this mysterious thing called "personality"? Many answers can be given, but there are two ways of answering it that seem to have considerable psychological importance.

The definition of a "good personality" that is probably most widely accepted in everyday life is that it is an *effective personality*. It is the capacity to secure favorable responses from others, to make them like you and to influence their actions. Dale Carnegie has summed up the characteristics of this type of personality in the title of his best-seller, *How to Make Friends and Influence People.* Without doubt, there is no trait more sought and yearned after by men than the possession of an effective personality. Mr. Carnegie believes that the secret lies in liking and being interested in other people, in always considering their feelings first, and, above all, in trying to see their point of view and presenting things to them from that point of view. Without doubt, these qualities are essential aspects of the effective personality. Other qualities, quite as necessary, are courage, enthusiasm, energy, and aggressiveness. But, as Mr. Carnegie points out, we must learn to be aggressive in a pleasant way and to call attention to ourselves by talking about the other fellow and his interests, rather than about ourselves and our own interests. Actually, we have no carefully worked-out scientific knowledge of what constitutes the effective personality. What we do have is a knowledge of the methods of making friends and influencing people which men have worked out by trial and error in everyday life. And, to a considerable extent, an effective personality is a gift which descends upon the individual whose genetic constitution and experience in life have developed in him qualities of self-confidence, cheerfulness, aggressiveness, and friendly interest in people.

The second definition of the good personality is the one that has been worked out by psychologists and psychiatrists (medical men who specialize in nervous and mental disorders) in their dealings with all sorts of personalities which seem somehow to have gone astray and fallen into difficulties. According to this definition, the good personality is the *well-adjusted* personality, the personality of one who is fundamentally at peace with himself and with the part that he is called upon to play in life. Ordinarily we do not recognize the warfare that is going on within the mind of the maladjusted personality, but we do recognize such individuals as being "unbalanced" or "queer."

On the whole, the well-adjusted personality is the effective personality, although this is not always true. Sometimes people with ill-balanced personalities develop a considerable degree of social effectiveness and are able to exert great influence over others, especially other maladjusted personalities. The leader of the eccentric religious cult usually furnishes a good example of a maladjusted but highly effective personality. On the other hand, there are many quiet, unambitious people who are content with a few friends and little personal influence who possess well-balanced but not particularly effective personalities. But the person who strongly desires personal effectiveness but who is unable to attain it is almost always handicapped by some degree of personal maladjustment.

Information relative to the extent to which personality is affected by the genetic or the cultural factors has not yet progressed as far as it has relative to the trait of intelligence, chiefly because it has proved difficult to develop good tests of personality. But the little that we do know suggests that an individual's personality is much less dependent upon his heredity and more dependent upon his environment than is his intelligence; and we do have a considerable amount of information concerning the manner in which a maladjusted personality is developed through the contacts of the individual with others. Maladjustment grows out of the sense of hopeless anxiety which the individual develops when he is faced with a situation where he feels himself unable to come up to the standards demanded of him by his parents, friends, or other members of society, and fears that they will therefore turn against him. In the preceding chapter, we pointed out how the desire to please others becomes the most important social attitude developed in the child, since he is entirely dependent upon others for his welfare. This attitude becomes so completely a part of our nature that we never wholly outgrow it, although it may fall into the background of our consciousness so that we scarcely realize it is there. Indeed, it usually undergoes a complex development, similar to the development of the possessive urge which we noted in the preceding chapter. While this development has never been worked out in full experimental detail, it appears to proceed about as follows: First the child learns that he is dependent upon adults for the care and protection that he needs. Gradually the pleasing of adults, which was at first chiefly a means to get what he wanted, becomes an end in itself. Now, if he fails to please others, whether or not this results in punishment or deprivation, he will feel the anxiety that would naturally go with the threat of punishment or deprivation. Using this motive to gain their ends with the child, others will now commend him for desirable actions and show anger or contempt when he fails to come up to their standards. Gradually, the desire to come up to standards becomes in itself a desirable thing, although it was originally merely a means to an end. The child develops an *ego ideal,* namely, a conception of the sort of person he would like to be; and now, if he fails to come up to this ideal, he develops the feelings of anxiety that formerly were characteristic of his failure to please others. These feelings of anxiety which result from failure to live up to the ego ideal are ordinarily referred to as feelings of *guilt* and *inferiority.* That they originate from our need to please others is suggested by the fact that we usually feel much more guilty when we are caught doing the wrong thing than when we only know about it ourselves.

Taking advantage of these universal desires to please others and to attain an ideal character, society is able to impose its standards of behavior upon the individual. But in a complex society like our own, standards may come into conflict. For instance, a young man who has grown up in a home in which the doctrine of evolution is held to be irreligious and false comes to college and learns that all his professors and most of his fellow students believe that it is true. If he holds to his anti-evolutionary point of view, he fears that he will be looked upon with contempt by the people in his immediate surroundings. At the same time he feels a strong compulsion to retain his loyalty to his parents and, as he believes, to his religion. Out of the conflict between these two incompatible motives, he develops an evergrowing feeling of anxiety.

Or a young woman may have been given the impression that she is not attractive to men, and at the same time have been led to believe that being attractive to men is the one important quality that a girl can possess. Wihout it she feels that her life is doomed to failure. The anxiety which she experiences will be vastly greater than that developed by the young man with a religious conflict. To her way of looking at it, her whole existence as an acceptable member of society is threatened.

Thousands of instances of similar situations with which human life is beset could be cited. We are all of us certain to meet with conflict and frustration, and in those circumstances we develop feelings of anxiety. There is almost always some solution to the conflict, some method of overcoming the frustration. The young man may come to realize that he is no longer a child who must take his opinions ready-made from either parents or teachers, and so he may be able to come to conclusions concerning evolution on a basis of an objective consideration of the evidence. The young woman may learn that the girl does not exist who cannot make herself attractive to men by providing them with companionship and by taking intelligent care of her personal appearance. Those who are fortunate enough to discover the way out of their difficulties develop well-adjusted personalities. But frequently, before we find the way, our minds, anxious to escape the strain of anxiety, play tricks upon us and hide the anxiety from us before we succeed in overcoming the situation which has produced it. These tricks of the mind are called *escape mechanisms*. They are means of concealing anxiety without actually ridding us of it, and thus they leave us fundamentally at war with ourselves and with the parts that we are called upon to play in life. In short, they cause our personalities to be maladjusted.

In the remainder of this chapter, we shall describe certain of these escape mechanisms, namely, *repression, dissociation, fixation, regression, projection, compensation,* and *rationalization.*

Repression.—Repression is the inhibition of the conscious realization of anything that produces anxiety. If, for instance, we have a desire to do something that we know is wrong, we refuse to admit to ourselves that the desire exists; thus we get rid of any conscious anxiety about the matter. Sometimes people speak of "repressed desires" when they simply mean that the full expression of the desire is inhibited. Such a use of the term is incorrect, since repression means inhibition of conscious recognition and recall. For example, if you wish to kill a man and are perfectly aware of your wish but do not carry it into fulfillment because you consider such an action to be wrong, you are not repressing your wish, you are simply inhibiting its fulfillment; but if you wish that someone was dead but inhibit the recognition of your wish, so that you are not aware of it, then you possess a "repressed desire."

Frequently we repress the memory of an entire incident in order to escape unpleasantness in remembering it. The following story illustrates what may happen in such cases:

A seven-year-old girl went for a picnic with her mother and aunt. When it came time for the mother to return home, the little girl begged to stay with her aunt, who was planning a walk through the woods. She was allowed to stay upon promising that she would obey the aunt, but she forgot this promise and ran off to play about a small waterfall. Somehow, as she was climbing about, her foot got wedged between two rocks and she was held helpless in a position where the water came tumbling down and rushing past her on all sides. When her aunt found her there sometime later, she was badly frightened and fearful that she would be punished when she got home. The aunt promised her that she would never tell about the incident and shortly thereafter went away and did not return for several years.

The little girl, however, had been considerably upset. Her sense of security had been shaken and she had been made to feel ashamed of herself and fearful of punishment. Perhaps she felt that she ought to be punished for her misdemeanor and that she was dishonest not to tell about it, and the recall of it aroused in her a gnawing sense of guilt. The whole affair was so distasteful that she put it completely away from her, forgot about it.

But she did not get rid of the emotional feelings connected with it. Every time she came near running water, she would suddenly be struck by a horrid fear which she could neither understand nor conquer. So great was her terror that it sometimes took three members of her family to give her a bath. Once when she heard the sound of a drinking fountain, she fainted away. Her horror of water continued until she was twenty years of age, when her aunt returned to visit the family. Upon hearing of her strange fear, the aunt told the story of her accident at the waterfall. As soon as the incident was recalled to the young woman, her strange symptom disappeared.

The story illustrates the danger of attempting to escape the anxiety by repression. One is faced with a problem, yet one refuses to deal with the problem consciously and intelligently, and the result is that the problem is never adequately settled. The little girl repressed any intelligent response to the situation at the waterfall, so that only her childish emotional reaction remained. This reaction asserted itself, even though the memory of the incident which produced it was gone. As soon as her aunt's story enabled her to react to the incident from an adult point of view, her troubles were over. She could laugh it off as a childish peccadillo, whereas at the time it occurred it had seemed to threaten her moral integrity.

Dissociation and Hypnotism.—When the young woman was made to recall the incident at the waterfall, the emotional attitudes aroused there could be reacted to by her entire personality. Previously, they had been leading a life of their own, a strange life, separated from the everyday, common-sense world in which the young woman lived. They were living in a world in which a ghastly retribution falls upon little girls who disobey their parents and in which running water is the means of bringing about the retribution. Somehow, because of the repression exerted upon them, these childish, superstitious emotional attitudes could not come into contact with the real personality of the girl, a personality that could dispose of such superstitions immediately, once it made contact with them. In other words, the fear of water and the emotional attitudes that lay back of it constituted a *dissociated* system of response. *Dissociation* is the separation of a system of responses from the main personality, so that they carry on activities quite apart from those that are a product of the main personality.

An excellent illustration of dissociation is the phenomenon of "automatic writing," that is, writing without being aware of the fact that one is doing so or having any knowledge of the words put down. A student, enrolled in a course in which, despite almost desperate efforts on his part, he seemed almost certain to fail, was seated one day with his pen in hand, doing his best to grasp the meaning of a difficult lecture. He had long since given up the attempt to take notes and had fastened all his attention upon the lecturer in hopes of getting some inkling of his meaning. Suddenly his hand began to trace lines on the sheet of paper that lay on the arm of his chair. After some preliminary scrawling, the following words were slowly spelled out: "I can't stand it! Let me go, let me go!" Subsequent questioning showed that he had been entirely unaware of writing anything at all.

Automatic writing can frequently be produced by hypnotic methods. Indeed, hypnosis is an artificially produced state of dissociation, in which all the symptoms of natural dissociation can be secured. It differs from natural dissociation in that it usually results, not from a desire to escape the anxiety, but rather from a simple willingness to follow the suggestions of the "hypnotist" or hypnotic operator. A study of hypnotism will therefore give us some idea of what dissociation is like.

To begin with, the following statements may serve to contradict some of the more widespread fallacies concerning the nature of hypnotism:

1. Hypnotism is not "just a fake"; it actually occurs. Probably over ninety per cent of the population can be lightly hypnotized. A much smaller number of individuals, however, is susceptible to really deep hypnosis.

2. Hypnosis is not brought about through the operator's overcoming the "will power" of the subject. It is a response which the subject makes to the operator, and in practically all cases the response is a voluntary one. The subject is by no means forced to make it.

3. To be susceptible to hypnosis is not a sign of "weak will" or any other sort of inferiority. In fact, the only really marked difference between a person susceptible to hypnosis and one who is insusceptible is that the former is a good subject for a hypnotist to work with and the latter is not.

4. A good hypnotic operator does not necessarily have a "strong will," a glittering eye, or a dominating personality. He only needs to be able to win the confidence of his subjects.

5. While the few medical men and psychologists who employ

hypnotism in their work do not encourage its practice among irresponsible persons who are merely doing it for entertainment, they are pretty well agreed that in the hands of competent and responsible operators it is not dangerous.

There are numerous methods of putting a subject into a hypnotic state. One of these methods is to have him lie quietly on a couch while the operator repeats over and over some such words as these: "You are falling sound asleep! You are falling into a deep sleep." The subject simply fixes his attention on the operator's words and thinks of nothing else. Gradually, his attention becomes more completely fixed on the operator's suggestions. Everything else is being shut out. Now the operator tells the subject that his eyes are tight shut and that he cannot open them. Soon, even though the subject tries, he cannot open his eyes. All the everyday world of common sense has been shut out for him. He no longer responds to it, but only to the suggestions of the operator. His true personality is in the background, and a dissociated remnant of it has control over all his actions.

Now, if the subject has been deeply hypnotized, he will accept almost any suggestion which the operator makes. If the operator tells him that he has no feeling in his right arm, a needle stuck into the arm will apparently arouse none. If he is told that the arm is paralyzed, he will be unable to move it. It is possible to make him see things that are not present and to fail to see things that are present. All his responses are narrowed down to one channel: accepting the suggestions of the operator. If he is awakened, he will usually forget everything that occurred during the trance, especially if it is suggested to him that he is going to forget it. This forgetting as a result of suggestion very closely resembles repression; and it can be shown that the system of responses which was set into action during hypnosis is still alive, just as repressed responses are active.

While the subject is still in the trance, the operator may instruct him to perform some action after he awakens. Such an instruction is called a *post-hypnotic suggestion.* Let us say that, fifteen minutes after he comes out of the trance, he is to walk over to a window and open it. Almost exactly at the correct time he will perform the action and he will be *forced* to perform it, although his overwhelming desire to do so may be quite as mysterious to him as the young woman's fear of water was to her. He remembers nothing of the instructions he received during the trance and simply feels an unaccountable impulse to open the window. The story is told of a man who bet that he could resist a post-hypnotic suggestion. When the impulse came to carry out the act, he recognized it and resisted it. But at midnight that night he returned to the spot and performed the act. He lost the bet but he wanted to get some sleep!

Although an individual loses all memory of what has happened to him in a hypnotic trance, if he is hypnotized again he will be able to recall accurately everything that occurred. The hypnotic system of responses is not destroyed by awakening; it is merely inhibited from direct conscious contact with the system of responses characteristic of the waking state. In other words, it is dissociated.

Multiple Personality and Fugues.—One of the most dramatic forms of dissociation is that known as *multiple personality.* Personality may be defined as the total organization of one's responses. In a few people two or more such total organizations have been found which alternate in their control over the individual's actions just as the hypnotic and waking states may alternate. The most famous case of multiple personality was that of a certain Miss Beauchamp, in whom three different personalities were discovered. At one time she would be a retiring, overconscientious, saintly individual; at another time she would be ambitious, selfish and realistic. She would change from one state to another quite abruptly, and neither "The Saint" nor "The Realist" could remember what the other had done. Indeed, when they learned about the doings of each other through other people, or through the notes that they wrote to one another, they usually thoroughly disapproved of each other's actions. In the course of hypnotic treatment whereby Miss Beauchamp's two personalities were eventually synthesized into one, a third personality made its appearance. This newcomer was a childish, prankish individual called Sally, who claimed to have been buried behind Miss Beauchamp's maturer personality (or personalities) ever since Miss Beauchamp began to learn to walk.

Somewhat less startling than the phenomenon of multiple personality is the *fugue*, during which the individual forgets all about his past life and wanders away from his former surroundings. Such a person is reported as an "amnesia victim" by the papers.

A young bond salesman had got himself into difficulty through certain dishonest business deals. When he saw trouble ahead, he got into his automobile and, with a bottle of whiskey to help ease his conscience, drove away. The next morning, he woke up in a ditch a few hundred miles away from his home. He had a large bump on his head, no automobile, and no memory for any part of his past life. He was taken to a hospital, and his description was published in the papers throughout the country. After two or three different women had appeared, claiming to be his wife, his father and his real wife arrived and were able to identify him. They brought him home, and his father arranged matters so that he could keep his job and would not be prosecuted for his dishonesty. Still he remembered nothing of what had happened to him previous to his finding himself in the ditch the morning after his disappearance. He did not recognize his former home or the members of his family, although on one occasion he reached up and turned on the cellar light, the button for which was located in a place where no stranger would be likely to find it without much search. He was taken to a psychopathic hospital where the doctors tried in vain to help him remember his former self; only flashes of memory could be aroused. Whenever his family visited him, they made plans for the great Christmas celebration they were going to have, and he began to look forward to it with keen anticipation. Then, just five days before Christmas, he was told that he could not leave the hospital until his memory returned. By the next morning he was completely cured.

The doctors who worked with his case did not believe that the young man was "faking." Nor did they believe that the blow on his head accounted for his loss of memory. Rather they believed that, because of his desire to escape the uncomfortable situation that faced him, he unconsciously brought about a dissociation of all the memories of his early life and maintained that dissociation until it became more convenient to remember.

Fixation and Regression.—The anxieties that one suffers as a child are believed to be the most important ones for the development of the personality. These anxieties seem to be centered around a child's relationship with his parents, and they are most likely to develop in children whose parents are themselves badly maladjusted. In subtle ways the child senses the parent's anxiety, fears that the parent is unable to care for him or to feel real affection for him. The child's anxiety is repressed, but it exhibits itself in an added feeling of dependence upon the parent. The parent may unconsciously take advantage of this situation by emphasizing to the child his dependence upon the parent, by keeping him from making normal social contacts in the guise of protecting him from the sins and dangers of the world, until he grows up with no confidence in his own ability to take care of himself and completely dependent upon the parent's love and care. Sentimentalists often speak of a child-parent relationship of this sort as a "beautiful love," but love has little to do with it. The young man or woman is motivated by fear and lack of self-confidence to be a "mamma's boy" or a "daddy's girl." The parent's hidden anxiety is appeased somewhat by the opportunity to dominate his child's life and monopolize his affection. The son or daughter is said to be "fixated" upon the parent.

Fixation upon parents is one of the major causes for failure to get along with a husband or wife. There is the husband whose wife fails to please him because she cannot cook like his mother, and the wife who cannot even learn to cook because mother always took care of everything at home. These and a thousand other marital difficulties arise because people fail to make a sufficiently complete transfer of their loyalty and affection from their parents to their husbands and wives, and, furthermore, fail to meet the responsibilities of adulthood because of failure to outgrow their childish dependence upon their parents.

Frequently a person who is fixated manages to get along fairly well until he faces some difficulty. Then he *regresses* to childish modes of behavior and begins to seek for someone to care for him and "baby" him. A few striking examples of this sort of behavior appeared during the war among soldiers who had been greatly frightened by shell fire. One such individual lost all powers of speech, began to toddle about like a one-year-old, played with various objects as if they were toys, and would cry if his toys were taken away from him. It is reported that "he quickly made friends and became a universal pet in the ward."

Less striking instances of regression occur every day. Many people, for instance, become very babyish when they are even slightly ill, while others begin to pout and stamp their feet whenever they fail to get their way.

Projection.—Many of our escape mechanisms consist of disguised expressions of feelings or desires that have been more or less repressed. Let us suppose, for example, that a four-year-old girl is severely scolded and punished for exhibiting some sort of sexual curiosity. The result may be a strongly repressed sense of guilt concerning anything sexual. As she grows up, this repressed guilty feeling may keep her from having a normal interest in the opposite sex. She becomes a "man-hater." She is particularly impressed by the "wickedness" of men, and soon she begins to take a strong interest in the misdoings of other people. Thus her repressed sexual curiosity receives a roundabout satisfaction and at the same time her feelings of guilt are turned outward toward other people, rather than toward herself. She punishes others by indignantly spreading the news of their misdoings, but this is really a roundabout way of punishing herself for a childish curiosity concerning which she felt so guilty. In short, she becomes a gossiping old maid through the influence which her repressed attitudes of curiosity and guilt exert on her personality.

The gossip has adjusted to the hidden, gnawing sense of sinfulness which, unknown to herself, continually assails her, by *projecting* her guilt. She no longer feels horrified at herself, but at other people, and the latter feeling is much more comfortable than the former. *Projection* means believing that other people have the traits or attitudes which one does not wish to recognize in oneself. Some individuals project, not their own *guilt*, but their own *accusing sense of guilt* into other people. They believe that others are accusing them of crimes and misdemeanors, although those others may have no such thoughts. It is their roundabout way of accusing themselves.

Compensation.—A little boy is sternly treated by his father and develops a feeling of fear and inferiority. He goes off to school, gets into a fight and wins. This victory brings an exaggerated exaltation to him, since it helps to relieve his feeling of inferiority. He is so pleased at winning that he immediately seeks other battles and soon he becomes the best fighter in the school. But still, hidden deeply away, is his incurable sense of inferiority, driving him on to other victories. Life comes to mean for him nothing but competition, getting ahead of the other fellow. As he grows older, he works sixteen hours a day to make money, since money is the symbol of victory over competitors. He is ruthless in his business dealings. He amasses millions of dollars and is finally stricken with indigestion because he cannot find time to eat his meals properly. He ends his days in Florida, playing winning, if not always sportsmanlike, golf against men half his age and making himself hated because of his bragging.

The "hard-boiled" millionaire has adjusted to his repressed feeling of inferiority by *overcompensation. Compensation* is the process of making up for a felt weakness by a conspicuous success. If not carried too far, it is one of the best methods of adjustment to feelings of guilt and inferiority. The saintliest man is the one who is compensating for a deep sense of guilt, and the greatest genius is one who is reacting to repressed feelings of inferiority.

Unfortunately, few people are able to compensate in wholly desirable ways. Compensation for the feeling of guilt too often takes the form of a nagging, puritanical conscience, concerned with keeping the individual from committing the slightest moral error, and it has in it nothing of the generosity and unselfishness which characterize the truly good man. The sense of guilt makes Pharisees. Again, compensation for inferiority usually produces only competitive, domineering individuals who must demonstrate their superiority over others at all costs.

Rationalization.—One of our favorite methods of deceiving ourselves concerning ourselves is to invent *good* reasons for our acts, beliefs, or misfortunes, and thus hide from ourselves the *real* reasons. This universal method of self-deception is called *rationalization.* For instance, a student who has failed a certain course explains his failure to himself and others by asserting that the subject matter of the course was not worth acquiring. At the same time, the professor who teaches the course may be ready with a thousand proofs that such a course must form an essential part of any adequate program of education, although his real reason for wanting the course to stay in the curriculum is that he finds studying it and teaching it a pleasant sort of a job, and pleasant or unpleasant jobs are not to be sneezed at nowadays.

A "true believer" in almost any sect or creed can find many reasons for his belief, although the real reason is usually a sentimental attitude that he has developed which would make it painful for him to abandon his faith.

It would be interesting to make a catalogue of the reasons given by people for buying new automobiles before the old ones are worn out. In nine cases out of ten, the fundamental motive is the same one that impels a Mexican harvest hand to spend half his week's pay for a green silk shirt. Possibly the fun of displaying one's magnificence and feeling superior is worth the money, to both the driver of the car and the wearer of the shirt, although the owner of the new car seldom explains it that way, since such expensive methods of "showing off" are usually considered somewhat foolish and vulgar.

Escape Mechanisms and the Personality.—The individual who has perused the above account without finding some of his own weaknesses described therein may be assured that he possesses a set of escape mechanisms that work with such efficiency that they never allow him to catch the slightest glimpse of the truth about himself. All personalities are maladjusted to some extent, and all men employ escape mechanisms to hide their anxieties from themselves. It is the intricacy and ingenuity of the escape mechanisms that impart a unique flavor to each human personality, that make it so difficult to measure or even to appreciate the individuality of each man and woman.

But if the anxieties that have been buried away by repression, half satisfied by fixation, regression, projection and compensation, and carefully glossed over by rationalization are especially severe, the outcome for the personality may be most unfortunate. The individual will be markedly unhappy, though his lot viewed from the outside may be a most fortunate one. He seems nervous and queer, and eventually he may develop the symptoms of a definite mental disease.

For the symptoms of mental disease are merely escape mechanisms—either the ones described above or others that we have not had space to describe—carried to a point where the individual's efficiency is markedly handicapped, or still further to the point where he can no longer be trusted to take care of himself and must be confined to a hospital. For this reason, perfectly normal people may be led to see their own traits exemplified in any description of the symptoms of the mentally diseased. If in your reading of the next chapter, therefore, you begin to wonder if there isn't something the matter with yourself, you may be assured that many other people completely free from mental disorder have had the same experience. Indeed, you may accept any apprehensions you feel as indications of your own sanity—for if you were really crazy, you wouldn't know it.

Chapter Summary

Mental tests have been found useful in arriving at judgments of the manner in which one individual differs from another. Their advantage over mere estimates lies in their thorough standardization. Intelligence tests—which measure ability to deal with symbolical situations and spatial relationships—are the best known of the many types of mental tests. Intelligence is measured in terms of I.Q. (intelligence quotient) which is secured by dividing the mental age by the chronological age and multiplying by 100.

An individual's intelligence is the resultant of three factors: the genetic, the physiological, and the cultural; and neither heredity nor environment is solely responsible for differences in intelligence.

Races display differences in average intelligence, although there is usually much overlapping in intelligence between two races; that is, a considerable proportion of the individuals of the inferior race are superior to the average of the superior race. It has been shown that at least a part of the intellectual inferiority of the Negro race in America is a product of the cultural factor. Whether Negroes are on the average genetically inferior to whites has not been determined.

The intelligence of children is correlated positively with the socio-economic status of their parents, but it is uncertain whether this relationship is due chiefly to the cultural or to the genetic factor.

The eugenist stresses the importance of the genetic factor in producing superior human beings; the euthenist, the importance of the cultural and physiological factors. Each appears to be right as far as his positive program is concerned, but wrong in his attack upon the program of the other.

In terms of individual welfare, a good personality is probably more important than high intelligence. The type of personality one develops is probably dependent more upon the environment and less upon biological heredity than is the degree of one's intelligence. The term "good personality" may be applied in two senses to mean either the effective personality or the well-adjusted personality. The former characterizes the individual who is capable of "making friends and influencing people"; the latter belongs to the man who is fundamentally at peace with himself and with the part that he is called upon to play in life.

Maladjustment of the personality occurs through the development of feelings of anxiety, guilt, and inferiority, and is usually associated with conflicts between opposing motives. If these difficulties cannot be overcome, we take refuge from them in escape mechanisms such as repression, dissociation, fixation, regression, projection, compensation, and rationalization.

Repression is the inhibition of conscious recollection or recognition of our failure to meet cultural standards and personal ideals. Repressed desires frequently express themselves through a dissociated system of responses, that is, a system separated from the main personality so that it carries on activities quite apart from those of the main personality. Automatic writing, multiple personality, and fugues are instances of dissociation. Hypnotism is a form of artificial dissociation in which the individual's attention is centered completely upon what the operator suggests, and the system of responses formed during the hypnotic state becomes cut off from the waking personality and is not remembered when waking occurs.

The failure to outgrow childish emotional attitudes is called fixation, and the return to childish modes of behavior in the face of difficulties is called regression.

Projection is the belief that other people have the traits and attitudes that one does not wish to recognize in oneself.

Compensation is the process of making up for a felt weakness by a conspicuous success. This is a good method of adjustment unless it is carried too far and unless the individual fails to recognize the reason for his compensatory conduct.

Rationalization is a process of self-deception whereby we invent good reasons for our acts, beliefs, or misfortunes, and thus hide from ourselves the real reasons.

QUESTIONS

1. What is the cause of the superiority of mental tests over other estimates of individual differences?
2. What is intelligence? Why is it important to the individual? To society?
3. Discuss differences between races and classes in intelligence.
4. Discuss eugenics and euthenics.
5. What is meant by a "good personality"?
6. Define and illustrate each of the following escape mechanisms: repression, dissociation, fixation, regression, projection, compensation, rationalization.

GLOSSARY

fugue (fūg) A form of dissociation in which an individual forgets his identity and wanders away.

hypnosis (hip-nō'sis) Process of putting an individual in a dissociated state in which he readily accepts all the suggestions of the operator.

post-hypnotic suggestion Suggestion made during the period of hypnosis which is followed after awaking from the hypnotic trance.

CHAPTER XXVII

MENTAL ILLNESS AND MENTAL HEALTH

What Is Mental Disease?—Many people view the study of mental disease with a sort of unreasoning aversion. They feel that it is a morbid preoccupation. This attitude has probably descended from the ancient superstitious belief that insane people were "possessed of demons." The idea was that a mysterious and malignant spiritual being had made his way into the afflicted man's body and was using it for a dwelling place. You will probably recall the story in the New Testament in which a "legion of devils" was forced to escape from a certain madman and take up their abode in a herd of swine, whereupon the swine rushed down the mountain and drowned themselves in the Sea of Galilee, while the man went home in his right mind. During the Middle Ages, one of the accepted methods of curing mental disease was to tie the unfortunate sufferer up to a post and whip him in hopes of driving out the demon that possessed him. Another method was to read to the devil inside the insane man a solemn proclamation, or exorcism, warning him to depart immediately and calling him all sorts of thunderous and vile-sounding names, whereupon he was expected to leave the body of his victim and creep off to hell in sheer terror and humiliation. With this theory of demoniacal possession current, it is no wonder that people felt a horror of the "madman." One could never be sure that the devil would not leave his victim and take up his residence in oneself. And, while people no longer believe in demoniacal possession, some of this superstitious fear of insanity persists even to our own times.

The scientific study of mental diseases which has gone on during the past hundred years, however, has shown that they are really only manifestations of normal tendencies in the growth of the personality which have somehow become exaggerated or warped out of their normal line of development. They are like the gnarls that form in a tree trunk when the tree has been bruised or wind-blown during its youth. They are kinks in the process of mental growth. Every one of us has such kinks, and, indeed, we would probably be exceedingly dull fellows if we didn't. The deranged personality is simply somewhat kinkier, and the kinks are of a more exaggerated kind.

The psychiatrist, who studies and tries to help the interesting, if somewhat bizarre, individuals who live in our psychopathic hospitals, finds most of them to be extremely human persons, struggling as best they know how with the problems that face every human being in adjusting to cultural standards and finding strange, but often fascinating, solutions to those problems.

Kinds of Mental Disease.—Most people have very vague notions of the nature of mental diseases. The term insanity usually calls up in their minds pictures of "raving maniacs" or of persons who consider themselves to be Napoleon Bonaparte. Although the excited, overactive individual and the man with delusions of grandeur are found in hospitals for the insane, a much more common type is the rather dull, apathetic patient who sits in his chair all day and mumbles to himself. The majority of persons suffering from mental diseases do not need to be put in hospitals at all; their ailment is termed a *neurosis,* or minor mental disorder, and many of them are capable of conducting their business and social affairs as well as anyone else. The more severe mental diseases are called *psychoses,* and the majority of people who have them are definitely insane and need to be treated in a special hospital for the insane where they will be kept from doing damage to themselves or others. The psychoses are divided into two main groups: the *functional psychoses,* for which no definitely *causal* physical defects have yet been demonstrated; and the *organic psychoses,* in which the disease can be shown to be due, partly at least, to some actual damage to the nervous tissue of the brain.

In the next few pages, we shall outline briefly the characteristics of the more important types of mental disease. It should be understood, however, that few actual cases of neurosis or psychosis conform exactly to any classificatory types and that we are only describing what is typical, not what occurs in every case.

The Neuroses.—It is most usual to classify the neuroses into three major disease types, namely, neurasthenia, psychasthenia and hysteria.

Neurasthenia might be considered the basic form of mental ill health. It is characteristic of many persons who show other forms of mental disorder, and, on the other hand, in its milder forms it is found in a large percentage of the population. The neurasthenic's personality seems to be one which is dominated by unpleasant and conflicting emotions, of which he is often not fully aware, and these more or less repressed emotions seem to set his autonomic nervous system into complete disorder. He has strange palpitations of the heart, headaches, stomach troubles; his circulation doesn't perform properly; his hands become cold and yet sweaty, while his face may be burning; he has spells of dizziness, and he is very readily fatigued. At the same time he experiences feelings of anxiety; he fears that something dreadful is going to happen, although he hasn't the slightest idea of what it is going to be. He is troubled with insomnia. In brief, he is a puzzled, unhappy person who has become "all upset" because, buried deep where he can't get at them to deal with them intelligently, are impulses which he fears to satisfy and tormenting feelings of inferiority and guilt.

The neurasthenic has usually compensated for his feelings of inferiority by setting up for himself an imaginary goal of great superiority. He feels that he ought to be—indeed, that he *must* be—the winner in all contests. But unlike the "hard-boiled" millionaire described in the previous chapter, he frequently fails to make an *active* compensatory adjustment. When an opportunity to compete with others presents itself, he backs out for fear that he might not win, since not winning would be for him a tragedy. Then he frequently begins to rationalize his lack of success. Wishing to explain to himself that it is not fear of failure that makes him unwilling to compete, he begins paying close attention to his stomach troubles, or heart flutterings, or insomnia. Usually he is not in particularly robust physical condition, but he greatly exaggerates his illness. He goes to the doctor and tries to get him to discover some fatal disease that is attacking him. He is disgusted when he is told that there is nothing much the matter with him, and starts looking for a better, less encouraging doctor. Frequently he is able to find a quack, or even several quacks, willing to fuss over him to his heart's content. He becomes almost happy, treating his symptoms and developing new ones. His rationalization is complete; and he has a perfect alibi for never doing anything worth while.

Any description of the neuroses or psychoses can only give what is typical of them, and very few cases actually conform to type. Many neurasthenic people never become *hypochondriacal*, that is, engrossed in their symptoms; indeed, they often fight against them. Charles Darwin, for example, could seldom write or study for more than two hours at a time without being assailed by nausea. Apparently a part of his personality was doing its best to give him an excuse for not working, and, since he had an independent income, he could hardly have been blamed for accepting such an excuse. Yet for twenty years he struggled to secure complete proof for his theory of evolution, although on many days he was unable to spend more than half an hour at his work and at times he was totally incapacitated. In the end, in spite of the difficulties which his own repressed anxieties set in his way, he made one of the greatest contributions to human knowledge that it has been the privilege of a man to make throughout the history of human life.

Psychasthenia is the name given to neurotic ailments that are characterized by *obsessions, phobias, compulsions,* or *doubts* and *scruples.*

An *obsession* is a useless thought which comes to an individual over and over again, which the individual recognizes as useless, abnormal, and unpleasant, but which he cannot get rid of. Nearly everyone has had the experience of being unable to forget a tune which keeps running through his head. A man suffering from an obsession has a similar difficulty. Some thought, for example, "I am going to kill myself," may keep repeating itself to him; and, though he has no intention of committing suicide, he is quite incapable of getting rid of the idea.

A *phobia* is an irrational, uncontrollable fear of some thing or situation. The reader will recall the phobia for water which was described in the last chapter. Other individuals show abnormal fears of open places or closed places, of the dark, of certain animals or certain kinds of people, or of thousands of other things. Many people whom we would class as perfectly normal show irrational fears of rats, snakes or insects, or of blood, or of the dark, or of thunder and lightning; and if the reader does not have one or more slight phobias—fears which he realizes are foolish—he is a rather exceptional person. Indeed, from the standpoint of the steeple jack or construction man, nearly everyone has a phobia for high places. But in the psychasthenic, a phobia may be strong enough to dominate the individual's life, so that he is unable to go out on the street for fear of meeting a dog, or must stay away from all public gatherings because of his fear of being in a crowd.

A *compulsion* is an uncontrollable impulse to perform some act which the individual may recognize as foolish or wrong, yet which he cannot avoid doing. *Kleptomania,* the uncontrollable desire to steal, belongs among the compulsions. Some years ago Dr. William Healy, working with children in the Chicago Juvenile Court, found that many of them experienced desires to steal because of a repressed sexual interest. For example, a child might have been taught certain obscene words and also led into stealing by an older companion. Having already secured the impression that any interest in sex is the most reprehensible of crimes, the child would try to forget, or repress, the obscene words. At the same time there would be a strong impulse to think about them or use them. This latter impulse, being repressed, would seek roundabout satisfaction through the performance of another wrong act which had become associated with the unrecognizable wickedness of using obscene language. The child would experience an overwhelming impulse to steal. Without any recognition of the fact on the part of the child, stealing would be *substituted* for what, to him, was a much graver misdeed.

It seems possible that all the obsessions, phobias, compulsions, and scruples of the psychasthenic are substitutes or *symbols* for repressed desires or for the repressed feelings of guilt which the psychasthenic harbors. A psychasthenic symptom reminds one of the children's game of walking along a sidewalk, being careful to avoid stepping on the cracks where the stones are joined together and chanting in unison:

> "If I step on a crack
> I'll break my mother's back!"

After enjoying the pastime for a while, the youngster begins to be cautious about stepping on cracks even when he is not playing the game. He has developed a mild *scruple,* that is, a hesitancy at performing a certain act. Stepping on the crack has come to symbolize for him doing harm to his mother. Indeed, the writer remembers that once when parental discipline had irked him mightily, he went out and stepped on all the cracks he could find in the sidewalk; as a matter of fact, he jumped up and down on them. A psychasthenic compulsion may have a similar symbolic meaning of defiance of one's parents, but the psychasthenic has a better conscience, he hides his hatred from himself, and his symptom seems utterly unaccountable to him.

Hysteria is a neurosis especially characterized by the operation of dissociated systems of response. Both the phenomena of multiple personality and of the fugue belong to the hysterical group of disorders. Hysterical people are subject to fits in which they lose all control of themselves, apparently being under the control of a dissociated system of responses; for this reason when someone begins to laugh or cry in an abandoned fashion, we frequently say that he or she is "hysterical."

Very frequent among hysterical ailments are *anesthesias* and *paralyses.* Hysterical anesthesia is a loss of sensitivity in the eyes, ears, or other receptors which is due not to any impairment of the sense organs themselves or of the nerves running to the brain, but rather to the dissociation of sensations coming from that region. It is usually called "functional" anesthesia since it is brought about by a defect in the *working* of the nervous system rather than by a defect in its *structure.* We have already mentioned how such anesthesia may be produced by hypnotic suggestion. Functional anesthesia (as well as other hysterical symptoms) is frequently also brought about by suggestion. For instance, a laborer is working at a job which he dislikes when a hot oily rag catches on a belt, is whirled along and thrown into his face. When the oil is wiped away he finds that he is blind; but the accident has not caused the blindness, it has only suggested that method of escape from his job. Functional paralysis is the loss of ability to move some part of the body, although no damage has been done to the nerves or muscles concerned. It occurs frequently after accidents. Various sorts of muscular twitches and tremblings and likewise many different kinds of fits also belong among the hysterical disorders.

The "shell shock" suffered by men during the war was usually some sort of functional disability brought on to enable the individual to escape from the horrors of trench warfare. It should be understood that in the majority of cases there was no intentional malingering, that is, "faking." Nevertheless, there was a marked increase in the rate of cures immediately after the signing of the armistice.

Mild disorders of the hysterical or functional type are not at all uncommon in everyday life. From the little boy who wakes up with a headache which persists until it is too late to go to school, to the college student who develops writer's cramp in the midst of an examination, we are all inclined to escape difficulties by the route of the functional disorder. Some doctors claim that in practically every case of illness there is a persistence of symptoms after the physical causes of the symptoms have been removed, such "hangover" symptoms being the product of suggestion.

The majority of cures wrought by "faith healers" are cures of functional ailments, and anyone who has any knowledge of the work of a faith healer must have noticed the high proportion of cures of blindness, deafness, or paralysis that are effected by faith.

The Functional Psychoses.—We shall deal rather briefly with those types of mental illness which regularly result in commitment to a hospital for the insane. The important thing to understand about them is that they are all methods of adjusting to the difficulties (whether consciously recognized or repressed) with which the individual is faced. Just as the hysteric adjusts to his troubles by dissociation, so the individual with *manic-depressive psychosis* adjusts by *emotional excess*; the man with *paranoia*, by *compensatory ideas*; and the person with *dementia praecox*, by *shrinking away and daydreaming*.

Manic-depressive psychosis is characterized by two opposite emotional conditions. An individual may come to the hospital in a greatly elated state of mind. His whole mental life is colored by his joyous mood. He talks rapidly, although somewhat incoherently, is extremely active, sleeps little. He has "big ideas" about himself and, if not brought to the hospital quickly enough, may spend all his money in some extravagant business adventure. He is domineering, and may fight with anyone who opposes him. He is, to himself, the joyous conquering hero. As he becomes more and more elated, his beliefs and his very perceptions may be completely colored by his mood. He entertains delusions of being the greatest, most powerful man in the world. He suffers illusions, being very likely to mistake one person for another, and will hail the doctor as his long-lost brother whom he is going to seat on the right hand of his throne as vice emperor of the universe. He may even experience *hallucinations* and see and hear angel choirs coming down from heaven to worship at his feet.

A few days later, this same man may be in the depths of despair. He hardly moves, except to wring his hands. When spoken to he does not answer for a long time, then his voice is low and despondent. Questioning, however, may reveal the fact that he now has new delusions and hallucinations in harmony with his new mood. He believes that he has committed the unpardonable sin, that he has ruined his family, and he hears voices of friends, threatening him with punishment for his wrongdoing.

Among manic-depressive patients, there exist all degrees of elation and depression. Some go only into the manic (elated) condition, others only into the depressive state, but most of them alternate between mania and depression. Usually they remain in these states for comparatively short periods of time (from a few days to a few months) and then swing into the opposite state or into a normal mood. Most manic-depressives are normal for the greater part of their lives, but suffer from recurrent episodes of insanity. For the most part they are sociable, likable people whose only defect seems to be their tendency to go on emotional "sprees."

The individual with *paranoia* possesses an entirely different personality from that of the manic-depressive. He appears to be one who has experienced an intolerable sense of inferiority, but instead of rationalizing his failure by attributing it to ill health, as does the neurasthenic, he blames it on other people who have schemed against him and given him a "dirty deal." The more he broods on the matter, the more he becomes sure that a large society of some sort is plotting his destruction. He interprets everything that happens to him in this light, and builds up strong *delusions of persecution.*

Now he begins to *compensate for* as well as to *rationalize* his inferiority. If people are plotting against him he must be a very important person. He discovers that he is a great inventor whom the General Electric Company is trying to get out of the way because his inventions would run all their products off the market. Or he is a heaven-sent reformer, a veritable prophet, whom those agents of the devil, the Masons, are trying to destroy. Or, again, he is secretly beloved by a certain rich heiress whose father plots to have him killed. He is building up *delusions of grandeur* along with his delusions of persecution. He writes letters to the President of the United States, telling him of the wrongs that are being done him and demanding redress, or he brings legal suits against his enemies, or he gets a pistol and begins to put them out of his way. These activities bring him to the psychopathic hospital, where he usually spends the rest of his days, since it is almost impossible to convince him of the falsity of his delusions. At the same time, he may remain an intelligent, capable individual, and occasionally he may talk a visitor at the hospital into believing that his delusions are true; he is so sure of himself and so rational!

Dementia praecox (frequently called schizophrenia) is the psychosis that is developed by individuals who shrink from the pains of adjusting to reality and build up in daydreams a world that is "nearer to the heart's desire." The individual who suffers from this malady cannot get along with people; they hurt his feelings because, being very much interested in himself, he cannot bear to have that self treated with any but the utmost respect. Because the social world pains him, he withdraws all emotional interest from it. He seems cold and unfeeling, but he is only cold and unfeeling toward others; for himself and his daydreams he entertains the tenderest regard. Everyone has daydreams, but the dementia praecox patient *believes* in his. Nothing else, to him, is important, and he makes no effort to criticize them in the light of reality. As a consequence his entire stream of thought is a figment of dreamlike delusions and fantasies. His delusions are not well thought out and rationalized, as are those of the paranoid, nor are they products of an overpowering mood, as are those of the manic-depressive. They are dreams, and they often possess all the incoherence and inconsequentiality of a dream. Occasionally one may hear a schizophrenic uttering a strange meaningless gibberish, called a "word salad." The following is an illustration:

> The invention of the electric steam locomotive with rubber wheels while they were chopping up the kindling wood went to a place called St. Paul, Minnesota, because if you listen to a parrot, it will pick your insides out because when you are full of electricity and electric wires run the steam locomotive which went a hundred miles an hour on rubber wheels, because it set fire to your insides although the kindling wood was outside when McKinley ran for president between Wall Street and St. Paul, Minnesota, you have to blow your nose after the Mexicans had chopped the wood the electric steam locomotive ran on rubber wheels and they ate so many bananas after McKinley ran for President over my dead body.

Here the man's dream has "gone to pieces" and become quite incoherent.

Dementia praecox appears utterly bizarre to us because the sufferer is not in contact with us; he is living in a different world. Sometimes he stands rigidly peering out the window all day long, or walks up and down, performing incomprehensible movements, perhaps repeating the same set of movements over and over. These apparently meaningless performances are in reality "dream movements," having some inner significance to the patient which cannot be deciphered by outsiders; indeed, for all we know, the patient himself may not be conscious of their meaning. Yet somehow they symbolize his innermost wishes. They are his way of getting what he wants, of escaping his anxieties.

It would be impossible here to catalogue all the symptoms of this psychosis. They are all variations on a fundamental *pattern of life*, that is, shrinking from reality and obtaining satisfaction from daydreams.

It has been found that these dreams are usually regressive and are symbolic of childhood situations when the patient had no difficulties to meet and was cared for by loving parents.

Like the paranoid, the dementia praecox patient is a hard man to cure, since he could get well only by a return to reality, and he finds his dreams much more attractive. Perhaps in the majority of cases he is happy because, although he may have bad dreams as well as good ones, he has abandoned the host of responsibilities that worry normal people. As his psychosis continues, his mind, divorced from the need of concerning itself with real problems, deteriorates. His thoughts become more and more incoherent. Yet he may continue to live in his hospital environment for years, fed and sheltered by the "cruel world" of men which he, emotionally at least, has entirely abandoned.

The Organic Psychoses.—It would take too long to describe the symptomatology of the organic psychoses, and we shall confine ourselves largely to listing the more important agents which, acting upon the nervous system, can cause organic psychoses to appear.

1. *Bacterial Infections.*—Various kinds of microbes, attacking the brain, can bring about abnormal mental conditions, by far the most frequent of such attacks being made by the spirochete of syphilis. Syphilitic diseases of the brain are responsible for about ten per cent of patients admitted to mental hospitals. The outstanding syphilitic disorder is known as *paresis.*

The spirochetes attack the brain some five to ten years after the time of the original infection of the blood stream; and if a cure is not effected, their ravages bring about a gradual deterioration of the patient until he becomes quite empty-minded and helpless and finally dies through the sheer incapacity of his nervous system to take care of his bodily functions. In recent years it has been found that many cases of paresis can be improved or cured by giving the patient a case of malaria. (After the malaria has done its work, of course, it is cured by administration of quinine.) An even more recent method of attacking paresis is the use of *diathermy*, a treatment employing certain electromagnetic waves to produce a high artificial fever.

There is an organism which occasionally makes its way from the nasal passages into the brain, and produces a type of brain infection called *encephalitis lethargica* or, sometimes, "sleeping sickness," although it is entirely different from the well-known African sleeping sickness produced by the tsetse fly. Many unfortunate symptoms appear both during and after the attack, among the outstanding ones being uncontrollable impulses to attack and destroy. At present no means of curing this disease is known.

2. *Toxins produced by bacteria* can bring on psychotic symptoms. It has been found that some cases of dementia praecox and

manic-depressive insanity can be cleared up by removing infected teeth, tonsils, and the like.

3. *Narcotic drugs,* when taken continuously in excessive quantities, poison the tissue and bring about various psychoses. The most frequent of such mental diseases are those caused by alcohol, of which the best known is delirium tremens. Alcohol accounts for about as many hospital admissions as does syphilis.

4. *Physical injuries to the brain tissues,* caused by blows or by brain tumors, may produce many different kinds of mental disease.

5. *Dying out of the brain cells* in old age produces the forgetfulness, mind-wandering, and egocentricity of senility.

6. *Hardening of the arteries going to the brain,* usually in old age, deprives the brain cells of sufficient nourishment from the blood and produces a variety of symptoms.

7. *Disorders of the endocrine glands* are coming to be recognized as causes of mental disturbance. The mental difficulties attendant upon over- or under-secretion of the thyroid have already been mentioned. At the time of the menopause, or shortly after, many women suffer from a depression that is called *involutional melancholia.* Treatment with ovarian hormones or with ovarian and thyroid hormones has been found to relieve this condition in many cases. Apparently some, but by no means all, cases of dementia praecox and manic-depressive insanity are brought on by endocrine disorders of various kinds. The former especially seems often to result from inadequate functioning of the gonads.

The Causes of Mental Disease.—The symptoms of all mental diseases, with the exception of a few that are due to damage done to circumscribed regions of the brain and a few others that involve only the loss of intelligence, show some failure to adjust to the strain of socialization and a falling back upon escape mechanisms of an exaggerated sort. In the organic psychoses, the failure to adjust seems to be due to some damage done to the nervous system which makes the individual incapable of carrying the burden of adjustment to cultural standards without a resort to escape mechanisms. These diseases are therefore best attacked by attempts to remove or prevent any attack upon the nervous system.

With respect to the functional psychoses and the neuroses, two points of view are held. One school, called the *organicists*, holds that these are also really organic psychoses, but that the organic causes have not yet been discovered. They point out that such so-called functional diseases as dementia praecox and manic-depressive insanity have in some cases been cured by gland therapy and by clearing up focal infections. They claim that these diseases are really a number of different diseases, each having its own special cause, but that most of these causes have not yet been discovered.

During the past year or two, cures of dementia praecox have been effected through daily injections of insulin in such quantities as to drive the sugar out of the blood and into storage in the tissues. This change in blood chemistry has a marked effect upon the nervous system, producing mental confusion and trembling of the limbs. The condition is called "insulin shock," and it sometimes occurs in diabetics who take an overdose of insulin. A series of insulin shocks does not always bring about a cure in cases of dementia praecox, but, according to present reports, insulin treatment is remarkably effective with patients who have not had the disease for more than a year or two. As yet it is impossible to say whether these cures are permanent, nor is the cause of the cure understood. But if a change in the chemistry of the blood can cure this disease, there is some reason to believe that blood chemistry may have something to do with its cause. In short, the insulin cure of dementia praecox apparently supports the contentions of the organicists.

The other school, that of the *functionalists*, holds that the functional psychoses and neuroses occur in individuals who have encountered special difficulties in adjusting to cultural standards and have become habituated to the employment of extreme escape mechanisms in attempting to adjust. This school therefore advocates the employment of *psychotherapy* in treating such disorders.

The best-known method of psychotherapy is the one originated by the Viennese neurologist, Sigmund Freud. It is called *psychoanalysis*, and it consists essentially of a series of long interviews between the doctor and patient in which the patient is encouraged to tell the doctor everything that comes into his mind, no matter how silly, meaningless or indecent it may sound. The series of treatments may continue for two or three years, and the patient's repressions are gradually broken down, so that he is able to face and conquer the anxieties that have been hidden away in his personality since childhood. There is much dispute at the present time concerning the effectiveness of psychoanalysis, and much argument among psychoanalysts over the precise course of development which the human personality undergoes. Indeed, some of their theories appear outlandish, and they have been roundly attacked by more conservative scientists. Nevertheless, Freud has profoundly influenced the thinking of all psychologists, for his method does have the virtue of exploring deeply into the hidden recesses of human nature. Furthermore, both the practitioners of psychoanalysis and their patients are profoundly convinced that it produces cures.

Other methods of psychotherapy do not involve going all the way back to the childhood anxieties on the basis of which the later anxieties develop, but believe in educating the patient to face the difficulties of life without too much recourse to escape mechanisms. Frequently a change in occupation or in the family situation in which he lives will enable a patient to adjust adequately to life, provided his mental disorder is not of too serious a nature. These less thorough methods of treatment possess the virtue of not being as expensive as psychoanalysis, which requires the services of a highly paid physician over a long period of time.

Psychotherapy has been rather successful in dealing with the neuroses. Occasional cures of the functional psychoses by psychotherapy are reported, just as cures by organic therapies occasionally occur; but most of these cases either get well of their own accord or else never get well. Medical science does not yet know how to deal with them effectively.

Since both psychotherapy and organic therapy are useful in curing mental disease, it seems probable that both one's habits of adjustment and the health of one's nervous tissues combine to determine whether or not one shall show symptoms of mental disease. It is probable that a well-adjusted personality can stand much more damage to the nervous tissues than a poorly adjusted one before signs of psychosis or neurosis appear, and it seems possible that a very poorly adjusted personality may develop mental disease without any damage to the nervous system at all.

Both psychotherapy and organic therapy are indicated in the treatment of mental disease.

It is frequently asserted that mental disease is inherited, and this belief has doubtless caused much anguish and apprehension to those whose parents or other near relatives have succumbed to some psychosis. There is one rather infrequent malady, known as Huntington's chorea, which develops in early middle age and which is the product of a single dominant gene; but with the exception of certain types of feeble-mindedness, we know of no other mental disease which an individual is certainly fated to develop on account of the characteristics of his genes.

It is true, however, that certain gene combinations make one susceptible to such diseases as manic-depressive insanity and dementia praecox, just as certain combinations make one susceptible to tuberculosis. Probably a number of genes contribute to produce this susceptibility; and just as the individuals of a given family vary considerably in height, so they vary considerably in susceptibility to mental disease. But for all we know at present, the most susceptible person may completely avoid mental disease if he is brought up in a mentally hygienic environment.

Mental Hygiene.—Few people have any conception of the extent to which mental ill health afflicts our population. It is said that half the hospital beds in this country are in hospitals for the mentally abnormal. Furthermore, it has been estimated—or at least guessed—that half the people who come to doctors' offices are suffering from ailments of a functional nature, that is, they are mildly neurasthenic or hysterical. Mental ill health is nearly as widespread as other forms of sickness, and it probably causes quite as much loss of efficiency and happiness.

Very few people are perfectly strong and well physically, and, similarly, very few people are perfectly adjusted mentally. In addition to those that have easily recognized mental diseases there are unhappy people, overenthusiastic and unreliable people, grouchy people, timid people, spendthrifts, misers, drunkards, prudes, sexually frigid people, people who are obsessed with sexual thoughts, liars, swindlers and thieves, all of whom display these undesirable traits because of maladjustments they have developed and methods of escape that they have learned to use. All are mentally unhealthy to some extent; and when you take all such people out of the population, how many do you have left?

The problem of mental hygiene, then, is an extremely broad one, since it involves not only the cure of obviously diseased persons, but the better mental adjustment of well-nigh the entire population. Practically all the "social problems" with which we are faced, such as criminalism, poverty, divorce and other failures in marriage, are *in part* problems of mental hygiene; while the problems and difficulties which individuals find in their own lives are very frequently problems which hinge around the failure of themselves, their friends, or the members of their families to adjust adequately to the problems of life.

The remainder of this chapter will deal with the ways in which the general mental health of the population may be improved.

Need for Improvement of Medical Service.—Up to the present time the medical profession has been poorly prepared to deal with mental maladjustments. The unintelligent horror of madness that has survived since the days of demoniacal possession has kept most medical men away from the study and treatment of such diseases. Psychiatry has often been looked upon as a not very respectable field of work, and the psychiatrist has frequently been considered as not much better than his patients. This unfortunate and fundamentally superstitious attitude has retarded research in the field, so that only in recent years has much knowledge concerning mental ill health been acquired. As a result, there are not nearly enough well-trained specialists in psychiatry, and almost none of our general practitioners have received the training that would enable them to deal intelligently with the many maladjusted people who come into their offices. Gradually, as knowledge increases, the medical profession as a whole is becoming better informed, and skilled psychiatrists are becoming more numerous. Furthermore, a new profession, that of clinical psychology, is developing for the treatment or reeducation of cases of maladjustment in which no organic disease is present. The clinical psychologist does much of his work with children who, while not mentally diseased, fail to get along well in school, with their playmates, their parents or with the officers of the law.

Parent Education.—The clinical psychologist has discovered that when something is wrong with a child, the fundamental difficulty almost always lies in his relationships with his parents. And the psychiatrist has found that when he traces a mental maladjustment back to its beginning, that beginning is almost always in the home. Mental maladjustment begins in childhood, and preventive mental hygiene can be applied only to children and young people. One of the strange anomalies of our civilization is that, while we demand special training for teachers who do nothing more difficult and important than to instruct the young in reading, writing, history, and foreign languages, the education that is of profoundest importance to the individual, namely, the acquisition of those emotional attitudes and sentiments which constitute what we call his character and personality, is left in the hands of people (i.e., parents) who are not required to know anything at all about what they are doing. What we learn at school is of necessity the most superficial part of our education; it is what we learn at home that counts the most. This education at home is rendered no less fundamental by the fact that frequently neither parent nor child is aware of the fact that it is taking place; often the child accepts the attitudes of his parents without either being capable of formulating those attitudes. For instance, if a mother conducts all her affairs in such a way that she sacrifices every other interest to securing the admiration and envy of her friends and neighbors, her children will usually acquire the attitude, "social standing is the most important thing in the world," although neither they nor their parent would ever think of stating it in such terms. Or if a parent is continually suspicious of the motives of others, the child will quite unconsciously develop the attitude, "People are not to be trusted."

If a parent has consciously or unconsciously developed a system of attitudes which adjust him adequately to the culture in which he lives, his children will learn these attitudes and will grow up to be mentally healthy. If the parent's attitudes are unhygienic, those of the child will also become unhygienic. Occasionally, of course, young people react negatively to their parents' way of life, but such negative reactions are likely to be exaggerated through overcompensation, and a maladjustment develops that is simply the reverse of the parental "kink." For this reason, the education of parents in a knowledge of what attitudes make for hygienic mental and emotional development and what make for the reverse constitutes the greatest hope we now possess for the development of mental health throughout the population. Here we can only briefly outline some of the things that every parent should know.

1. The child's first strong emotional attachment is to his parents and many maladjustments result from failure on the part of parents to return warmly the child's affection. Indifferent or hostile parents develop in a child a feeling of insecurity which he is frequently quite unable to overcome in later years. It is normal for parents to love their children, and if a parent fails to do so it is probably the result of some failure of his own to adjust properly.

2. The child needs to grow away from his first emotional attachment, to find many friends outside his family, and finally to find a mate. Many parents, usually those whose married life is not quite satisfactory to them, attempt to hold too much of their child's affections. When a young man's affections remain too closely attached to his mother, any adequate marital adjustment on his part is almost impossible.

Friendships with youngsters of his own age and with adults other than the parents should be encouraged from earliest childhood upward, and the parent should avoid jealous attempts to monopolize the child's affections.

3. When a parent feels somewhat insecure himself, he is likely to protect and care for his children too assiduously. The children never learn to care for themselves, and usually develop a strong feeling of helplessness and inferiority. Children should be encouraged from babyhood upward to achieve independence and self-confidence, to dress themselves, to take care of their possessions, and to fend for themselves in rivalry with their playmates. The way they can learn to do these things is to be given opportunity to practice.

4. Parents who are anxious to compensate for their own feelings of inferiority are often too anxious about their children's achievements. They try to force them to do things that they are incapable of doing and are never satisfied unless their child is at the head of the procession in everything. Such an attitude inevitably develops a feeling of inferiority in the child.

5. Parents who have a thwarted urge for mastery, or who have developed a strong sense of guilt, are likely to regulate their chil-

dren's lives to the point of tyranny. This makes it impossible for the children to develop moral responsibility of their own, and they react either by going explosively to the bad as soon as they get out from under the parents' thumb or by developing such a set of repressions and inhibitions that life becomes utterly painful to them.

6. Ignorance concerning the development of the sexual impulse and the feeling that sexual relations are nasty and shameful (but at the same time horribly enticing) are probably responsible for more mental ill health and personal maladjustment than all other causes combined. Parents who possess these attitudes and enjoy such ignorance are likely to pass on both to their children. To very young children, every aspect of the world is an object of curiosity. But the instant this curiosity is turned toward the sex organs, a horrified parent is all too likely to convey to the child his own feelings of fear and shame toward such objects, with the result that a feeling of anxiety concerning sexual matters is developed almost before the child has learned to talk. As the child grows up, this attitude develops even more strongly, and the more or less repressed feelings of guilt inhibit a normal development of the emotions of sexual love. The result is that the sex drive seeks roundabout means of expression. Many of the symptoms of the psychoses and neuroses are expressions either of repressed sexual impulses or of feelings of guilt in relation to sex.

It should be thoroughly understood that we do not mean that normal inhibition and control of the sex urge result in mental ill health. The individual who frankly recognizes his sexual impulses but who, through prudence or moral idealism, inhibits expression of them, is obviously subject to some strain, but he is meeting this strain in an intelligent manner. It is the unintelligent horror of the sexual, rather than its intelligent control, that results in maladjustment; and individuals most often learn this unintelligent horror from their parents.

The Education of the Individual.—Obviously, if the parent is to be a good teacher of hygienic attitudes, he must himself become well adjusted; and, indeed, every educated individual should make it his business to know something about the principles of mental hygiene, for even if he himself is well adjusted, he needs to know how to sympathize and deal with people who are not.

It is impossible here to give anything like an adequate outline of the knowledge that everyone should have, but one who is interested in securing that knowledge may find it in books, in magazines, in lectures, and in a few high school and college courses; and it is hoped that the past two chapters may serve as a preface for further study on the part of the readers of this book.

Briefly, good mental hygiene requires that we frankly face whatever difficulties we experience in adjusting to cultural standards and social realities, and avoid resorting to escape mechanisms. It involves the building up of a conscience that is responsive to the welfare of others and an ambition to take a worth-while, but not necessarily exalted, part in the work of the world, while avoiding as completely as possible useless fears of doing wrong or of failing. It involves the ability to make friends and the overcoming of the egocentricity and "touchiness" that make friendship difficult; and, finally, it involves training and practice in those habits that make for successful adjustment to culture and society.

Chapter Summary

Mental diseases are merely extreme forms of the maladjustments common to many people. They are divided into two groups: the neuroses, or minor mental ailments, and the psychoses, or major mental ailments. The psychoses are divided into two groups: the functional psychoses, for which no definitely causal physical defects have yet been demonstrated, and the organic psychoses, of which actual damage to the nervous system is known to be a cause.

Three types of neurosis are distinguished, namely, (1) neurasthenia, which is characterized by physical ailments that are due to maladjustment of the autonomic nervous system, anxiety, and hypochondria; (2) psychasthenia, characterized by obsessions, phobias, compulsions, doubts, and scruples; and (3) hysteria, which is a disease of dissociation, being characterized by fugues, various types of fits, anesthesias, and paralyses.

Three types of functional psychoses are distinguished, namely, (1) manic-depressive psychosis, characterized by spells of elation and mania alternating with depression and retardation of thought and activity; (2) paranoia, characterized by delusions of persecution and of grandeur; and (3) dementia praecox, characterized by withdrawal from reality and regression.

Seven causes of organic psychoses are listed, namely, (1) bacterial infections, especially those of syphilis which cause paresis and other diseases, and those which cause encephalitis; (2) bacterial toxins, which may produce certain cases that are diagnosed as dementia praecox and manic-depressive insanity; (3) narcotic drugs, especially alcohol; (4) physical injuries to the brain, caused by blows or by tumors; (5) dying out of the brain cells in old age which produces the senile psychoses; (6) hardening of the arteries going to the brain; and (7) disorders of the endocrine glands, which bring about several abnormal mental states, including involutional melancholia and certain cases diagnosed as dementia praecox and manic-depressive insanity.

There is considerable dispute concerning the causes of mental disease. The organicists believe that the failure to adjust to the strain of socialization is in all cases due to some actual damage done the nervous tissues, while the functionalists believe that many cases of neurosis and functional psychosis can be produced by poor habits of adjustment alone. One's hereditary allotment of genes can determine one's susceptibility to mental disease, but in only a few exceptional cases are the genes known to be the crucial determiners of a mental disorder.

Not only because of the great prevalence of mental diseases, but because of the still greater prevalence of minor maladjustments, a program of mental hygiene is highly desirable. Such a program involves, first, the better training of medical practitioners and specialists and the development of the profession of clinical psychology; second, the proper training of parents, since mental maladjustment is usually handed on from parent to child; and, finally, considerably greater knowledge of mental hygiene throughout the entire population.

QUESTIONS

1. Outline the various types of mental disease.
2. What may be said concerning the causes of mental disease?
3. What are some of the things needed to produce more hygienic mental conditions in our civilization?

GLOSSARY

anesthesia (an′es-thē′zhi-a) Loss of sensitivity.

compulsion A morbid, uncontrollable impulse to perform an act which is usually recognized by the individual to be wrong or foolish.

dementia praecox (dē-men′sha prē′coks) Name for disorders characterized by extreme withdrawal from reality.

encephalitis lethargica A type of nervous and mental disease caused by brain infection.

hypochondria (hī′pō-kon′dri-a) Morbid concern about one's usually imaginary illnesses.

hysteria (his-tē′ri-a) Name for disorders characterized by loss of emotional control, fugues, functional anesthesias and paralyses, and many other symptoms whereby the patient escapes difficulties through dissociation.

manic-depressive psychosis Name for disorders characterized by excessive elation and depression.

neurasthenia (nū′ras-thē′ni-a) Name for disorders characterized by malfunctioning of the autonomic nervous system, fatigue, anxiety, and hypochondria.

neurosis (nū-rō′sis) Minor mental disorder.

obsession A morbid idea which continually recurs against the individual's will.

paranoia (par′a-noi′a) Name for disorders characterized by compensatory delusions of persecution and grandeur.

paresis (par′e-sis) Insanity caused by syphilitic attack upon the cerebral cortex.

phobia (fō′bi-a) A morbid, uncontrollable fear.

psychasthenia (sīk′es-thē′ni-a) Name for disorders characterized by obsessions, phobias, compulsions, doubts and scruples.

psychoanalysis (sī′kō-a-nal′i-sis) A method of treating mental diseases by causing the patient to talk about his troubles until he becomes conscious of the repressed anxieties that produce his symptoms.

psychosis (sī-kō′sis) A major mental disorder.

CONCLUSION

We have completed our survey of the rôle of the human organism in the world of life. We find that man, by virtue of his biological heritage, is essentially an animal, and yet that he has become somehow uniquely human by virtue of his cultural heritage. We realize at the same time that culture itself is not something quite apart from and above other biological phenomena, but rather a special aspect of the total activity of the world of life, being made possible by the special anatomy and physiology that developed in the human response system during the course of evolution.

In conclusion, we shall turn our attention to the sciences that have provided us with this picture of the human race, to discover what their contributions have been to the cultural tradition which we have found to be of such importance in human life.

In the first place, the scientific study of life has provided us with an entirely different picture of man and of the world in which he lives than we possessed prior to the development of biology. Just as the science of astronomy has greatly enlarged our picture of the physical universe, so the discoveries of Darwin and of other biologists who preceded and followed him have revolutionized our picture of the origin of the human race. We find that our history goes back for hundreds of millions of years, involving a gradual emergence of living beings from inorganic materials and the slow modification of these beings to produce millions of differing patterns of organic structure, of which the human pattern is only one.

Biological science, especially in the fields of physiology and psychology, has provided us with a different view of our own make-up than we previously had. The traditional view held that we are composed of two parts, a physical body, and a non-physical or spiritual mind. It cannot be said that this idea has been disproved by biological research, but merely that no evidence in favor of it has ever been unearthed. Moreover, the very attitude of the scientist tends to lead him to think of the human organism as a unitary affair in which the traditional mental qualities of consciousness, purpose, and capacity for reasoning are looked upon as the outcome of the special kinds of physical and chemical activities that go on in the organism.

It would be impossible and out of place here to go into a discussion of the relationship of these new points of view to traditional religious belief. The picture of the world and of man with which science provides us is indubitably different from the picture provided by our religious tradition, but that does not mean that the really essential truths of religion have been overthrown by science. Many of the greatest religious thinkers of the present era believe that the changes in outlook which scientific evidence has forced upon us involve only the non-essential parts of the Christian religion.

Religion is concerned with the relationship between God and man. The most essential change in our point of view concerning that relationship which acceptance of the scientific point of view entails is that it seems to make man a less important part of God's universe than he formerly considered himself to be. But religion is the worship of God, not of man; and when the human race has had time to assimilate scientific knowledge and make it an integral part of its religious thought, the most important change may be merely that man will walk much more humbly before his God than he ever has in the past.

But although the biological sciences, along with other branches of science, may have struck blows at man's self-conceit, they have, by increasing his control over the forces of nature, given him grounds for greater self-confidence than ever before. By means of biological knowledge, man has begun the conquest of disease and has been able to increase his store of wealth through plant and animal breeding, through the elimination of plant and animal diseases, and through knowledge of how to provide proper conditions of nutrition for the organisms upon which he depends for his livelihood.

At the same time, there is reason to wonder whether the civilization that has been built up on the basis of science during the past few hundred years has actually produced a better and happier society of men than have the numerous prescientific cultures that have preceded it. The mere fact that the weapons forged by science can be employed to wage warfare on a more destructive scale than ever before should free us of complacency concerning the value of our scientific civilization. Up to the present, the biological sciences have done more to make war humane than to make it more terrible. But already the physiological properties of poison gas constitute an interesting problem for those who are engaged in getting us ready to defend our rights against the assertions of right which other nations hold equally dear; and already men are beginning to talk of attacking their enemies through the dissemination of the germs of disease.

Furthermore, in spite of the opportunities for wealth which scientific inventions have opened up to us, millions of the earth's population still live in direst poverty, and we seem unable to organize our economic life in such a manner as to assure even a modest degree of material welfare for all our people. And while we have done much to overcome the ravages of pathogenic organisms, human ignorance, prejudice, and superstition still block the way to accomplishing as much as we could in that direction. Only a few nights before the writing of this conclusion, a radio commentator was prevented from talking on the campaign to eliminate syphilis because it was against the policy of the authorities to allow such things to be discussed in public.

There are so many human problems to which science as yet can offer no solution. If anything, our civilization has produced an increase in the number of people who live out long lives wracked by the subtle torture of mental maladjustment. The mental hygiene that we know may offer some alleviation for this condition, but only further knowledge can enable us to eliminate it.

It is well to recognize these problems, these failures on the part of our scientific civilization. But they should not cause us to lose our faith in science. Indeed, only modern men imbued with the modern tradition, which is essentially a scientific tradition, could think of any other attitude toward these conditions than fatalistic acceptance. Today, because we have solved certain problems in the past, we feel that we can solve others in the future. Much of the failure of science to benefit mankind may be laid to what we call "human nature." But already we know that if we can only find out how to go about it we can change human nature. There is only one cure for the ills of a scientific civilization, and that is more science, better directed, and more intelligently assimilated into the program of human life.

It can be so assimilated only if educated human beings come to understand science and the part that it can play in everyday life. To *begin* your education in that direction has been the major purpose of this book. As for the better direction of scientific endeavor, there are two points on which we believe most well-informed persons would agree. First, without decreasing the amount of work going on in the physical sciences, there is need for a great increase in the scientific study of man himself, within the range of both the biological and the social sciences. Second, without decreasing the amount of study of practical scientific problems, there should be a considerable increase in the study of purely theoretical problems which at the moment seem to have no bearing on human welfare. This is a principle which is at first difficult to understand, but a careful consideration of what you have learned in the reading of this book should enable you to see that scientific knowledge constitutes a unified whole, in which the great general principles direct us toward the information we need to solve specific problems. The discovery that all organisms are composed of cells was at first of purely theoretical interest, but every student of pathology employs this information in his efforts to find how our tissues may be made resistant to the attacks of pathogenic organisms. Mendel's fundamental laws of heredity would never have been discovered by an individual who was interested only in how to breed better race horses; but they have provided us with the basic key to the control of the inheritable potentialities of all organisms. The most important thing for the non-scientific public to learn about science is that purely theoretical studies constitute the most important aspect of scientific research. For it is the public which supports scientific work and makes possible scientific activity on a large scale, and the direction of scientific endeavor lies in its hands.

The aim of this brief conclusion has been to discuss the significance of science, especially of the biological sciences. The point of view expressed comes from no higher authority than the authors themselves; you need not agree with it. But if the discussion has suggested to you that scientific knowledge should become an integral part of your life, as science itself is an integral part of the civilization in which you live, and that both you and your civilization need to consider how science may best be fitted into the whole scheme of human life, the chief end of this conclusion—and, indeed, of this entire book—will have been attained.

Appendix I

THE CLASSIFICATION OF ORGANISMS

The world of life contains a vast number of species, the naming and classification of which is a study in itself. In order to orient the reader to the methods of classification, and to the relationships among animals and plants, an outline of this system of classification is given here.

The basic unit of the system is the *species*, which is defined in Chapter XV. Subdivisions of the species which have different geographic ranges but which intergrade with each other in their morphological characteristics and are infertile are known as *subspecies* or *varieties*. Two or more species that are alike in many characteristics, as are the various species of foxes, are grouped together in the same *genus*. The scientific name of any species is made up of the Latin name for the genus, followed by the Latin for the species itself. Thus the red fox is called *Vulpes fulvus*; *Vulpes* to indicate that it belongs to the fox genus, and *fulvus* to show that it is of the species red fox. Similarly the blue fox is called *Vulpes lagopus*.

The genus *Vulpes* is classed, along with other genera having dog-like characteristics, in the dog family, or family *Canidae*. The Canidae are similar to several other families, such as the bear family and the cat family, in that they have teeth especially developed for killing and eating other animals; and on the basis of that similarity all these families are placed in the *order Carnivora*. The carnivores show resemblance to horses, rats, bats, monkeys, men, and various other animals in that they have hair and suckle their young. All of these belong to the *class Mammalia*. The mammals in turn are like birds, reptiles, fishes, and certain other classes in that they all have a cord of nervous tissue running down their backs, similar to our spinal cord, and are therefore classified in the *phylum Chordata*. Finally, the chordates, along with all other animal phyla, belong to the animal *kingdom*, rather than to the plant kingdom. In addition to the above categories, subkingdoms, subphyla, subclasses, suborders, subfamilies, and subspecies—or varieties or races—are used whenever they are necessary for classificatory purposes. The chordate phylum, for example, is divided into four subphyla, of which the subphylum containing the animals with backbones, the *Vertebrata*—including, as it does, the fishes, reptiles, birds, mammals, and two other classes—is the most important.

This scheme of classification is used for all living forms. As an illustration of how it works out, we may give the biological classification of a human being:

KINGDOM: Animalia
PHYLUM: Chordata
SUBPHYLUM: Vertebrata
CLASS: Mammalia
ORDER: Primates
FAMILY: Hominidae
GENUS: Homo
SPECIES: Homo sapiens

The reader will doubtless be startled to learn that the biologist has him filed away under such a complicated system of headings and subheadings. As a matter of fact, the biologists look upon the species as the fundamental unit of classification, and for ordinary purposes a member of the human race would be just another *Homo sapiens.*

The following is a list of the major phyla of the plant and animal kingdoms. Several minor phyla are omitted, the list being confined chiefly to the phyla containing members that have been introduced in the body of this book. In some cases the classes included in a phylum are mentioned.

THE MAJOR PLANT PHYLA

SCHIZOPHYTA—Includes the bacteria and blue-green algae, which resemble each other in that they have no well-defined nucleus and never reproduce sexually.

CHLOROPHYTA—The green algae.

CHRYSOPHYTA—A group of yellow-green algae, including the unicellular diatoms which constitute an important element of the plankton.

PHAEOPHYTA—The brown algae.

RHODOPHYTA—The red algae.

FUNGI—All the colorless thallus plants except the bacteria. They include yeasts, molds, mildews, blights, rusts, smuts, mushrooms, and bracket fungi. The lichens are classed as fungi, although they always have green algae living with them symbiotically.

BRYOPHYTA—Non-vascular seed plants. The phylum includes two classes: (1) *Hepaticae,* or liverworts. (2) *Musci,* or mosses.

PTERIDOPHYTA—Vascular land plants without seeds. The most important plants of this phylum are the ferns. Others, less well known, are the club mosses and horsetails.

SPERMATOPHYTA—The seed-bearing plants. The phylum includes two classes: (1) *Gymnospermae,* or cone-bearing plants, composed chiefly of such evergreen trees as the pines, hemlocks, and spruces. (2) *Angiospermae,* the flowering plants, including the plants we ordinarily term flowers and grasses, together with the non-cone-bearing trees and shrubs. Nearly all our domesticated plants belong in this class.

MAJOR ANIMAL PHYLA

PROTOZOA—The unicellular animals. There are four classes: (1) *Rhizopoda,* which display ameboid movement. (2) *Flagellata,* which move by means of flagellae. (3) *Infusoria,* which possess cilia. (4) *Sporozoa,* which reproduce by means of spores.

PORIFERA—The sponges. These are non-motile animals which ingest their food by means of ciliary movements that drive currents of water through thousands of pores placed in their sides.

COELENTERATA—Animals with a body composed of two fundamental cell layers, with a mouth, but no anus. In the addition to Hydra, this phylum includes jellyfish, sea anemones, and corals.

ANNELIDA—Segmented worms, including many marine worms, the earthworm, and the leech.

MOLLUSCA—Sessile or slow-moving animals, usually having a shell. The phylum includes snails, slugs, clams, oysters, octopi, and squids.

ARTHROPODA—Animals with jointed legs and an external skeleton. The phylum includes insects, spiders, centipedes, crabs, lobsters, and many similar forms. It is the most numerous of all the phyla, and the class *Insecta* alone contains far more than half of all the known animal species.

CHORDATA—Animals with a dorsal nerve cord. It includes four subphyla, of which the subphylum *Vertebrata* is the most important. Of all the forms in the other subphyla, Amphioxus alone has been mentioned in this book. The subphylum *Vertebrata* is divided into seven classes: (1) *Cyclostomata,* long, thin, fish-like creatures without jaws or lateral fins, including the lampreys and hagfish. (2) *Elasmobranchii,* fish with cartilaginous skeletons, of which the sharks are most widely known. (3) *Pisces,* the bony fishes, including the greater proportion of all fishes. (4) *Amphibia,* frogs, toads, salamanders, and newts. (5) *Reptilia,* snakes, turtles, lizards, alligators. (6) *Aves,* or birds. All members of this class are warm-blooded and have feathers. (7) *Mammalia.* The members of this class are warm-blooded, have hair, and suckle their young. The class is divided into three subclasses: (1) *Prototheria,* or egg-laying mammals, commonly called *monotremes,* from the name of their order. They include the duckbill, shown in Fig. 74. (2) *Metatheria,* or animals that carry their young in a pouch. They include the kangaroo and opossum, and they are often spoken of as *marsupials,* from the name of their order. (3) *Eutheria,* or placental mammals, having a placenta to nourish their unborn offspring. The following is a list of the most important orders among the placental mammals:

Insectivora—the insect eaters, small brained and very primitive—shrews, moles, hedgehogs.

Chiroptera—winged mammals—bats.

Primates—lemurs, monkeys, apes, men—distinguished chiefly by their large brains and prehensile digits, with thumb opposed to finger.

Carnivora (suborder *Fissipedia*)—flesh eaters, with strongly developed canine teeth—lions, tigers, cats, hyenas, raccoons, bears, otters, weasels, skunks, foxes, dogs.

Carnivora (suborder *Pinnipedia*)—aquatic, carnivorous mammals with fin-like limbs—seals, sea lions, walruses.

Rodentia—small, clawed, with strongly developed front teeth for gnawing—squirrels, woodchucks, beavers, rats, mice, gophers, rabbits.

Edentata—slow moving, teeth absent from front jaw—anteaters, sloths, armadillos.

Ungulata—herbivorous, hoofed, molars large and broad—elephants, horses, camels, deer, cattle, sheep, swine.

Sirenia—aquatic, herbivorous, front limbs fin-like, hind limbs absent, hair almost lacking—includes the dugong and manatee.

Cetacea—aquatic, fish-like in shape, front limbs many-jointed fins, hind limbs absent, hair almost lacking—whales, dolphins, porpoises.

Appendix II

THE BRANCHES OF BIOLOGICAL SCIENCE

The study of living organisms has grown into such a vast, complex field of science that it is impossible for one man to possess all of the knowledge that constitutes biology. As a result, the science is divided into a number of branches, which differ chiefly in their methods of approaching the study of life. None of these branches, however, is independent of the others, and it is impossible for a scientist really to grasp any one of them without knowing something about the rest. For a long time biologists, as well as scientists in other fields, tended to become more and more specialized and to "know more and more about less and less," but this attitude is gradually changing, and biologists in all branches of the science are realizing more and more what contributions the other branches can make to their own.

Each of the branches is itself a "pure" science, i.e., the scientists working in it are concerned chiefly with discovering new facts and theories in it, thereby adding to the world's knowledge. Much of this knowledge, however, has a practical application to the needs of man, and there is consequently a series of "applied" branches of biology, which are concerned with the application of science to the needs of mankind. In the following the applied branches are mentioned after the pure branches to which they correspond most closely.

Botany is the study of the plant kingdom, and *zoology* that of animals. This division more or less separates biologists into two groups, although many branches, such as physiology and genetics, include parts of both botany and zoology.

Systematic biology (botany or zoology) or *taxonomy* is concerned with the classification of animals and plants. When studied by itself, it centers about the interrelationships and the evolution of species (as well as genera, families, and orders), but it is a valuable tool for the other branches, since one cannot understand the significance of the form or functions of an organism unless one knows its name and its relationships to other organisms. This branch of biology is divided into a number of subbranches concerned with the different divisions of the animal and plant kingdoms, such as *protozoology, entomology* (the study of insects), *icthyology* (the study of fishes), *ornithology* (birds), *mammalology, bacteriology, algology, mycology* (fungi), *bryology* (mosses), etc. The application of systematic zoology is general, but is, of course, most important when concerned with organisms that are either useful or harmful to man. Thus icthyology and the systematic study of plankton organisms are very important in studies of fisheries, economic entomology is of great importance in studying the characteristics and the identification of insect pests, and systematic bacteriology and mycology are of obvious value in conquering the diseases of animals and plants. Systematic botany of the higher plants is of particular economic value when concerned with trees (*dendrology*) or with the various crop plants (*economic botany* in general).

Ecology is the study of organisms in relation to their environment. Many of the problems in this field are discussed in Chapter XV. Particularly in the form of animal ecology, it is largely a more exact, scientific study of the same problems taken up formerly by students of natural history. Plant ecology is largely the application of the principles of plant physiology to the study of natural communities of plants in the field, and forms the scientific background of forestry. The applications of animal ecology are chiefly in the study of our fish and game resources, as well as in the management of cattle and other stock ranges.

Pathology is the study of diseases of animals and plants. It is, of course, largely an applied science, animal pathology being one of the major divisions of medicine, and plant pathology is essential to agriculture. Medical pathology is, of course, closely linked with bacteriology, while plant pathology is similarly associated with the study of fungi, or mycology, and with economic entomology.

Morphology and *anatomy* are the study of the form and structure of organisms, the former emphasizing the external, and the latter the internal features. The men who study these branches of biology use their knowledge to help explain the evolutionary history of the larger divisions of the animal and plant kingdoms, i.e., the orders, classes, and phyla, using criteria such as those described in Chapter XIV under "The Evidence from Comparative Anatomy."

The application of the study of human anatomy is obvious, as it is the basis of all surgery, while mammalian anatomy in general is equally important to veterinary science. The anatomy of woody plants is valuable to forestry and the lumber industry; and in economic botany the anatomy of the fiber-producing plants, such as cotton, hemp, and flax, is of great practical value, as is also that of the plants which produce valuable secretions, such as rubber.

Embryology is the study of the early development of organisms, and as a separate branch of biology is practically confined to animals, since the embryology of plants is too simple to be a study in itself. The embryologist is occupied with the relation of his subject to evolution, but more particularly to the problem of the differentiation of organs and tissues. The application of mammalian embryology to medicine and veterinary science is obvious.

Histology is the study of tissues, and, like embryology, is confined as a separate branch to zoology, since plant tissues are simple enough so that their study comes within the field of the plant anatomist. The histologist, like the embryologist, is concerned with the differentiation of cells and tissues, and also with their function, including such problems as glandular secretions, pigmentation, etc. The application of histology to medicine is great, since most disease bacteria confine their activities to particular tissues.

Cytology is the study of the cells of organisms. Although many cytologists are concerned with the nature of protoplasm in general, and thereby join hands with the physiologists, the importance of the chromosomes in heredity has attracted so much attention to these bodies that the bulk of modern cytology is the study of the structure and behavior of the chromosomes, as well as their importance in heredity and evolution. The application of cytology is chiefly to plant and animal breeding.

Genetics, or the study of heredity, is only thirty-seven years old as a separate branch, dating from the rediscovery of Mendel's laws. (See Chapter XIII.) But it has become one of the largest and most complex of the branches of biology. Geneticists are occupied primarily with the nature and mode of operation of the factors controlling inheritance, chiefly the gene, but are also interested in the study of mutations as applied to evolution. The application of genetics to the improvement of domestic animals and cultivated plants has already been discussed, and comprises the applied sciences of animal breeding and plant breeding; the study of human genetics with a particular view toward bettering the inheritance of mankind is known as *eugenics.*

Physiology is the study of the organism from the point of view of its activity and functions. There are three main aspects of this most important branch of biology. *General physiology* aims to study the nature of protoplasm and of the essential processes which keep it alive. *Animal physiology* studies in particular those processes most essential to animals, such as circulation of the blood, muscular and nervous activity, and the digestion and absorption of food. *Plant physiology* studies such problems as the manufacture of food by photosynthesis, the intake and outgo of water, the absorption of mineral salts, and the translocation of substances through the plant.

The applications of physiology are very numerous and varied. Animal, or rather human, physiology is, of course, the basis of a very large proportion of the science of medicine. Furthermore, it forms the background of animal husbandry, an applied science dealing with the problems connected with domestic animals, such as milk production in cows and egg production in poultry. Plant physiology is equally important in its applications to agriculture. Efficient production in agriculture depends on a scientific knowledge of the factors affecting the growth of plants. The problem of the fertilization of plants is within the field of plant physiology, as is that of irrigation in dry regions and of hardiness and frost resistance in regions with cold winters.

Psychology is the study of the behavior and experience of animals. Plant behavior is so slightly developed that a specialized science is not required for its study. The chief interest in psychology has centered in the human organism; but, while it is difficult to study the experience of animals, the branch of psychology known as *animal behavior* is now developing rapidly. Certain branches of psychology are closely allied in interest to the physiology and anatomy of the sense organs and the nervous system, but the psychologist studies the behavior of the intact organism, rather than the responses that take place in isolated cells, tissues, and organs. Scientific psychology came into being about sixty years ago through a fusing of the interests of physiologists and philosophers. Those who view it as chiefly descended from philosophy are inclined to class it with the social sciences; and, indeed, it is basic to social science, since social science is very largely a study of the behavior of human beings. However, much of the most important part of psychology has little social significance, and other biological disciplines, such as genetics and the study of evolution, are also important to social science. Hence, we feel that psychology is properly a branch of biology, although it is doubtless near the border line between the biological and social sciences; and we feel certain that most psychologists, in this country at least, would concur in that classification. Psychology is being applied in industry, merchandising, education and child care, and in dealing with criminals and delinquents as well as with others who are mentally ill or socially maladjusted. *Psychiatry* is the medical specialty which has to do with the care of the insane and neurotic. Since, in the past, psychology has not been sufficiently advanced to furnish an adequate set of principles for dealing with the complex problems of mental abnormality, psychiatry has been developed largely by practical medical men, without much contact with the main body of psychological research; but at the present time psychologists and psychiatrists are taking more and more interest in one another's work; and in due time psychiatry will doubtless take its place as that part of applied psychology which has to do with the cure of mental disease.

The Relationships Between the Biological, Social, and Physical Sciences

There is a close connection between biology and *physics* and *chemistry*, since an organism is essentially a highly complex system of physico-chemical processes. *Biophysics* and *biochemistry* study the physics and chemistry of protoplasm and its activities. By doing this they link physiology closely with physics and chemistry. *Mathematics* is an integral part of the science of *biometry*, in which biological problems, chiefly those involving large populations of organisms, are treated statistically. Statistical methods also play a large part in genetics and psychology. The study of extinct, fossil forms of life, i.e., *paleontology*, links biology with *geology*. Another connection between biology and geology, as well as *geography*, is through *plant* and *animal geography*, i.e., the study of the present distribution of plants and animals. Since the distribution of the species of organisms often is intimately bound up with the history of the region in which they occur, this branch of biology has made contributions to geology and geography. Through *human biology*, connections are established between biology and the various social sciences. *Archaeology*, or the study of ancient cultures and civilizations, and *anthropology* and *ethnology*, the study of human races and cultures, connect the biological aspects of human evolution with *history* and *sociology*.

SUGGESTED READING

The following are a few of the many books that deal with the matters discussed in this text. Some of them, especially the textbooks, have been chosen because they give a comprehensive account of certain fields of biological science. Others are included because they embody interesting and valuable treatments of special topics.

General

Wells, H. G., Huxley, J. S., and Wells, G. P. *The Science of Life.* Doubleday, Doran, 1931. This book deals with nearly all the subjects covered in this text, but in much greater detail. It is interestingly written for the general reader.

Introductory Textbooks

Jean, F. C., Harrah, E. C., and Herman, F. L. *Man and the Nature of His Biological World.* Ginn, 1934. An elementary text stressing the importance of biological knowledge to human life.

Brown, W. H. *The Plant Kingdom.* Ginn, 1935. An excellent elementary botany.

Guyer, Michael F. *Animal Biology.* Harpers, revised edition, 1937. An outstanding text, stressing the functional aspects of animal life.

Hegner, R. W. *College Zoology.* Macmillan, revised edition, 1936. The standard introductory text in structural zoology and animal taxonomy.

Crandall, Lathan A. *An Introduction to Human Physiology.* Saunders, 1934. A brief elementary text.

Williams, J. F. *A Text-book of Anatomy and Physiology.* Saunders, 1935. This short text is especially good for its anatomical charts.

Martin, H. N. *Human Body.* Holt, 12th edition, 1934. A somewhat more advanced, but clearly and interestingly written text in anatomy and physiology.

Dashiell, J. F. *Fundamentals of General Psychology.* Houghton Mifflin, 1937. A leading textbook stressing the psychology of behavior.

Boring, E. G., Langfeld, H. S., and Weld, H. P. *Psychology.* Wiley, 1935. The best text for the study of the psychology of consciousness.

Ruch, Floyd L. *Psychology and Life.* Scott, Foresman, 1937. An elementary text dealing especially with the aspects of psychology that are of greatest interest and practical value to the college student.

Plants, Animals, and Their Evolution

Romer, A. S. *Man and the Vertebrates.* University of Chicago Press, 1933. An interesting account of the evolution of the vertebrates. About half the book is devoted to human evolution and the development of the human body.

Coulter, Merle C. *The Story of the Plant Kingdom.* University of Chicago Press, 1935. A description of plants and their evolution.

Mason, Frances, ed. *Creation by Evolution.* Norton, 1935. Points of view on evolution by several authorities.

Lull, Richard S. *Organic Evolution.* Macmillan, 1927. The classic textbook in the field of evolution.

Morgan, Thomas H. *The Scientific Basis of Evolution.* Norton, 1935. A discussion of the causes of evolution by a leading geneticist.

Heredity and Development

Snyder, Lawrence H. *The Principles of Heredity.* Heath, 1935. A standard textbook on genetics.

Holmes, S. J. *Human Genetics and Its Social Import.* McGraw-Hill, 1936. A clearly written discussion of heredity and eugenics.

Davenport, Charles B. *How We Came by Our Bodies.* Holt, 1936. A description of the mechanisms of heredity and the course of development.

Mohr, Otto H. *Heredity and Disease.* Norton, 1934.

Sinnott, E. W., and Dunn, L. C. *Principles of Genetics.* McGraw-Hill. 2nd edition, 1932.

The Human Body and Its Hygiene

Clendening, Logan. *The Human Body.* Knopf, revised edition, 1937. A popular and fascinating account of human physiology and anatomy.

Haggard, Howard Wilcox. *The Science of Health and Disease.* Harpers, revised edition, 1938. A popular account of human ills and how to avoid them.

Diehl, Harold S. *Healthful Living.* McGraw-Hill, 1935. A good book dealing with the everyday hygiene of the normal individual.

Hoskins, R. G. *The Tides of Life.* Norton, 1933. A popular, authoritative treatment of the endocrine glands.

Cannon, Walter B. *The Wisdom of the Body.* Norton, 1932. A description of research on the functions of the vital reflexes.

Parran, Thomas. *Shadow on the Land: Syphilis.* Reynal & Hitchcock, 1937. An appraisal of a serious public health problem by an outstanding leader in the present campaign against venereal disease.

The Human Mind and Its Hygiene

Anastasi, Anne. *Differential Psychology.* Macmillan, 1937. A well-written book on the differences between individuls and groups.

Guthrie, E. R. *The Psychology of Learning.* Harpers, 1935. An understandable discussion of how learning takes place.

Warden, Carl J. *The Emergence of Human Culture.* Macmillan, 1936. Culture is shown to be an emergent appearing in the course of biological evolution.

Kellogg, W. W. and L. A. *The Ape and the Child.* McGraw-Hill, 1933. The story of an interesting experiment to discover how human an ape would become if reared like a normal child.

Mead, Margaret. *Sex and Temperament in Three Primitive Societies.* Morrow, 1935. How culture molds human nature. A description of the life of three primitive tribes.

Hepner, Harry W. *Finding Yourself in Your Work.* Appleton-Century, 1937. A stimulating discussion of the problem of choosing a vocation and succeeding in it.

Menninger, Karl. *The Human Mind.* Knopf, revised edition, 1937. A very popular book on the mind as the psychiatrist sees it.

Hart, Bernard. *The Psychology of Insanity.* Macmillan, 1934. The best book for acquiring an elementary understanding of functional insanity and its causes.

Guthrie, Edwin R. *The Psychology of Human Conflict.* Harpers, 1938. Maladjustments are viewed as resulting from the wrong sort of learning.

Horney, Karen. *The Neurotic Personality of Our Time.* Norton, 1937. An interesting account of human maladjustments and their relation to our particular form of culture.

Scientists and Their Work

Jaffe, Bernard. *Outposts of Science.* Simon & Schuster, 1935. Tells of the work of many outstanding modern biologists.

Locy, W. A. *Biology and Its Makers.* Holt, 1908. A history of biology in terms of the men who have contributed most to it.

de Kruif, Paul. *Microbe Hunters.* Harcourt, Brace, 1926. The work of the bacteriologists.

de Kruif, Paul. *Hunger Fighters.* Harcourt, Brace, 1928. Many kinds of biologists who have contributed to the increase and improvement of our diet.

Keller, F. S. *The Definition of Psychology.* Appleton-Century, 1937. Tells of the men who have laid the basis for the development of present-day psychological thought.

Garrett, Henry E. *Great Experiments in Psychology.* Appleton-Century, 1930.

Darwin, Charles Robert. *Life and Letters.* D. Appleton, 1888, 2 vols. Notable for a single chapter which contains the simple, modest autobiography which Darwin wrote for his children.

Vallery-Radot, R. *The Life of Pasteur.* The Garden City Publishing Company.

Pruette, Lorine, E. *G. Stanley Hall.* Appleton-Century, 1926. An analysis of the mind and character of an early leader of American psychology.

Curie, E. *Madame Curie.* Doubleday, Doran, 1937.

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(References to figures are in italics.)