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BIOLOGY

THE SCIENCE OF LIFE

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BIOLOGY

THE SCIENCE OF LIFE

BY

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BIOLOGY: THE SCIENCE OF LIFE

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PREFACE

Fundamentals of biology are the same the world over, but instructors differ regarding the order in which they wish to present the subject. One of the most important reasons for this is that the training of the teachers varies according to the institution from which they come. Practically every college and university offers a course in elementary biology that differs in some respects from that offered in other colleges and universities. This book, intended for beginning college students, has been arranged in such a way as to allow a considerable amount of flexibility in the presentation of material. This is desirable not only because of differences in the training of instructors but also because of differences in the equipment and laboratory space available and in the location of the college.

The first few chapters present general fundamentals. Following these, some teachers will wish to take up Part IV, General Biology, and refer students to Parts II and III for reading assignments in preparation for laboratory work; others will wish to study the plant and animal types first; still others will wish to begin with the study of insects, because of the field work that can be done in the fall, reserving the study of plants until spring, when there are flowers in the fields and woods. Finally, in a survey course with emphasis on human biology, Parts II and III may be used for reference only.

It is a common practice to begin the study of biology, especially the zoology part of the course, with a detailed study of the frog as a type, but it is quite as usual to begin with the Protozoa and work up to the vertebrates.

As a result of long experience, it seems to the author that the beginning students should at first devote their time to descriptive work. Students then have part of the material to be presented in the laboratory. The study of structure, coupled with an understanding of the use of these structures, furnishes a good preparation for a clear understanding of the important biological concepts with which the book is very largely concerned. Parts II and III provide a good preparation for Part IV, whether this work is done in the laboratory alone or in the usual laboratory-lecture combination.

Parts V and VI deal with the more abstract side of biology. The subject matter in this section is presented as simply as possible in the hope of stimulating the interest of the students.

A general course in biology should emphasize human biology; at first glance the book may seem to be loaded in favor of zoology. Careful review, however, will reveal that plant biology is considered in every discussion of principles—respiration, excretion, reproduction, etc. Much more botany is included than is usual in a general course in biology. This is in keeping with the growing understanding that plant and animal vital processes have much in common. No well-rounded course could be complete without including the fundamentals of plant structure and processes.

Special bibliographies are placed at the ends of chapters and general bibliographies at the ends of some of the sections. These afford ready reference to special books for a more extended study of various subjects. No attempt has been made to include a complete bibliography.

The practical applications of biology are so interesting that there is always grave danger in emphasizing this aspect of the subject at the expense of the fundamentals of the study. An effort has been made to keep a proper balance between these two aspects of biology. Any suggestions to increase its usefulness will be most welcome.

The untimely death of Prof. Hegner occurred while the final draft of the manuscript of this book was being prepared. When the book was being organized, however, the two authors worked together one summer at Salisbury, Maine, and later at Baltimore. All suggestions and criticisms by Prof. Hegner were taken into full account in the preparation of the final manuscript.

MARY STUART MACDOUGALL.

DECATUR, GA.,
November, 1942.

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Many people have helped in the making of this book. The author wishes to express thanks especially to Dr. Ernest Runyon, professor of botany at Agnes Scott College, for invaluable help in the botany sections of the book and for use of certain figures; to Dr. Schuyler Christian, professor of physics, and Dr. Philippa Gilchrist, professor of chemistry, both of Agnes Scott College, for help in those sections dealing especially with physics and biochemistry. Miss Blanche Miller and Miss Frances McCalla aided in making certain dissections that were used as a basis for original figures. To Dr. Catherine Torrance, professor of Greek and Latin at Agnes Scott College, the author expresses appreciation for her help, especially with the glossary.

The drawings, which are an important part of the book, were done by Mrs. Betty Fountain Edwards, Miss Beatrice Shamos, Mrs. Ernest Runyon, Miss Frances Baker, Mrs. Florence Kendrick, and Miss Jane Wyatt. To these artists grateful thanks are due for their never-failing patience in the execution of their work.

The author wishes to thank the friends and the companies that furnished photographs or gave permission for copying figures and diagrams. These are acknowledged where the figures appear.

MARY STUART MACDOUGALL.

NOTE TO THE FOURTH IMPRESSION

It is the aim of this book to provide specific information in the survey part of the book as a basis for the comparative and theoretical portions studied later; and from the first page to the last to emphasize the organization and unity of the living world that a study of biology makes clear. Through the cooperation of the friends and teachers, many corrections have been made in the third and fourth printings. These include not only corrections in the text but substitutions and additions to figures where it was found that these figures could be improved for teaching purposes.

My thanks are due especially to Dr. W. B. Unger of Dartmouth College, Dr. H. W. Jackson of Virginia Polytechnic Institute, Dr. W. B. Redmond, of Emory University, Dr. E. H. Runyon (especially for corrections in the Botany sections), and Miss Frances McCalla, of the Agnes Scott College staff.

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March, 1944.

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BIOLOGY: THE SCIENCE OF LIFE

INTRODUCTION

The year's at the spring
And the day's at the morn;
Morning's at seven;
The hillside's dew-pearled;
The lark's on the wing;
The snail's on the thorn;
God's in his heaven—
All's right with the world!
—BROWNING.

The study of biology is a great adventure, for it is the study of life itself. *Biology* (Gr. *bios*, life; *logos*, discourse) deals with many things besides the study of living things themselves. There is the question of how the environment affects all types of organisms, plant and animal; questions arise as to how living things affect each other; there are questions concerning agriculture, health; there are even social questions. A knowledge of how the human machine works, or how some things are inherited, may be of vital importance in our lives. These and many similar questions stimulate curiosity as to the how and why of life processes.

Living things are everywhere. Every stream, plain, and forest is alive with hordes of animals and multitudes of plants. Even in great cities, birds fly overhead; many trees and plants exist under artificial conditions created by man; and in these trees and shrubs, birds build their nests and insects find permanent homes. In addition, in these same situations, every bit of substance that may be used as food is soon occupied by a multitude of microscopic forms of life. Family pets are welcome in our homes, but very often many unwelcome insect pests, flies, mosquitoes, fleas, and the like are troublesome guests. Man is himself an animal and is the home in which other kinds of animals dwell, whether he knows it or not.

Human activities are constantly influenced by living things. The sources of food and the origin of clothes are practical biological problems; there are many others. Certainly health problems are both practical and important. A good example of this type of problem is the working out of the method of transmission of malaria and of ways to prevent the spread of this dread disease. The happiness, health, and prosperity of a whole country may depend upon a knowledge of these things.

Conservation has become a necessity in this country. Any intelligent program to save the land and wild life for future generations calls for many kinds of knowledge: the result of cutting timber, the role of soil bacteria, the nature of the animals that prey upon each other, and many kindred problems. Many other practical problems might be mentioned that give authority to the statement that the study of biology gives valuable and useful knowledge.

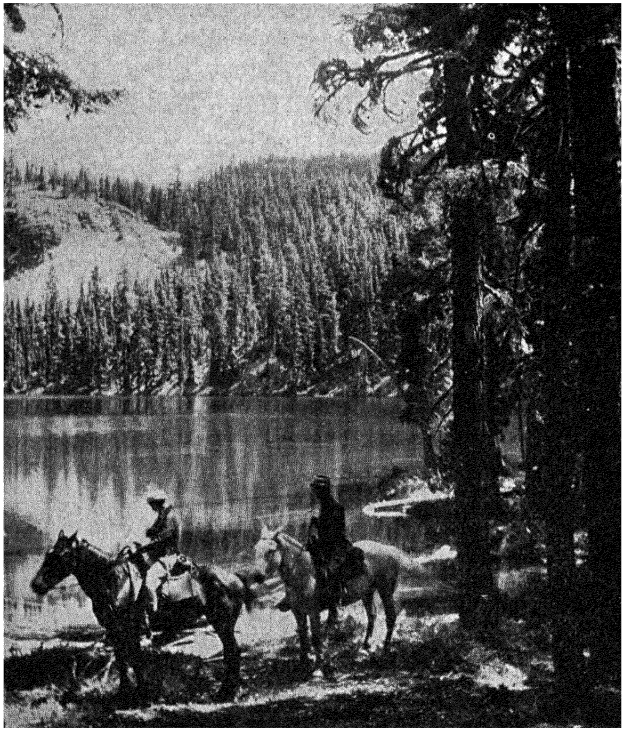

Fig. 1.—Lake Como from the northeast side, Mountain Lake primitive area. Rogue River National Forest. (Photo by the U. S. Forest Service.)

One has only to view the plants and flowers of the hills and forests in order to realize that these satisfy a sense of beauty common to the vast majority of people (Fig. 1). Browning could not have written the verse at the beginning of this chapter if he had been unacquainted with the lowly snail. Many of our poets live close to nature and are well acquainted with the woods and creatures found there. "All's right with the world" means that everything not only is beautiful but is *in order*. This is an idea that the study of biology demonstrates, *i.e.*, that there is a definite organization on earth and among the living things that are

its inhabitants. Each living thing is beautifully made, whether the finished product is attractive or not. Each tiny cell has an organization that even the best informed scientist only partly understands. This knowledge gives a deeper meaning to life itself.

For leisure time, the study of nature will richly repay one for the time spent. In addition to the millions of plants and animals that may be easily seen, there are millions more that can be seen only with the aid of a microscope. A knowledge of organisms, of how they are made and what they do, enables one to understand how they fit into the scheme of life. And this is an enriching study from any point of view.

Finally, the most important result of any scientific study is the learning of the *scientific method.* This training is useful in any field of endeavor. It means the accumulation of facts from first-hand observation and the arrangement of these facts in such a way as to lead to definite conclusions. No guesses are allowed, and haphazard methods are barred. In the Dark Ages, learned men may have argued and quoted authority as to whether a cow lacked teeth in the upper or lower jaw. The scientific method requires that one examine the jaws of the cow and by observation alone reach a correct conclusion. Exact knowledge is of inestimable value in the struggle for existence with environment and fellow man. The best way to acquire exact knowledge is to learn to apply the scientific method.

The Chief Divisions of Biology

The science of life, which is called *biology,* covers many fields. For convenience in studying the enormous populations of the earth, two great divisions are made: *botany* (Gr. *botane,* an herb or plant), the study of plants, and *zoology* (Gr. *zoon,* animal; *logos,* discourse), the study of animals. However, as will be seen later, the fundamental properties of living substance are common to both plants and animals. For example, the life processes of nutrition, respiration, and reproduction are fundamentally the same in both the plant and animal kingdoms.

Botany and zoology may be further subdivided into a number of other subjects, as indicated in the accompanying diagram (Fig. 2). Some of these subjects deal with the structures of living things and hence are called *morphology* (Gr. *morphe,* form), and others deal with life processes and are called *physiology* (Gr. *physis,* nature). As shown in the figure, some of the subdivisions of the subject of biology involve a study of both morphology and physiology.

The student should bear in mind from the beginning that basic facts must be learned as a means to an end and not as an end in themselves. Facts are important only as they serve as a basis for understanding fundamental biological principles. Principles or laws can be formulated only after study in great detail of many types of organisms.

It has been the aim of the authors to present in the very simplest manner possible those fundamental principles of the life science biology

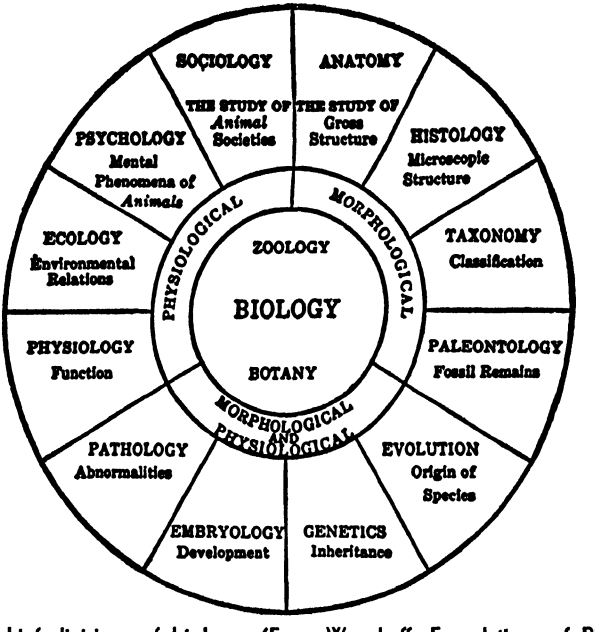

Fig. 2.—The chief divisions of biology. (From Woodruff, Foundations of Biology, The Macmillan Company.)

that are a necessary part of any liberal education. And so the great adventure, the study of the living world, including man, begins.

Part I
THE FOUNDATIONS OF BIOLOGY

CHAPTER I

LIVING AND LIFELESS MATTER

Everything in Nature contains all the powers of Nature. Everything is made of one hidden stuff.

—EMERSON.

I. What Is Life?

Any precise definition as to what life is seems impossible. In general, the difference between something that is alive and something that is dead is fairly obvious. If life is defined as "the state of living," the term *living* would have to be defined; if it is defined as "the sum total of vital processes," the term *vital* needs further explanation. However, the terms *living* and *lifeless* may be defined as states or conditions of matter. Lifeless matter is usually divided into two kinds: *organic* matter, such as cellulose, sugar, fats, and the like, produced by living things, and *inorganic* matter, which includes minerals, elements, and other chemical substances. This distinction between organic and inorganic substances was due to the old belief that only living things could produce or synthesize organic materials. In 1828, however, Wöhler synthesized urea, an organic waste material, in the laboratory. Since that time, many organic substances have been synthesized in scientific laboratories. The distinction between organic and inorganic matter, then, is one of convenience only. Inorganic matter may have once been a part of something living, but after the death of the organism it is resolved into its original state.

Though it is not known what life is, the characteristics that set it apart from lifeless matter are well known. In studying these characteristics, it has been found that all living things, whether lowly plants, humble one-celled creatures, complex animals, even man himself, have certain fundamental features in common. A study of these fundamentals gives one a basis for study of the order that is characteristic of the living world. It matters not whether one studies structure, the use of the structures, or the more fundamental organization of protoplasm; the orderly organization of nature and nature's processes is everywhere apparent.

II. The Unique Characteristics of Living Matter

A. Organization.—Living organisms have a definite range of size and shape and a definite internal organization. Nothing living is formless,

as are water and clouds One of the most fundamental characteristics of anything living is the presence of *protoplasm* (Gr *protos*, first, *plasma*, form) This semifluid, colorless material is present wherever there is life It has been aptly called *life stuff*, for life cannot exist without it, indeed, the unique features of living things are due to the structure and activities of protoplasm As will be seen later (page 21), protoplasm is a complex system and includes many materials, both organic and inorganic

Protoplasm is organized into units or cells Each cell has a *nucleus* (page 32) surrounded by *cytoplasm* (page 32) Cells may vary greatly in general characteristics in different organisms, or in different parts of the same organism, but this fundamental life unit, the cell, has all the characteristics that set apart the living from the nonliving world In later chapters, it will be seen that cells are organized into tissues, tissues into organs, organs into systems, and systems into organisms that make up the living world

B Chemical Composition.—The chemicals found in living matter are the same as those found in nonliving matter It is emphasized that the unique character of living matter is due to the particular organization of certain chemicals in the form of protoplasm Although there are about 92 elements, only 12 to 14[1] are found in appreciable quantities living matter, and only 4—carbon, oxygen, hydrogen, nitrogen—compose about 90 to 99 per cent of living matter. The air contains 2 of these 4 elements in the form of gases, oxygen and nitrogen, as well as small amounts of carbon dioxide and water

The organic substances always associated with living matter are *carbohydrates*, such as starches and sugars, *lipids* (fat-like substances), and *proteins*, which are the most complex of all chemical substances.

C. Protoplasmic Activity. 1 METABOLISM —LIVING matter is not static but is always changing Protoplasm carries on all life activities It is continuously breaking down and rebuilding itself This involves the taking in of substances (foods), transforming them, and getting rid of wastes. It also involves repairing itself as well as adding to its volume The sum total of the activities, maintenance, repair, and growth, is known as *metabolism* (Gr *metabole*, change) The building-up phase of metabolism is *anabolism* (Gr *anabole*, that which is thrown up), and the tearing down phase is *katabolism* (Gr *katabole*, throwing down). Anabolism requires energy, and energy comes from foodstuffs The energy is released as the foodstuffs are broken down, chiefly through the oxidation that goes on in the cells This is respiration and involves the taking in of oxygen and the giving off of wastes, chiefly carbon dioxide, which is formed by the oxidation process All living things respire as long as they live

[1] For a list of these chemicals, see p 22

2. MAINTENANCE AND GROWTH.—As explained above, protoplasm is being continually broken down and rebuilt. When these two processes exactly balance each other, protoplasm maintains itself but does not grow. If there is more breaking down than rebuilding, the organism wastes away, and, if this process continues, it must die. If, however, the building process outweighs the destructive process, growth takes place. A familiar characteristic of life is growth from small to larger organisms. Lifeless things may grow, but they grow in a different way. The snowball and the crystal grow, but the new material will be on the outside. This is growth by *accretion*. Living substance has the unique power of transforming materials (foods) and incorporating them into its substance. This is growth by *intussusception* (L. *intus*, within; *suscipere*, to take up). At maturity, the processes of destruction and repair in organisms tend to balance themselves.

Growth is not haphazard but proceeds according to a definite plan. A maple tree will grow according to its own pattern, and so will all other organisms, plant and animal.

3. REPRODUCTION.—Another characteristic feature of living things is their power of reproducing themselves. Lifeless matter cannot do this. No reproductive process is really simple, but one of the simplest types that take place in the one-celled creatures is *cell division*. Lower plants and animals may reproduce themselves in this manner several times a day. In most of the higher organisms, there are two parents, each producing specialized types of reproductive or germ cells. A cell from the male parent, sperm, must fuse with a cell from the female parent, egg, to form a zygote (Gr. *zygotos*, yoked) or fertilized egg. The new organism will develop from this fertilized egg into its own particular adult form.

One of the most interesting facts of reproduction is the great detail with which individual characteristics of parents are transmitted to their offspring. This gives a basis for the study of *heredity*.

4. IRRITABILITY AND ADAPTATION.—The ability of living substance to respond to stimuli is well known. A plant does not have as complex mechanisms for receiving stimuli as the higher animals. Nevertheless, plants respond in varying degrees to stimuli. This characteristic irritability is responsible for the power of adaptation shown by living things. An organism adapts itself to its environment or dies. It is a familiar fact that plants and animals that live in water are adapted to that medium and are very different from those that live on land; also, the character of vegetation changes as one ascends from the plains to the mountaintop. As will be shown later (page 48), the how and why of distribution are one basis for the study of the adaptation of an organism to one environment.

III. Vitalism and Mechanism

The metabolic activities of protoplasm proceed in an orderly manner; living things develop, each according to a characteristic pattern. Everywhere in nature there is law and order. The question naturally arises as to whether there is some *vital force* at work that is different from chemical and physical energy. The *mechanistic conception* is that all life processes may be explained in terms of chemical and physical phenomena; the *vitalistic conception* assumes an additional "vital force" of a nature different from those of physics and chemistry. Biologists do not agree on this point. It is a fact that many life processes may now be explained in terms of physical and chemical phenomena. Yet not all vital processes are fully understood. There can be no answer to this question until more information has been obtained. One point in favor of the mechanistic conception is that it stimulates study in an attempt to solve all the unexplained problems of life.

IV. The Origin of Life

A. Spontaneous Generation.—Any person who observes living things sooner or later asks himself, where did life begin? To this there can be no real answer, for the answer is not known. Speculation on this subject led ancient peoples to formulate theories as to how life arose. In Aristotle's time (384–322 B. C.), living things were supposed to arise spontaneously. The belief in the theory of *spontaneous generation* or *abiogenesis* (*a*, not; *bios*, life; *genesis*, origin) of living things persisted for hundreds of years. In the light of what is now known, some of the theories as to how animals came into existence are amusing. For example, to create mice, one was supposed to place some cheese in a dirty sheet and then place these in a dark closet. It was common belief that maggots arose from decaying meat, insects from dew, and frogs and toads from mud. These are only a very few of the many strange beliefs as to the origin of animals in ancient times. The common goose barnacle (*Lepas hilii* Fig. 272*B*) gets its name from the fact that ancients believed that geese came from these barnacles.

1. Some Famous Experiments. *a. Redi's Experiment.*—Francesco Redi (1626–1697) was an Italian physician who set out to prove that flies did not come from decaying meat. He placed meat in three bottles, leaving one bottle uncovered, covering the second with gauze and the third with parchment (Fig. 3). The meat in all three decayed, since bacteria were already present when meat was placed in the bottles. Maggots developed in the first bottle in due time; none was found in the two covered bottles. Flies, attracted by the smell of decaying meat, laid eggs on the gauze that covered the second bottle. The parchment-covered bottle did not attract the flies; not much of the odor from decay-

ing meat could come through. This disproved the theory of spontaneous generation for the larger animals.

b. Pasteur's Work.—Although Redi's experiment proved that animals did not arise spontaneously, it was a long time before belief in the theory

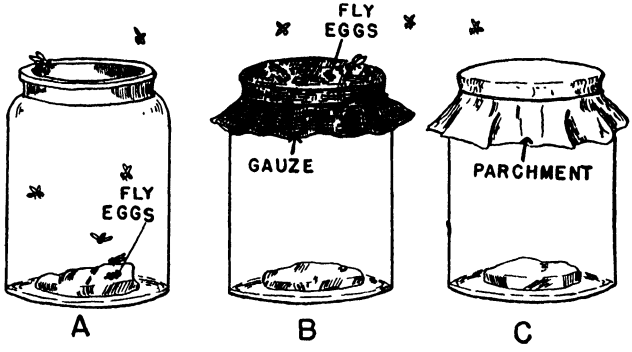

Fig. 3.—Redi's experiment to disprove spontaneous generation. A. Open jar. B. Jar covered with gauze. C. Jar covered with parchment. Since bacteria were present, the meat decayed in all three jars. However, maggots were found in Jar A only, though eggs were laid on the gauze of Jar B. (B. F. Edwards.)

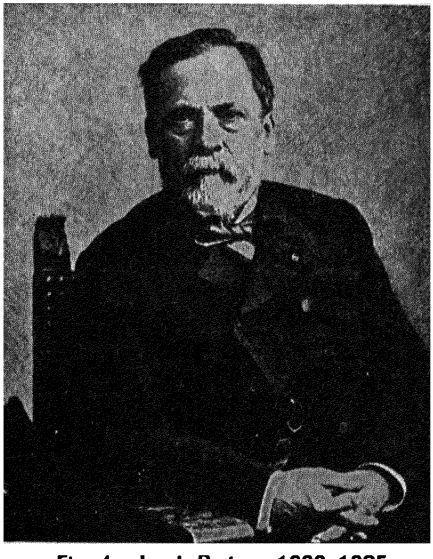

Fig. 4.—Louis Pasteur, 1822–1895.

died entirely. It remained for the genius Louis Pasteur (1822–1895) (Fig. 4) not only to prove that microorganisms did not arise spontaneously but to demonstrate the relation of yeasts to fermentation (page 193) and of certain bacteria to disease (page 190). Figure 5 illustrates the simple

experiment performed by Pasteur that disproved the theory of spontaneous generation of microorganisms. Unless beef broth is sterilized, it spoils very quickly Pasteur boiled beef broth in a flask with a bent tube As the contents of the flask cooled, water condensed in the bend of the tube and so sealed it against the entrance of outside air No bacterial growth was found in the flask even after a long time When the bent tube was unsealed and the germ-laden air entered, putrefaction set in promptly

c *Experiment of Tyndall* — John Tyndall (1820–1893) carried the work still further by demonstrating that putrefaction is caused by organisms in the air He called these *floating matter* and used a closed box (Fig 6) with a glass front for observation and glass windows through which a strong beam of light could be passed He showed that in a darkroom, the beam of light sent through the box could be seen only so long as there were dust particles in the box After all these had settled and the light was no longer visible inside the box, the materials in the tubes were boiled by applying heat to the bottom of the tubes below the chamber. No microorganisms appeared in the tubes

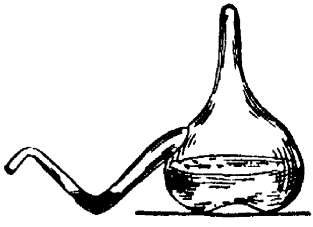

Fig 5

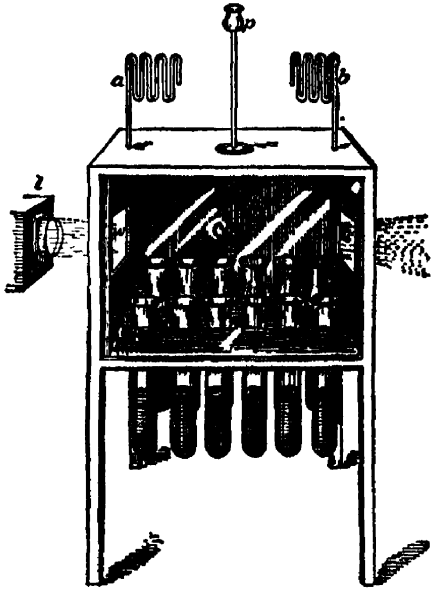

Fig 6

Fig 5 —Flask used by Pasteur in his experiments to prove that all life must come from life already in existence A sterile culture was placed in a sterile flask and the top sealed After boiling, water vapor condensed and filled the low curve in the side tube thus preventing entrance of air-borne organisms (From various sources)

Fig 6 —Apparatus used by Tyndall in his experiments on spontaneous generation The front and side windows (w, w) of the cabinet are made of glass Air can enter through the two tubes (a, b) The optical test for the purity of the atmosphere within the cabinet was made by passing a powerful beam of light from the lamp (l) through the side windows When the atmosphere contained no suspended 'dust' particles, the tubes (c) within were filled, through the pipet (p), with sterile culture medium suitable for the growth of germs, but none developed (After Tyndall)

2. WHY BELIEF IN SPONTANEOUS GENERATION PERSISTED SO LONG.—In spite of the foregoing experiments, it was found that microorganisms often appeared in cultures after they were sterilized. For this reason, belief in spontaneous generation persisted for a long time. It was found, however, that certain types of *bacteria* form spores that can withstand much heating. Therefore, cultures are now often heated a second or even a third time on successive days. By that time, all the spores have had time to germinate, and the growing organisms are killed by heating. The cultures will remain sterile so long as they are properly sealed.

B. Other Theories.—Some of the other theories as to the origin of life take into consideration the theory that the earth was once a molten mass. As it cooled, the theory is advanced, conditions might have made possible the chance combination of elements that produced life.

Another theory, the *cosmozoa theory*, is that life came from another planet. How the life germs got here cannot be explained. They probably could not have come on meteors, since in passing through the earth's atmosphere, meteors become red hot.

There are various other theories, but since none can be either proved or disproved, they must rest on speculation.

C. Omne vivum e vivo.—All life from preexisting life is accepted as the only way living things are known to develop today. Where life originally arose no one knows, and the theories as to the origin of life rest mainly upon speculation. All attempts to synthesize living matter have so far failed.

In our modern day, there is considerable speculation as to the nature of *filterable viruses*. They go through the finest filters, and some of them may be crystallized; yet they are self-propagating and cause such diseases as smallpox, rabies, measles, etc. Whether they are animate or not is still debatable.

Questions

1. How can living and lifeless matter be distinguished?
2. Why is a good definition of life not possible?
3. Distinguish between organic and inorganic matter.
4. Give a full account of the characteristics of living matter.
5. Explain the difference between vitalism and mechanism.
6. *a.* What is spontaneous generation?
   b. How was it disproved as an explanation for the origin of life?
   c. Why did belief in the theory persist so long?
   d. Is there any evidence that, under present conditions, life arises *de novo*?

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CHAPTER II

THE SMALLEST UNITS IN NATURE

For the World was built in order,
And the atoms march in tune;
Rhyme the pipe, and time the warder
The sun obeys them and the moon.
—EMERSON.

I. The Nature of Matter

As has been said, the terms *living* and *lifeless* refer to states or conditions of matter. After learning something of the characteristics of living matter, it is natural to inquire, what is the basic nature of matter? Although any full understanding of the basic nature of matter would require an extensive knowledge of physics, it will be sufficient, for the purposes of this book, to learn the ABC of the subject. To begin with, it can be said that all matter, living or lifeless, is definitely organized into units, each with its characteristic structure.

A. Definition of Matter.—Matter may be defined as anything that occupies space and has mass. It may be solid, as wood or stone; or liquid, as water; or it may be a gas, such as air. It is easy to see that wood and water occupy space and have mass; it can be proved that air has these same two properties. A simple experiment will make this clear. If one attempts to pour water into a narrow-necked bottle in which there is no other opening for the air to escape, the water will go in with difficulty. Or, better still, if an apparatus such as shown in Fig. 7 be arranged, it will be found that as water is being poured into the bottle, air is being displaced and forced through a vent tube. This is shown by the fact that air comes out of the bottom of the tube. It can be seen in the form of bubbles rising to the surface of the water in the test tube. The water is evidently displacing the air, thus proving that air has volume. That air has weight can be proved by weighing a bottle full of air, then pumping out the air with a suction pump, and weighing the bottle again. It will weigh less than it did before the air was removed, thus proving that the air has weight.

B. The Smallest Units in Nature. 1. ATOMS.—All matter on earth, living or lifeless, is composed of *atoms*, of which about 92 kinds are known. They are so small that they cannot be seen with a microscope, and it is difficult even to imagine them.

As to their structure, physicists are still struggling with many difficult unsolved problems, which require elaborate apparatus and methods for solution and may not be satisfactorily solved for many years.

The following account is only one of several theories but is the simplest and generally most useful. The newest conception treats electrons as *waves*, but it is sufficient for us to consider them as particles.

Each kind of atom has its own peculiar characteristics. A gold atom is different from a silver atom, a lead atom is different from a chlorine atom, etc., the unique properties of each being due to its own internal

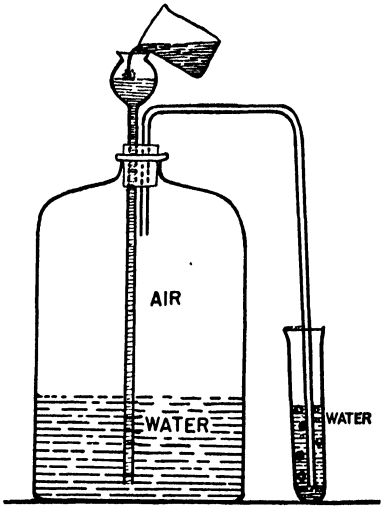

Fig. 7.—Experiment to prove that air has mass. As water is poured into the bottle, air is displaced, enters the bent arm and bubbles out through the water in the test tube. (L. Runyon.)

organization. The organization of an atom may be compared to a miniature solar system. Each atom has a *nucleus* that is the center of a system, just as the sun is the center of the *solar system*. Around the nucleus revolve the particles, the *electrons*, in much the same manner that planets revolve around the sun. The electrons carry negative charges of electricity, and the *protons* in the nucleus carry positive charges of electricity. In addition to the protons, there may be neutrons in the nucleus that bear no charge at all. The *electrons* arranged around the nucleus are those with *negative electric charges* that just balance the excess *positive charges* of the protons in the nucleus. In a diagrammatic way, Fig. 8 shows the structure of an atom of *oxygen*, an atom of *hydrogen*, and an atom of *carbon*. Electrons seem to be all alike; only their number and arrangement appear to be responsible for the different kinds of matter. This fact gives the key to the

composition of all matter. The atom with the largest number of electrons is uranium, which has 92; the atom with the smallest number of electrons is hydrogen, which has only 1.

2. ELEMENTS.—Materials made up of one kind of atom, such as gold, silver, iron, chlorine, and the like, are called *elements*. Of the 92 elements usually listed, 90 are well known, and 2 (or more) are suspected to exist, though rare.

The character of each element is due to the structure of the atoms of which it is made. Just as a builder can take a few kinds of materials and build many kinds of buildings, so nature has used first atoms to make elements and then elements to make the infinite variety of substances both organic and inorganic that make up the world and all that it contains, living and nonliving.

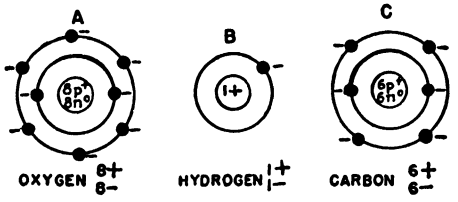

Fig. 8.—Diagram illustrating the atomic structure oxygen, hydrogen, and carbon. These atoms are neutral unless they give up or add an electron.

3. MOLECULES.—A molecule of a compound is the smallest part of that pure substance which has the same composition as any larger portion of the substance. For example, a molecule of sugar is made up of carbon, hydrogen, and oxygen atoms. If the molecule is taken apart, it will no longer be sugar. Therefore, a molecule of sugar is the smallest part of sugar that can exist and still be sugar. There may be molecules consisting of one element, as oxygen, hydrogen, chlorine, etc., or there may be molecules consisting of two or more elements, such as sodium chloride. A molecule, then, is usually made up of two or more atoms, though some exceptional molecules consist of single atoms—helium, for example. These may be alike or different in kind. Sodium chloride (table salt), for example, is made up of one atom of sodium and one atom of chlorine (see below). Large molecules consist of many kinds of atoms. It is important to remember this, because molecules of proteins, which are substances characteristic of living things, are very large and very complex.

4. IONS.—An atom is *neutral* because the positive charges of the nucleus exactly balance the negative charges of the electrons. If an atom gains or loses an electron, the electric balance is disturbed. If it gains an

[1] The nucleus of oxygen has 8 protons carrying positive charges and 8 neutrons carrying no charges; the nucleus of carbon has 6 protons carrying positive charges and 6 neutrons carrying no charges.

electron, it becomes negatively charged; if it loses an electron, it becomes positively charged. These electrically unbalanced particles are ions; they carry either negative or positive charges of electricity. It is a well-known fact that objects that carry like charges of electricity repel each other, whereas objects that carry unlike charges, positive and negative, attract each other. With this in mind, it is easy to understand how compounds are formed.

5. COMPOUNDS.—Figure 9 is a diagrammatic representation of sodium and chlorine atoms. As has been explained, these atoms are neutral because the positive charges of the protons of the nucleus just balance

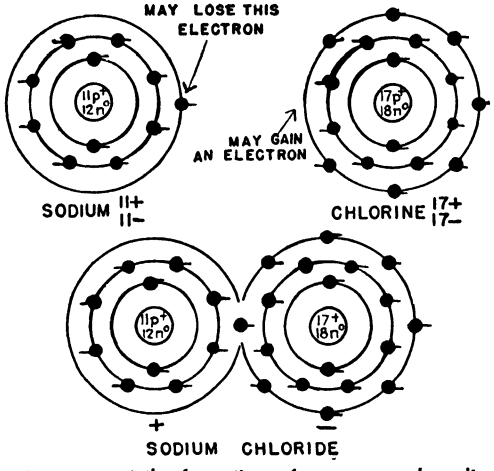

Fig. 9.—Diagram to represent the formation of a compound, sodium chloride, from an atom of sodium and an atom of chlorine. If the neutral sodium atom loses an electron, it becomes positively charged; if the neutral atom of chlorine gains an atom, it becomes negatively charged. When the positively charged sodium meets the negatively charged chlorine, they unite to form sodium chloride.

the negative charges of the electrons. Atoms may give up or add electrons.[2] If sodium loses the one electron in its outer shell, the balance is upset, and the number of positive charges becomes greater than the

[1] The nucleus of sodium has 11 protons carrying positive charges and 12 neutrons carrying no charges; the nucleus of chlorine has 17 protons carrying positive charges and 18 neutrons carrying no charges.

[2] The number of electrons in the outside orbit of atoms varies from one to eight. When eight are present in the outer orbit, the atom is inactive. When there are less than eight in the outside orbit, the atoms tend to gain or lose electrons to make an outside orbit of eight. Atoms with one, two, or three electrons tend to give electrons to other atoms during chemical changes. Atoms giving up electrons become positively charged; atoms gaining electrons become negatively charged. Atoms with four electrons in the outside orbit may give them up, becoming positively charged, or may add more and become negatively charged. Atoms with five or more electrons may give them up but tend to take on the needed ones and to make up eight and so to be negatively charged.

negative charges. The particle is then a positively charged ion. Referring again to Fig. 9, it will be noted that the outer shell of chlorine has only seven electrons. If it takes up another electron, the number of negative charges will be greater than the number of positive charges. The particle will then be negatively charged. Now when the positively charged sodium ion meets a negatively charged chlorine ion in a solution, the two attract each other and unite, forming a molecule of sodium chloride. This molecule will be neutral, since the positive charges balance the negative charges. We can say, then, that sodium chloride is a compound made up of molecules of sodium chloride. The molecule of sodium chloride is, in turn, made up of a positively charged sodium ion and a negatively charged chlorine ion. These ions will separate under the influence of an electric current.

6. ELECTROLYTES.—The molecule of sodium chloride, as has been said, is neutral. If, however, it is dissolved in water, the ions are free to move and are able to carry electric charges. Now, if a current of electricity is carried through the solution, the ions with a positive charge, as sodium (Na^+), will go to the negative pole and the negative ions, such as chloride (Cl^-), in this case, will go to the positive pole. Sodium and chlorine will thus be separated from each other by the process known as *electrolysis*. The definition of an electrolyte is "a substance that will form ions in solutions." The substances forming ions in solution are called electrolytes because the ions carry charges of electricity, either positive or negative. Acids, bases, and salts are electrolytes; sugar and alcohol are nonelectrolytes.

C. Valence.—When chemical reactions take place and compounds are made, the positive and negative charges must balance, as Na^+Cl^-, $H^+H^+O = H_2O$, etc., for all compounds. The *valence* of an element depends on the number of electrons it tends to gain or lose and expresses the unit combining power of the element for other elements. Sodium has a valence of one and can take on one atom of chlorine; calcium has a valence of two and can take on two atoms of chlorine, forming calcium chloride ($CaCl_2$). As has been pointed out, the tendency of an atom to gain or lose electrons is related to the number of electrons in its outer shell. Sodium, as we have seen, has one electron in its outer shell, which it may lose. The positive charge that the atom gains when it loses the negatively charged electron is its valence. The oxygen atom has six electrons in its outer orbit (Fig. 8*A*). When it enters into chemical change, it tends to take on two electrons, to fill out the number eight in its outer orbit. This gives it 10 negatively charged electrons and 8 positively charged protons. It follows that it has two more negative than positive charges. Its valence is therefore two. It will be seen that valence is a definite property of each element.

D. Radicals.—Radicals are groups of atoms that remain together during most chemical reactions. They may be considered as a single ion with a characteristic valence. Some common examples are the hydroxide radical $(OH)^-$, with a negative valence of one; the sulphate radical $(SO_4)^{--}$, with a negative valence of two; and the ammonium radical $(NH_4)^+$, with a positive valence of one. An example of how this works out may be shown in the formula for sulphuric acid. The sulphate radical, with a valence of two, would take two positively charged hydrogen ions (with a valence of one) to balance its two negative charges, as H_2SO_4.

E. Acids, Bases, Salts.—That acids are sour is a fact familiar to us all. Litmus is colored red in a simple test for acidity. Acids are compounds that liberate free hydrogen ions upon contact with water. If the definition of an ion as a particle that has lost or gained an electron is recalled, it is easy to understand that an ion of hydrogen is one that has lost its one electron (Fig. 8*B*). A hydrogen ion will unite with a chloride ion to form hydrochloric acid, HCl, or it will unite with the sulphate ion to form sulphuric acid, H_2SO_4, etc.

Bases are compounds that contain *negative hydroxyl ions.* A hydroxyl ion is a radical that consists of hydrogen and oxygen $(OH)^-$ and that has a valence of one. Bases are alkaline and turn red litmus paper blue. An example of a base is sodium hydroxide, NaOH.

Salts are formed in several ways, but in each case an acid reacts with another substance, or two salts react with each other to form a different salt. A good example of the formation of a salt is the reaction of an acid with a base, *e.g.*, hydrochloric acid + sodium hydroxide gives sodium chloride, which is a salt, and water ($NaOH + HCl = NaCl + H_2O$). If the solution containing the salt is evaporated, crystalline sodium chloride is left.

F. Energy.—Energy may be defined as the power to do work or to produce change in matter. The familiar forms of energy are heat, light, sound, and chemical, electric, and mechanical energy. The two types of energy are *potential* and *kinetic.* Potential energy is due to position; kinetic energy is expressed in motion. Energy fixed or stored in foods or in a lump of coal is potential energy due to the positions and arrangements of atoms therein. When energy in foods is converted into heat and motion by chemical reactions, it becomes kinetic energy; similarly, when a lump of coal is burned, the stored-up potential energy is converted into heat and light and, therefore, becomes kinetic energy.

All living processes involve the use of energy in some form. As we shall see, when a plant makes its food from the carbon dioxide of the air and the water from the soil, it must have energy from the sun. This is stored up in the sugar that is made (see page 140). It is released when this sugar is utilized either by the plant itself or by other organisms.

II. Why Biologists Need to Know Something of the Structure of Matter

From the foregoing account, it will be seen that all matter, living or lifeless, has the same fundamental composition. Living processes are very complex, and not all of them are yet fully understood. It is important, however, for biologists to understand that these living processes are possible because of the nature of matter. That all matter is one, differing only in the make-up of the atoms, seems almost unbelievable. Even a superficial study, such as we have made, should give a concept of law and order in the make-up of the universe, including the living things in that universe.

Questions

1. What is matter? How can you prove that air has both mass and weight?
2. What are the smallest units in nature? Discuss the structure of an atom, defining planetary system, proton, electron, nucleus.
3. If the nucleus of an atom is changed, how is the nature of the atom altered? If the number and arrangement of the electrons is changed, how is the nature of the atom affected?
4. What is an ion? What is its role in the formation of compounds?
5. Define element, molecule, electrolyte.
6. Discuss the significance of valence.
7. Explain why the sulphate radical SO_4 requires two hydrogens, H_2, in the making of the sulphuric acid molecule.
8. Define acid, base, salt.
9. Discuss energy and its relation to living things.
10. Why do biologists need to know something of the nature of matter?

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CHAPTER III

PROTOPLASM

Life is a wave which in no two consecutive moments of its existence is composed of the same particles.

—JOHN TYNDALL.

I. Not All Protoplasm Is Alike

The unique characteristics of living things are due to the character of protoplasm. Max Schultze (1825–1874) called protoplasm *the physical basis of life.* Later, Thomas Huxley (1825–1895) used this definition as the title of a famous essay. "The physical basis" of life is a good description of protoplasm, for, whether at work in the brain of the wisest man or in the cells of the lowly plant, it is the fundamental "life stuff." It is capable of infinite variety and constant change. Cat protoplasm and dog protoplasm are not alike; the protoplasm of the corn leaf differs from the protoplasm of the oak leaf; indeed, the protoplasm in different parts of the same organism differs to some extent. For example, the protoplasm of a liver cell is different from that of a muscle. Yet, in spite of this, the fundamental nature of all kinds of protoplasm is the same. The differences are due to variations in organization; *i.e.*, the proportions and kinds of molecules are not always the same. Although something is known of the chemical and physical nature of protoplasm, an explanation of its peculiar and changing organization has not been worked out satisfactorily. However, it is known that protoplasm is made up of the same atoms that are common in nonliving materials. A glance at the table of elements present in protoplasm, as given below, will bring out this fact. No atom peculiar to living things has been discovered.

II. First Studies of Protoplasm

In 1835, Dujardin, a Frenchman, observed a semiliquid substance in the cells of animals that he called *sarcode* (Gr. *sarx*, flesh; *eidos*, form). The name *protoplasm* was proposed in 1846 by Hugo von Mohl, a German botanist, for the living material in plant cells, "slime." Purkinje (1787–1869) was the first to make use of the name protoplasm for living matter, but the term was not in general use until Max Schultze, about 1861, demonstrated that the sarcode of animal cells and the protoplasm of plant cells were one and the same thing. This was a great discovery that influenced the development of the cell theory.

III. The Chemical Composition of Protoplasm

A. The Chemical Elements Present in Protoplasm.—Protoplasm is chemically complex, yet all the chemical elements present occur in nonliving materials. As a matter of fact, many nonliving substances are produced by protoplasm, such as feathers, fingernails, hoofs, etc. Four elements, carbon, hydrogen, nitrogen, and oxygen, make up from 80 to 99 per cent of protoplasm. Most of the substances that are contained in living matter, or are secreted by it, are compounds of carbon; hence the element carbon is considered the most characteristic of elements that occur in protoplasm. Without carbon there would be no life.

The percentages of elements in different organisms *vary*, but the following table[1] will give a good idea of the averages of several kinds of plant and animal tissue:

	Per Cent	
Required by all organisms		
Oxygen....	76	
Hydrogen...	10	
Carbon.....	10 5	
Nitrogen. ...	2 5	99.00
Sulphur . ..	0 2	
Phosphorus	0 3	
Potassium..	0 3	
Iron . ..	0 01	
Magnesium..	0 02	0.83
Not required by all organisms		
Calcium. .	0 02	0 02
Not required by plants		
Sodium..	0.05	
Chlorine	0 1	0 15
		100 00

Note that in the foregoing table only 12 of the 92 elements usually included in the list of elements are listed.

There are also traces of iodine and copper and several other elements.

The preceding elements are not free but are combined in the elaborate compounds of protoplasm. When chemical compounds are formed, the elements comprising them lose their characteristics. For example, when hydrogen and oxygen form water, hydrogen as such and oxygen as such disappear.

B. Inorganic Salts.—Many salts are present in protoplasm. The most abundant of these are sodium, potassium, phosphorus, and calcium, which combine with other substances to form chlorides, sulphates, nitrates, carbonates, and phosphates. Salts are used in building protoplasm.

[1] Mainly after Plunkett.

They also play an important part in life processes and are of importance in the growth of supporting structures, such as bone, since these consist largely of phosphates and calcium carbonate.

C. Water.—Protoplasm is made up of 60 to 90 per cent water. The quantity of water may be reduced to less than 5 per cent in dry seeds; on the other hand, jellyfish may consist of about 96 per cent water. Even bone contains from 25 to 40 per cent water. Organisms can live longer without food than without water. Water has some unique properties. In the first place, more solids, liquids, and gases will dissolve in water than in any other known liquid. Life is dependent upon many complex chemical reactions, and it is well known that these reactions take place more readily if the substances are dissolved and are thus mobile. Water enters into the structure of protoplasm itself and gives it its watery nature, thus making protoplasmic streaming, diffusion, and the like possible. Water is also concerned with the regulation of temperature and the manufacture of carbohydrates by green plants (page 140).

D. Organic Compounds. 1. PROTEINS.—Most organic compounds, or the compounds of carbon found in protoplasm, are proteins, carbohydrates, and fats. *Proteins* (Gr. *proteios*, holding first place) are extremely complex. They are made up of large molecules and always contain carbon, hydrogen, oxygen, and nitrogen; often they contain sulphur and other elements. Most of the proteins do not dissolve in water but can absorb great quantities of it. This absorption of water causes them to swell up. On account of their large molecules, proteins do not pass through animal membranes such as the wall of a bladder. Under certain conditions, they coagulate; *i.e.*, they change from a more or less liquid condition to a thick mass, just as the white of an egg coagulates when cooked.

2. CARBOHYDRATES.—The carbohydrates (L. *carbo*, coal; Gr. *hydor*, water) are made up of carbon, hydrogen, and oxygen. The common carbohydrates are starches, sugars, and cellulose. They are stored in plants as reserve foods, sometimes as sugars but mostly as starches. In animals they are stored as animal starch or glycogen.

3. FATS AND FAT-LIKE SUBSTANCES (LIPIDS).—Fats are also composed of carbon, hydrogen, and oxygen, but these elements are present in proportions different from those of carbohydrates. Although fats resemble carbohydrates in composition, they are more complex. Fats, as well as carbohydrates, are fuel foods and are used in the production of energy. They are stored up as a reserve food supply by both plants and animals.

4. ENZYMES.—Enzymes (Gr. *en*, in; *zyme*, to leaven) are produced by protoplasm and are indispensable for life. Their chemical composition is known in some cases. A few have been isolated and seem to be protein in nature.

a Enzyme Activity —Enzymes bring about chemical change without themselves being used up in the process This means that they themselves do not enter into the composition of the products of the reaction They may act over and over again, and a surprisingly small amount of enzyme may bring about chemical changes in a large amount of material For example, an enzyme extracted from the pancreas of an animal was found to digest 2 million times its own weight of starch A substance capable of bringing about a change of this kind is called a *catalyst* (Gr *kata*, down, *lysis*, loosening) Many sorts of catalysts are known.

b Are Enzymes Living?—Since some enzymes can be extracted and are able to carry on their activity in test tubes, they are not living It was thought by Pasteur and others that fermentation of sugar by *yeast* cells (page 193) was dependent upon the presence and the activity of the yeast cells In 1897, Buchner demonstrated that enzyme activity can take place in test tubes, provided that a compound extracted from the cells is present This compound was, of course, the enzyme

c The Unique Characteristic of Enzymes —One of the unique characteristics of an enzyme is that it will cause only one type of chemical reaction, *i e*, it is *specific* Special enzymes exist for breaking down carbohydrates, others, for proteins, still others, for fats More than one enzyme is always involved in breaking down these compounds For example, carbohydrates eaten by animals are affected by one enzyme in the mouth and by another, secreted by the pancreas, when they reach the intestine (page 543)

d Importance of Enzymes —If a chemist wishes to break down proteins or carbohydrates into simpler substances, he must treat them with strong alkalis or acids, often at high temperatures The reactions are very slow, and much time is consumed But these reactions are taking place all the time, quite rapidly, in living things without the use of strong alkalis or strong acids, at low temperatures Enzymes are responsible for this Similarly, with oxidation processes, if sugars or fats are oxidized in a test tube, even in the presence of an abundance of oxygen, the process is very slow unless great heat is applied Yet oxidations of these same compounds are going on all the time in the cells of living things, with a relatively small amount of heat Enzymes make this possible also They are responsible for the great amount of chemical activity that goes on in cells.

They may be active, also, outside living cells In this case, the enzyme is poured out by the cell upon the substance to be decomposed The cell then absorbs the products of digestion that it needs. The enzymes of yeast, bacteria, some fungi, protozoan parasites, and others act in this way.

5. VITAMINS.—Vitamins (L. *vita*, life; *amine*, a chemical compound having the radical NH_2) are substances found in plants and plant products. Animals have them, also, having secured them from plant sources. It is well known that different plants and animals vary greatly with respect to the types and amounts of vitamins that they contain. Only minute amounts of vitamins are necessary for the performance of their functions. As is well known, vitamins are important in nutrition, growth, and development in both plants and animals. (For a list of vitamins and their work, see page 525; for a table of food containing vitamins, see page 873.)

IV. The Physical Nature of Protoplasm

A. General Characteristics.—Protoplasm is a semiliquid substance, heavier than water and a little more dense. Its fluidity varies under

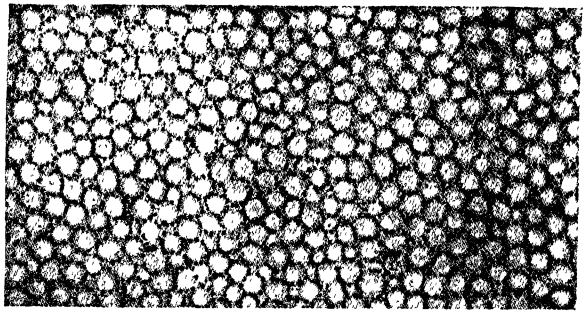

Fig. 10.—Structure of living protoplasm as seen in the starfish. (After Wilson.)

different conditions. A "streaming movement" is one of the characteristics of living protoplasm. "It lets light pass through (is translucent), but bends it more than water does (is more refractive)." Thus, a perfectly colorless animal may be seen in the water by its refraction image.

B. Appearance and Theories of Structure.—Living protoplasm is jelly-like and colorless. The white of an egg somewhat resembles protoplasm. On account of the activities which it carries on at all times, protoplasm changes constantly. Under a good microscope, the formless material may appear foam-like (Fig. 10) at one time and granular at another. When it is killed and stained, its appearance may be due to the method of preparation. Different fixing fluids and stains have different effects upon this delicate substance. For this reason, several theories as to the structure of protoplasm have arisen. It is generally conceded that the *colloidal theory* most nearly fits all the known facts. Since protoplasm is ever-changing, there can be no universal formula as to its structure. The theories advanced, with the exception of the colloidal theory, are mainly of historical interest.

The *alveolar theory* holds that protoplasm is foam-like or is like an emulsion; the *granular theory* sets forth the idea that protoplasm is made up of tiny granules, sometimes massed into solids, sometimes arranged in a linear series so as to form fibrils; the *reticular theory* holds that fibers are arranged to form a network, the fibers being knotted together; the *fibrillar theory* emphasizes the fibers in the cytoplasm, the idea being that protoplasm is a feltwork of fibers; the *colloidal theory* maintains that protoplasm is made up of colloidal systems, and this view is generally accepted. This theory does not exclude the possibility, however, that some of the foregoing theories may have some truth in them (Fig. 11).

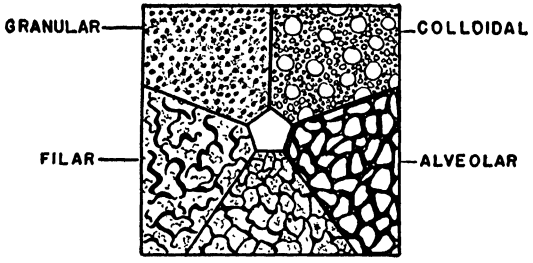

Fig. 11.—Diagram to illustrate the various theories of the structure of protoplasm.

C. Protoplasm, a Colloidal Mixture.—The term *colloid* was first used by Graham in 1861. The substances that he was investigating reminded him of glue (Gr. *kolla*, glue); hence the name.

1. THE COLLOIDAL STATE.—A substance in a colloidal state is distributed in the form of minute particles within another substance. Thus, in a colloidal solution or *sol*, there are a *dispersed phase* of finely divided particles and a *continuous phase* that is the medium in which the particles are dispersed. The particles of a colloidal dispersion are so large that they do not diffuse appreciably or pass through certain filters (dialyzing membranes). But they are too small to be visible except with the ultraviolet microscope. The size range of colloidal particles is estimated to be between 0.0001 and 0.000001 mm. in diameter.

There are many types of colloidal solutions. Some of the most common are (1) a solid in a liquid, as starch in water; (2) a liquid in a solid, as water in gelatin; (3) a liquid in another liquid, as cream in milk; (4) a gas in a solid, as air in white hair. There are many other types.

Protoplasm is a complicated system of dispersions. Its colloidal nature is exhibited in many ways, some of which are too complicated to go into here. It can undergo changes in viscosity at constant temperatures, as in the changing from a liquid to a jelly when new plasma membranes are formed or in the flowing of protoplasm, as seen in amoebae or in dividing

cells. Some of the optical qualities of colloids, as shown by their appearance under a dark field illuminator, are also characteristic of protoplasm.

2. Surface Properties of Colloids.—The surface properties of colloids are due to the enormous aggregate surface area of their particles. The manner in which the amount of surface increases if the material is finely divided may be illustrated by the division of a cube, 1 cm. on each edge. This cube is 1 cm. square on each side and has a surface area of 6 sq. cm.; if it is cut into eight cubes of equal size, each would measure ½ cm. on the edge, and the total surface area would be increased to 12 sq. cm. If now this cube is cut into particles 100 microns[1] on the edge, the surface would be increased to 6,000 sq. cm. This enormous surface area allows of great activity because of the possibility of concentration of

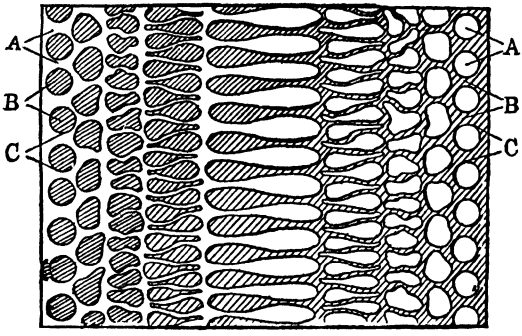

Fig. 12.—Diagram illustrating phase reversal in a colloidal solution. A. Aqueous phase. B. Oil or other nonaqueous phase. C. Interfacial film formed by emulsifying agent. (After Clowes, from Sharp, Introduction to Cytology.)

ions or molecules on the surfaces, or *adsorption*. The ions are said to be adsorbed on the surfaces of the particles. Particles in the cytoplasm of a cell carry positive charges and thus adsorb more strongly negative ions; the particles in the nuclear material carry negative electrical charges and correspondingly adsorb positive ions more strongly.

D. Brownian Movement.—If one looks at living protoplasm under the microscope, the granules in some parts appear to be in constant motion. This is because the small granules are being bombarded by the molecules of water. Brownian movement was named for Robert Brown, who, in 1827, noticed that pollen grains suspended in water were constantly in motion. Later, the nature of the motion was discovered. Cessation and recurrence of the Brownian movement in protoplasm is one of the visible evidences of changes in protoplasmic viscosity. These viscosity changes may be of the nature of sol-to-gel transformations.

E. Sol and Gel States.—A sol state may be defined as a dispersion of solid particles in a liquid; a gel state, as a dispersion of a liquid in a

[1] A micron (Gr. *mikros*, small) = 1/1,000 part of a millimeter or 0.000039 in.

solid. These states may be reversible, as shown in Fig. 12. The coagulation of the blood to form a clot is an example of a sol changing to a gel.

F. Activities of Protoplasm.—The activities of protoplasm are the activities characteristic of life itself. They are metabolism, maintenance, growth, reproduction, irritability, and adaptation. These were briefly described in Chap. I and will be more fully described in connection with the study of organisms. This short account will serve as a foundation for the study of characteristics of life with which this book is largely concerned.

Questions

1. Why is "the physical basis of life" a good description of protoplasm?
2. To what character do you attribute the differences in protoplasm?
3. What four chemical elements form a large percentage of protoplasm? What five other elements are required in small quantities by all organisms?
4. Why are inorganic salts necessary to growth and life of organisms?
5. What is the role of water in living things?
6. What three types of organic compounds are always present in organisms?
7. How do enzymes do their work? Are they living?
8. Where are vitamins found? How do they compare with enzymes?
9. What are some theories as to the structure of protoplasm?
10. Explain the nature of colloids. How is the nature of protoplasmic activity attributable to its colloidal make-up?
11. Explain the nature of Brownian movement.
12. Discuss sol and gel states. Give examples not mentioned in the book.
13. Discuss the electrical properties of colloids. What is adsorption?
14. What are some activities of living protoplasm?

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CHAPTER IV

THE CELL

We have seen that all organisms are composed of essentially like parts, namely cells; that these cells are formed and grow in accordance with essentially the same laws; hence that these processes must everywhere result from the operation of the same forces.

SCHWANN.

I. Units of Living Organisms

The cell is the unit of living organisms. Some plants and animals are single cells while others contain billions of cells; yet even these were at one time single cells since they have developed from a fertilized egg.

II. Discovery of Cells

A. Why Cells Were Not Discovered Earlier.—Most cells are so small that they cannot be seen with the naked eye; a compound microscope

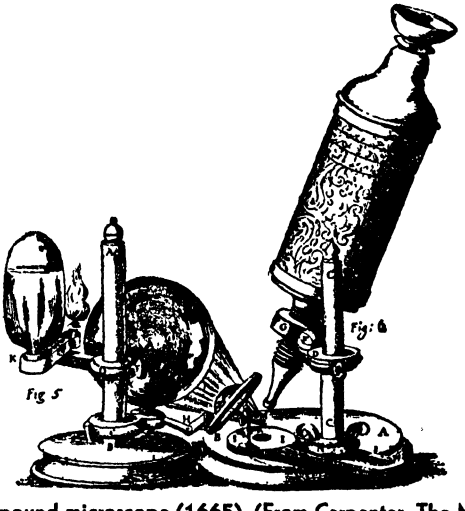

Fig. 13.—Hooke's compound microscope (1665). (From Carpenter, The Microscope and Its Revelations, J. and A. Churchill.)

must be used to study them. The discovery of cells had to wait upon the perfecting of the microscope (Fig. 13) and the development of technical methods of preparation of tissues for study. Really to see what a cell is

like, one must first kill it and then stain it with a dyestuff. Over two hundred years of research were required to perfect the methods of preparing cells for study that are employed today.

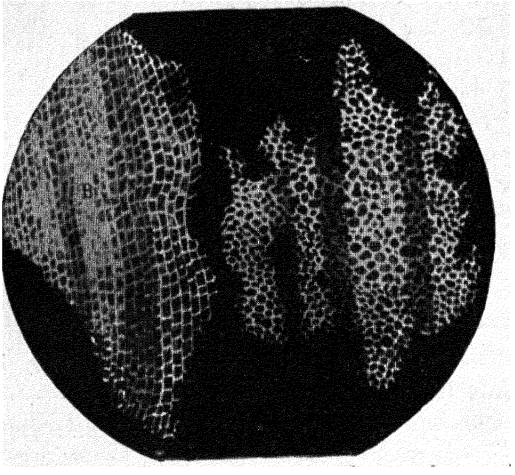

Fig. 14.—Robert Hooke's illustrations of cork cells as he saw them under his microscope. (Reduced facsimile reproduction from his "Micrographia" published in 1665.)

Fig. 15.—Anton J. Leeuwenhoek, 1632–1723.

B. Robert Hooke (1635–1703).—Robert Hooke, of England, is usually credited with the discovery of cells. When he looked through his microscope at a thin piece of cork, he noted that the cork was made up of little box-like compartments that reminded him of the cells of a monastery

(Fig. 14). For this reason, he called the compartments cells. What he saw were only the cell walls that he supposed were the important parts. It is known now that the protoplasm within the cells is the "stuff of life" and that most cell walls are not even living. Illustrations of the cells of cork were published by Hooke in 1665 in his "Micrographia."

C. Development of the Microscope and the Early Study of Cells.—Many men took part in the development of the microscope and in the early study of cells. One of the most interesting of these was Anton van Leeuwenhoek (1632–1723), of Holland (Fig. 15). Leeuwenhoek was a businessman, a linen draper, who became interested in microscopes. He ground his own lenses and constructed many microscopes. As was natural, he examined much material of various kinds and is credited with discovering Protozoa in 1674 in the scum from a fresh-water pond. Later he discovered bacteria and many other types of microscopic organisms.

Grew (1641–1712), of England, Malpighi (1628–1694), of Italy, and Swammerdam (1637–1680), of Holland, were also among those who took part in the development of the microscope and in bringing to light the marvels of the microscopic world.

III. Cell Theory

Gradual progress was made in the perfection of the microscope and in the knowledge of the cell during the eighteenth century. It remained for Schleiden (1804–1881), a botanist (Fig. 16), and Schwann (1810–1882), a zoologist (Fig. 16), to make the generalizations that all plants and all animals are composed of cellular units. This was set forth in papers published in 1838 and 1839. Even then, the nature of the cell itself was in doubt. Many biologists contributed to the study of the cell, but it was Max Schulze (about 1861) who proved that protoplasm is the important part of the cell. He proposed the definition that a "cell is a mass of protoplasm containing a nucleus."

The formulation of the cell theory was of great importance because of its far-reaching effect upon the study of biological phenomena. It suggested that living things had a common basis of organization. Its full significance, however, had to wait upon a more precise knowledge of the structure and activities of cells. It was inevitable, however, as knowledge of the nature of cells grew, that all biological work should be influenced, especially embryology, physiology, and studies in heredity.

IV. Structure of Cells

A. Sizes and Shapes.—Although most cells are so small that they can be seen only with the aid of a microscope, a few cells are very large. For example, the eggs of a hen or an ostrich are at first single cells. Their large size is due to the accumulation within them of nutritive

material, the yolk, destined for the use of the young embryo. Some nerve cells may have processes several feet long, though these are very slender. In the human body are cells of many sizes. In general, however, cells are microscopic units.

Matthias Schleiden 1804–1881 — Theodor Schwann 1810–1881

Fig. 16.—Schleiden, a botanist, and Schwann, a zoologist, formulated the cell theory in 1838 and 1839. (The Bettmann Archive.)

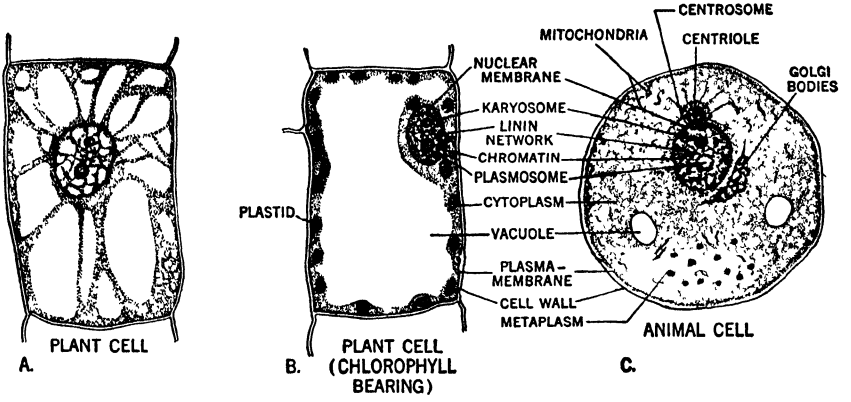

Fig. 17.—(A) Plant cell without chlorophyll. (B) Plant cell with chlorophyll. (C) Animal cell. (L. Runyon.)

Cells vary in shape as greatly as they vary in size. Some are disk-shaped, like our own red corpuscles; others are crowded together and are often 14-sided; striped voluntary-muscle cells are spindle-shaped; nerve cells are very irregular on account of their processes. There are many varieties of both shapes and sizes of cells. However, all cells have certain definite characteristics in common.

B. Details of Cell Structure and Functions. 1. THE CELL BODY OR CYTOSOME (Fig. 17).—The cytosome (Gr. *kytos*, hollow vessel, cell; *soma*, body) is the body of the cell as distinguished from its nucleus. It is the protoplasm outside the nucleus and is usually referred to as the *cytoplasm* (Gr. *kytos*, hollow vessel; *plasma*, something molded). The cytoplasm has two regions, an inner, more fluid region, the *endoplasm* (Gr. *endon*, within; *plasma*) and an outer viscous region, the *ectoplasm* (Gr. *ektos*, outside; *plasma*).

a. Plasma Membrane.—This important membrane limits the ectoplasm, and is located inside the cell walls. It is present in all cells, even in those that have thick walls, and determines what materials go in and out of the cells.

b. Cell Walls.—In the early days, biologists thought that the important part of a cell was the cell wall. Later, it was found that not all cells have cell walls. Walls are most prominent in plant cells where they are made up of a complex carbohydrate substance, *cellulose*. Although cellulose is not living, it is secreted by the protoplast (Gr. *protos*, first; *plastos*, formed). The term *protoplast* is used to denote the living parts of the cell as distinguished from the nonliving parts. Other examples of nonliving materials secreted by the protoplast are the hair and nails of animals, oil and other substances in plants.

The rigid cell walls in plants give the tissues strength.

Most animal cells have membranes that are composed of a protein material. In addition, some cells have a very thin flexible covering, a *pellicle*. This is characteristic of some one-celled creatures like Euglena and Paramecium.

c. Centrosphere, Centriole, Aster.—Within the cytoplasm, lying near the nucleus, is a region where the protoplasm is more dense than in other parts of the cytoplasm. This is the centrosphere (often called the *centrosome*). In the center of this is a very minute, deeply staining body, the *centriole*. More often than not, it is double. When present, centrioles serve as division centers of cells. Not all cells contain them, however. They are absent in the cells of the higher plants.

Radiating out from the centrosphere are lines that make up a star-like figure. This is the *aster*, which is conspicuous during cell division. At other times, it may be seen only with difficulty.

d. Plastids (Gr. *plastos*, one who forms).—In certain cells, particularly plant cells, there are protein bodies concerned with constructing substances. Good examples of this type of body are the *chloroplasts* (Gr. *chloros*, green; *plastos*, formed) of green plants that are concerned with food making (page 140). Other types are the *leucoplasts* (Gr. *leukos*, white; plastids), colorless plastids and *chromoplasts* (Gr. *chroma*, color; plastids), colored plastids. The leucoplasts may be found in storage

centers. For example, they are present in potato tubers, where they serve as centers for accumulating starch. The chromoplasts give color to some flowers and fruits. They are instrumental in changing the color of these fruits as they mature. An example of this is the color of a green tomato, which is changed to red as it ripens.

e. Mitochondria and Golgi Bodies.—Special staining methods reveal the fact that *mitochondria*, characteristic cytoplasmic bodies, are present in most cells (Fig. 17). They may be in the form of granules, filaments, or rods, sometimes networks. Although there is some evidence that they may have something to do with cytoplasmic respiration, their use is not fully understood. They appear to be formed bodies that reproduce themselves and some authorities believe that they may be transformed into other structures. The *Golgi bodies* behave something like the mitochondria, but they are quite distinct from them. They may be diffuse or may be localized near the nucleus and are often netlike in form. There is some evidence that they are concerned with secretion. Special staining methods are required to demonstrate their presence in cells (Fig. 17).

f. Vacuoles.—These are cavities filled with a watery fluid or cell sap (Fig. 17). Each vacuole is bounded by a membrane that determines what materials go in and out of it. They are more common in plants and in one-celled animals than in higher animals. In the one-celled animals may be found two types of vacuoles: (1) *food vacuoles*, which contain food in the process of digestion and assimilation, and (2) *contractile vacuoles*, which disappear when they contract to empty their contents, water and liquid wastes, to the outside. They reappear again after a short time.

g. Metaplasm (Gr. *meta*, beyond; *plassein*, to mold).—Included within the cytoplasm are many nonliving bodies spoken of as cell inclusions or metaplastic bodies. These include crystals, droplets of various kinds, water, oil, liquid foods, wastes, starch grains, and the like. Some of these will or eventually may be assimilated or eliminated.

2. The Nucleus.—The nucleus, the most important part of the cell, cannot exist without some cytoplasm. It is also true that a cell, deprived of its nucleus, dies within a short time. Apparently the nucleus governs the activities of the cell. Certainly there is a constant interchange of materials between the nucleus and the cytoplasm.

a. Position of the Nucleus in the Cell.—Usually the nucleus is located near the center of the cell. It may, however, be found in almost any position in the cytoplasm. In cells that secrete mucus, in fat cells, and in most mature plant cells having large vacuoles, the nucleus often lies on one side and is flattened against the cell membrane.

b. Number of Nuclei in a Cell.—The number of nuclei in a cell is, typically, one. However, certain giant cells may have two or more. In one group of the Protozoa, there are two types of nuclei, a *macronucleus*, which appears to govern the metabolic activities of the cell, and a smaller

micronucleus, which is concerned with reproduction. There may be several micronuclei in certain species.

c. Nuclear Membrane.—The nucleus is set off from the cytoplasm by a membrane. If this membrane be injured in any way, the nuclear material mixes with the cytoplasm, and the cell dies in a short time. The nuclear membrane very evidently determines what materials enter and leave the nucleus.

d. The Framework of the Nucleus.—It is hard to see distinctly the structure of the living nucleus, even with a good microscope. When it is stained, however, certain structures stand out. The framework is seen to be a thread-like material called *linin* (L. *linum*, thread). On this, or imbedded in it, is the *chromatin* (Gr. *chroma*, color), which stains very deeply with certain dyes. The linin has a different staining reaction. The chromatin and the linin are very probably responsible for the formation of *chromosomes* (Gr. *chroma*, color; *soma*, body), which are rod-shaped masses of chromatin, prominent during cell division. The chromosomes carry hereditary units, and each plant and each animal has its own specific number of chromosomes. For example, the cells of the onion contain 8 pairs of chromosomes, and the cells of human beings contain 24 pairs.

e. Nucleoli (dim. of nuclei).—One or more nucleoli may be present in the cell. There are two types: (1) the *plasmosomes*, which stain with cytoplasmic stains and are regarded as the true nucleoli, and (2) *karyosomes*, which appear in the form of chromatin knots in the chromatin network. Several functions have been suggested for the true nucleoli, or plasmosomes. It has been suggested that they are waste products. Since they disappear during cell division, the idea is advanced that they constitute a reserve supply of materials used in cell division. They have also been regarded as a reserve food supply for the nucleus. Since the karyosome often stains, as does chromatin, it may be a reserve supply of that substance.

3. Relation of the Nucleus and the Cytoplasm.—Neither the nucleus nor the cytoplasm can exist without the other for a very long time. However, much of the cytoplasm may be removed by cutting, and the cell will still survive as long as the nucleus is intact. Pieces of a cell containing only cytoplasm will exist for a time but never survive for very long. As has been said, there appears to be a constant interchange between the nucleus and the cytoplasm.

V. All Cells from Cells

A. Cell Division.—One of the most remarkable characteristics of cells is their power to grow and divide. New cells must come from preexisting cells. This fact was not fully understood until long after the discovery of the cellular nature of living organisms. In 1855, the idea was expressed by Virchow in his saying, "*Omnis cellula e cellula.*" When a cell reaches

the limit of the size peculiar to it, it divides into two parts. These parts grow to their full size and then divide again. In this way, tissues are repaired, or plants and animals grow to their normal size.

B. Amitosis and Mitosis.—Cells may divide in two ways: (1) by direct division, in which case there is a simple cleavage of the nucleus,

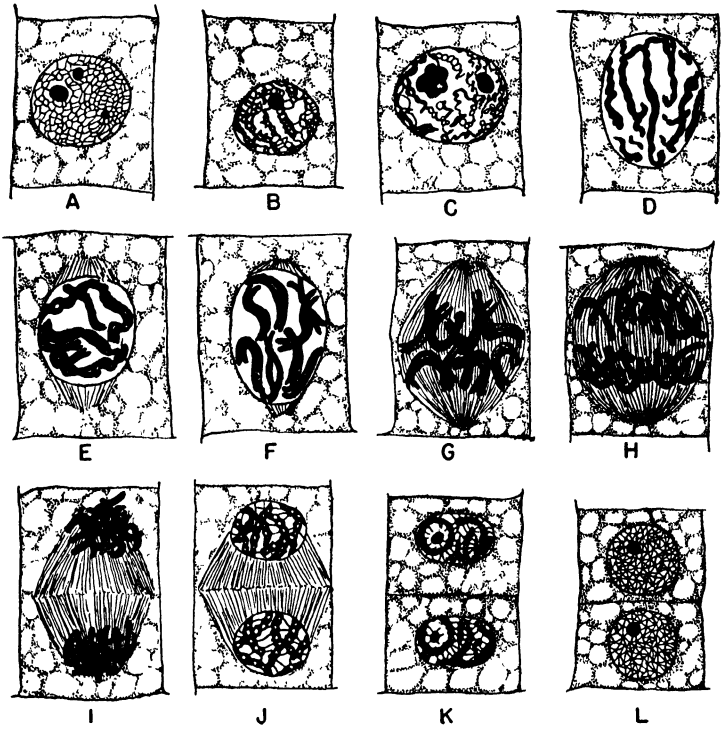

Fig. 18.—Mitosis and the division of a plant cell: (A–F) prophase; (G) metaphase; (H) anaphase; (I–J) telophase; (K–L) two-celled stage. (L. Runyon.)

amitosis (Gr. *a*, without, *mitos*, thread), followed by division of the cell, a rare method; or (2) by indirect division, preceded by a nuclear division involving formation and splitting of the chromosomes and their equal distribution to two daughter nuclei. This is *mitosis* (Gr. *mitosis*, thread) and is the usual method. Mitosis is a complicated but very orderly process, the stages of which are clearly defined. In spite of this, there is much about cell division that is not fully understoo l.

In general, the details of mitosis in plant and animal cells are much alike. As has been pointed out, the higher plants do not have centrioles, so that some details are different. Comparison of the diagrams in Figs. 18 and 19 shows the great similarity of the stages of the mitotic process.

[1] Karyokinesis (Gr. *karyon*, kernel; *kinein*, to move).

Before there are apparent signs of division, a cell is said to be resting. This refers to the condition of the nucleus. Naturally, the cell activities, metabolism and the like, go on constantly. A living cell *never rests* entirely.

C. Stages in Mitosis. 1. PROPHASE (Gr. *pro*, before; *phasis*, appear). Prophase is the early stage in mitosis. Before it begins, in the so-called *resting stage*, the chromatin in the nucleus appears as a network of fibers, and other structures of the cell have a normal appearance. When the

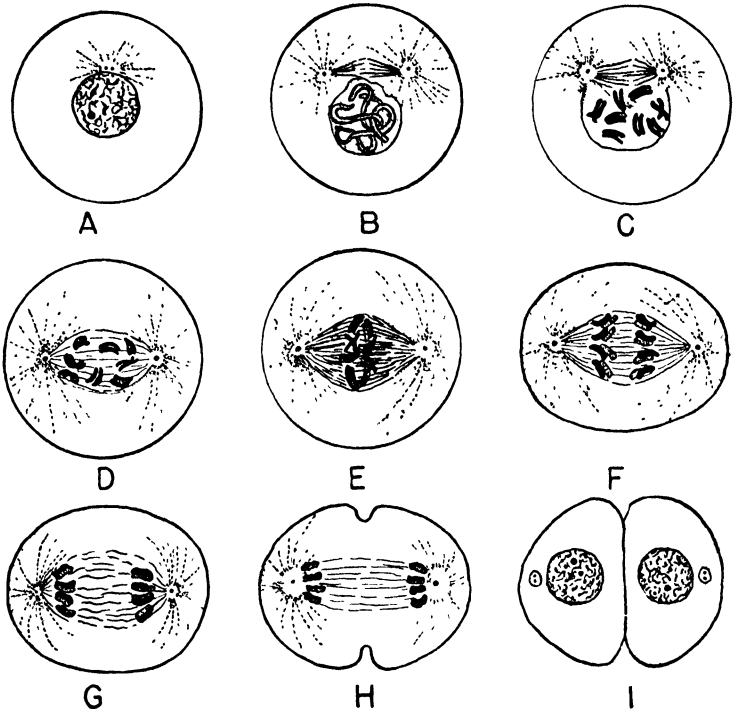

Fig. 19. Diagrams illustrating mitosis and the division of an animal cell: (A–D) prophase; (E) metaphase; (F–G) anaphase; (H) telophase; (I) two-celled stage. (From slides, L. Runyon.)

prophase begins, the chromatin network forms long, slender threads. These threads look as though they were coiled together and are, therefore, spoken of as a *spireme* (L. *spira*, a coil). The threads then become thicker and shorter and form the chromosomes. They are so named because they stain very deeply with certain dyes.

While the events mentioned above are occurring, the nuclear membrane disappears, and a structure known as the *spindle* makes its appearance. In animal cells, there is a characteristic aster at each end of the spindle, and in the center of these is a centriole. In plant cells, the asters and centrioles are absent. After its appearance, the chromosomes

appear to be drawn toward the spindle. All these events occur during the early, middle, and late prophases (Figs. 18*A–F* and 19*A–D*).

2. METAPHASE (Gr. *meta*, between; *phasis*, appear).—During the metaphase of mitosis, the chromosomes become attached to the spindle by fibers and arranged around the "equator" or middle. Each chromosome is now seen to consist of two halves, there being a longitudinal split in each. This splitting may have occurred at a much earlier stage. In any case, the two halves of each chromosome now separate. This method of longitudinal division assures that each daughter cell now being formed will receive exactly half of each chromosome. This is important, for the chromosomes are the bearers of the hereditary units.

3. ANAPHASE (Gr. *ana*, up; *phasis*, appear).—During the anaphase, one-half of each chromosome moves to one end of the spindle and the other half toward the other end (Figs. 18*H*, 19*G*). These chromosomes are apparently drawn to their new positions at the poles of the spindles.

4. TELOPHASE (Gr. *tellos*, end; *phasis*, appear).—The final phase of cell division is the *telophase*. The chromosomes that have been drawn to the poles now become vacuolated, forming a network characteristic of resting nuclei. A membrane appears around the nuclei. In the meantime, a partition appears down the middle of the cell, sometimes called the *cell plate*. In animal cells, there is an indention in the cell wall (Figs. 18*G*, 19*K*) that is not usually found in plant cells, though many pollen mother cells and Algae exhibit this indention in the cell wall. The cell now divides into two cells, and cell division is complete.

VI. Relation of Cells to Each Other

Single cells, such as blood corpuscles and one-celled creatures, may "live alone and like it," but the great majority of cells live in association with other cells. In the multicellular organism, there is interdependence of cells in the activities that affect the organism as a whole, such as the transfer of materials, water, food, and body fluids, and the electrical phenomena. Further, cells may be modified in development and their activities guided by cells around them.

In some cells that are associated together, protoplasmic filaments have been demonstrated to pass from one cell to another, forming a sort of protoplasmic bridge.

VII. Entrance and Exit of Materials

As has been stated, the plasma membrane governs the exchange of materials between the cell and the environment. Certain processes such as diffusion, osmosis, and plasmolysis (see below) are concerned in this exchange. It is also true that the plasma membrane is semipermeable; *i.e.*, some substances can enter, and some cannot. Water and dissolved

food must enter the cell, and wastes must pass out. The plasma membrane governs all this. Its permeability may be changed by certain ions. Sodium and potassium *increase* permeability, whereas other ions, magnesium and calcium, *decrease* permeability. A balanced solution of these ions maintains the normal permeability of the cell unchanged. This balance may be upset, however, and the permeability of the cell vary under changed conditions.

A. Diffusion.—Protoplasmic activity is affected by the physical processes of diffusion and osmosis. If a small piece of copper sulphate is

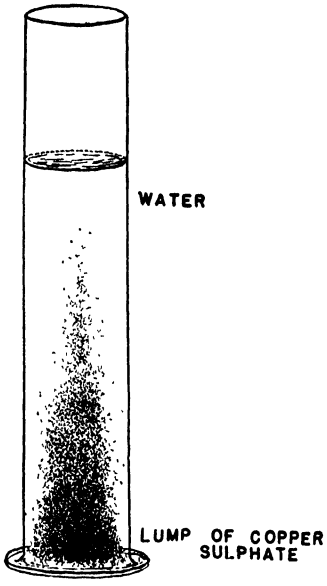

Fig. 20.—Experiment to illustrate diffusion. (B. Shamos.)

placed in a beaker containing water, it will dissolve. At first the region around the lump will be bluer than the rest of the fluid in the vessel (Fig. 20), because the copper sulphate is concentrated there. If it is allowed to stand long enough, the color of the liquid becomes uniformly blue. This shows that the copper sulphate has diffused and is now uniformly distributed in the liquid. The explanation of this is that the molecules of copper sulphate move from place to place until they are uniformly distributed. This force motion is their "kinetic" motion, and it is this motion that causes Brownian movement.

B. Osmosis.—A membrane that allows the passage of materials through it is said to be permeable. If two solutions are separated by a membrane that is permeable to all the dissolved substances in these two solutions, diffusion will, of course, take place through the membrane until

the solutions on both sides will be of the same concentration. Some membranes are permeable to some substances and not to others; they are, therefore, called *semipermeable membranes*. Membranes differ in permeability. One reason may be the size of the pores in the membrane. For example, certain particles, or molecules, may be small enough to go through the microscopic pores of a membrane; others may be too large. Many membranes are quite permeable to crystalloid solutions, yet these same membranes are not permeable to colloids because of the size of the colloidal particles. Another reason for differences in the permeability of membranes may be illustrated by means of a rubber membrane. Such a

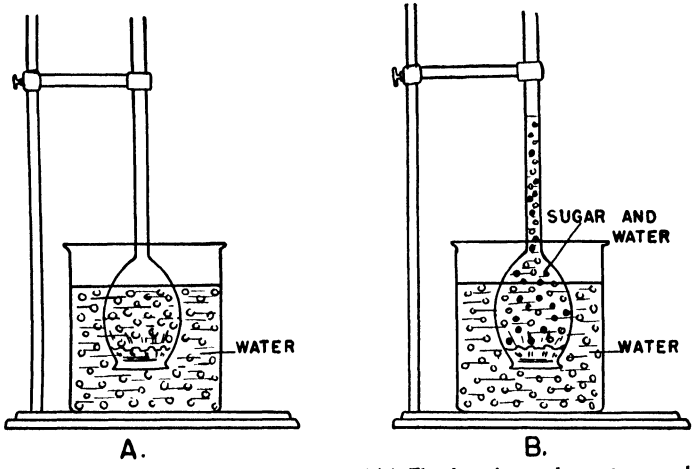

Fig. 21.—Experiment to illustrate osmosis. (A) Thistle tube with semipermeable membrane tied over the large end, then partially filled with water and finally immersed in a beaker of water. (B) Apparatus set up the same way but sugar solution is placed in the thistle tube in place of pure water. The water now rises in tube B but not in tube A.

membrane is not permeable to water but is permeable to other liquids, such as ether. Why? Because rubber is soluble in ether and not in water.

When two solutions of different concentrations are separated by a semipermeable membrane, which is permeable to the solvent but not to the dissolved substance, the solvent will pass through the membrane from the less concentrated to the more concentrated solution. This process is known as *osmosis*. It is well illustrated by the following experiment: If sugar and water are placed in a thistle tube having a semipermeable membrane tied over the large end and the tube is then immersed in water, the solution will begin to rise in the tube almost immediately (Fig. 21). This process will continue until the pressure due to the increased height of the column of the solution (hydrostatic pressure) just offsets the pressure caused by the diffusion of water into the sugar solution (osmotic pressure). In this case, water diffuses into the tube.

This is *endosmosis* (Gr. *endon*, within; *osmos*, pushing). A familiar example of water diffusing out instead of in is that of sugar being placed on strawberries or other fruit and the juice being drawn out. This is *exosmosis* (Gr. *ex*, out; *osmos*, pushing).

C. Plasmolysis.—When water diffuses out of cells, it leaves the protoplasm a shrunken mass. This (Fig. 22) shrinking of a protoplast from its cell wall, owing to exosmosis, is known as *plasmolysis* (Gr. *plasma*, form or mold; *lysis*, loosening). If a piece of *Spirogyra* is placed in a 10 per cent salt solution, the water will diffuse out, leaving the shrunken mass of protoplasm behind. If the process is not allowed to go on for too long a time, the *Spirogyra* can be restored by placing it in water again.

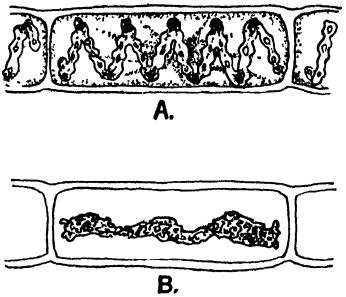

Fig. 22.—Experiment to illustrate plasmolysis. Spirogyra lives in water normally. If some of the filaments be placed in a 10 per cent solution of salt in water, the cell contents will shrink away from the wall, or plasmolyze. (Jane Wyatt.)

In animal cells that are covered by a less rigid cell membrane, the cell becomes wrinkled or shrinks.

VIII. Functions of Cells

At this point, it is not possible to discuss fully the activities that go on in cells. There are many cells with specialized functions, such as gland cells, muscle cells, and nerve cells. The functions of the various parts of of the cells can, however, be summarized in a general way.

A. Cell wall. May or may not be present. In plant cells especially, it *strengthens* the tissues. Also, it offers protection from mechanical injury and (especially important) *drying.*

B. Cytoplasm. It is the seat of *absorption, secretion, digestion, excretion, respiration, irritability,* and other physiological activities.

1. *Plasma membrane.* This regulates the *materials* that *go in and out* of the cells, such as water and dissolved foods.
2. *Centrosphere, centriole, aster.* These are present in animal cells and in some of the lower plant cells. When present, the centriole is the *division center.* The centrosphere and *aster* accompany the centriole.
3. *Plastids.* These are bodies concerned with *constructing substances* in the cells. There are three main types:

a. Chloroplasts. Green bodies in plants concerned with the *manufacture of carbohydrates.*

b. Leucoplasts. Colorless bodies in plants, found especially where *storage* is taking place; *e.g.*, starch in a potato tuber.

c. Chromoplasts. Bodies that give *colors* to some flowers and fruits.

4. *Mitochondria and Golgi bodies.* These are present in most cells. Mitochondria may have something to do with *cell respiration;* they may also be transformed into other substances. Neither these nor other functions suggested are proved. Golgi bodies may be concerned with *secretion.*

5. *Vacuoles.* May have different functions. In one-celled animals, they may be concerned with *excretion, equilibrium,* or other activities. In plant cells, they contain *cell sap* in which *food substances* may be dissolved. They may have other functions; *e.g., digestion* (food vacuoles), *storage.*

6. *Metaplasm. Lifeless* materials. May be stored *food,* as starch and oil; may be *droplets of food* waiting to be assimilated; or may be *water* or *crystals.*

C. Nucleus. The nucleus *governs the activities of the cell,* undergoes *mitosis* during cell division.

1. *Nuclear membrane.* This gives the nucleus its *shape* and *governs* the *exchange of materials* between the nucleus and the cytoplasm.

2. *Linin and chromatin.* The *linin* is the *framework* on which the chromatin is carried. Together, linin and chromatin appear to condense to form the *chromosomes,* and the chromosomes carry the units that control heredity in organisms.

3. *Nucleoli.* Two types: (1) *true nucleoli* or plasmosomes and (2) *chromatin knots* or *karyosomes.* Functions are uncertain.

IX. Body Cells and Germ Cells

Body cells live and multiply, but finally all of them die; germ cells are the cells that produce succeeding generations. The mitosis described above is the method by which the majority of cells, including germ cells, multiply. When the germ cells are maturing, however, they go through a process known as *meiosis* (Gr. *meioun,* to make smaller). This is a complicated process that is fully discussed on page 703. Since frequent reference must be made to the results of this process, they are briefly stated as follows: Each plant and animal contains a definite number of chromosomes characteristic of the group to which it belongs, one-half having been contributed by its male parent and one-half by its female parent. Each individual, then, has two sets of chromosomes in all its cells. For example, the cells of man have 48 chromosomes, 24 received from his mother and 24 from his father. In most organisms, when the male and female germ cells are maturing, this number of chromosomes is reduced by one-half; the eggs and sperm of man will then contain 24 chromosomes each (a full set). This is called the *haploid* (Gr. *haploos,* single) number. When the egg is fertilized by a sperm, the double, or *diploid* (Gr. *diploos,* double) number is restored, and the individual that develops from the fertilized egg will have a diploid number of chromosomes in each of its cells. When the germ cells of these organisms mature, reduction division occurs again, and the number of chromosomes is restored when the eggs

are fertilized by the sperm. This mechanism provides for cross-fertilization, a reassortment of the chromosomes, and so for the production of essentially new individuals (page 707).

Details of meiosis differ in various groups of plants and animals, as will be learned later, but the fundamental process is the same for all.

Questions

1. Give an account of the discovery of cells.
2. What is Schultze's definition of a cell? Do you think that this is a good definition? Give reason for your answer.
3. Who formulated the cell theory? What was the effect of this theory on biological thought?
4. Describe the structure of a generalized cell. What are the living and nonliving parts?
5. Give an account of the orderly process of indirect cell division.
6. What are chromosomes? Is there any significance in the fact that chromosomes split longitudinally? Do all cells have the same numbers of chromosomes? Explain.
7. Define: diffusion, osmosis, plasmolysis.
8. State the function of each part of the cell.
9. What are some differences between body cells and germ cells? Explain one important result of meiosis in germ cells. Define: haploid, diploid.

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COWDRY, E. V. (ed.): "General Cytology," University of Chicago Press, 1924.

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CHAPTER V

TISSUES, ORGANS, SYSTEMS

Pluck one thread and the web ye mar;
Break but one
Of a thousand keys, and the paining jar
Through all will run.
—WHITTIER.

I. Tissues

A. Combinations of Cells.—In organisms of more than one cell, cells are combined to form *tissues*. A tissue may be defined as an aggregation

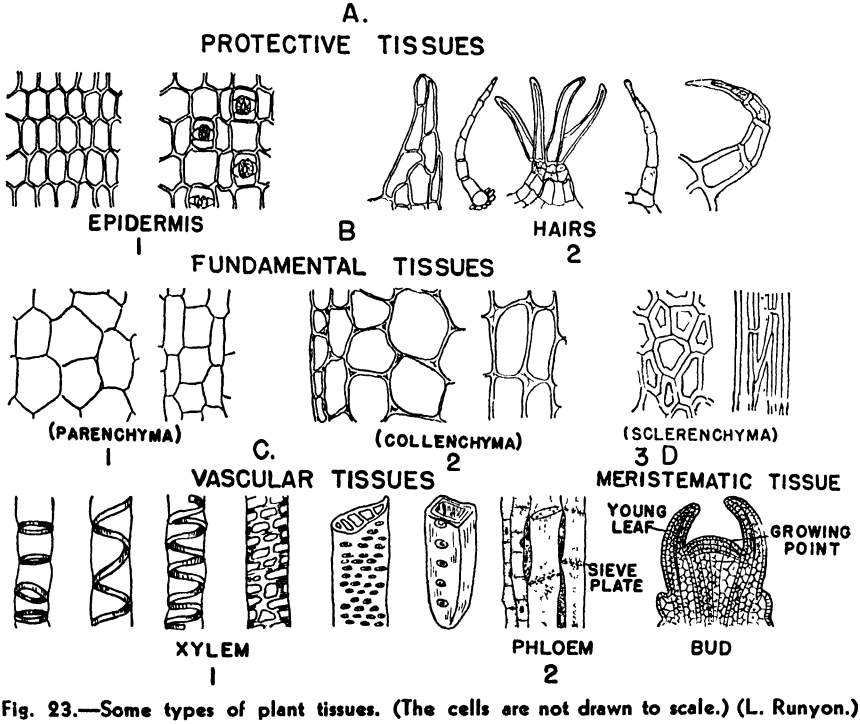

Fig. 23.—Some types of plant tissues. (The cells are not drawn to scale.) (L. Runyon.)

of similar cells that perform a particular function. They come into being through (1) the *multiplication* of cells and (2) the *differentiation* of cells

into various types. A mother cell divides into two daughter cells, as has been described, but that is not the whole story. During the development of an individual from an egg, cells become modified in both appearance and function. A division of labor is established among cells as a result of

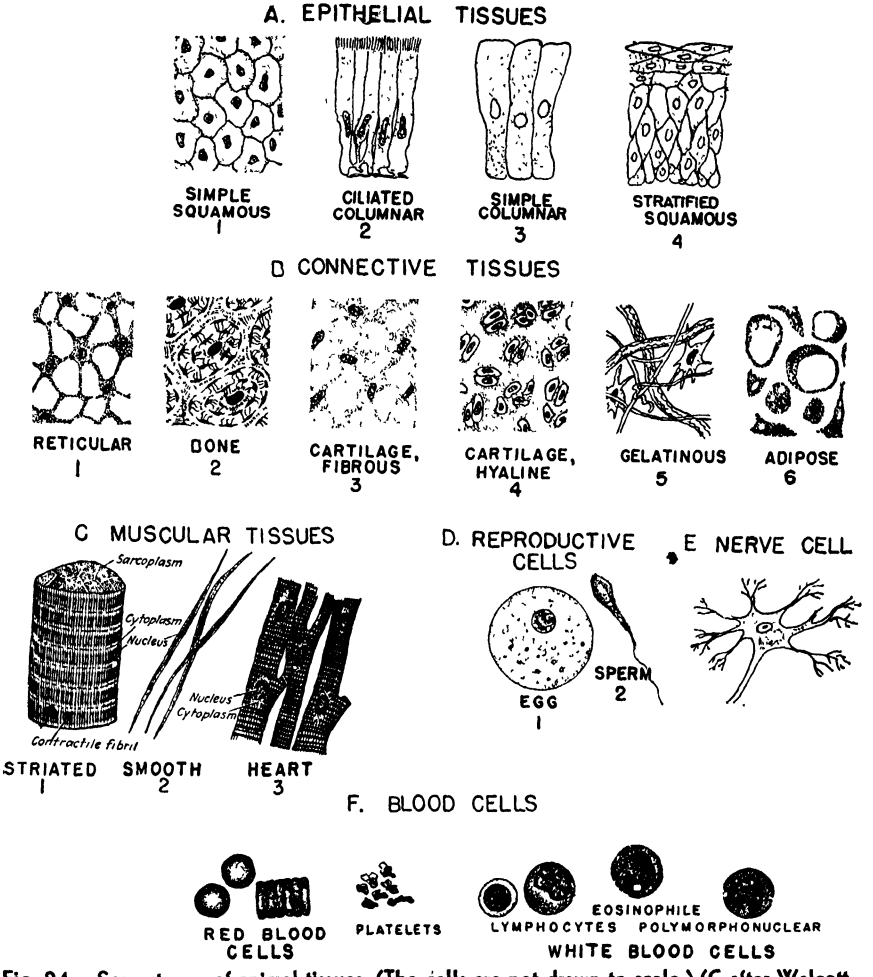

Fig. 24.—Some types of animal tissues. (The cells are not drawn to scale.) (C after Walcott, F after Hegner.)

this modification. Each type of cell then produces others of its kind by *mitosis*, and so different types of tissues are built up. Each type of tissue consists of the same kind of cells and differs from all other tissues in both appearance and function. For example, liver tissue differs from muscle tissue, and each performs different functions.

B. Types of Tissues.—There are many types of plant and animal tissues, each having special duties. In Fig. 23, some types of tissues of higher plants are shown; in Fig. 24, various types of tissues of higher animals are illustrated. Even a brief study of these will reveal the fact that functions of tissues are varied. They may be protective; they may be adapted for the transfer of fluids and food; they may serve as supporting or connective tissue; they may secrete important substances; they may be adapted for receiving stimuli or for coordination; finally, the tissue may be reproductive.

Various types of plant and animal tissues, as well as their functions, are better understood after a study of a typical plant or a typical animal. The microscopic structure of tissue is called *histology* (Gr. *histos*, tissue; *logos*, science of study).

C. Classification.—Tissues may be classified in several ways. It is sometimes convenient to classify them on the basis of *form* or *structure;* at other times, they are classified on the basis of *function*, or method and place of *origin*, stage of *development*, etc.

II. Organs

As aggregates of cells form tissues, so combinations of various types of tissues make up *organs*. For example, the heart has in it muscular, vascular and connective tissue. Each tissue has its separate function, but the heart has the job of a pump. An organ, then would be defined as an association of different tissues acting together to perform some vital function.

III. Systems

Finally, organs are associated together into systems of organs working together for a specific function. One has only to think of the digestive system to realize that it is made up of several organs, the stomach, intestines, glands, teeth, etc., that work together to accomplish the work of digestion. Yet in this task each organ has its own work to do, and this work is a part of the complex process of digestion.

IV. Unity in the Living World

The work of living organisms is done, in the last analysis, in the cells of that organism. Yet it is the marvelous organization of these cells into tissues, the tissues into organs, and the organs into systems of organs that makes the multicellular organism possible. All parts work together for the good of the whole organism.

The organization in living things is carried still further in the natural grouping of the kinds of organisms. Order is brought out of chaos by finding that all organisms fit into an orderly scheme of classification.

But organization does not end there; certain groups of living things are found together in special habitats or *communities*. Organisms are adapted to live in certain situations, and, as will be seen later, an understanding of the relationships of organisms to their environment is one of the most amazing chapters in the study of biology.

Questions

1. Distinguish between the terms *tissue*, *organ*, and *system*.
2. Discuss three ways in which unity is shown in the living organism.

Suggested References

SHARP, L. W.: "Introduction to Cytology," The McGraw-Hill Book Company, Inc., 1934.
WILSON, E. B.: "The Cell in Development and Heredity," The Macmillan Company, 1925.

CHAPTER VI

WHERE PLANTS AND ANIMALS LIVE; THE INTERDEPENDENCE OF LIVING THINGS

Hot, cold, moist and dry, four champions fierce
Strive here for mastery.
—JOHN MILTON.

I. The Environment

It is a matter of common knowledge that certain types of organisms live in particular environments. For example, whales and seaweeds live in the ocean; some types of fish and water lilies live in fresh-water ponds; innumerable plants and animals live on the ground; moles, under the ground; hookworms, in animal bodies. As these familiar examples show, there are many natural abodes or *habitats* (L. *habitare*, to dwell) of plants and animals. Each type of habitat serves as a dwelling place for certain definite communities of living things. The question naturally arises as to why certain organisms are found only in certain localities. With a little study, one soon learns that the physical and biological factors present in these communities determine what species are able to live in each. How different are the conditions in a desert compared with those in a fresh-water pond! Organisms that live in the former could not possibly live in the latter. The study of organisms in relation to their environment is the science of *ecology* (Gr. *oikos*, house; *logos*, discourse); the *response* of organisms to their environment is the basis for study of *adaptations*. This important subject will be dealt with in Part V of this book. The following description of the factors that affect the environment, types of habitats, and realms is meant to serve as a sort of "stage setting" for the living world, a discussion of which follows in the next chapter.

II. Factors Influencing the Environment

A. Physical Factors.—Some of the physical factors that help determine where a plant or an animal lives are temperature, light, moisture, gravity, soil, currents, tides, winds, barriers, and chemicals.

1. TEMPERATURE.—Life is possible for a plant or animal only within a certain range of temperature. Yet organisms possess to a remarkable degree the power of adjustment to heat and cold. There is, however, a minimum and a maximum temperature at which they can live success-

fully. There is also the *optimum*[1] (L. *optimus*, best) temperature that is best suited to their highest development. For example, tigers live only in hot countries, whereas elephants, which live in hot countries, also, are able to adapt themselves to much colder climates. And so every range of temperature—hot, cold, temperate—has its own peculiar flora and fauna.

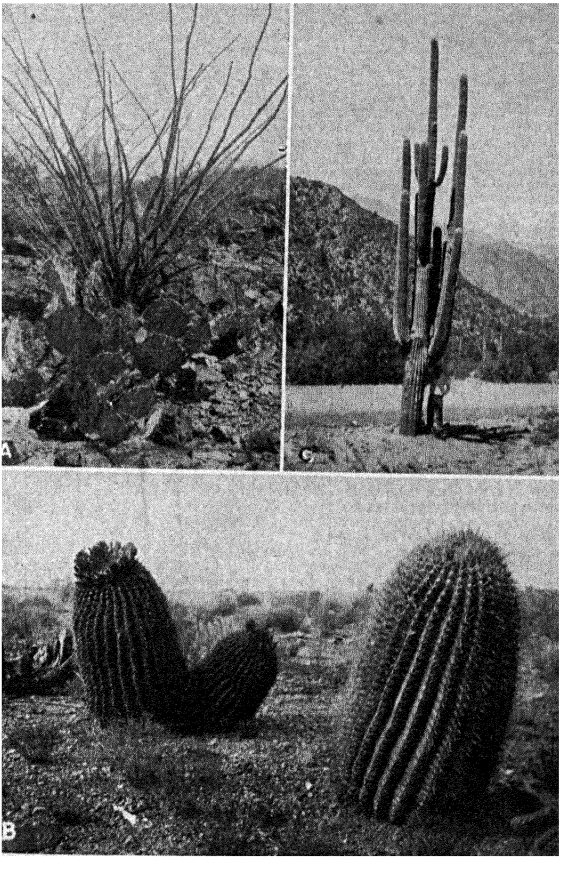

Fig. 25.—A group of desert plants. (A) Ocotillo, a shrub which has leaves only in the wet season. In the foreground, a common cactus. (B) Opuntia, barrel cactus. (C) Carnegia, giant cactus. (Courtesy Dr. E. H. Runyon.)

2. Light.—It will be seen later that green plants must have light in order to live. Some must have strong light; others prefer varying degrees of shade. Light is important for most animals, also (page 598); many animals cannot stand the direct sunlight. There is a day-and-night rhythm in many organisms. Some animals, such as bees, move about

[1] The terms *minimum*, *maximum*, and *optimum* are used to describe other factors besides temperature.

only in daylight; others are nocturnal in their habits, as some birds,

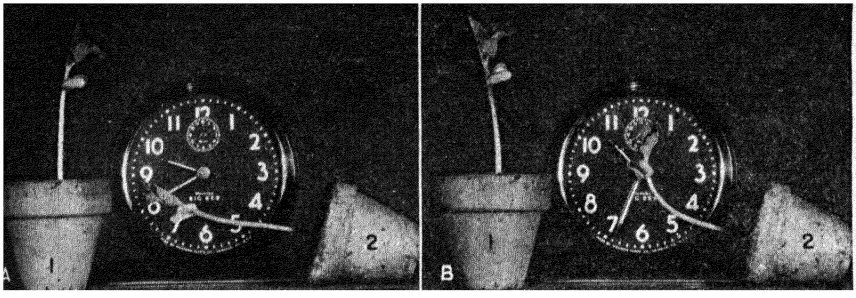

Fig. 26.—Negative geotropism. In a dark room (to exclude the influence of light), two bean seedlings were set up as in A. As shown by the clock, in a little less than an hour, the plant in pot 2 had changed its position. As the stem has grown in a position opposite to the force of gravity, it is negatively geotropic. (Photograph by Dr. E. H. Runyon.)

3. MOISTURE.—All living things have water in their bodies; some have very little; others, a great deal. Many are organized so as to withstand the harshest drought, as in the desert (Fig. 25); others can live only in water. However, too much moisture can be as injurious as too little. Earthworms will die in water-soaked soil that is normally only moist. They are unable to get the oxygen they need because the air is driven from the soil by the water. One type classification of plants and animals is upon the basis of the moisture they need (page 57).

Fig. 27.—Influence of the environment. Mature stunted pine tree growing in rocky ground. Note cones on the tree. (Courtesy of Dr. W. B. Baker.)

4. GRAVITY.—Gravity affects the majority of organisms either negatively or positively. In plants, roots usually grow downward, and stems usually grow upward (Fig. 26), whereas horizontal branches appear not to be affected in the same way. The hollow bones and air spaces in the bodies of birds are modifications that help overcome the force of gravity.

5. SOIL.—In addition to the alkaline, acid, or neutral conditions of the soil, the texture of soil is important for living organisms. The character

of soil may be dense, porous, clayey, sandy, or it may contain much humus; rocky land may have shallow soil, yet organisms try to live there (Fig. 27). These varieties of soil are suited to special groups of plants and animals. Further, the rocky beds of streams or soft mud bottoms of ponds may harbor very different animal and plant associations.

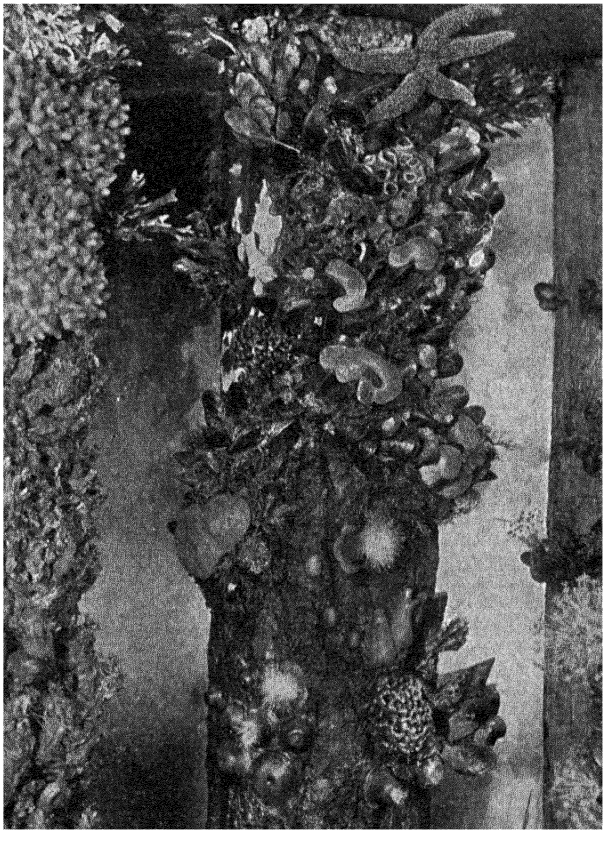

Fig. 28.—Animal community on wharf piles in shallow salt water, Vineyard Haven, Mass. (Courtesy of American Museum of Natural History.)

6. WINDS, CURRENTS, TIDES.—Winds may affect the moisture content and the temperature of an environment and hence affect the organisms living there. Winds break limbs of shrubs and trees, blow birds and insects many miles, and air currents may distribute seeds and pollen. Many animals swim against currents; some do not. Many plants and animals can live between high- and low-tide marks (Fig. 28) that could not live either in deep water or on dry land.

7. BARRIERS.—Often there are natural barriers to the distribution of living forms. These may be *topographic*, as mountains, bodies of water,

deserts, jungles, and the like; *climatic*, as dryness, heat, lack of moisture, etc.; or *vegetative*, *i.e.*, there may be the presence or absence of suitable plants for food supply. It must be borne in mind that what may be a natural *highway* for certain types of animals is a barrier to others. For example, fish can go in search of food in the water highways, whereas many land animals cannot cross large bodies of water.

8. CHEMICALS.—Chemicals found in food, in water, or in the soil may affect profoundly organisms in any type of environment. Plants such as the loco weed (Fig. 152) may be poisonous and injure animals; there may be too much alkali in the water to allow the water to be absorbed by the plants; cranberries, mountain laurel, azalea, and many other plants demand acid soil, but the great majority of plants do not do well in soil that is either too acid or too alkaline.

Carbon dioxide in the air is necessary if plants are to make sugar (page 140). *Oxygen* is important to most living things, whether they dwell in the water or on the land.

B. Biological Factors; the Interdependence of Organisms.—Biological factors, or the effect of living things upon each other, are called the *biotic* (Gr. *biolikos*, pertaining to life) factors. Whether one studies a single organism in relation to its environment, or communities or associations of various species of organisms in their particular environment, certain factors of a biological nature are apparent.

1. COMPETITION.—The "struggle for existence" among organisms is a very real struggle. Food is necessary for life, so that the competition for food may be an important factor in the ability of organisms to remain in a given environment. Strong plants may preempt the soil or grow so tall as to shade the lower layers of plants. There may not be enough moisture to go around. Animals may multiply in great numbers and use up the available food supply.

2. FOOD AND SHELTER.—Food that is suitable for the organisms must be present. Plants, of course, furnish food and shelter for animals, but the right sorts of plants must be present. As the forests disappear, the animals that live in them must disappear also for lack of shelter. Animals that eat only flesh are dependent, in the last analysis, upon plants. For example, a lion may eat a zebra; but the zebra eats only plants.

3. ENEMIES.—Enemies may be of two kinds: (1) organisms that prey upon each other and (2) *parasites*. An owl may kill off all the mice in a given area, or the chestnut blight may kill all the chestnut trees. There is an eternal struggle for existence. It has had, and must continue to have, its effect upon life upon this earth.

Parasites exist at the expense of other organisms. They live inside the bodies of organisms as *endoparasites* or on the outside as *ectoparasites*. All organisms have parasites, even the tiny microscopic plants and

animals. Parasites will be discussed in detail later. It is sufficient to point out here:

> So, naturalists observe, a flea
> Hath smaller fleas that on him prey;
> And these have smaller still to bite 'em
> And so proceed *ad infinitum.*
>
> —SWIFT.

4. ORGANISMS THAT HELP EACH OTHER.—Not all organisms that are present in a given environment are either competitors or enemies. Some are mutually helpful.

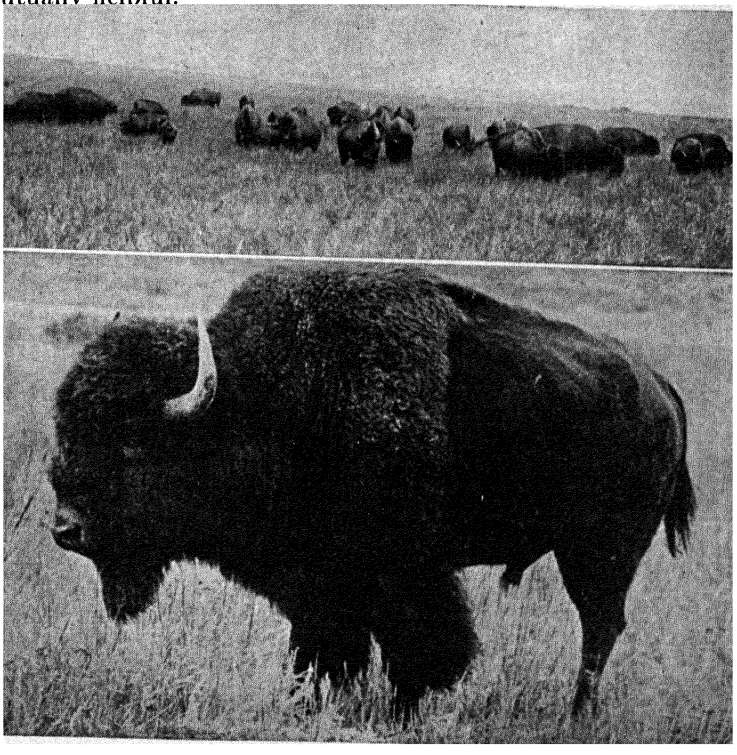

Fig. 29.—Buffalo or Bison. Great herds of these mammals once roamed the plains of America. Buffalo are gregarious animals. (Courtesy of the U.S. Biological Survey.)

a. Gregarious Animals.—Many animals band together for protection or for hunting and are called *gregarious animals* (Fig. 29). It is well known that certain animals travel in herds: the horse with a male for a leader or the buffalo with a female for a leader. Wolves and killer whales may hunt singly, or they may combine to secure their prey. Another type of association is the rhinoceros bird, which accompanies the rhinoceros and

picks the ticks from its back. In return for its food supply, it gives warning when the rhinoceros is near danger.

b. Commensals (L. *com*, together; *mensa*, table).—There are some organisms that live together in a sort of permanent association. The word *commensal* means literally together at the same table. A good example of this type of association is shown in Fig. 30. The sea anemone is carried around by the crab and has thereby a better chance to secure food; the crab is protected by the sea anemone in two ways: the anemone is good at stinging, and it conceals the crab.

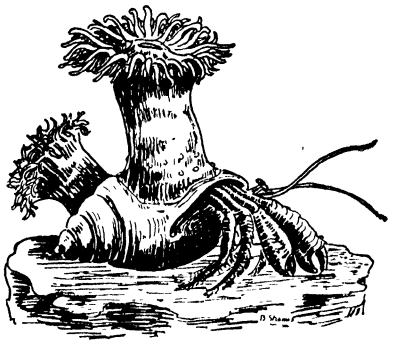

Fig. 30.—Commensals. Sea anemones growing on the shell of a hermit crab. (Drawn by B. Shamos.)

c. Symbionts (Gr. *symbiosis*, a living together).—In this type of association, there is organic union. The green hydra is green because small green plants, *chlorella*, are imbedded in its cells. As do all living things,

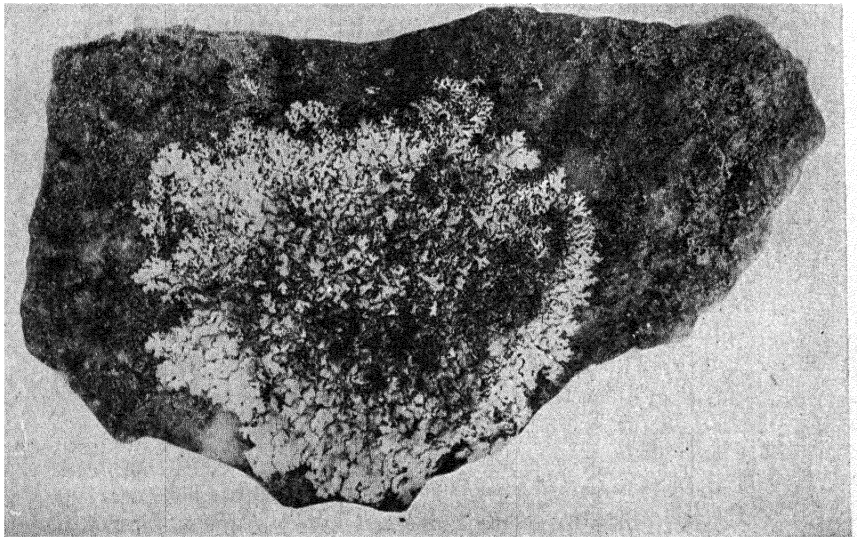

Fig. 31.—Symbiosis. Crustose and foliose Lichens growing on a rock. A lichen is composed of an alga and a fungus living together symbiotically. (Photograph by Dr. E. H. Runyon.)

the *Hydra* gives off carbon dioxide and certain nitrogenous substances that can be utilized by the plant. The plant uses water and carbon dioxide and with the aid of energy from the sun manufactures its food supply of sugar, which is usually stored as starch (page 140). During this

process of manufacture, it liberates oxygen that can be used by the *Hydra*. A whole group of plants, the *lichens* (Fig. 31), represents a partnership between an alga and a fungus. Still another type of symbiotic relationship is shown by the beneficial bacteria that live in the alimentary canals of the higher animals. They aid in the digestion and absorption of food and in turn are protected and get their own food supply.

Some authors believe that *commensalism*, *symbiosis*, and *parasitism* represent varying degrees of the same principle. From a loose sort of association, there is progression to organic union that is mutually helpful. When the association is carried to extreme, organisms living together become parasites, and one lives at the expense of the other and is usually detrimental.

III. Some Types of Habitats

A. Life in the Water.—The water furnishes an ideal situation for untold numbers of organisms from microscopic size to the largest of all animals, the whale. Many factors affect the distribution of organisms in water: winds, currents, depth of the water, type of shore, type of soil on the bottom, migrations of animals, etc.

1. Salt Water.—Seventy-two per cent of the earth's surface is covered by the sea, and many types of organisms live in this salt water. Many float on the surface; some live at great depths; others, at varying depths: fish, whales, and the like. Some, like barnacles and seaweeds, are attached to rocks or piles (Fig. 28). The sea beaches are populated by vast numbers of animals.

2. Fresh Water.—There are many types of fresh-water habitats: pools, ponds, lakes, streams. Many factors influence the types of organisms to be found in these situations. The size of the stream, the character of the soil under the water, the amount of vegetation present, pollution of the water by erosion or by the wastes of industrial plants are only a few of the things that affect the population, both plant and animal, in the streams.

B. Life on Land.—The plants and animals that live on the surface of the earth are the ones most frequently seen. Yet there are many types of adaptations that organisms must make to live in the varied land situations. Desert organisms (Fig. 25) are very different from those that live in the depth of the forest, on top of mountains, on the prairies, the plains, and in many other places.

Not all organisms live on the surface of the land. Some burrow into the soil, as the mole (Fig. 32) and larva of the 17-year locust. Every ounce of garden soil contains not only billions of plants but many animals so small as to be seen only with the aid of the highest powers of the microscope.

C. Life in the Air.—Many animals that live on land and water fly through the air, especially the birds and insects. Some plants (epiphytes) are designated as air plants, and some Algae live on rocks and tree trunks. In the air are carried countless spores and seeds of plants as well as cysts of many one-celled creatures. All organisms that are able to navigate in the air are adapted for this purpose by a tendency toward lightness (page 170).

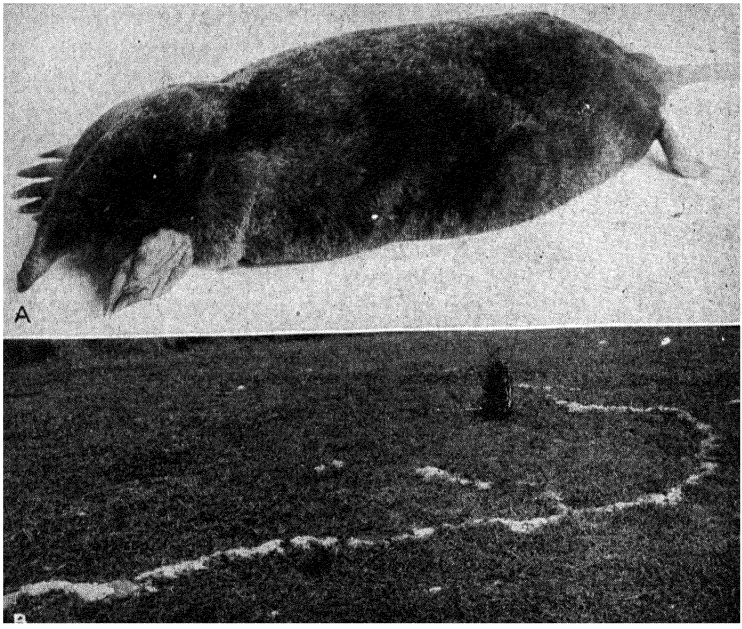

Fig. 32.—(A) An animal that lives underground, the mole. (B) Ridges made by a mole. Often a mole burrows close to the surface, throwing up ridges like this one. (Courtesy of the U.S. Biological Survey.)

D. Parasitic Life.—Parasites are found in all types of organisms, from the highest to the lowest. It has already been observed that even the one-celled creatures have their parasites. The parasitic habitats vary; some parasites inhabit the blood of animals; some are found in tissues of both plants and animals; still others are found in practically every part of living things. Some parasites are partial parasites, as mistletoe (Fig. 70); others, like the hookworm, are total parasites (pages 322–324).

IV. Biological Communities or Associations

No organism lives alone; all organisms live in association with other living things. The distribution of plants and animals in any community

depends upon the physical and biological factors that have been mentioned. No one factor is all-important. If the statement is made that temperature is the all-important factor, exceptions will be found immediately. Food, conditions for breeding, etc., all together give sufficient reason for the presence or absence of certain forms. A single factor may often explain distribution of some forms, but more often there are several factors that determine the flora or fauna of a community.

Organisms may be separated into communities upon the basis of their habitat (page 48). For example, the water plants are *hydrophytes* (Gr.

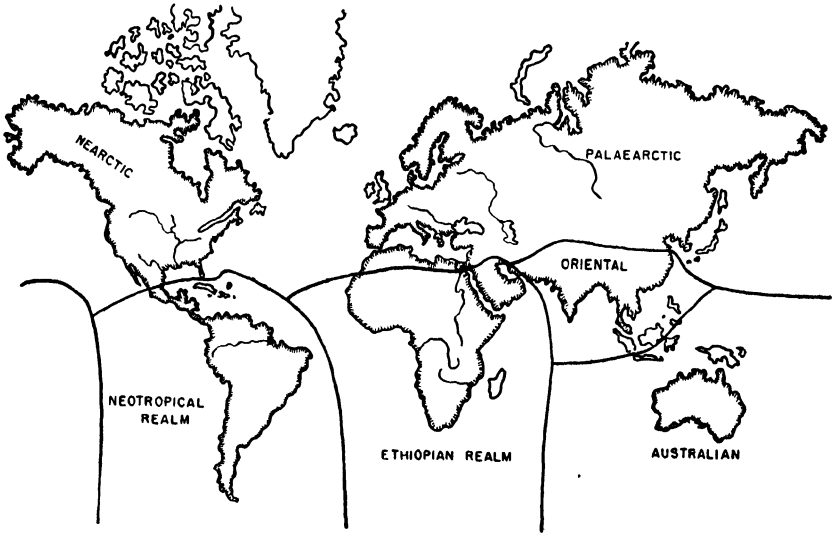

Fig. 33.—Map showing geographical realms of the world. (Adapted from various sources by B. Shamos.)

hydor, water; *phyton*, plant); the desert plants are *xerophytes* (Gr. *xeros*, dry; *phyton*). Plants needing a moderate water supply are *mesophytes* (Gr. *mesos*, middle; *phyton*, plant). Animals that live in the water are *aquatic* (L. *aqua*, water); those that live on land, *terrestrial;* if they live both on land and in water, they are *amphibious* (Gr. *amphi*, both; *bios*, life). There are many other bases of classification into communities. The Ecological Society of America has adopted a classification of the land and water communities. A synopsis of this classification will be found in the Appendix, pages 871, 872.

V. Life Realms

A. Life Realms or Geographical Realms.[1]—The world has been divided into realms or life zones. Figure 33 shows the six regions most

[1] For a description of these realms, see the Appendix. The seventh, or Polyneasian region, is often included in the Australian region.

commonly recognized. These are based upon the distribution of mammals; yet regions are shown in which many other organisms are found nearly as often. Each realm has its own characteristics and includes its own type of organisms. As the map shows, most of North America lies in the *Nearctic region* (Gr. *neo*, late or new; arctic). This region has been subdivided into four subregions, each with its characteristic groups of mammals.

B. The Four Subregions or Life Zones.—The four subregions in North America are the (1) Californian, (2) the Rocky Mountain, (3) the Alleghenian, and (4) the Canadian. These life zones are not sharply limited; transition zones lie between them. Also, all the plants and animals that live in one zone are not limited to that zone, but enough of them are so limited as to make it possible to separate one zone from another.

Moisture and temperature are the two great factors that largely determine the character of plant and animal life in a zone. But moisture and temperature may vary greatly within a single zone. This is particularly true where a zone contains mountains. A single mountain in a tropical region may be divided into as many as five zones: (1) At the base of such a mountain, tropical conditions prevail, and plants and animals characteristic of the tropics occur. (2) Higher up, mountain conditions exist like those in a warm temperate zone, with well-defined summer and winter seasons. (3) At still greater altitudes, the temperature is cool, trees lose their leaves or may be unable to live. (4) Above the tree line are grasses, mosses, and lichens. (5) And finally, at the top, above the snow line, arctic conditions may endure throughout the year. The types of animals and their behavior in these various zones are similar to those encountered as one proceeds from the equator northward or southward toward the poles.

VI. Nature's Balance

A. The Web of Life.—As pointed out above, in every biological community there is competition of various kinds between organisms—between plants and plants, animals and animals, and between plants and animals (Fig. 34). If one type of plant multiplies very rapidly and takes up the food materials of the soil, little is left for the others; or if plants make a dense growth, young plants do not get enough light and so die. Among the animals, there may be enemies of certain kinds; for example, lions will eat many types of animals, or animal parasites may destroy large numbers of plants or animals. The presence of many sheep in a limited grazing area means that the land will be overgrazed and that then the entire character of the area will be changed. In spite of this, the number of species in any given environment remains about the same, because of many delicate adjustments.

Darwin figured out a case that illustrates the way in which one type of organism depends upon another. The chain of events begins with the fact that certain types of clover are pollinated only by the bumblebees. Red clover is one of these, and if pollination does not occur, the plants will die out. Now the number of bumblebees in a community depends upon the number of field mice that are present, since the latter destroy the nests of the bumblebees. So it would seem that cats are necessary for the clover crop. Huxley added to this chain by suggesting that, on the

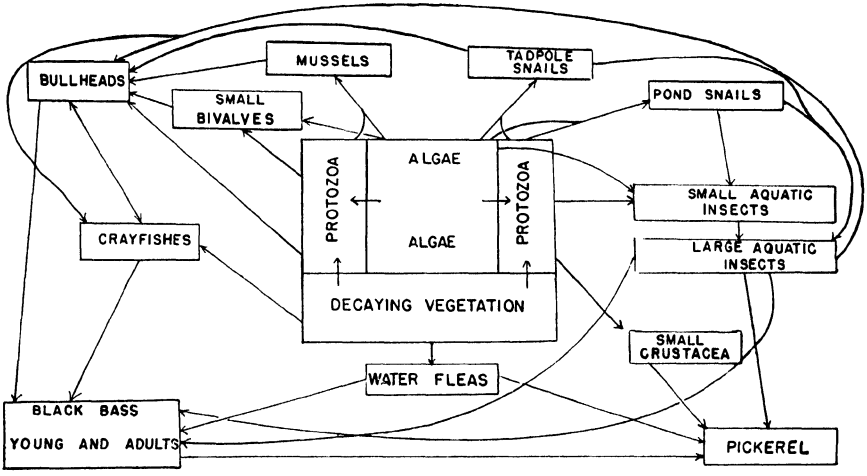

Fig. 34.—Diagram illustrating "the web of life," or food relations in a fresh-water community. Arrows point from the organisms eaten to those doing the eating. (Adapted from Shelford.)

one hand, "old maids" were responsible for the number of cats and that, on the other hand, the clover furnished the "roast beef of Old England" that nourishes her valiant sons, the source of England's great power. Old maids are thus credited with being an important cog in the economic system!

B. Upsetting Nature's Balance.—The delicate adjustments of nature may be upset by man. A good example is the English sparrow, which was imported into this country to help destroy insects. It did this work but soon began to drive away the native birds. It has been called the "street gamin" of the bird tribe, because it can obtain a living where other birds would starve to death.

Another example is shown by the rabbits in Australia. It has not been many years since rabbits were introduced into Australia. They had no natural enemies to hold them in check, and so they multiplied in huge numbers. Today they are a great pest, and many people are employed to do nothing but hunt them in an effort to rid the country of this pest.

C. Is Nature's Balance Ever Restored?—The answer to this question is illustrated by the story of the scale insect, which was accidentally introduced into California from Australia. This insect is very injurious to orange trees. After mechanical means failed to eradicate it, search was made for a natural enemy in Australia, and the ladybug Rodolia cardinalis was brought over (page 822). The ladybug is a beetle, not a bug; but it is often erroneously called *ladybug*. It is very interesting to note that as the scale insects disappeared, destroyed by the lady beetles, the latter had no food and died in turn. Now these are reared in protected colonies, to be used where the need arises.

VII. Successions and Their Causes

Plant and animal communities, or associations, are not fixed or static. Because of many types of changes in environment, there is a continuous succession of organisms in a given locality. One of the best illustrations is the succession of plants in a shallow pond that is drying up. Around the edges there will be certain types of plants like sedges and cattails; further back, there will be water lilies and the like; and where the water is deeper, there may be submerged and floating plants. There will be distinct zones according to the depth of the water. As the pond dries up, a typical swamp will develop that has a very characteristic swamp life (Fig. 35). Herbaceous plants will then come in, followed by shrubs, and finally a succession of trees. These will range from willows, swamp maples, poplars, pines; later, oak and hickory; and, finally, beech, maple, or other climax forests typical of a special region.

The animal population will also change with the changing environment. As the water disappears, the animals that live only in the medium of water will disappear. New plants which appear will furnish food and shelter to a different set of animals. And so the succession goes on. Organisms adapted to the new environment will appear, and, as new conditions arise, brought about partly by the new organisms, other forms will arrive, and this process will continue until the climax for that region is reached.

Interference with Natural Successions.—It has been seen that there are many physical and biological factors that determine the character of communities. Fires that destroy climax forests upset many types of communities. The succession must "start over." First herbaceous plants and then the succession of trees leading to the climax forest again; and so new types of animals come in; a great drought will destroy the life of a given region, and new plants and animals will then become established.

Just as nature's balance between competing organisms is often upset by man, so the natural successions are often interfered with. Forests are cleared, streams are polluted with wastes from industrial plants, and new

species of organisms are brought in. All these upset the balance of life and cause new successions.

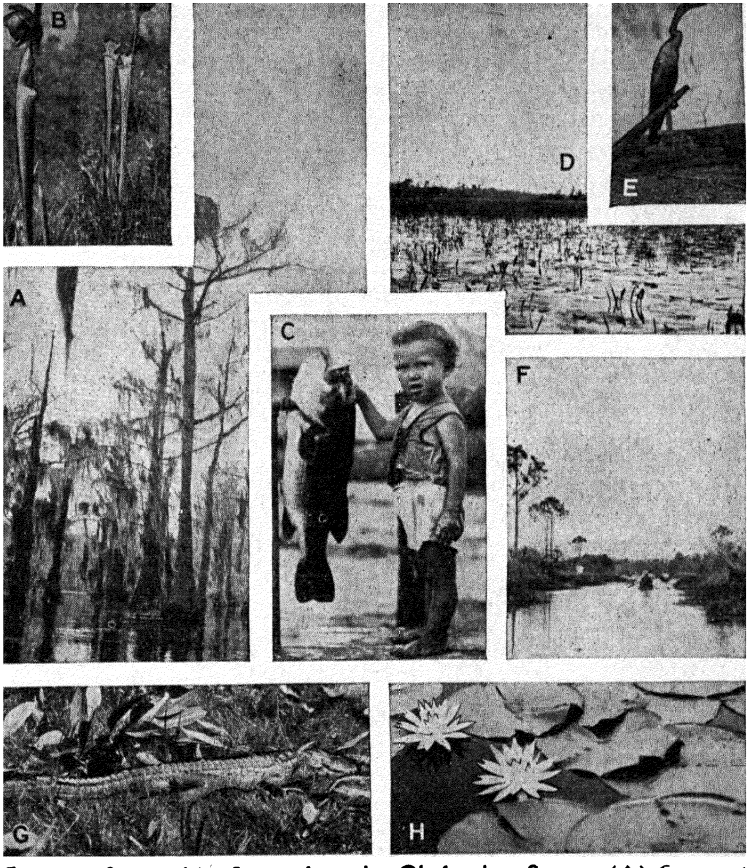

Fig. 35.—Swamp life. Scenes from the Okefenokee Swamp. (A) Cypress trees with "knees." (B) Pitcher plants. (C) Fish. (D) and (H) Plants in shallow water. (E) An anhinga. (F) Open water. (G) Alligator. (Courtesy of Charles Elliott.)

VIII. The Cycles of Elements in Nature

Earth, that nourished thee, shall claim thy growth,
to be resolved to earth again
And, lost each human trace, surrendering up
Thine individual being, thou shalt go
To mix forever with the elements,
And be a brother to the insensible rock
And to the sluggish clod, where the rude swain
Turns with his share, and treads upon. The oak
Shall send his roots abroad, and pierce thy mould.

—BRYANT.

There is a saying that "nothing is ever destroyed." Matter and energy may change form but are used over and over again in the various cycles of nature. The three most important elements used by living things are carbon, oxygen, and nitrogen. Compounds of these, after being used by plants and animals, are returned to the soil or to the air, either by the processes of respiration, excretion, and the like, or by decay. The familiar

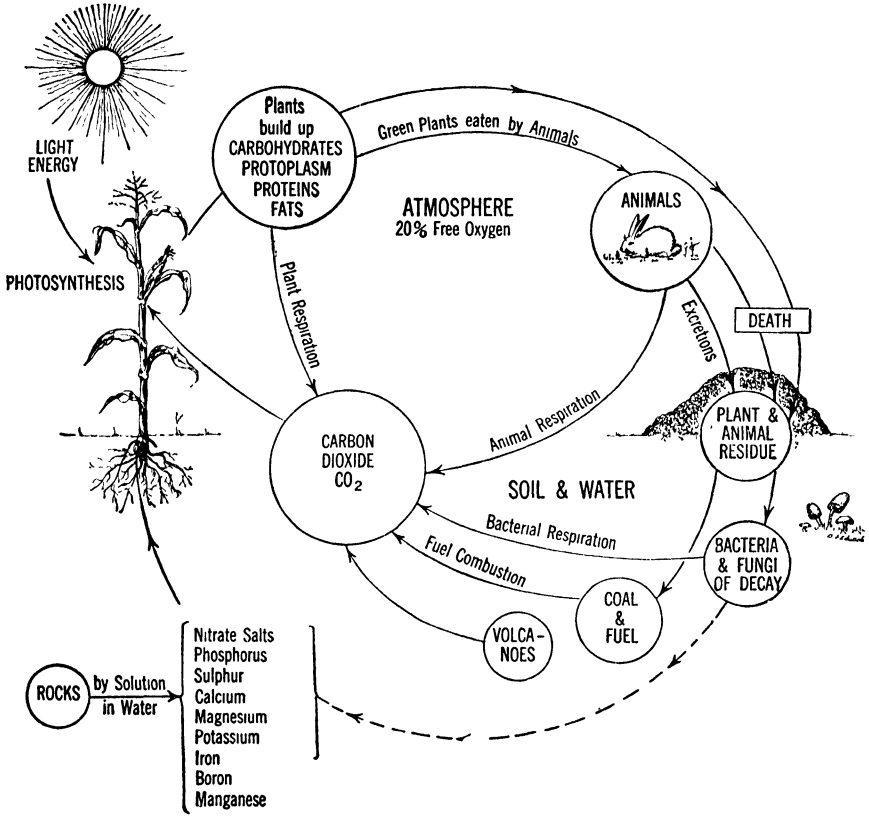

Fig. 36.—The carbon cycle. (Betty F. Edwards.)

"dust to dust" is only part of the story. The materials are used over again.

A. The Carbon Cycle.—In Fig. 36, the carbon cycle in nature may be followed. The green plant is able to take in carbon dioxide from the air, water from the roots, and, with the aid of minerals in the form of salts from the soil, to build up still other foods. Thus, the plant grows and prospers so long as conditions are favorable. During its life the plant gives off to the atmosphere carbon dioxide as a waste product of respiration.

The fate of the plant is either (1) to be eaten by animals, (2) to die what is known as a "natural" death, or (3) to be killed. If the plant dies,

by whatever means, the bacteria and fungi of decay bring about, in course of time, complete disintegration. If the plant is eaten by animals, the excretions of these animals are acted upon by the bacteria and fungi of decay, also. The dead bodies of plants and animals, as well as their excretions, particularly of animals, are gradually broken up, as we have said, by the bacteria and fungi of decay into simpler and simpler compounds until all of the carbon is oxidized and returned to the air as carbon dioxide. Animals, in the process of respiration, also give to the air carbon

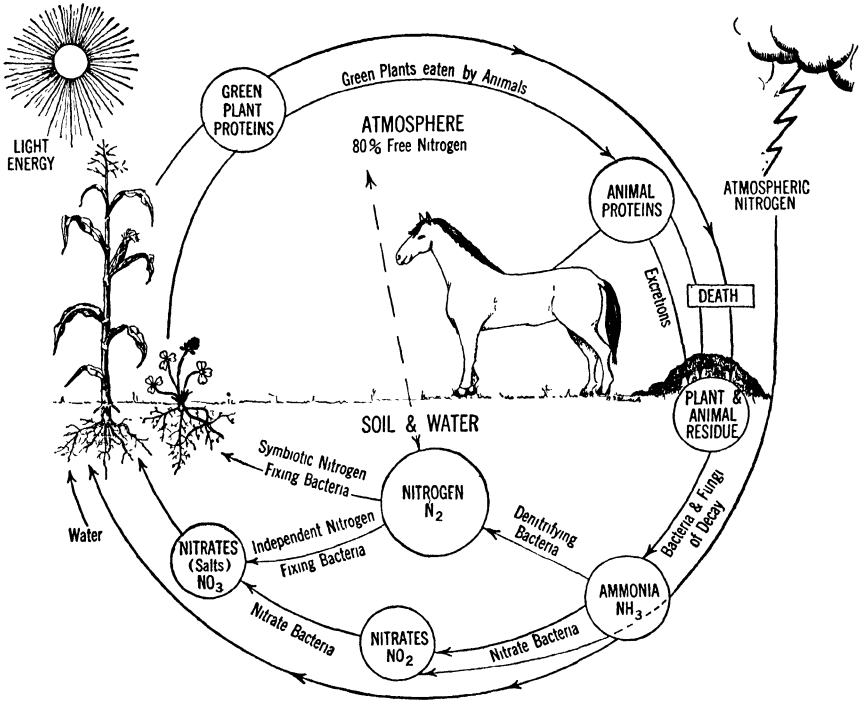

Fig. 37.—The nitrogen cycle. (Betty F. Edwards.)

dioxide. Other sources of carbon dioxide in the air are the combustion of coal and other fuels and volcanoes. The green plant is able to take in the carbon dioxide and use it in the manufacture of food. This completes the carbon cycle in nature.

B. The Nitrogen Cycle.—The nitrogen cycle is a little more complex than the carbon cycle but is easily followed (Fig. 37). Nitrogen is always present in proteins and in plants and animals containing proteins. As said before, plants may die naturally, be killed, or may be eaten by animals. Animals share a similar fate. As the dead bodies of plants and animals disintegrate through the action of decay resulting from the activities of bacteria and fungi, other substances besides the carbon

dioxide already noted are produced. Odors from the decaying plant material are not so offensive as those from animal excretions and from dead bodies.

Ammonia is always given off from the bodies of decaying plants and animals. The formula for ammonia (NH_3) is nitrogen 1 part and hydrogen 3 parts and the source of it is the breaking down of proteins. Several types of bacteria possess the power of changing ammonia so that it can be used by plants. It is first changed by one special group of bacteria to *nitrites* (NO_2) and then by another group of bacteria to *nitrates* (NO_3). Higher plants can take up nitrogen most readily in the form of nitrates, although ammonium salts and, apparently, some organic compounds may at times be utilized. Figure 37 indicates the sources of nitrogen. To begin with, the atmosphere consists of about 80 per cent of free nitrogen. Some of the atmospheric nitrogen is changed to nitrite by the action of lightning during thunderstorms. This nitrite is further acted upon by the nitrate bacteria and thus becomes nitrate. Two types of bacteria are able to fix nitrogen from the air. One type lives free in the soil, and the other lives in the roots of certain plants. These bacteria live symbiotically in the roots of legumes, which belong to the pea family. Examples are found in certain other plants that obtain their food from the cells of their host and take free nitrogen from the air. This nitrogen is used in synthesizing proteins.

Since certain types of bacteria can fix the nitrogen from the air, farmers often raise in their fields plants that support bacteria that possess this power, and then the farmers plow them under. The nitrogen so fixed will be changed by bacteria into a form that can be used by plants, *i.e.*, into NO_3, which is a nitrate. Denitrifying bacteria also exist. These bacteria reduce nitrates and nitrites to free nitrogen, which escapes into the air. The character of the soil is important in encouraging nitrifying bacteria to multiply and do their work. The best soil is that which is porous, thus allowing plenty of air to penetrate into it, and contains a medium amount of moisture. Temperature is also important, about 30°F. being the most favorable. On the other hand, the conditions that are favorable for the activities of denitrifying bacteria are acid soil, much water, not much air in the soil, abundant organic matter, and low temperature. The steps in the nitrogen cycle in nature may be traced in Fig. 37. This cycle is occurring at the same time as the carbon cycle; the two are separated in this discussion for the sake of clearness.

C. The Oxygen Cycle in Nature.—The oxygen cycle in nature is quite as important as either the carbon or nitrogen cycles. Oxygen forms a part of all tissue and is necessary for all oxidations (page 548). Wherever plants or animals respire, wherever fire burns, there must also be oxygen. The question arises as to why all the oxygen is not used; also, if it is

taken out of the air and combined as carbon dioxide, water, or as other oxides, how is the supply renewed? The answer to these questions is photosynthesis (page 140). To repeat, the plant takes in carbon dioxide and water, and, with the aid of energy from the sun, manufactures starch, at the same time releasing oxygen, thus completing the oxygen cycle in nature.

IX. Summary

There is order on the earth in every situation in which life is to be found. Organisms are where they are because they are suited to live in that situation and because they find there the food and shelter they need. In established communities, there is a struggle for existence, but nature has established a balance whereby the number and kinds of organisms remain about the same. This balance may be upset through natural causes, drought, fire from lightning, storms, and the like, or by man—for example, when forests are cleared; or animal forms are imported that are parasites or that do not have natural enemies.

Instead of competing with each other, however, certain types of organisms live together in associations that are mutually helpful. This may be a banding together for protection; or there may be a close relationship that is beneficial in the struggle to live.

There is a natural succession of plants and animals that follows a change in the environment. When a forest is destroyed, certain types of plants that can tolerate much light come in; then other types that need less light come in; and so the process continues over a period of years; finally, the climax forest is reached. There is a natural succession that follows change in each type of habitat, the drying up of streams, the accumulation of humus on rocky surfaces, etc.

Nothing is ever lost. Matter and energy may change form, but they are used over and over again. This is shown in the *cycle of elements in nature.* Certainly the keynote in the universe is *organization.*

Questions

1. What is ecology?
2. In what way does each of the physical factors temperature, light, moisture, gravity, type of soil, winds, currents, tides, barriers, and chemical factors influence the environment?
3. Show how the biological factors competition, food, and shelter determine the distribution of living organisms.
4. Distinguish between the following: gregarious habits; commensalism; symbiosis; parasitism.
5. Discuss types of habitats, giving examples.
6. How may organisms be separated into: (*a*) communities, (*b*) life realms, (*c*) life zones?
7. Explain how nature maintains a balance between living organisms. How may this balance be upset? How may it be restored? Do you know from personal observation of a case in which nature's balance has been upset?

8. Discuss successions in nature and their causes. How may they be interfered with?
9. Give an account of the cycles of elements in nature: (*a*) the carbon cycle; (*b*) the nitrogen cycle; (*c*) the oxygen cycle.
10. Summarize the evidence or organization, unity, and interdependence of living things as shown by the brief discussion in this chapter.

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CHAPTER VII

CLASSIFICATION

Not chaos-like together crushed and bruised,
But, as the world, harmoniously confused;
Where order in variety we see,
And where, tho' all things differ, all agree.
—POPE.

I. The Wealth of Life

Plants and animals are everywhere. They exist in infinite variety as well as numbers. Until one knows something of where they live, how they vary in the different stages of their life cycles, and something of the hidden millions in the microscopic world, it is impossible to appreciate how varied is their size, shape, color, and activity. Many plants and animals have not yet been named or even seen. About 250,000 kinds of plants are known, and about 840,000 different animals have been described. The number in both the plant and animal kingdoms increases every year as new forms are discovered and described.

A. Classification Brings Order Out of Chaos.—Separating such a vast assemblage of plants and animals into groups at first seems hopeless. Yet order has been brought out of chaos by the efforts of thousands of biologists who have studied plants and animals during the past two hundred and fifty years. It has been found possible to collect into groups organisms that resemble one another in ways that will separate them from other organisms. For example, only birds possess feathers. On the basis of this one characteristic the 14,000 species of birds can be separated from all other animals. Similarly, only mammals possess mammary glands for the secretion of milk. This characteristic distinguishes the 4,000 known species of mammals from all other animals. By the use of characteristics of this type, biologists have found it possible to classify all living things. This branch of biology which is concerned mainly with classification is called *taxonomy* (Gr. *taxis*, arrangement; *nomos*, law). Botanical taxonomy is called systematic botany and zoological taxonomy is called systematic zoology.

1. SCIENTIFIC AND COMMON NAMES.—The question is often asked, "Why bother with scientific names?" The common names are descriptive and easy to remember, it is true, but only so long as one locality is taken into account. Different localities have different names for the same

organisms. For example, the bird to which biologists have given the name *Colinus virginianus* is known in some parts of the country as a bobwhite; in other regions, as a partridge; in still other localities, as a quail. The scientific name *Colinus virginianus*, however, is the same not only everywhere in this country but everywhere throughout the world, regardless of language.

Fig. 38.—Aristotle (384–322 B.C.). From a bas-relief found in the collection of Fulvius Ursinus. (From Locy, Growth of Biology, Henry Holt and Company.)

The following reasons may be listed as to why scientific names are desirable:

a. They make lengthy descriptions of kinds of plants and animals unnecessary and so simplify the study of biology.

b. When scientific names are used, one is always certain which organism is meant.

c. Organisms are grouped on the basis of resemblance; hence scientific names usually indicate relationships.

d. Scientific names are universal; *i.e.*, they may be used throughout the world, regardless of the language of the people.

2. Early Systems of Classification. *a. The Greeks.*—The early Greek naturalists had devised systems of grouping plants and animals for convenience in studying. Most of these systems now seem to us artificial, because they are based upon superficial characteristics, habits, and the like. These early naturalists were without the knowledge of the structure of living things that has now been accumulating for hundreds of years. It might seem natural to group plants as herbs, shrubs, and

trees or animals as air dwellers, land dwellers, and water dwellers; but these groupings do not show the true relationships of organisms.

Probably the first attempt to classify animals scientifically was made (Fig. 38) by Aristotle (384–322 B. C.). Theophrastus and other Greeks made attempts to use some scheme of classification as noted above. After their time came the Dark Ages, when scientific study was at a low ebb. In the early sixteenth century, an increasing number of people became interested in biology. Many of these were trained doctors and

Fig. 39.—Carolus Linnaeus (1707–1778), a great botanist who established our present system of classification of living things.

preachers who took up the study of plants and animals as a hobby. At this time, there were many attempts to develop systems of classification.

b. John Ray (1627–1705), an Englishman, is often spoken of as the first systematist, because he used structure as the basis of his classification. Some of his groups were natural groups, but his system of branching, always by twos (dichotomous) did not prove practical. His work was important, however, and was the foundation upon which the Linnaean system was built.

3. The System of Linnaeus.—Our present system of classification may be said to begin with Linnaeus (Karl von Linné, 1707–1778), a Swedish biologist who lived at Upsala (Fig. 39). He is often referred to as the *father of classification*, for, with some additions, he developed the system that is the foundation for the system we now use. Like many of

the early biologists of his time, he was educated to be a doctor. His especial interest was botany, but he did much work in classifying animals. The accepted scholarly language of Linnaeus' day was Latin, and he wrote his famous book "Systema naturae," first published in 1735, in that language. Twelve editions of this book appeared between the years 1735-1778, but it is the tenth edition, published in 1758, that contained the system upon which the system now used in naming of animals was based. The "Species plantarum," published in 1753, furnished the basis for the naming of plants.

Linnaeus divided the living world into plant and animal kingdoms. He recognized four other groups in his system of classification. Organisms that were alike except for small differences he considered as belonging to the same *species* group; then a number of species, all having the same fundamental features, were placed in a larger group, a *genus* (pl. *genera*). Following the same plan, genera with similar features were placed in a group called a *class*. The whole of the animal kingdom was divided by Linnaeus into six classes, four of which were vertebrates. Naturally, these classifications were inadequate, but the orderly arrangement of plants and animals into definite groups was a great step forward. Linnaeus held the erroneous belief that species were fixed and unchangeable. This, of course, differs from modern conceptions based upon precise research.

The Binomial System of Nomenclature.—The system of Linnaeus is often called a *binomial system* (L. *bi*, two; *nomen*, name), because he gave to each plant and each animal two names: a genus name and a species name. The scientific name for man, for example, is *Homo sapiens*. This system becomes a trinomial system when a subspecies is indicated, as *Homo sapiens europeus*.

4. Modern Classification.—The Linnaean system is still used, but other divisions have been added. These are *phyla* (sing, *phylum*) and *families*. In addition, prefixes super and sub, usually the latter, are used. For example, subspecies, subclass, etc. Some systematists use other terms, as *legion*, *division*, *section*, etc.

a. How the System Works.—This is best made clear by examples. If a common representative of the animal and plant kingdoms is traced through all the divisions, it becomes clear how the system works.

(1) Species and variety.—Perhaps one of the animals most familiar to everyone is the dog. His species name is *familiaris*. It is not easy to define what a species is. For the purposes of this book, it is sufficient to say that a species is a group of plants or a group of animals in which the individuals resemble each other but differ visibly from other plants and animals. Further, they will interbreed freely but will only rarely cross with other groups. A smaller division than species would be *variety*. For

example, there are many varieties of dogs (page 745), the fox terrier, bulldog, greyhound, and many other breeds, all belonging to the one species *familiaris*. The species name is written in italics but is not capitalized.

(2) GENERA (Fig. 40).—The scientific name of the dog is *Canis familiaris*. The name *Canis* is not restricted to dogs but is used also for a number of other animals that resemble the dog. Among the dog-like animals are the timber wolf and coyote, or prairie wolf. These wolves

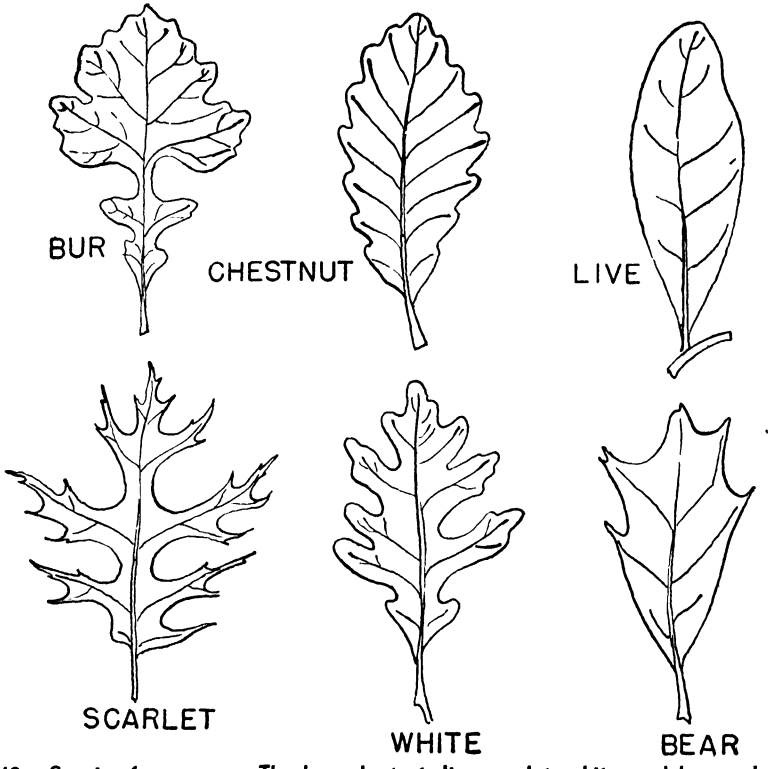
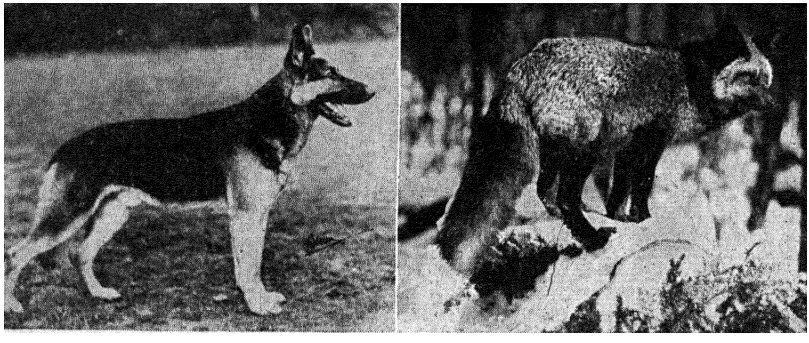


Fig. 40.—Species form genera. The bur, chestnut, live, scarlet, white, and bear oaks are different species belonging to one genus, Quercus. (B. Shamos.)

resemble the dog in some ways but differ from the dog in other respects. Dogs and wolves are, however, closely related, their first name being *Canis*. This is the *genus* name. It is usually written with an initial capital letter and in italics. The complete scientific name for the dog is *Canis familiaris;* that of the wolf is *Canis nubilis;* that of the coyote, *Canis latrans*. There are many varieties of each of these.

(3) FAMILIES (Fig. 41).—Genera that resemble one another are organized into families. Foxes, for example, resemble dogs and wolves in many respects. For this reason, the genus *Vulpes*, which contains the

red fox, the genus *Urocyon*, which includes the gray fox, and the other genera of foxes are included with the genus *Canis* in one family, the Canidae. Similarly, cat-like animals such as lynxes and panthers are included in the family Felidae; bears, in the family Ursidae; seals, in the family Phocidae; etc.



(Courtesy of Dog News.) (Silver King, Courtesy of Fromm Brothers.)

Fig. 41.—Genera form families. The dog (genus Canis) and the fox (genus Vulpes) both belong to the family Canidae.

The name of the family always ends in *idae* and the subfamily in *inae*, and the name of the family is derived from the type genus of the group. For example, the name genus for dog is *Canis;* the family name would be Canidae, the subfamily Caninae.

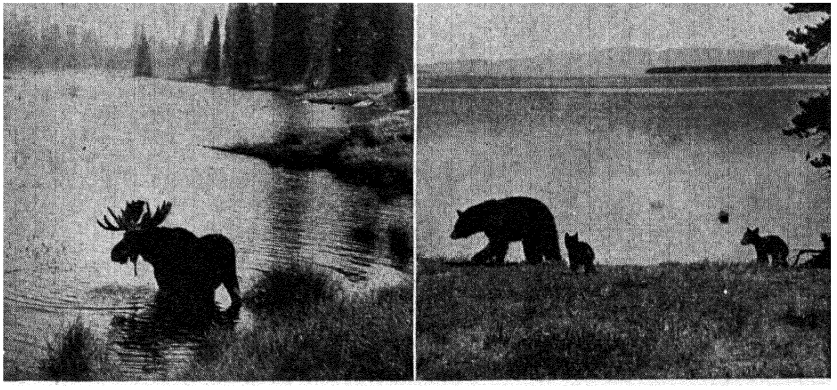
(R. Hegner.) (Natural History Society of Maryland.) (U.S. Biological Survey.)

Fig. 42.—Families form orders. The house wren (family Troglodytidae), white-throated sparrow (family Fringillidae), and the raven (family Corvidae) all belong to the order Passeriformes.

The names of all the groups above the genus group begin with a capital letter, but the names are not italicized.

(4) ORDERS (Fig. 42).—The four families mentioned above are placed together with other flesh-eating groups into one order, the Carnivora (L. *caro*, flesh; *vorare*, to devour).

(5) CLASSES (Fig. 43).—Following the same scheme, the orders having similar features are placed into classes. For example, the order Carnivora is combined with certain other orders into the class Mammalia. All the animals in these orders nourish their young with milk secreted in

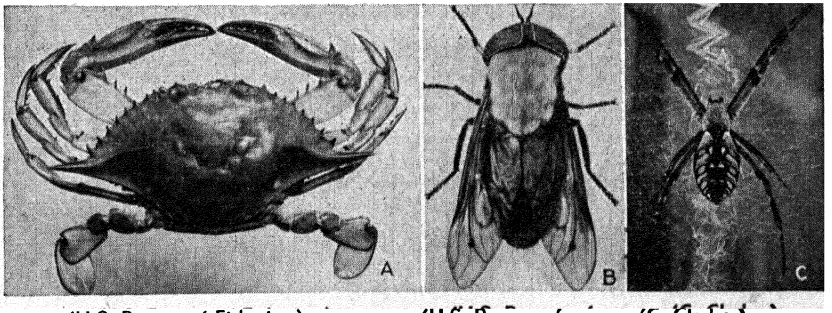


(U.S. Forest Service.) (U.S. Biological Survey.)

Fig. 43.—Orders which have similar features form classes. The moose, an even-toed ungulate (order Artiodactyla) and the bear (order Carnivora), a carnivorous animal, both belong to the class Mammalia.

the mammary glands of the female. Eighteen orders of mammals are recognized. Examples of these are shown in Fig. 52, page 91.

(6) PHYLA (Figs. 44 and 45).—The class Mammalia, together with six other classes of animals that are characterized by the presence of a



(U.S. Bureau of Fisheries.) (U S. Bureau of Entomology.) (C. Clarke.)

Fig. 44.—Classes form phyla. The blue crab (class Crustacea), the horse fly (class Insecta), and the garden spider (class Arachnoidea) are all "jointed footed" animals belonging to the phylum Arthropoda.

backbone, are placed into a single *subphylum* (G. *sub*, below; *pylon*, race or tribe), the *Vertebrata*. These are fish, amphibians, reptiles, birds, etc. Then the subphylum Vertebrata and three other subphyla are grouped together in the phylum Chordata (L. *chordatus*, having a chord).

(7) KINGDOMS (Figs. 46 to 52).—Finally, the whole of the living world is divided into two kingdoms, the animal kingdom, Animalia, and the plant kingdom, Plantae.

b. Classification of Plants.—The same system is used in naming and classifying plants. The oak is a familiar tree, and the white oak is a fine representative of that genus. The species name for the white oak is *alba*, which is a Latin word meaning white; the species of the oak trees are

(E. R. Mosher.) (a) (Courtesy of U.S. Forest Service.) (b)

Fig. 45.—Subphyla form phyla. The elm (subphylum Angiospermae) and the fir (subphylum Gymnospermae) are both members of the phylum Spermatophyta, or the seed plant group. (For a different classification see page 205.)

grouped together in the genus *Quercus* (L. *quercus*, Oak). The scientific name of the white oak, therefore, is *Quercus alba*. Oaks, beeches, chestnuts, and some other trees are grouped together in the family Fagaceae. Then this family, together with the birch family and some others, are included in the order Fagales. Plants that have two seed leaves are all placed together in the class Dicotyledoncae. The dicotyledons, together with plants having one seed leaf, the monocotyledons, form the subphylum Angiospermae. All the seed-bearing plants (angiosperms and gymnosperms) are included together in the phylum Spermatophyta. (Newer classification, page 205.)

After the method of operation of the classification system is understood, it may be helpful to contrast the classification of the dog and the white Oak.

	The Dog	The White Oak
Kingdom	Animalia	Plantae
Subkingdom	Metazoa	
Phylum	Chordata (animals with notochords)	Spermatophyta (seed plants) (page 210)
Subphylum	Vertebrata (animals with backbones)	Angiospermae (flowering plants)
Class	Mammalia (animals with mammary glands)	Dicotyledoneae (plants with two seed leaves)
Order	Carnivora (animals that eat flesh)	Fagales (birch order)
Family	Canidae (dog like carnivores)	Fagaceae (beech family)
Subfamily	Caninae (dogs and their relatives)	Castaneae
Genus	*Canis* (dogs)	*Quercus* (oak)
Species	*familiaris* (the domestic dog)	*alba* (white)

It is easy to see from the preceding examples what a workable method of classifying plants and animals our present system is. In spite of this, however, there are wide differences of opinion as to divisions and subdivisions. For example, many botanists use the term *division* in the sense in which zoologists use the term *phylum*. International congresses[1] have formulated rules for classification, but in spite of this, differences in classification will be found in reference books.

B. Classification Is a Tool.—A system of classification is only a tool to be used in understanding the relationships of living things. Such an understanding involves something more than knowing "who's who" among organisms. A knowledge of life cycles, distribution, development, and structure of the form to be classified is essential before the form can be fitted into the general scheme of the organization of the living world. With this in mind, it is hoped that the following abridged and simplified classification will furnish the student with a bird's-eye picture of the world of plants and animals. It is hoped also that it will serve as a *ready reference* to answer questions that will very naturally arise about representative organisms that illustrate the principles of biology. It is not expected that the student shall memorize the classification here presented, but through it he should understand something of the relationships of the living world. A more detailed classification will be found in the chapters of Parts II and III.

[1] In 1898, the International Congress of Zoology appointed an international commission that drew up a set of rules applying to the divisions of the animal kingdom. The International Rules of Botanical Nomenclature were originally adopted by the International Botanical Congresses of Vienna (1903) and Brussels (1910). Modifications of the original rules drawn up are made from time to time.

II. Representatives of the Living World

A. The Plant Kingdom

Phylum I. **Thallophyta** (thă lŏf′ ĭ tă). Thallus plants (page 180); no roots, stems, or leaves.

Subphylum *A.* **Algae** (ăl′ jē). Thallus plants that contain chlorophyll. About 20,000 species.

Class I. Myxophyceae (mĭk′ sō fī′ sē ē). Blue-green Algae; *Gleocapsa, Oscillatoria.*

Class II. Chlorophyceae (klō′ rō fī′ sē ē). Green Algae; *Protococcus; Spirogyra.*

Class III. Phaeophyceae (fē′ ō fī′ sē ē). Brown Algae; *Fucus, Sargassum.*

Class IV. Rhodophyceae (rō′ dō fī′ sē ē). Red Algae; *Polysiphonia.*

Class V. Bacillariaceae (băs′ ĭ lā′ rĭ ā′ sē ē) or *Diatomaceae.* Classification uncertain. Often classed with brown Algae. Diatoms.

Subphylum *B.* **Fungi** (fŭn′ jī). Plants without green coloring matter (page 181) and hence unable to manufacture their own food; about 60,000 species.

Class I. Schizomycetes (skĭz′ ō mī sē′ tēz). Fission Fungi, including bacteria; classification uncertain; often placed here for convenience.

Class II. Myxomycetes (mĭk′ sō mī sē′ tēz). Slime molds; classification uncertain.

Class III. Phycomycetes (fī′ kō mī sē′ tēz). Alga-like Fungi; bread mold (*Rhizopus nigricans*).

Class IV. Ascomycetes (ăs′ kō mī sē′ tēz). Sac Fungi; blue molds, powdery mildews, yeasts.

Class V. Basidiomycetes (bă sĭd′ ĭ ō mī sē′ tēz). Club Fungi; mushrooms, puffballs.

Class VI. Imperfect Fungi. Relationships of this group are uncertain.

Phylum II. **Bryophyta** (brī ŏf′ ĭ tă). Liverworts and mosses (page 200); about 20,000 species.

Class I. Hepaticae (hē păt′ ĭ sē). Liverworts; *Marchantia.*

Class II. Musci (mŭs′ sī). Mosses; *Polytrichum, Sphagnum.*

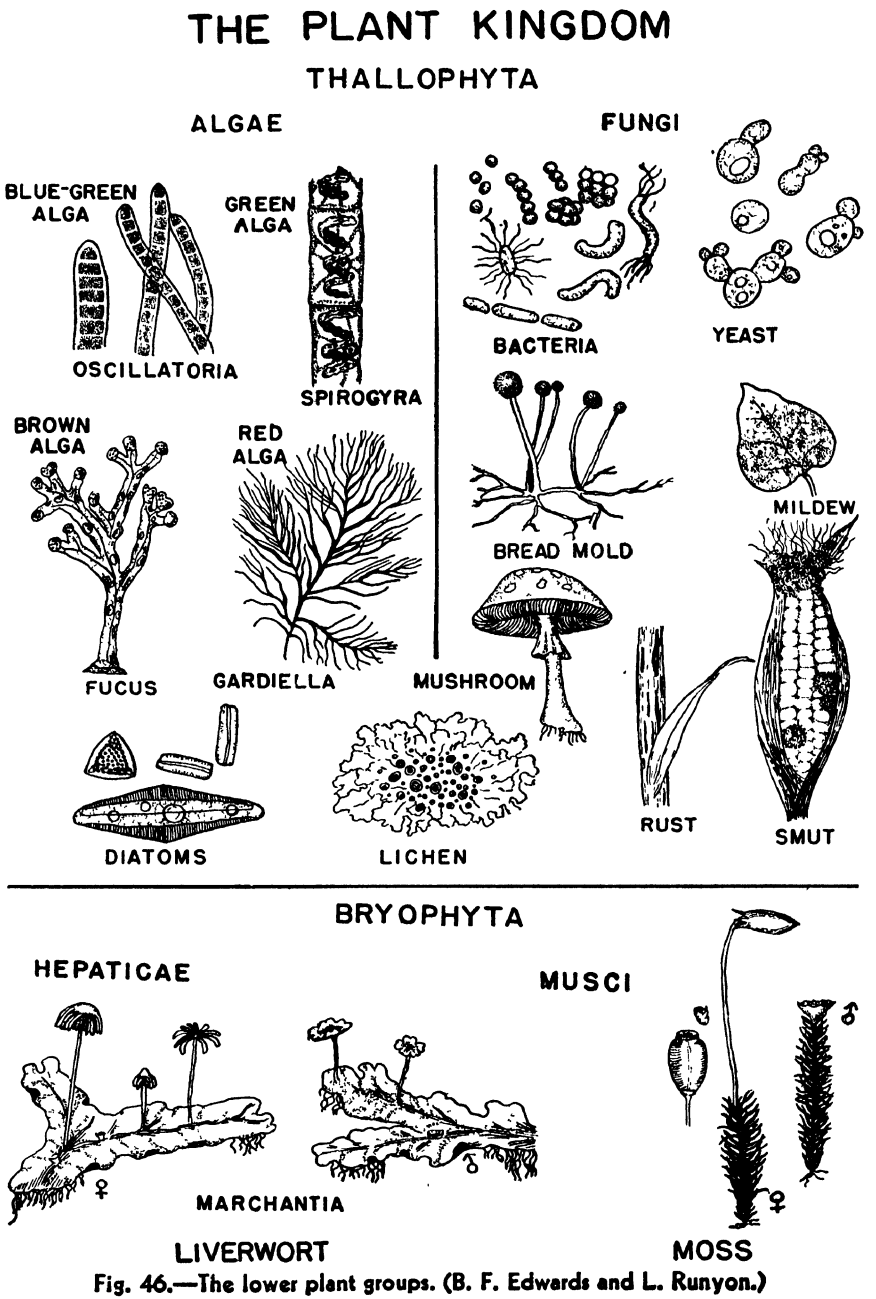


Fig. 46.—The lower plant groups. (B. F. Edwards and L. Runyon.)

Phylum III. **Tracheophyta** (trā kē ŏf′ ĭ tà). Vascular plants (page 205).

Subphylum *A*. **Psilopsida** (sĭ lŏp′ sĭ dà). Primitive vascular plants; mostly fossils. Psilotum.

Subphylum *B*. **Lycopsida** (lī kŏp′ sĭ dà). Club mosses.

Subphylum *C*. **Sphenopsida** (sfē nŏp′ sĭ dà). Horsetails (*Equisetum*).

Subphylum *D*. **Pteropsida** (tē rŏp′ sĭ dà). Ferns and seed plants.

Class I. FILICINEAE (fĭl′ ĭ sĭn′ ē ē) Ferns, about 6,000 species.

Class II. GYMNOSPERMAE[1] (jĭm′ no spûr mē). Cycads and conifers; about 600 species.

Class III. ANGIOSPERMAE[1] (ăn′ jĭ ō spûr′ mē). Flowering plants; about 110,000 species.

Subclass 1. DICOTYLEDONEAE (dī′ kŏt ĭ lē dō′ nē ē). Plants with two seed leaves; violet, rose, oak, maple.

Subclass 2. MONOCOTYLEDONEAE (mŏn′ ō kŏt ĭ lē dō nē ē). Plants with one seed leaf; lillies, grasses, orchids.

[1] Seed plants are often classed together as Spermatophyta (spûr′ mà tŏf′ ĭ tà).

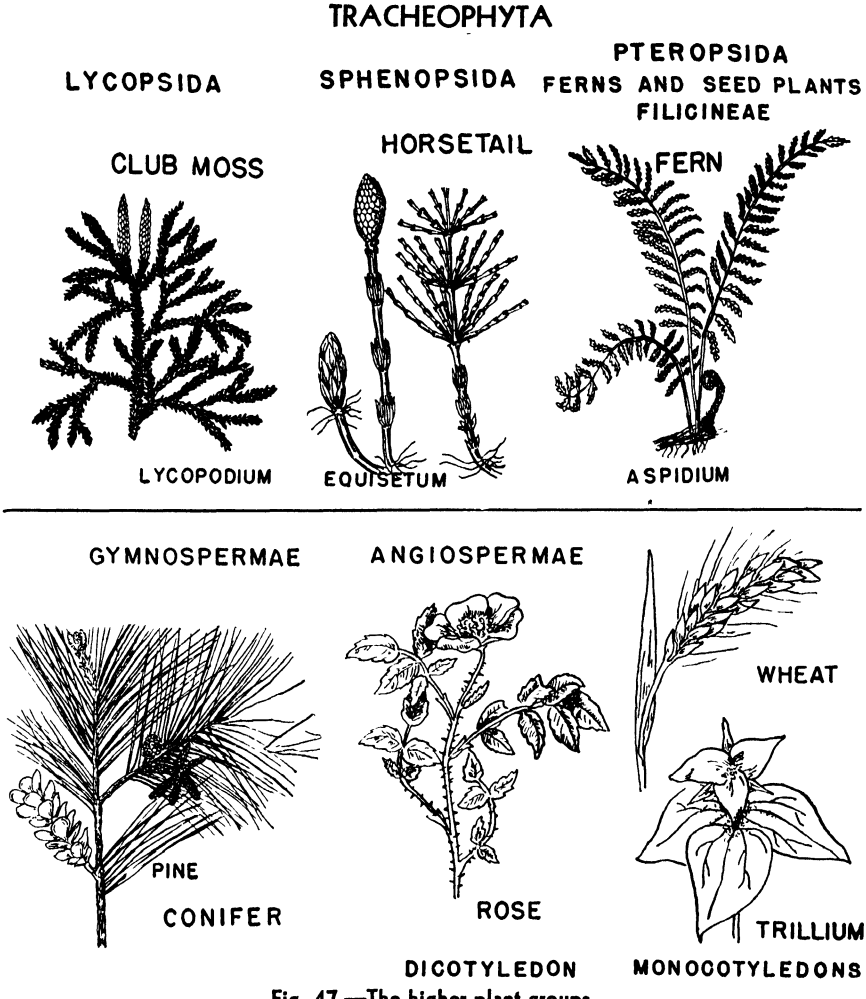


Fig. 47.—The higher plant groups.

B. The Animal Kingdom

Animals without Backbones; the Invertebrata

Phylum I. **Protozoa** (prō′ tō zō′ ȧ). Single-celled animals (page 265); about 20,000 species.

Class I. Flagellata (flăj′ ĕ lā′ tȧ) or *Mastigophora* (măs′ tĭ gŏf′ ō rȧ). Protozoa with flagella; *Euglena, Volvox.*

Class II. Rhizopoda (rī zŏp′ ō dȧ) or Sarcodina (sär′ kō dī′ nȧ). Protozoa that move by means of pseudopodia (false feet); *Amoeba, Arcella, Actinophrys sol.*

Class III. Sporozoa (spō′ rō zō′ ȧ). Spore bearers; malaria parasite, *Plasmodium, Gregarina, Coccidium.*

Class IV. Ciliata (sĭl′ ĭ ā′ tȧ) or *Infusoria* (ĭn′ fū sō′ rĭ ȧ). Protozoa with cilia; *Paramecium, Euplotes, Vorticella.*

Class V. Suctoria (sŭk tō′ rĭ ȧ). Often classed with ciliates because larvae have cilia; adults have sucking tentacles; *Acineta, Podophrya.*

Phylum II. **Porifera** (pō rĭf′ ĕr ȧ). Sponges (page 290); about 3,000 species.

Class I. Calcarea (kăl kā′ rē ȧ). Sponges with skeletons of lime; *Grantia.*

Class II. Hexactinellida (hĕk′ săk tĭ nĕl′ ĭ dȧ). Sponges with skeletons of silicon; Venus's-flower-basket.

Class III. Demospongiae (dē′ mō spŏn′ jĭ ē). Sponges with skeletons of spongin; bath sponge.

Phylum III. **Coelenterata** (sē lĕn′ tĕr ā′ tȧ). Animals with two-layered body walls (diploblastic) (page 294); about 10,000 species.

Class I. Hydrozoa (hī′ drō zō′ ȧ). *Hydra* and hydra-like coelenterates; *Obelia.*

Class II. Scyphozoa (sī′ fō zō′ ȧ). Large jellyfish; *Aurelia.*

Class III. Anthozoa (ăn thō zō′ ȧ). Stony corals, sea anemones, sea fans.

THE ANIMAL KINGDOM

PROTOZOA

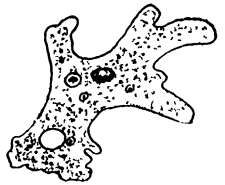
MASTIGOPHORA

CILIATA

RHIZOPODA

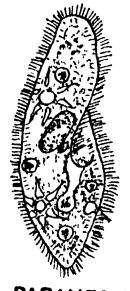
SPOROZOA

EUGLENA



AMOEBA

MALARIA PARASITE (PLASMODIUM)



PARAMECIUM

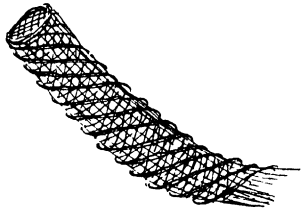
PORIFERA

CALCAREA

HEXACTINELLIDA

DEMOSPONGIAE

GRANTIA



VENUS' FLOWER BASKET

FINGER SPONGE

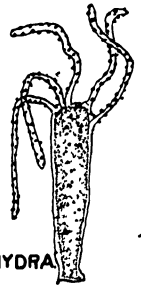
BATH SPONGE

COELENTERATA

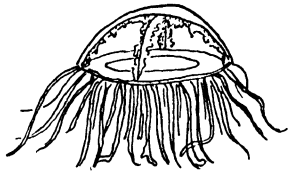
HYDROZOA

ANTHOZOA

SCYPHOZOA

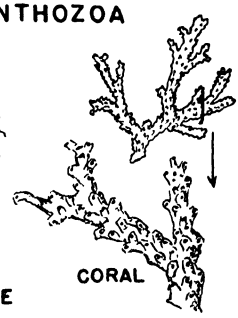


HYDRA



JELLYFISH

SEA ANEMONE



CORAL

Fig. 48.—Protozoans, sponges, and coelenterates.

Phylum IV. **Ctenophora** (tĕ nŏf′ ō rà). The sea walnuts (page 311); comb jellies; about 100 species.

Phylum V. **Platyhelminthes** (plăt′ ĭ hĕl mĭn′ thēz). Flatworms (page 312). About 7,000 species.

Class I. TURBELLARIA (tûr′ bĕ lā′ rĭ à). *Planaria.*

Class II. TREMATODA (trē′ mà tō′ dà). Liver flukes.

Class III. CESTODA (sĕs tō′ dà). Tapeworms.

Class IV. NEMERTINEA (nĕm′ ẽr tĭn′ ẽ à). Nemerteans.

Phylum VI. **Nemathelminthes** (nĕm′ à thĕl mĭn′ thēz). Roundworms (page 321); about 3,000 species.

Class I. NEMATODA (nĕm′ à tō′ dà). *Ascaris,* hookworm.

Class II. NEMATOMORPHA (nĕm′ à tō môr′ fà). *Gordius.*

Class III. ACANTHOCEPHALA (à kăn′ thō sĕf′ à là). *Echinorhynchus.*

Phylum VII. **Rotifera** (rō tĭf′ ẽr à). Rotifers (page 327); about 1,800 species.

Phylum VIII. **Bryozoa** (brī′ ō zō′ à). Moss animals (page 326); *Bugula;* about 3,000 species.

Phylum IX. **Brachiopoda** (brā′ kĭ ŏp′ ō dà). Lamp shells; *Magellania;* about 130 species (page 327).

Phylum X. **Annelida** (ă nĕl′ ĭ dà). Segmented worms (page 331); about 7,000 species.

Class I. ARCHIANNELLIDA (ar′ kĭ ă nĕl′ ĭ da). *Polygordius.*

Class II. POLYCHAETA (pŏl′ ĭ kē′ tà). *Nereis.*

Class III. OLIGOCHAETA (ŏl′ ĭ gō kē′ tà). Earthworms.

Class IV. GEPHYREA (jē fĭ′ rē à). Aberrent forms; Sipunculus.

Class V. HIRUDINEA (hĭr′ û dĭn′ ē à). Leeches.

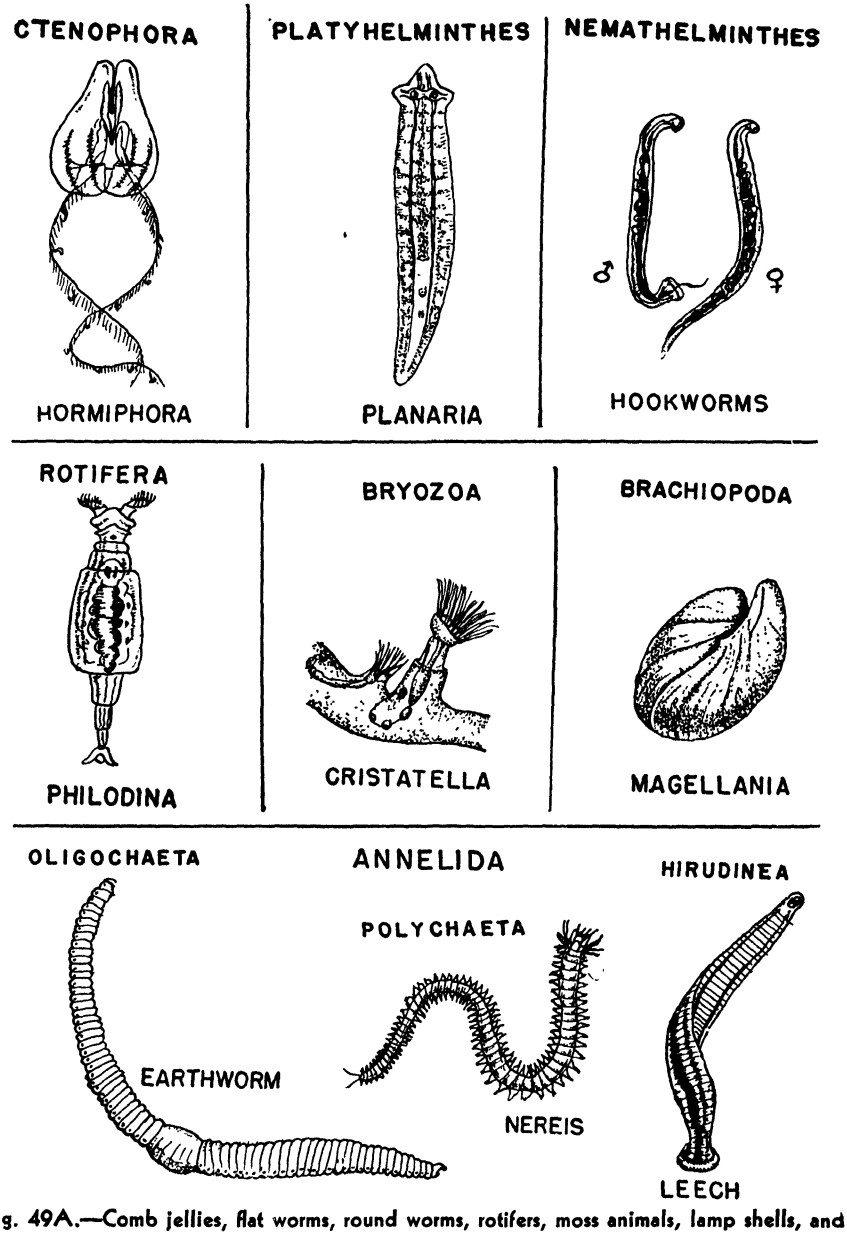


Fig. 49A.—Comb jellies, flat worms, round worms, rotifers, moss animals, lamp shells, and segmented worms.

Phylum XI. **Echinodermata** (ē kī′ nō dûr′ mȧ tȧ). Spiny-skinned animals (page 350); about 5,000 species.

Class I. ASTEROIDEA (ăs′ tēr ôi′ dē ȧ). Starfish.

Class II. OPHIUROIDEA (ŏf′ ĭ ū roi′ dē ȧ). Brittle stars.

Class III. ECHINOIDEA (ĕk′ ĭ noi′ dē ȧ). Sea urchins.

Class IV. HOLOTHURIOIDEA (hŏl′ ō thū′ rĭ oi′ dē ȧ). Sea cucumbers.

Class V. CRINOIDEA (krī noi′ dē ȧ). Sea lilies.

Phylum XII. **Molluska** (mŏ lŭs′ kȧ). Mollusks (page 360); about 78,000 species.

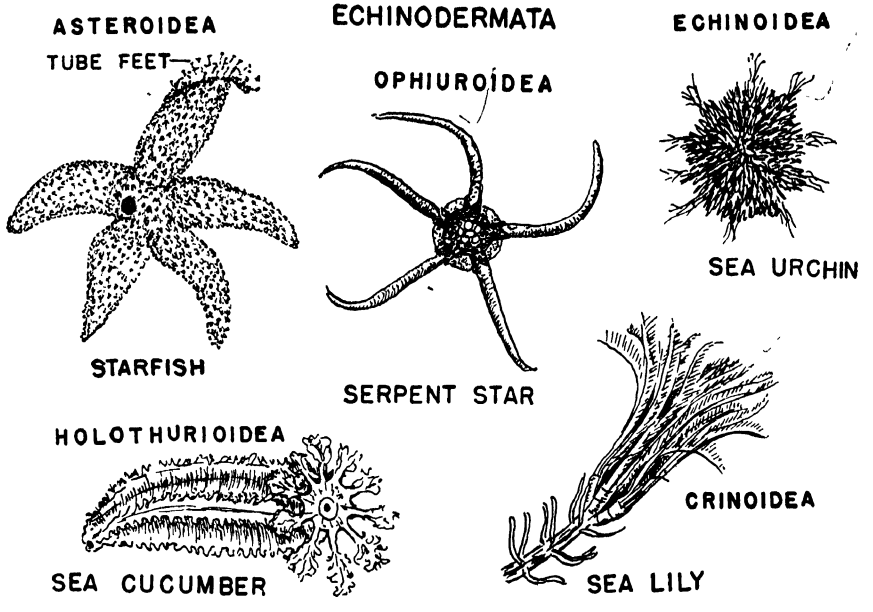
Class I. AMPHINEURA (ăm′ fĭ nū′ rȧ). Chitons.

Class II. SCAPHOPODA (skȧ fŏp′ ō dȧ). *Dentalium.*

Class III. GASTROPODA (găs trŏp′ ō dȧ). Snails, slugs.

Class IV. PELECYPODA (pĕl′ ē sĭp′ ō dȧ). Oysters, clams, scallops.

Class V. CEPHALOPODA (sĕf ăl ŏp′ ō dȧ). Squid, *Octopus, Nautilus.*



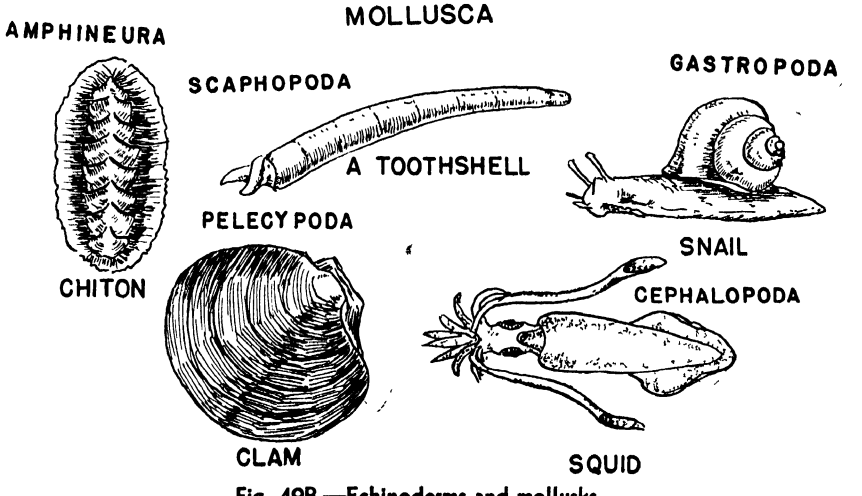


Fig. 49B.—Echinoderms and mollusks.

Phylum XIII. **Arthropoda** (ăr thrŏp′ ō dȧ). Jointed footed animals (page 374); about 700,000 species

Class I. CRUSTACEA (krŭs tā′ shē ȧ). Crayfish, lobsters.

Class II. ONYCHOPHORA (ŏn′ ĭ kŏf′ ō rȧ). *Peripatus.*

Class III. CHILOPODA[1] (kī lŏp′ ō dȧ). Centipedes.

Class IV. DIPLOPODA[1] (dĭ plŏp′ ō dȧ). Millipedes.

Class V. INSECTA (ĭn sĕk′ tȧ). Insects. For *orders* of insects, see pages 412–419.

Class VI. ARACHNOIDEA (ăr′ ăk noi′ dē ȧ). Spiders, ticks, mites, scorpions (page 421).

Class VII. TRILOBITA (trī′ lō bī′ tȧ). Extinct Arthropods (page 422).

Animals with Notochords

Phylum XIV. **Chordata** (kôr dā′ tȧ). Lower chordates (page 430) and Vertebrates; about 70,000 species.

Subphylum *A.* **Hemichorda** (hĕm′ ĭ kôr′ dȧ). Worm-like animals; *Balanoglossus.*

Subphylum *B.* **Urochorda** (ū′ rō kôr′ dȧ). Tunicates, sea squirts.

Subphylum *C.* **Cephalochorda** (sĕf′ ă lō kôr′ dȧ). Fish-like chordates; *Amphioxus.*

Subphylum *D.* **Vertebrata** (vûr′ tē brā′ tȧ) or *Craniata* (krā nĭ ā′ tȧ). Animals with backbones.

Class I. CYCLOSTOMATA (sī klŏ stō′ mȧ tȧ). Eel-like vertebrates without jaws; hagfish, lampreys.

Class II. PISCES (pĭs′ ēz). Fish.

Subclass 1. ELASMOBRANCHII (ē lăs′ mō brăng′ kĭ ī). Fish with cartilaginous skeletons; often placed in a class rather than a subclass; sharks, skates, rays.

Subclass 2. OSTEICHTHYES (ŏs′ tē ĭk′ thĭ ēz). Bony fish; salmon, perch, trout. About 20,000 species.

Order 1. *Dipnoi* (dĭp′ nō ī). Lungfish.

Order 2. *Teleostei* (tĕl′ ē ŏs′ tē ī). Salmon, perch, trout, cod.

[1] The Chilopoda and the Diplopoda are often classed together in the class Myriapoda (mĭr′ ĭ ăp′ ō dȧ).

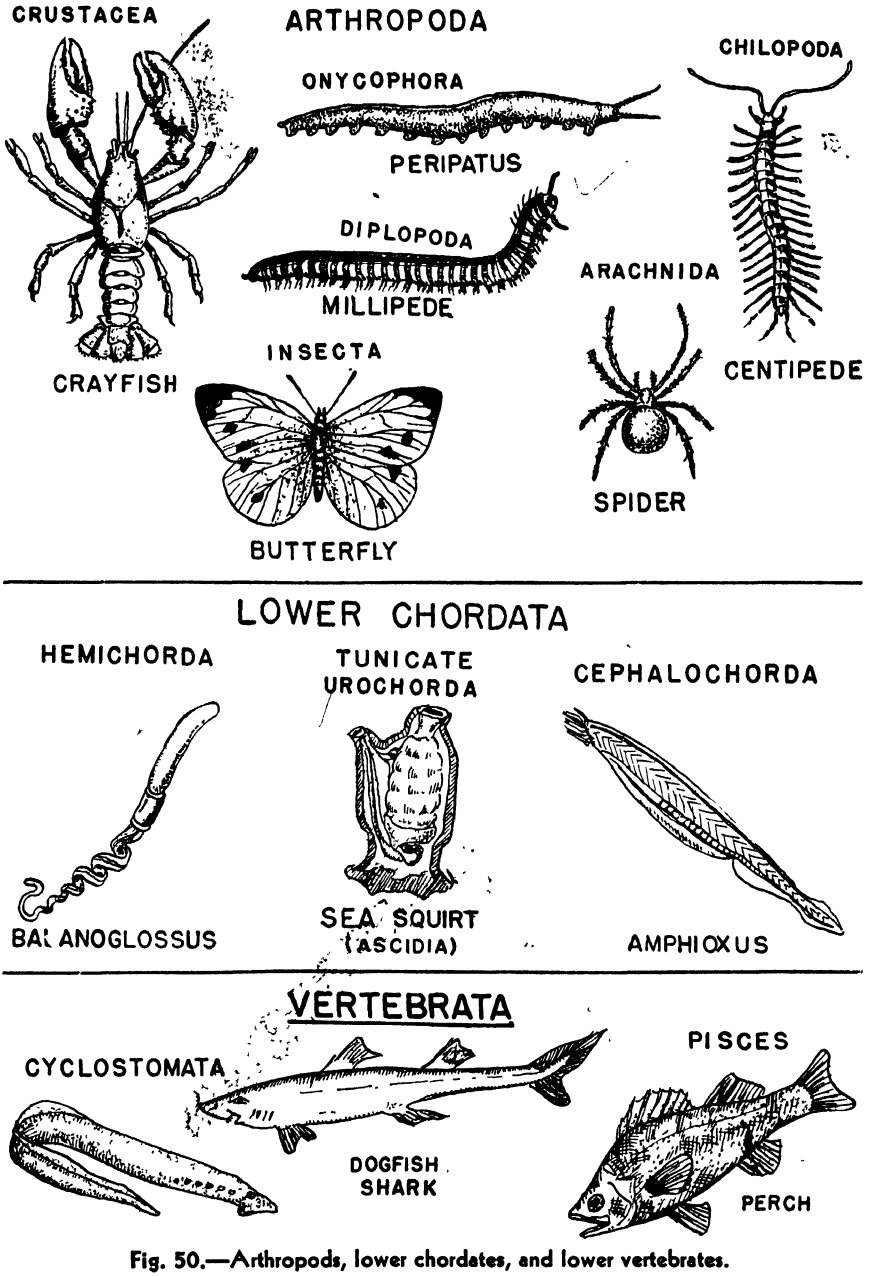


Fig. 50.—Arthropods, lower chordates, and lower vertebrates.

Class III. AMPHIBIA (ăm fĭb′ ĭ à). Vertebrates that live partly on land and partly in water (page 454); about 2,000 species.

Order 1. *Apoda* (ăp′ ō dà). Legless Amphibia; caecilians.

Order 2. *Caudata* (kô dā′ tà). Tailed amphibians; salamanders.

Order 3. *Salientia* (sā′ lĭ ĕn′ shĭ à). Amphibians tailless as adults; frogs, toads.

Class IV. REPTILIA (rĕp tĭl′ ĭ à). The reptiles (page 463). About 6,000 species.

Order 1. *Chelonia* (kē lō′ nĭ à). Turtles, tortoises.

Order 2. *Rhynchocephalia* (rĭng′ kō sē fā′ lĭ à). *Sphenodon.*

Order 3. *Crocodilia* (krŏk′ ō dĭl′ ĭ à). Crocodiles and alligators.

Order 4. *Squamata* (skwā mā′ tà). Lizards and snakes.

Class V. AVES (ā′ vēz). Warm-blooded, feathered vertebrates (page 479); about 23,000 species.

Subclass 1. ARCHAEORNITHES (ār′ kē ôr′ nĭ thēz). Extinct birds; *Archaeopteryx.*

Subclass 2. NEORNITHES (nē ôr′ nĭ thēz). All living birds. For orders of birds, see pages 496 to 499.

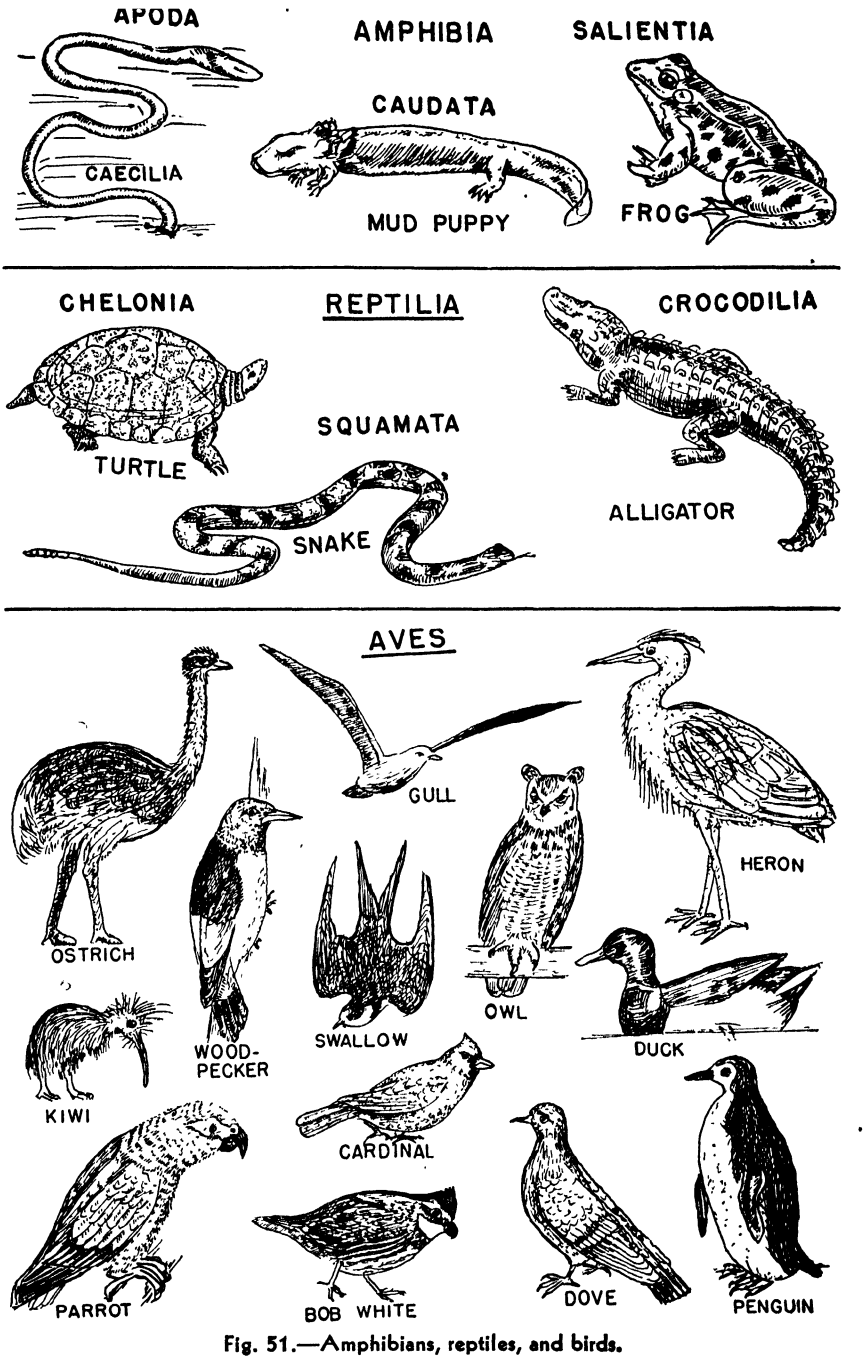


Fig. 51.—Amphibians, reptiles, and birds.

Class VI. MAMMALIA (mă mā′ lĭ ȧ). Warm-blooded vertebrates with hair (page 502); about 10,000 species.

Subclass 1. PROTOTHERIA (prō′ tō the′ rĭ ȧ). Mammals that lay eggs.

Order *Monotremata* (mŏn′ ō trē′ mȧ tȧ). The duckbill.

Subclass 2. METATHERIA (mĕt′ ȧ thē′ rĭ ȧ). Mammals with pouches.

Order *Marsupialia* (mär sū′ pĭ ā′ lĭ ȧ). Opossums, kangaroos.

Subclass 3. EUTHERIA (ū thē′ rĭ ȧ). Placentals.

Section *A*. Clawed Mammals

Order 1. *Insectivora* (ĭn′ sĕk tĭv′ ō rȧ). Moles, hedgehogs.

Order 2. *Dermoptera* (dĕr mŏp′ tĕr ȧ). "Flying lemurs" (not true lemurs).

Order 3. *Edentata* (ē′ dĕn tā′ tȧ). Toothless mammals or those having teeth without enamel.

Order 4. *Pholidota* (fol′ ĭ dō′ tȧ). Covered with large overlapping scales; pangolin (scaly anteater).

Order 5. *Rodentia* (rō dĕn′ shĭ ȧ). Gnawing animals with two incisors in upper jaw; rats.

Order 6. *Lagomorpha* (lăg ō môr′ fȧ). Gnawing animals with four incisors in upper jaw. Rabbits, hares (often classed with rodents).

Order 7. *Chiroptera* (kī rŏp′ tĕr ȧ). Flying mammals; bats.

Order 8. *Carnivora* (kär nĭv′ ō rȧ). Flesh-eating mammals; lions, tigers.

Section *B*. Hoofed Mammals, Often Classed Together as Ungulata (ŭng′ gū lā′ tȧ)

Order 9. *Perissodactyla* (pĕ rĭs′ sō dăk′ tĭ lȧ). Odd-toed mammals; horses, tapirs, rhinoceroses.

Order 10. *Artiodactyla* (är′ tĭ ō dăk′ tĭ lȧ). Even-toed mammals; cows, pigs, camels, deer.

Order 11. *Proboscidea* (prō′ bŏ sĭd′ ē ȧ). Elephants.

Order 12. *Hyracoidea* (hī rȧ koi′ dē ȧ). Coneys or hyraxes.

Section *C*. Aquatic Mammals

Order 13. *Sirenia* (sī rē′ nĭ ȧ). Sometimes included with whales but different from them; sea cows, manatees.

Order 14. *Cetacea* (sē tā′ shē ȧ). Whales, porpoises; often divided into two orders. *Odontoceti* (ō dŏn′ tō sē′ tī), the toothed whales; porpoises and sperm whale; and *Mystacoceti* (mĭs′ tȧ kō sē′ tī), whalebone whales.

Section *D*. Mammals with Nails

Order 15. *Primates* (prī mā′ tēz). Erect or nearly erect mammals.

Suborder 1. *Lemuroidea* (lĕm′ ū roi′ dē ȧ). Lemurs.

Suborder 2. *Tarsioidea* (tär sĭ oi′ dē ȧ). Tarsiers.

Suborder 3. *Anthropoidea* (ăn′ thrō poi′ dē ȧ). Monkeys, apes, man. For the *families of the Anthropoidea*, see page 512.

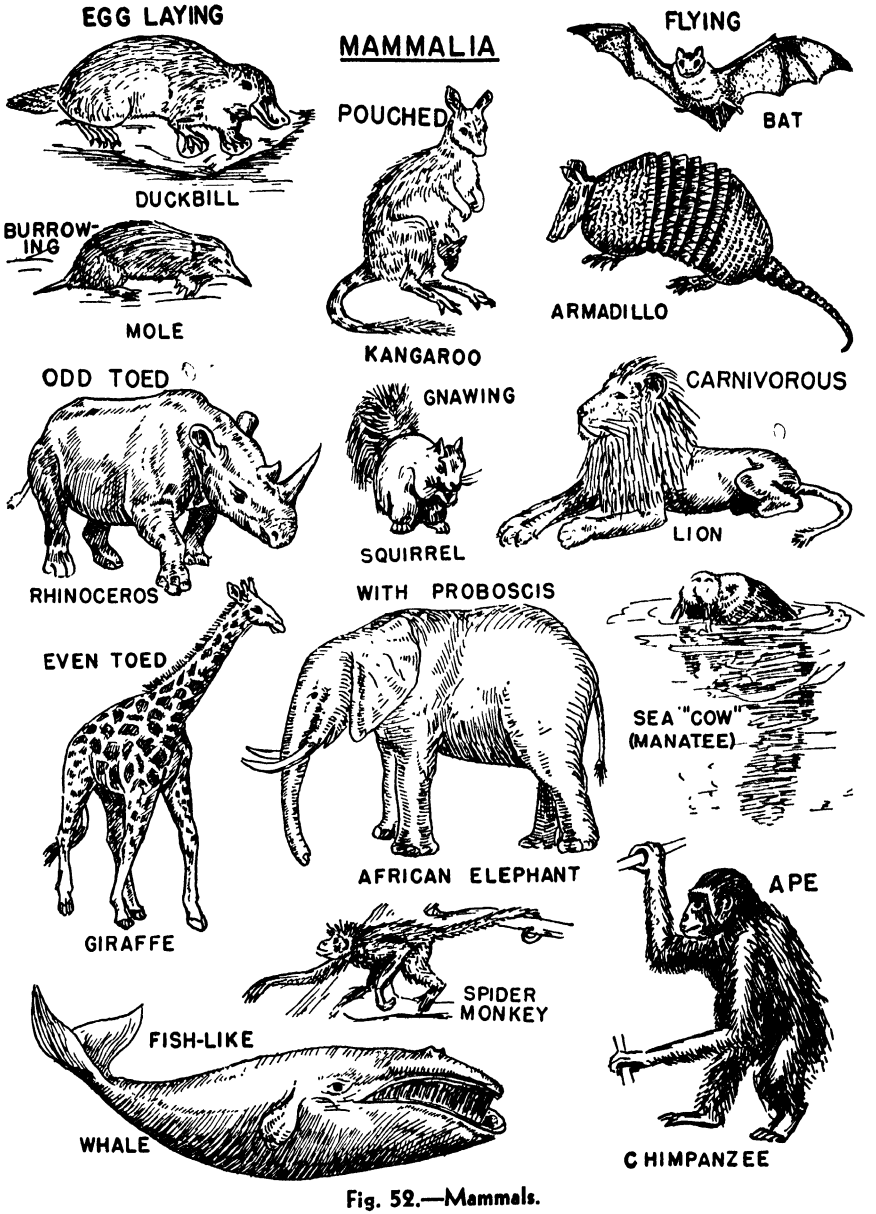
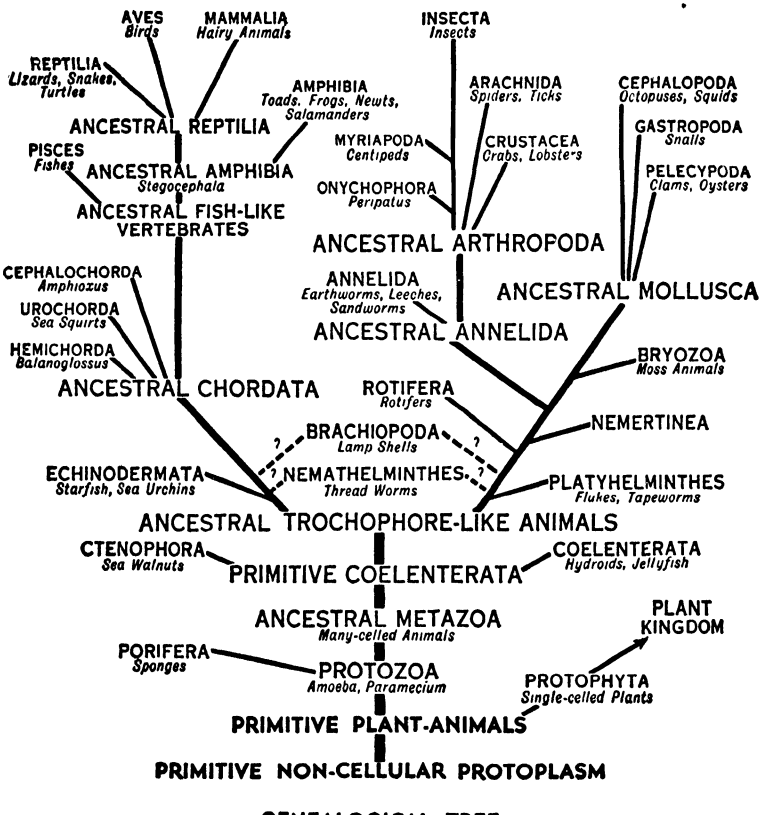


Fig. 52.—Mammals.

Relationships in the Animal Kingdom.—Because of the increasing emphasis upon the experimental method of research in biology, the study of the relationships of the animal groups that occupied such a large share of the time of the older biologists has been somewhat neglected. However, recently interest in this phase of biological study has revived. One of the best and most recent of the various genealogical trees that have appeared is shown below (Fig. 53). It would be out of place here to go into the many technical reasons for arranging the animals in two series (diphyletic), as shown in this tentative scheme. Such an arrangement helps to unify the various groups, however, and eventually the closer relationships will be worked out. As stated elsewhere in this book, there is law and order in our living world, and this enables specialists in the field of taxonomy to make a tentative "family tree" for the animal kingdom.



GENEALOGICAL TREE
SHOWING PROBABLE RELATIONSHIPS OF PRINCIPAL GROUPS OF THE
ANIMAL KINGDOM

Fig. 53.—(From Newman, Outlines of Zoology, The Macmillan Company. Designed by Sigerfoos after Allee.)

Questions

1. What are some reasons why classification of all organisms is necessary?
2. Who invented the binomial system of nomenclature? How does it work?
3. Distinguish between species, genera, families, orders, classes, and phyla. Classify fully a white oak; a dog.
4. Name 10 very different mammals, and state why they are all classified in the same group.
5. If you wished to name a new organism, how would you go about finding a new name? What information would you need?
6. Why are Greek and Latin names used in classifying organisms?
7. What is a chordate? A vertebrate? An invertebrate?
8. What animals are included in the primate group? Classify man.
9. Do you know of any reason why, in some cases, it is necessary to know the life history of an organism before it can be classified?

Suggested References

FULLER, H. J.: "The Plant World," Henry Holt and Company.

HEGNER, R. W.: "College Zoology," The Macmillan Company.

HOLMAN, R. M., and ROBBINS, W. W.: "Textbook of General Botany," John Wiley & Sons, Inc.

SINNOTT, E. W.: "Botany: Principles and Problems," The McGraw-Hill Book Company, Inc.

(Since classification changes constantly as new forms are found and since new editions of the foregoing books appear constantly, no dates are given.)

Part II
PLANT BIOLOGY

A. The Morphology and Physiology of a Typical Seed Plant
B. The Plant Groups; Morphology and Physiology of Representative Types

A. THE MORPHOLOGY AND PHYSIOLOGY OF A TYPICAL SEED PLANT

CHAPTER VIII

THE ORGANIZATION OF A SEED PLANT

I. Plants and Animals

Plants and animals have a similar fundamental structure; *i.e.*, they consist of protoplasm contained in cells. Since the activities of protoplasm are the activities of life itself, it follows that the processes in all organisms are similar. However, plants and animals are different in many ways, and a separate study of each group, how they are made, how their structures are fitted for their functions, the great variety of forms gives a sound basis for the study of the processes of living organisms, or physiology.

II. The Plant Kingdom

A. The Wealth of Plant Life.—Unless a special study is made, one has little idea of the multitude of varieties in the plant kingdom. About 250,000 species have already been described, and more are being added as botanists continue their studies.

B. The Groups of Plants.—The plant kingdom is divided into three main groups: (1) the *Algae* and *Fungi* (Thallophyta), (2) *liverworts* and *mosses* (Bryophyta), and (3) the *vascular plants* (Trachaeophyta), which include *club mosses* (Lycopsida), the *horsetails* (Sphenopsida), the *ferns* and the *seed plants* (Pteropsida). In the older classifications, the fern group was called Pteridophyta, and the seed plants were classed as Spermatophyta. Since the seed plants are the most familiar of all plants, a member of this group is selected as a type for the introduction to the study of the structure and physiology of plants.

C. The Seed Plants.—These are the familiar plants of our gardens. They range in size from plants hardly larger than a pinhead (Wolffia, a duckweed) to giant redwoods (Sequoia) of California, which may become 300 ft. in height.

1. GYMNOSPERMS AND ANGIOSPERMS.—The gymnosperms include the cone-bearing plants, our common evergreens. Today, this is a comparatively small group, but it was a very large group in ancient times. The

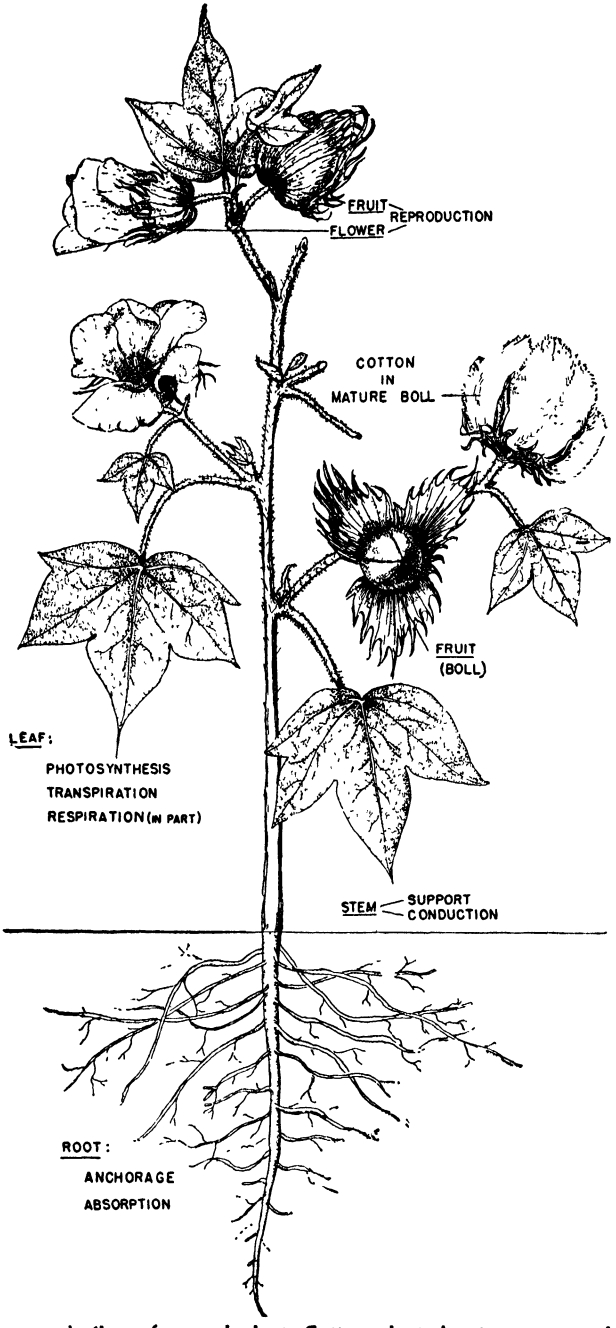


Fig. 54.—The organization of a seed plant. Cotton plant showing parts, and functions of each part. (B. F. Edwards.)

great group of the seed plants is the angiosperm group, or flowering plants; about 130,000 species of flowering plants have been classified.

2. The Organization of a Seed Plant.—The cotton plant is used as an example of a seed plant. It is made up of cells, as are all other plants. Thousands of these cells are associated together to form tissues and the tissues are combined to form organs (Chaps. III and IV). The parts of a flowering plant may be separated according to the functions they perform into (*a*) the vegetative body and (*b*) the reproductive bodies.

a. The Vegetative Body.—Figure 54 shows the parts of a cotton plant and their relations to each other. The vegetative body is made up of (1) roots, (2) leaves, (3) stems.

(1) Roots.—The roots anchor the plants in the ground. Through them enter the water and mineral salts essential to the life of the plant. It is a familiar fact that a plant deprived of water will first wilt, then die.

(2) Leaves.—The leaves are provided with veins that are connected with the transportation system of the stems and roots. In the leaves and other green tissues of the plant, the important process of food manufacture as well as other vital activities takes place.

(3) Stems.—The stems are the great highways for the transportation of water and food. They also support the plant, and leaves are arranged on them in such a way that they are exposed to the light. Green plants must have light, or they will die. Stems also support flowers in such a position that they may be pollinated readily.

b. Reproductive Organs.—Only by leaving offspring can organisms survive. Except for one-celled plants and animals (Protista) called *the immortals* (page 288), the law of life is that every living thing eventually dies of old age unless it is destroyed before that time. Provision for the continuance of the race varies with the type of organism, but it is universal. The higher plants provide for reproduction in two ways: (1) by vegetative reproduction or (2) by developing special organs in which the germs cells are produced.

(1) Cuttings, etc.—Sometimes parts of an old plant may develop into new plants. Familiar examples of this type of reproduction, which is vegetative, are cuttings that send out roots, the runners of strawberries, the rhizomes of various types of plants, and tubers of potatoes.

(2) Flowers, fruits, seeds.—The seed plants develop definite organs for reproduction: the flower, the fruit, and the seeds. In the flowers, the germ cells are produced, and fertilization takes place. The fruit is concerned in protecting the young, growing seeds, and may develop interesting structures for the dispersal of these seeds (hooks, barbs, fibers, etc.). The seeds contain young embryo plants together with food for the nourishment of the young plants until they are established and able to take care of their own food supply.

Questions

1. Describe briefly the parts of a seed plant, giving the functions of each.
2. Give examples of stems and roots modified for storage of large amounts of food.
3. What are some of the crops valuable to man on account of (*a*) roots, (*b*) stems, (*c*) leaves, (*d*) fruits, (*e*) seeds?
4. Why are the root systems in water plants not well developed?
5. What types of reproduction are found in plants?

CHAPTER IX

THE ROOT AND ITS FUNCTIONS

The outbound stem has branches three;
On each a thousand blossoms grow,
And old as aught of time can be
The root stands fast in the rocks below.
—STERLING.

The most important functions of roots are *anchorage* and *absorption*, but they perform other necessary functions for the plant. Land plants must be anchored in the ground, and all parts of the plant body must be supplied with water and mineral salts through the agency of the roots.

Roots are thought of as being underground, and that is where they are usually located. However, in addition to the *underground roots*, there are *prop roots*, *air roots*, and other types.

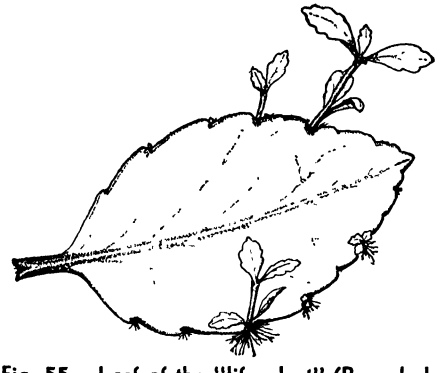


Fig. 55.—Leaf of the "life plant" (Bryophyllum). New plants grow in the leaf notches.

I. Types of Roots

Roots may be classified in many ways; according to the time of appearance, according to structure, or according to their special uses, etc.

A. Primary and Secondary Roots.—When a seed germinates, the first structure that appears is the root. This is the primary root (Fig. 122). Branches that grow from the primary root are the secondary roots.

B. Adventitious Roots.—The word *adventitious* means additional or accidental. Adventitious roots are those that appear in unusual places. For example, many "cuttings" will send out roots; roots will be sent out from the notch of *Bryophyllum* (Fig. 55); *Begonia* leaves will produce roots.

C. Fibrous and Taproots.—Although, as will be seen later, many types and forms of roots are especially modified for particular functions, there are two main types that are particularly common: fibrous roots and taproots (Figs. 56, 57, 58). Fibrous roots get their name because they are

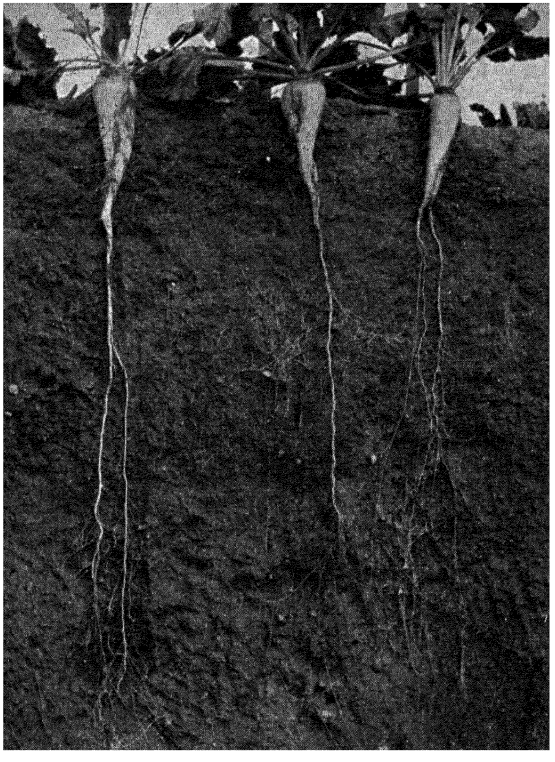


Fig. 56.—The sugar beet is a fleshy tap root. Besides sending its roots 6 or 7 ft. into the earth, it has an extensive lateral root system. (Courtesy of U.S. Beet Sugar Association.)

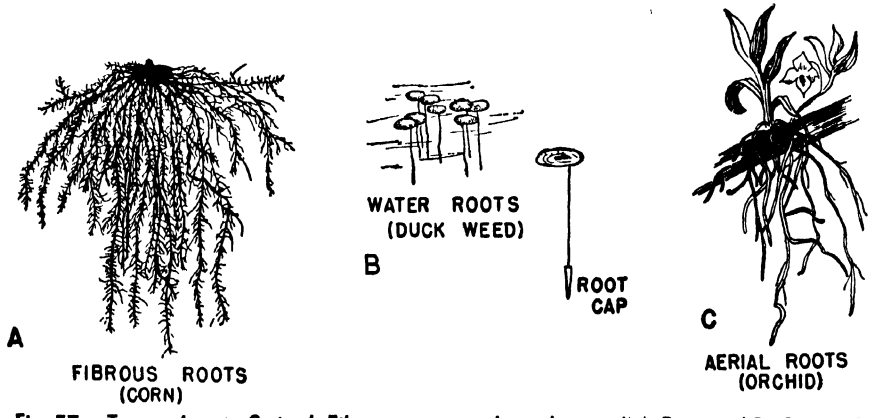


Fig. 57.—Types of roots, Series I. Fibrous, water, and aerial roots. (M. Price and B. Shamos.)

profusely branched and form a fibrous system. They may extend many feet into the ground. For example, a single alfalfa plant sometimes sends its roots down to a depth of from 20 to 30 ft. Since so many branch roots are formed, they produce a thick tuft or mat that aids in binding the soil together. The roots of grasses and grains are of this type. Such roots may absorb water only from the upper layers of the soil, whereas taproots typically extend down to great depths. A taproot is a primary root that continues its growth downward, becoming thereby the main root. In the taproot type of root system, the primary root may become modified for food storage, as in the dandelion, beets, etc. (Figs. 56, 58).

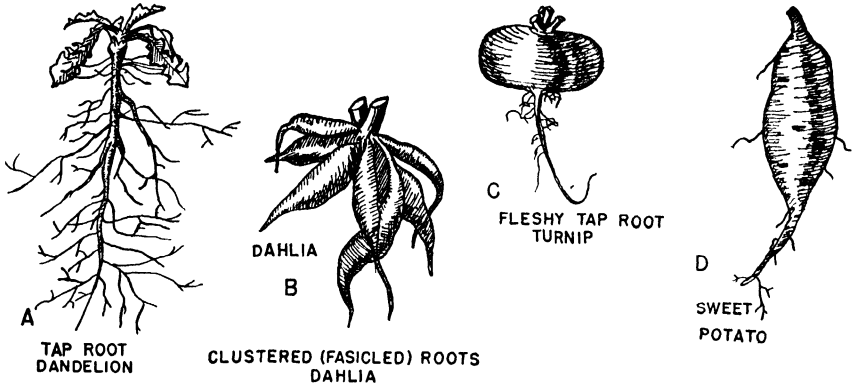


Fig. 58.—Types of roots, Series II. Storage roots of various kinds. (M. Price.)

D. Annual, Biennial, and Perennial Roots.—Plants can be classified as annuals that live for a year, biennials that store food one season and use it the next to produce flowers and seeds, and perennials that live from year to year. New roots are added to perennials each year, and these young roots carry on most of the work of absorption. This is true even of the giant trees of California and the cypresses of Mexico, which are thousands of years old.

II. The Structure of Roots

A. The External Features.—In appearance, roots may be delicate white structures, or they may be gnarled and woody. Roots of young seedlings show external features well. There are no leaves or buds, nodes, or internodes on roots.

1. Protective Layers.—Young roots are covered with a layer of cells that protects the tissues beneath. This is the *epidermis*. It is from this layer that the root hairs grow out. When roots begin to thicken and become woody, the epidermis is replaced by layers of *cork*. Such roots, of course, no longer function in absorption. As the outer layers of

cork crack, because of root expansion, new layers of cork form from within.

2. Root Cap and Growing Point.—One feature of roots that is absent from all other plant organs is the root cap. It is a protective

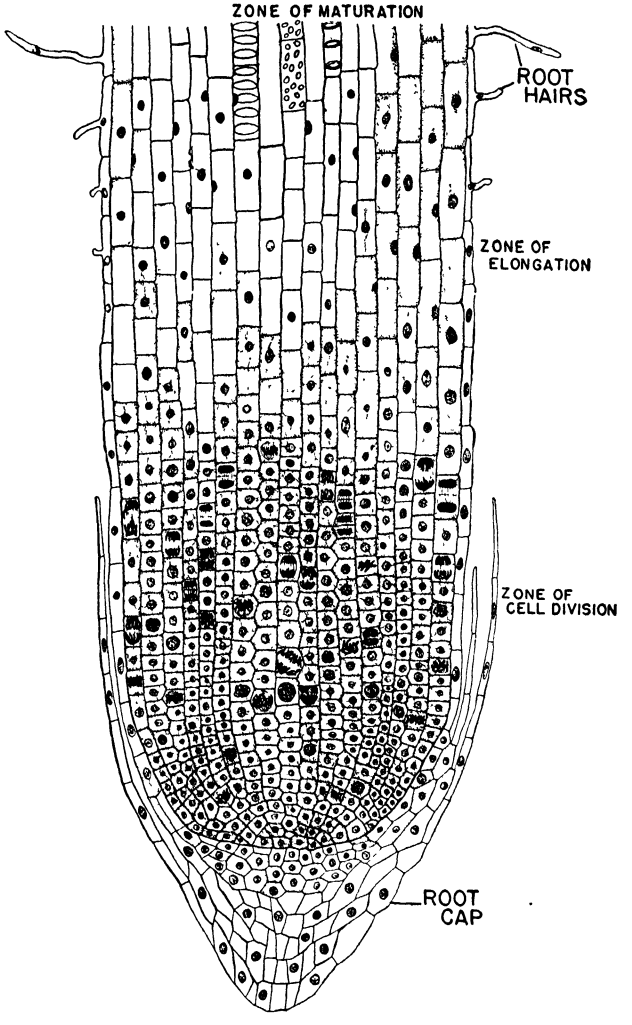
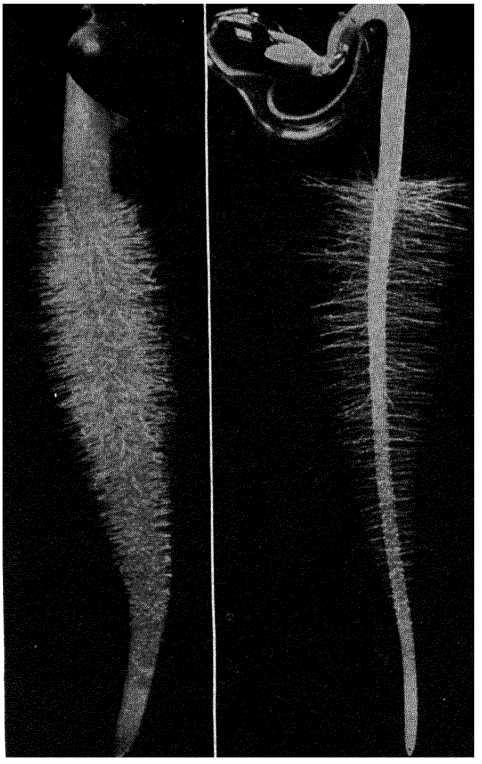


Fig. 59.—Longitudinal section through the tip of an onion root. (L. Runyon.)

covering for the delicate growing point as it is pushed through the soil (Fig. 59.)

3. Root-hair Zone.—Behind the growing point is a region of cell elongation and back of this the root-hair zone covered with dense white hairs (Fig. 60). Each hair grows out from a cell at the surface of the root.

These hairs are delicate structures that possess the power of clinging very closely to soil particles (Fig. 61). They absorb the thin film of water that surrounds these soil particles. The more root hairs there are, the larger the absorbing surfaces. As the root grows, the older root hairs die and are replaced by new ones close to the growing point. It follows from this that



A B

Fig. 60.—Root hairs. (A) Seedling of white clover grown in moist air (magnified 6 times). (B) Seedling of garden cress grown in moist air (magnified 4 times). (From Holman and Robbins, General Botany, John Wiley & Sons, Inc.)

only the younger portions of the root perform the function of absorption. The root hairs of some plants live longer than those of other plants, but most of them die within a few days or weeks. Some water plants—for example, the duckweed (Fig. 57*B*)—do not possess root hairs.

B. The Internal Structure of a Dicot Root.—A longitudinal section through a young root (Fig. 59) reveals four distinct zones: (1) the root cap, (2) the zone of cell division, (3) the zone of cell enlargement, and (4)

the zone of maturation or the root-hair zone. It can be readily seen that these regions are based on the degree of maturity of the cell.

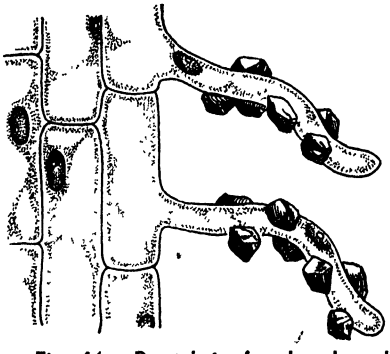


Fig. 61.—Root hairs (much enlarged). Root hairs grow out from epidermal cells and soil particles adhere closely to them. (F. Baker.)

Study of a cross section through the root-hair zone shows four main features of roots (Fig. 63):

1. The Epidermis.—The epidermis is a single layer of cells; it protects the tissue beneath. Figure 61 shows how the root hairs grow out from cells in the epidermis.

2. The Cortex.—The cortex (L. *corium*, leather, bark) is made up of thin-walled cells. The water, which contains dissolved minerals, that enters the plant through the roots passes across the cortex to the conducting tissue in the central cylinder. When the plant becomes older, the cortex may be used for storage or may disappear altogether.

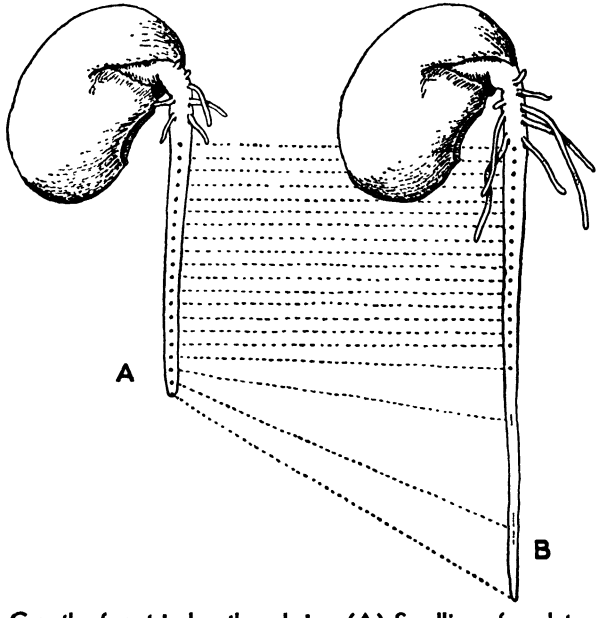


Fig. 62.—Growth of root in length and size. (A) Seedling of scarlet runner bean with equidistant dots placed along the primary root. (B) The same seedling 24 hours later, showing elongation only near the tip. (From Haupt, Fundamentals of Biology.)

3. The Endodermis.—The endodermis is a layer of thick-walled cells—the inner boundary of the cortex.

4. The Vascular Cylinder or Stele.—This is made up of cells highly specialized either for conducting the water and minerals that enter the plant through the roots to other parts of the plant or for translocating food materials. The *xylem* or wood occupies the central portion of the cylinder and extends outward in a three- , four- , or five-rayed arrangement, depending upon the kind of plant. Between the rays of xylem lies the *phloem*. The cells that lie in the arms of the star-shaped xylem, separating the xylem from the phloem, eventually become the cambium.

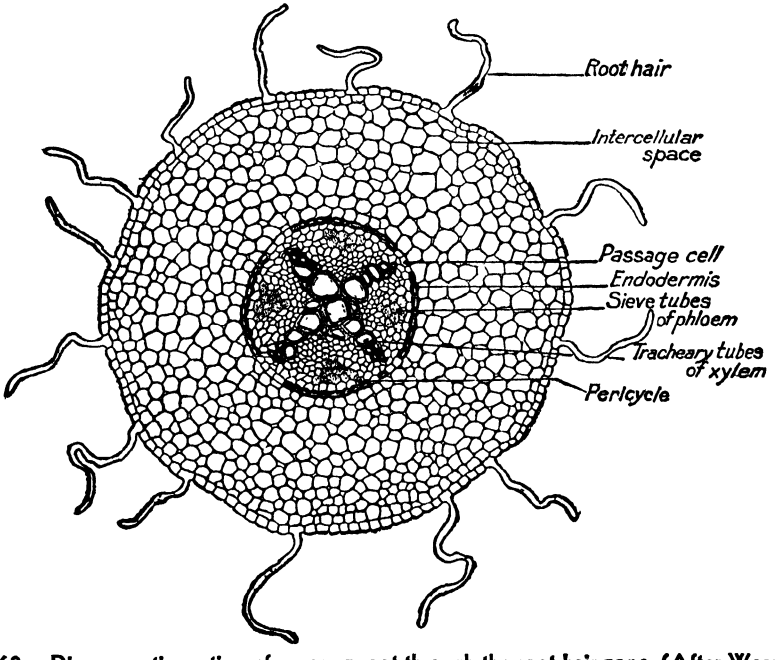


Fig. 63.—Diagrammatic section of a young root through the root hair zone. (After Weaver.)

Cambium is a delicate formative tissue that gives rise to new growth at the sides of roots and stems of dicotyledons. The function of cambium then, is to produce new cells. Figure 102 shows how these conducting tissues of roots connect with those of stems.

The *pericycle* is the outermost layer of the stele. In it branch roots arise.

5. Annual Rings.—As the roots grow older the picture changes. The xylem loses its star-shaped character by the accretion of successive layers and becomes a round cylinder surrounded by cambium and phloem. Each year the root lays down new wood tissue (xylem) just as this occurs in the stem, and thus *annual rings* in roots are formed.

III. Activities of Roots

Work of roots has been mentioned in connection with the description of the structures connected with the performance of that work; as has been noted, some of these functions are anchorage, absorption, conduction, and storage, and sometimes asexual reproduction.

A. Absorption.—Most of absorption in roots is through the root hairs, and these are located on young roots. Even old plants, then, must continually grow new roots in order to carry on the process of absorption.

1. Diffusion, Imbibition, Osmosis.—These physical processes are important in the work of absorption. (1) *Diffusion* (page 39) is the movement of molecules and atoms from places of greater concentration to places of less concentration. (2) *Imbibition* is the process by which water-attracting (hydrophyllic) colloids such as cellulose, starch, and protoplasmic proteins take up water. (3) *Osmosis* (page 39) is the movement or diffusion of water (or other solvents) through a semipermeable membrane.

2. Soil Texture.—Movement of water in soil depends upon its texture. Soil is made up of various-sized particles with air spaces among them. In damp ground, each particle has a film of water around it. When roots are grown in soil, the root hairs become closely united to the soil particles and are able to absorb these films (Fig. 102).

Of course, many types of soil exist. If the spaces between the particles are very small, as in clayey soil, water does not move freely through the soil, and it remains wet for a long time. On the other hand, sand allows water to move so freely that the soil dries out very quickly.

Several factors affect absorption of water from the soil. A plant will wilt in cold soil even if there is abundance of water present; water from an alkali soil is not easily absorbed by most plants, though the salt-loving plants (halophytes) are adapted to this type habitat. Naturally, the rate of root growth and the extent of the root system will affect the amount of absorption from the soil.

B. Movement of Materials.—Plants have mechanisms for transfer of materials and water; and dissolved minerals, food, and secretions are constantly being moved throughout the plant body.

1. Movement of Water.—The epidermis and root hairs have cellulose walls covered on the outside with a material that has an affinity for water, and this wall is permeable to both water and dissolved mineral salts; *i.e.*, water and dissolved mineral salts will go through the wall. The cells of both the epidermis and the cortex contain sugars and other substances manufactured by the plant. The plasma membrane (page 33) will not allow the sugar to pass out, but the water is able to pass in. The cortex consists of cells somewhat like those of the epidermis, and on this

account water will pass across the cortex from the epidermis to the water-conducting tissue. The route of water from the root hairs to the xylem can be seen in Fig. 102. The pull exerted by evaporation of water from the leaves may aid in the lifting of water in the plant. The whole story of the movement of the materials in the plant is not known, but imbibition, diffusion, osmosis, and the pull of transpiration are all concerned in this work.

2. Translocation of Food.—Food is translocated from the leaves to the stems and from the stems to the roots (Fig. 102). It moves in all directions to places where it will be used or stored. The direction of the movement may be changed from time to time, as shown by the fact that the sugar and the soluble protein pass from the leaves to the stem and from the stem to the root in the summer when the process of photosynthesis is at work. In some plants, for example in maple trees, the stored sugar moves upward in the spring to furnish food for the making of the new crop of leaves. In certain biennials, such as the beet and turnip, food that passes from the leaves to the root is stored in the root one season, and the next season this food is sent upward to the developing leaves and flower shoot.

C. Pressure, Contraction.—Several types of pressure are characteristic of growing roots.

1. Turgor Pressure.—This is the pressure exerted outward in every direction by the protoplasm upon the confining membranes or cell walls. It is brought about by the increase in the cell sap, or liquid in the vacuoles of the cell, due to the movement of water into the root hairs and the tendency of the protoplasm to absorb much water. This brings about a stretching of the cells walls that is important in providing rigidity for the plant. Turgor is the opposite of wilting.

2. Root Pressure.—This can be shown in some plants by cutting off the stem close to the ground. Considerable sap will exude from the cut xylem cells if the plant has been well watered. Root pressure is the pressure with which this sap exudes. It may be important in forcing the water into the conducting elements of the root and so in starting it on its way to the stem.

3. Growth Pressure.—Growth pressure is developed in all growing parts of a plant. When hundreds of cells are expanding at the same time through absorption of water, pressure naturally results. Great pressure may be exerted when roots pierce the soil. The question naturally arises as to why growing plants can break cement walks without the cells being burst open. The answer may be that their cells are of such small size that the walls of each cell do not have to resist great pressures. Both root pressure and growth pressure are probably due largely to turgor pressure.

4. Root Contraction.—Bulbs planted for some time are likely to be deeper in the ground than when first planted, owing to the fact that

when roots mature they may contract and draw the stem a slight distance down into the soil. This accounts for the fact that plants growing on the surfaces of rocks, in crevices, and in other situations of this kind hold their places in spite of the fact that the rock may "weather" or wear down, and in this way the crowns of the dandelion plants are sometimes pulled quite deeply into the soil.

D. Respiration in Roots.—All living cells respire, a process that requires a constant supply of oxygen. The root is much branched and

Fig. 64.—"Knees." In swampy regions, cypress trees develop swollen bases and the roots develop "knees" which may attain a height of 3 ft. (Dr. C. L. Baker.)

thus presents a large surface to the soil air. Except for those plants that have become adapted to life in water or in swamps, plants must obtain their oxygen from the air spaces in the soil. The process of respiration involves the taking in of oxygen and the giving off of carbon dioxide.

KNEES.—When roots of cypress trees are submerged in water, they develop curious structures, such as are illustrated in Fig. 64. These structures, or knees, are believed to aid in aeration.

E. Response of Roots to Stimuli.—Plants are not able to move around as animals do, yet they have a remarkable power of responding to various stimuli. They can change the direction of growth or the position of their various organs.

1. Response to Gravity—Geotropism (page 596).—The primary root and the taproot naturally grow downward. This is because the growing point responds to gravity positively. This response to gravity is termed *positive geotropism.* In Fig. 65, pea and corn seedlings were "turned upside down" for 24 hours. At the end of that time, the growing point of the root had turned downward.

It is easy to prove that the growing point of the root is responsible for this reaction. If the tip of the root of a corn or pea seedling (Fig. 66)

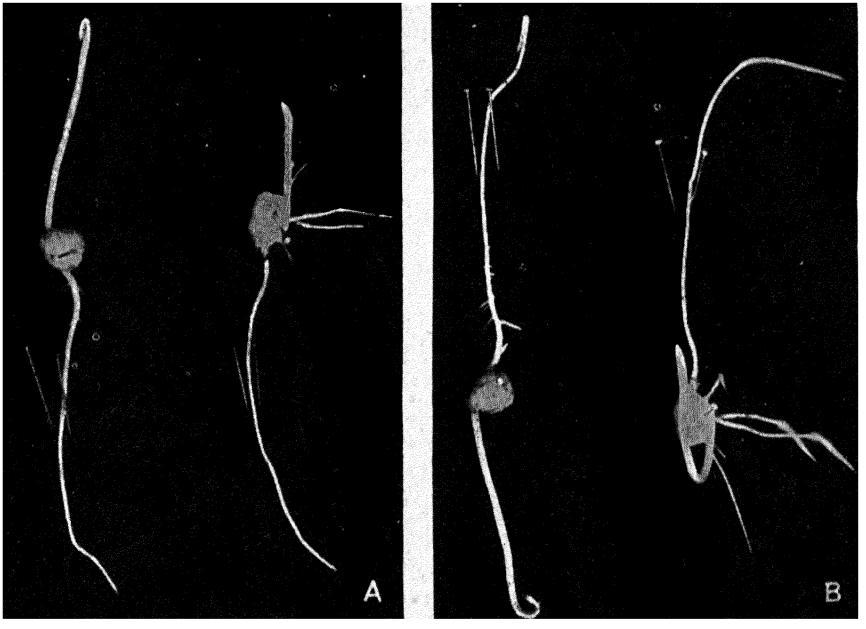


Fig. 65.—Response of roots and stems to gravity. (A) Pea and corn seedlings pinned on pasteboard. (B) The seedlings were turned upside down. After 24 hours, the root has turned down (positive geotropism), and the stem has turned up (negative geotropism).

is cut off and left in a moist chamber for 24 hours, the root will not turn down, as in Fig. 66*A*.

2. Response to Water—Hydrotropism (page 596).—Roots do not seek water but tend to grow better in soil where water relations are more favorable. The actual direction of growth, however, is due to the resultant of many forces, among which are the unequal distributions of water.

Water roots usually do not branch very much, but when the roots of land plants encounter water containing plenty of oxygen and nutrients, they produce innumerable branches. Cottonwood and willows especially behave in this manner, so that even a small rootbranch that enters a drainpipe will soon fill it and obstruct the flow of water.

3. Response to Temperature—Thermotropism (page 596).—Roots will bend in the direction of the temperature most favorable for their growth.

4. Response to Light—Phototropism (page 596).—Underground roots and stems are often indifferent to light, but some roots, such as those of the mustard, will grow away from the light, thus exhibiting negative phototropism.

5. Response to Contact—Thigmotropism (page 596).—Climbing roots—for example, the aerial roots of poison ivy—show a definite response to contact by flattening out on the support against which they are growing.

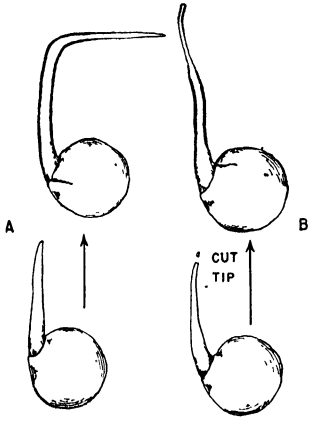


Fig. 66.—Response of the root tip to gravity. (A) Pea with the primary root turned upside down. In about 24 hours the root responds to gravity by bending down. (B) If the extreme tip be cut off, the root continues to grow but there is little, if any, bending down in response to gravity. (L. Runyon.)

IV. Roots of Modified Form and Function

As in the case of leaves, some roots are highly specialized and changed in appearance. This condition is related to the kind of work they do. The work may be of the nature usually performed by roots or by some other part of the plant. A few examples will make this clear.

A. Storage Roots.—Figure 58 illustrates a group of roots that have become especially modified for storage. Most of these are familiar. The structure of a taproot is favorable for storage, and in some cases the roots become very large and fleshy. Examples are the lower portions of carrot, turnip, radish, dandelion, burdock. In other cases, fibrous roots become fleshy. The clustered roots of the dahlia and the sweet potato are examples of this type.

B. Aerial Roots; Epiphytes.—An aerial root is, literally, an "air root." Such a root lives partly or entirely in the air. The corn plant, for example, may send roots down into the ground from an aerial stem (Fig. 67*B*). These are *prop* roots and help support the stem. The banyan tree sends down roots from its branches (Fig. 68). These may become so large as to resemble tree trunks. The result is a whole grove of banyan trees that have developed from a single plant. The prop roots of the mangrove help support the tree in the soft mud (Fig. 69). Other types of aerial roots are the roots of the orchid (Fig. 57*C*) and the adventitious roots of the English ivy (Fig. 67*B*). As is the case with poison ivy, the English Ivy roots flatten out and hold the plant on the support against which it is growing. The roots of the "strangling fig" twine around other plants.

1. Epiphytes.—Plants which, like some orchids, live perched upon another plant, are called *epiphytes*. Their roots absorb water and also act as hold-fasts to the trees upon which they are growing. Epiphytes are not parasites, however, since they do not take nourishment from their hosts. They get their water from rainfall and their minerals from the

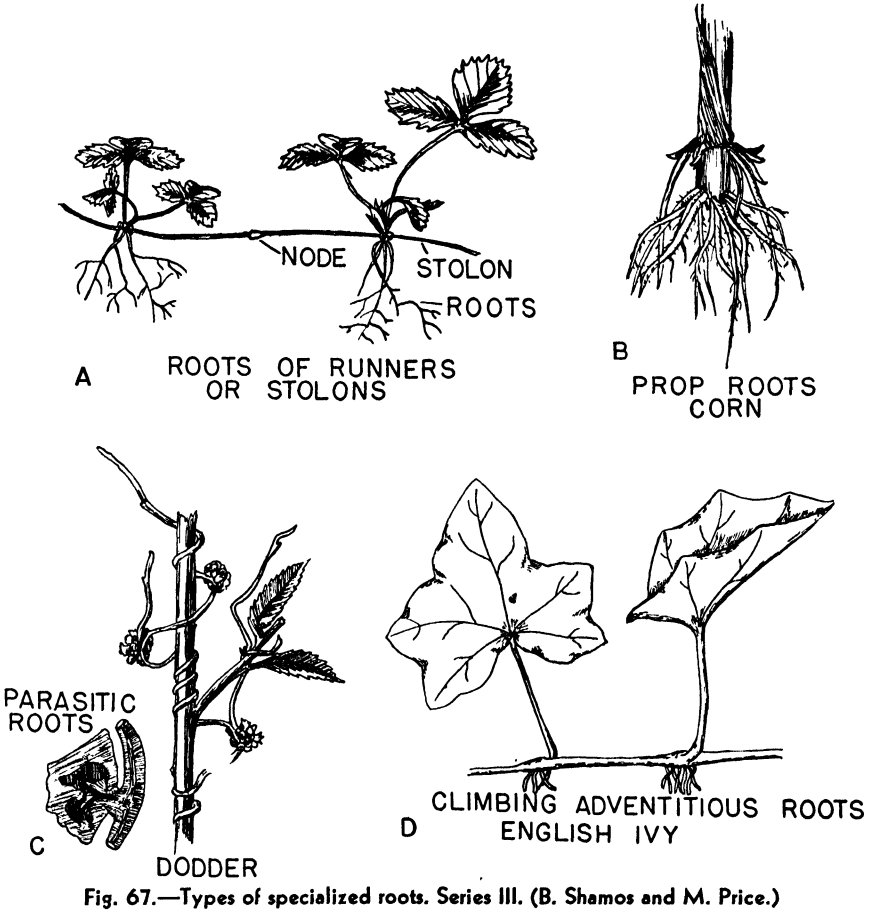


Fig. 67.—Types of specialized roots. Series III. (B. Shamos and M. Price.)

dust and decay of the outer bark to which they are attached; they manufacture food, as do other green plants (Fig. 57*C*).

C. Water Roots.—Water roots usually contain large air spaces. Usually water roots do not develop root hairs (Fig. 57*B*).

D. Parasitic Roots.—Mistletoe is a partial parasite. It is green and manufactures food as do other green plants, but it also sends roots down into the tree to which it is attached and absorbs from it water, minerals, and perhaps some food (Fig. 70). The yellow dodder, called in some

Fig. 68.—Prop roots of the banyan tree. Near Miami, Florida. (Courtesy of B. Miller.)

Fig. 69.—Mangrove tree on the coast of southern Florida. The prop roots help support the tree in the soft mud. (Courtesy of J. H. Davis.)

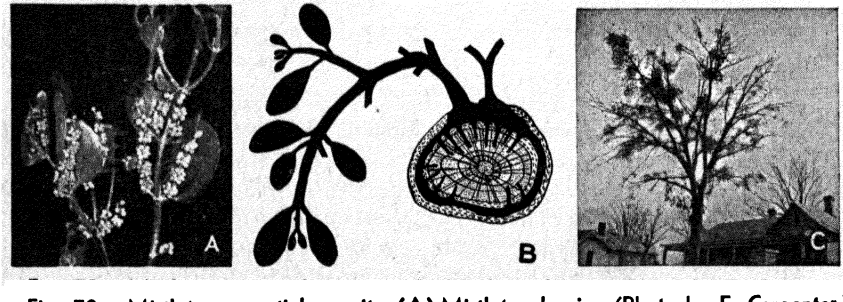


Fig. 70.—Mistletoe, a partial parasite. (A) Mistletoe berries. (Photo by E. Carpenter.) (B) Cross section of a branch infested with mistletoe. (From Heald, Introduction to Plant Pathology.) (C) Mistletoe growing on a tree. (Photo by Dr. J. M. Andrews.)

localities the *love vine*, is a parasitic twiner that lives at the expense of its host (Fig. 67*C*).

E. Plants without Roots.—Finally, there are plants that have no roots at all. Spanish moss (*Tillandsia*), found hanging on trees of the South, is an example. This is a true flowering plant, but other parts of the plant have taken over the functions of roots.

The foregoing account of roots tells something of their forms, structure, and relation to the life processes of the plant. For an account of their important functions in soil conservation and soil building, see Chap. XLIX.

Questions

1. Define the following terms, as related to roots: *epidermis, cortex, endodermis, stele, diffusion, inhibition, osmosis, translocation.*
2. Where are the growing regions of the root? Why is a root cap necessary for the growing point of a root? What work is done by the root tip? Cambium? Pericycle?
3. Where do you find root hairs? What is their function? How long do they live? What is the advantage of a large absorbing surface? Why are there no root hairs at the tip of the root? How does absorption take place in the root hair?
4. What are the advantages and disadvantages of a shallow root system? Of a deep root system?
5. Why do growing roots exert pressure? Have you seen examples that would prove this point?
6. How is the air in the soil used by roots? Why is flooded ground unfavorable for most roots? What are knees?
7. Give some good reasons for cultivating the soil.
8. What is meant by contraction of roots?
9. Why are there usually no root hairs on the roots of water plants?
10. In a young plant growing from the seed, the root usually develops before the leaves and stem. What is the advantage of this?
11. Explain why there are differences between the roots of desert and bog plants.
12. Explain why a clay soil will absorb and hold more water than a sandy soil.
13. Why is a finely pulverized soil favorable for most plants? What are some disadvantages of soil with large particles?
14. In transplanting plants, it is important to press the soil firmly around the plant roots. Why?
15. Water roots often are smaller and less branched than soil roots. How, then, would you account for the fact that roots of land plants such as the poplar, willow, etc., develop innumerable small branches when they enter the drainpipes?
16. Give an account of some roots of modified form and function.

Suggested References

LAURIE, ALEX: "Soilless Culture Simplified," The McGraw-Hill Book Company, Inc., 1940.

WEAVER, J. E., and BRUNER, W. E.: "Root Development of Vegetable Crops," The McGraw-Hill Book Company, Inc., 1927.

CHAPTER X

THE STEM AND ITS FUNCTIONS

Love thou the rose,
Yet leave it on its stem.
—OWEN MEREDITH.

The *stem* is the connecting link between the roots and the leaves. Besides serving as a support for parts of the plant above ground, it is the great transportation highway and does other important work essential to the life of the plant. On it the leaves are arranged so as to obtain the light so necessary for food manufacture, or *photosynthesis*. It matters not whether the stem is erect, trailing, or underground; the stem supports the leaves. Naturally, the stem supports the branches and the weight of the treetops also. Water and the minerals dissolved in water enter the plant through the roots; but it is through the stems that these materials are carried to every part of the plant, including the leaves. Although most of the food is manufactured in the leaves, it is through the stem that these food materials are transported to other parts of the plant. Sometimes, in such plants as the cactus, the leaves may be reduced or lacking; in such cases, the stem may become flattened and retain chlorophyll with which to carry on the work of the leaves. Stems may also serve as places of storage for food and as asexual reproductive bodies.

I. General Features of Stems

A. Sizes.—Stems may be very large, such as those of the giant redwoods; climbing stems may be more than a hundred feet long, and trailing stems may creep over the ground for varying distances. These long stems develop very little of the woody structure of shrubs and trees and hence must be supported. In contrast to all these, plants such as the dandelion, although provided with short stems, are sometimes said to be stemless. Stems may be thread-like, as in the case of some delicate vines, or may be thick trunks, many feet in diameter; they may be tender, fleshy, watery, or woody and hard. The classification of plants into *herbs*, *shrubs*, and *trees* depends upon the character of the stem. Herbaceous plants are the familiar plants of our gardens. Some of these may approach the shrub type, since they may contain a considerable quantity of woody tissue. In general, however, herbs are thought of as plants with more or less soft stems, whereas shrubs and trees are plants with woody stems. Shrubs do not grow as tall as trees and are more branched near the ground.

B. Form and Symmetry.—The general form and symmetry of the plant is determined by the characteristics of the stem and bud development. Tree trunks are really stems, and there are three main types.

1. EXCURRENT.—When the main stem extends to the top, it is called *excurrent* (L. *excurrens*, running out). This condition is the result of lateral bud inhibition by the terminal bud of each branch and a control of all the lateral branches by the bud or young growth of the terminal branch (Fig. 71*A*). This terminal shoot is strictly negative in its response to gravity, growing straight up. Although possessing no peculiar or different structures, the terminal shoot is, as it were, the brain of the plant: all the other branches are held strictly under its control with respect to gravitational response. The side branches are not vertical in their growth,

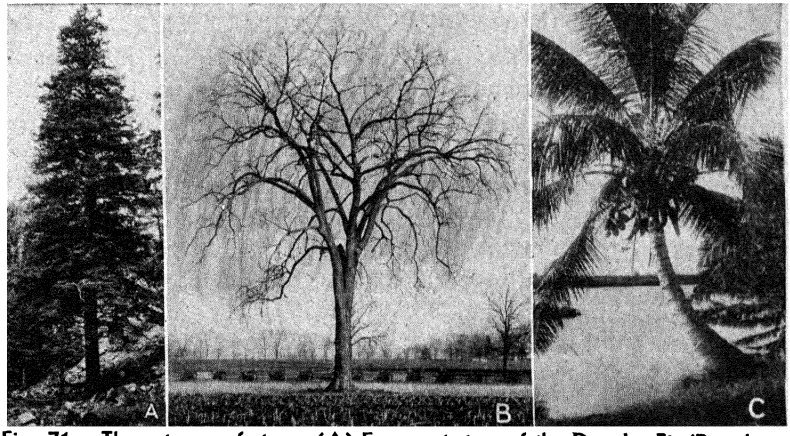


Fig. 71.—Three types of stems. (A) Excurrent stem of the Douglas Fir (Pseudotsuga). (B) Deliquescent stem of the elm (Elmus). (C) Columnar stem of the coconut palm (Cocos). (A and B, U.S. Forest Service.)

nor do they usually attain either the height or length of the terminal branch. The excurrent type is exhibited especially well in conifers. Many broadleaf trees are also excurrent, but in them the main stem is often branched near the top so that there is evidently more than one leader shoot.

2. DELIQUESCENT.—In the elm and apple, the terminal bud is not so predominant over the others; therefore, the lateral buds develop, and the main stem divides and subdivides, giving the characteristic "round-topped" tree that is so familiar. The method of branching of the elm tree in Fig. 71*B* is of the deliquescent type.

3. COLUMNAR.—The unbranched, cylindrical stems characteristic of palms are examples of the columnar type (Fig. 71*C*).

Pruning will bring about changes in the forms of plants. For example, trimming off the terminal buds will stimulate many of the lateral branches to develop that otherwise would not do so.

C. Length of Life of Stems.—All plants can be classified into three groups on the basis of their length of life. The *annual* (L. *annus*, year) plants live for a year, produce seed, and then die. Many flowering plants belong in this class, such as zinnias and morning-glories. The *biennials* (L. *biennium*, space of 2 years) require 2 years to reach their full development. The common mullein develops in the form of a rosette during the first year and stores up food; the next year, it sends up a flower stalk, and the seeds mature; then the plant dies. Plants that live longer than 2 years are *perennials* (L. *perennis*, lasting through the year).

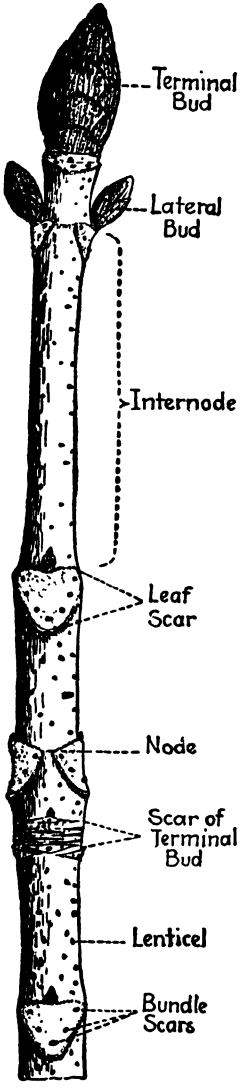


Fig. 72.—A woody twig of the horsechestnut in winter condition. (From Sinnott, Botany.)

Two kinds of perennials are recognized: (1) those with *herbaceous* stems and (2) those with *woody* stems. The aerial stems of herbaceous perennials die down to the ground at the approach of winter, and the underground part lives through the cold weather. In spring, these underground parts send up new shoots, and the plant is said to "bloom perenially." The woody-type stems do not die down, but each year they increase in size as the season's growth is added.

II. Structure of Stems

Stems vary very greatly in appearance and structure, but all stems show certain features.

A. External Features. 1. Buds.—The places of attachment of the buds to the stems are called *nodes*. The spaces between the nodes on the stem are the *internodes*. At the ends of the stems are the *terminal* buds; the buds on the sides are the *lateral* or *axillary* buds, so called because they are in the angle or axil formed by the attachment of the leaf to the stem (Fig. 72).

Leaves may be arranged on the stem opposite to each other or in a spiral (page 135). Since the lateral buds arise in the axils of the leaves, these buds must be arranged in the same way. As soon as leaves reach their full size in spring, the buds for the next season's stems and leaves are formed. Buds reach their winter condition by the time the leaves fall. The growth of new foliage each year is the function of the buds, for branches and twigs that have once borne leaves will not produce leaves

again. Buds may be enclosed in specialized *scale leaves* that may be covered with hair or contain resinous substances. In this way, the tender parts of the bud are protected during the winter. They may have no special covering, as is the case of some buds on underground stems, or they may be protected by simple coverings, as in the case of the tulip tree or magnolia, where the stipules fold over the bud.

2. Scars.—Other structures to be noted on the stem are *leaf scars*, the *bundle scars*, and the *bud-scale* scars. The bud-scale scars are usually small and close together. The section of the stem between terminal bud

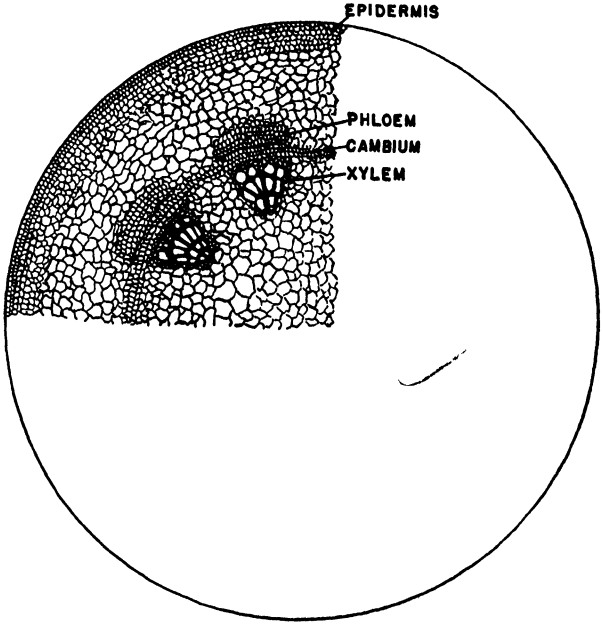


Fig. 73.—Cross section of a young dicot stem. Note that the vascular bundles are arranged in a ring. (B. Shamos.)

scars represents a year's growth. Plants with strong lateral buds usually branch continually and become bushy, as so many garden shrubs do. Plants with strong terminal buds usually possess a straight main stem, such as that of the sunflower or spruce, the excurrent type of stem, whereas those with strong lateral buds produce the deliquescent stem.

3. *Lenticels* (L. *lentis*, a lentil).—The plant gets most of its oxygen from the air that enters through the stomata (page 133). Young green stems all possess *stomata*, but in the stems of perennial plants a corky layer develops beneath the epidermis, and the stomata may be replaced by small openings or pores, called *lenticels* (Fig. 72), through which an exchange of gases takes place between the interior of the stem and the surrounding atmosphere. The lenticels are more prominent on some stems

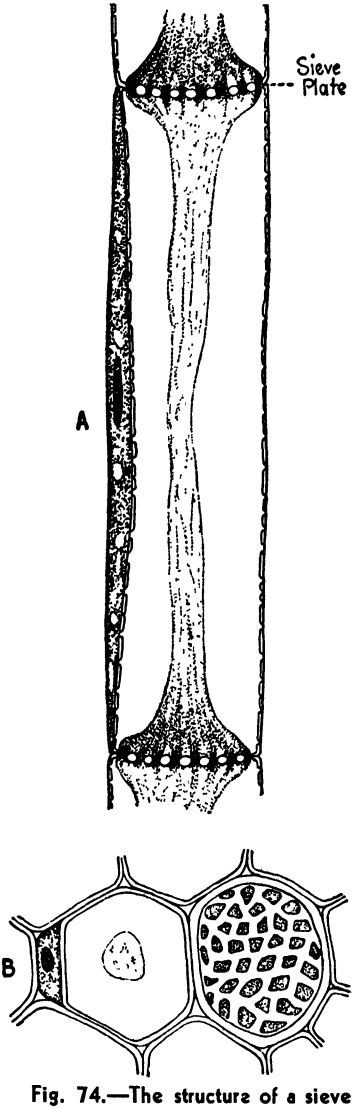


Fig. 74.—The structure of a sieve tube of the squash. (A) longitudinal section of a sieve tube, communicating by sieve plates with the adjacent sieve tubes above and below. Its companion cell is at the left. (B) transverse sections through two sieve tubes. The one at the left is cut near the middle, that at the right is cut near the end and shows the end wall or sieve plate. (From Sinnott, Botany.)

than on others. In stems with thick bark, the lenticels are in the furrows.

B. Internal Structures.—The structures of stems differ in their main features according to which of the three groups they belong to. These groups are: (1) dicotyledons, (2) monocotyledons, (3) gymnosperms.

1. The Dicot Stems.—Structures in stems change with age as shown below.

a. The Young Stems.—In a dicot stem, there are typically three regions: (1) the epidermis; (2) the cortex; (3) the stele (Fig. 73). Annual rings are formed by the growth of successive years.

The *epidermis* is a protective layer that completely encloses the rest of the tissues except for the openings of the stomata. There may be many modifications of the epidermis due to hairs, scales, and cuticle. It may be tough, as in cacti, or more delicate, as in herbaceous plants. Besides the function of protection, it conserves the water supply.

The *cortex* region is, in general, the region between the epidermis and the vascular cylinder. In the young stem, the cells of the cortex often have chloroplasts and crystals. The innermost layer of the cortex, as in the roots, is the *endodermis*.

The *stele* (Gr. *stelacho*, stem) is the central cylinder and is made up of a ring of conductive tissues, the vascular bundles, and pith, which is inside the vascular ring.

Vascular bundles are the conductive tissues and are separated from each other by parenchyma. The parenchyma of the pith may be continuous from the center to the cortex and forms the rays. The water-conducting tissue is the *xylem*, and the food-conducting tissue is the *phloem*. The phloem is on the outside of

the bundle toward the cortex. This food-conducting tissue is made up of characteristic sieve tubes (Fig. 74). Water tubes, or tracheae, usually possess heavy walls characterized by spiral or lattice-form markings. Sieve tubes are made up of cells placed end to end, their end walls being perforated by holes somewhat like those of a salt shaker (Fig. 74*B*).

The vascular bundles not only conduct fluids from place to place but also furnish support. Between the xylem and the phloem is the *cambium* (L. *cambiare*, to exchange). The growth of the cambium is a "two-way" affair; cells are added to the phloem on the outside and xylem on the inside. For this reason, dicot bundles are called *open bundles*.

b. Older Stems.—Older woody stems are different from the young stems in the following respects:

The epidermis is replaced by *cork*. During the time the epidermis is thin, transparent, living, it has a thickness of only one cell and is perforated only by stomata. On the other hand, cork is many layers of cells thick, quite or nearly opaque, dead, and perforated only by lenticels. New layers of cork are formed successively every season beneath the old layers, and these crack and wear away.

The green tissues of the cortex gradually disappear as the cork layer becomes thicker. Eventually, the original cortex is all used up in cork formation. Cork continues to be formed, however, from the meristems that develop from inner cortical and outer stellar tissues.

The stele makes up most woody stems, and most of the stele is wood, formed by the cambium. The wood appears to be a solid cylinder, vascular bundles are no longer evident in this region, but actually thin rays of parenchyma radiate through it in all directions outward from the pith.

Bark consists of all tissues outside the cambium. In a woody stem, the principal layers are cork, cortex, and phloem. The cambium forms the layer of separation of bark from *wood* that is xylem.

c. Annual Rings.—It is an interesting fact that the xylem cells formed in the spring and those formed later in the summer are not exactly alike; those formed in the earlier part of the season have larger, thinner cells than those formed later, which appear smaller and darker. The difference in appearance of these xylem cells makes possible the recognition of what are known as *growth* or *annual rings*. Usually, in temperate climates, one growth ring is formed each year, and thus a method of estimating the age of a tree becomes available (Fig. 75). Sometimes a long dry season followed by abundant rain may cause a plant to develop two "rings."

d. Heartwood and Sapwood.—These terms refer to those portions of the wood that are or are not still functional in conduction. The distinction is not one of living and nonliving. None of the vessels, tracheids, or fibers of the wood is living. They could not function if they contained

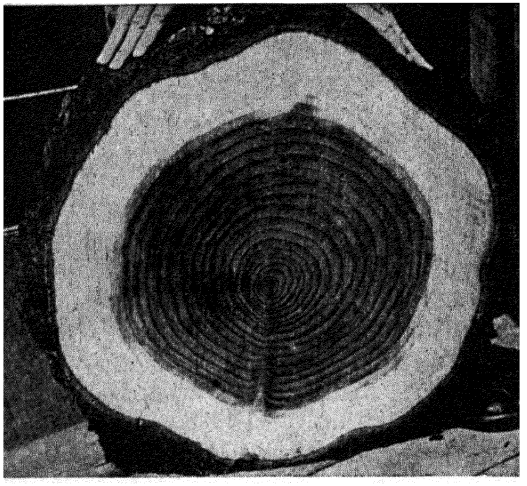


Fig. 75.—Annual rings. Section of a redwood (Sequoia) tree 28 years old, showing heartwood, sapwood, and bark. (Courtesy of U.S. Forest Service.)

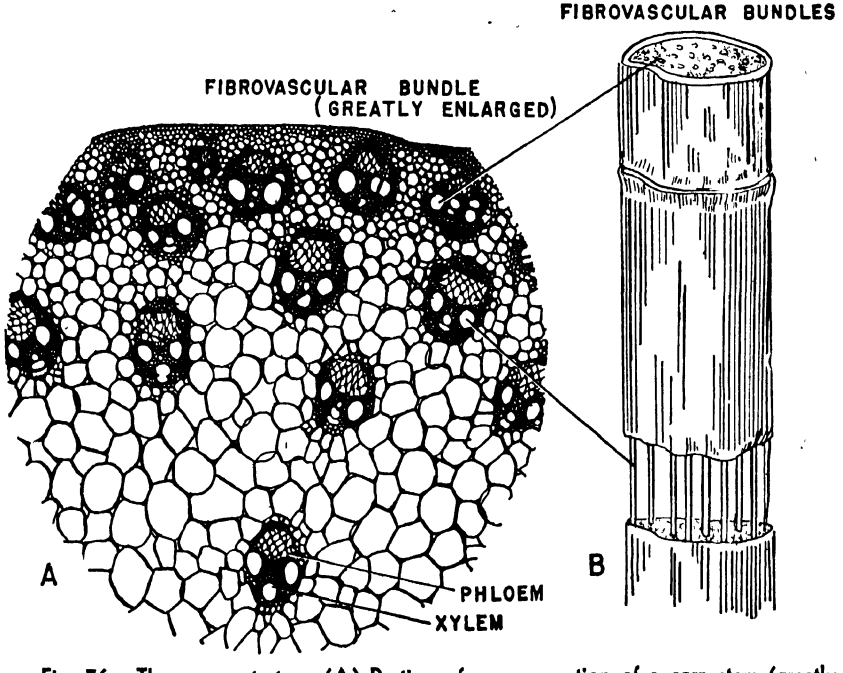


Fig. 76.—The monocot stem. (A) Portion of a cross section of a corn stem (greatly enlarged.) (B) Portion of a corn stem or stalk. Note that the vascular bundles are not arranged in a ring as in the dicot stem but are scattered. (L. Runyon.)

protoplasts. Only the ray cells and other parenchyma in the wood remain alive. It is the activity of these *living parenchyma* cells that transforms sapwood into heartwood. Resinous, or other dark-colored materials, may be excreted into the conductive cells; or they may be excluded by the actual growth of neighboring living cells into them.

Heartwood helps support the tree but no longer takes part in the transfer of materials. Trees may be hollow yet still be alive and growing.

2. Monocot Stems.—The stems of monocotyledons do not exhibit growth rings, because they lack cambium (Fig. 76). In most of these stems, the bundles are scattered. Because of lack of cambium tissue, the bundle cannot increase in size (closed bundle). Some monocot stems, like the palms, increase in size by the growth of a cambium in the pith between the bundles. This cambium forms new bundles between the older ones, and so the stems increase in diameter. However, no annual rings are formed.

3. Stems of Gymnosperms.—An example of a gymnosperm stem is the pine, a conifer. Conifers have essentially the same structures as those of the dicots. However, they lack vessels, fibers, and wood parenchyma. Tracheids in conifers, which are greatly elongated cells with pitted walls, function as both conductive and supporting cells. The evergreen habit seems to be related to the lack of storage parenchyma.

III. The Activities of Stems

In addition to the special activities of stems, their living cells carry on the same processes of food assimilation and respiration as do the other living cells of the plant. The energy needed by the stem for its work must come from the oxidation of food and the release of energy (page 532).

A. The Lifting of Water in Stems.—One of the factors in the lifting of water in the stem is the evaporation of water from the mesophyll cells of the leaf (*transpiration*). The water that is evaporated must be replaced by more water, and this must come by osmosis from the adjoining veins connected with water-conducting tissue. The mesophyll cells contain sugar and other substances in solution. This makes osmosis possible. The water tubes are very small, and hence the columns of water are very thin. It is possible to imitate what happens by filling a capillary tube with water and placing at the tip a porous cup as shown in Fig. 377. As the water evaporates through the cup, the column in the tube is drawn upward. Water enclosed in a tube holds together; *i.e.*, it is said to be *cohesive* (L. *cohaesum*, *co-*, together; *haesum*, to stick). Something like this happens in the plant. The water in the mesophyll cells evaporates into the air spaces; this is replaced by osmosis, the water coming into the mesophyll cells from the veins; this causes the lifting of the column of water in the xylem. In Fig. 102, it is shown that the conducting tissues of the stem

are in connection with the veins of the leaf and with the conducting tissues in the roots of the plant. If a carnation is placed in red ink, the red ink soon appears in all the parts of the flower. It has come through the water tubes of the stem to the veins of the flower petals.

B. Translocation of Food.—The word *translocated* means to move to a different place. The tissue that conducts food is the phloem. This extends from the veins of the leaves, through the stems, to the roots. The cells in this tissue are thin-walled and elongated; and sieve tubes are characteristic of the phloem or food-conducting tissue. The leaf is the main organ for food manufacture. In an annual plant, therefore, the food would move by *diffusion* from the leaves to the stem and thence to the root (Fig. 102). This food is used in the vegetative activities of the plant. In due time, flowers and, later, fruits and seeds develop. During this time, a great part of the excess food moves to these reproductive structures.

Translocation of Food in Trees.—In the summer and autumn, food moves from the leaves to the branches and from the branches to the trunk. Some of it is used up to carry on the work of the plant; some of it is stored in the rays, in the food-conducting tissue itself, and in the pith of young stems. In the spring, with the coming of warm weather, the food that has been stored up in the form of starch is changed to sugar and diffuses into the phloem, where, as sap, it passes to all parts of the plant. During the spring season, new roots are developing, and buds are growing into leafy shoots. These growth activities require energy. The energy of the sunlight is stored up in the carbohydrates. Early in the spring, the sap contains a considerable amount of sugar; later, very little is present. When photosynthesis begins, the food again passes from the leaves to the twigs, then to the branches and to the trunk.

IV. Sensitive Reactions of Stems

A. Response to Gravity—Geotropism.—The main or terminal stem responds negatively to the force of gravity; *i.e.*, it grows away from the earth. This can be demonstrated easily by turning seedlings of mature plants upside down or placing them in a horizontal position. The stem will grow upward (Fig. 26).

B. Response to Contact—Thigmotropism.—Certain plants, such as the morning-glory and pole bean, twine about supports. The tips of these plants exhibit spiral movements called *nutation* (L. *nutatio*, a nodding). If the movement brings the plant in contact with a slender support, it will respond to contact by twining around it, thus forming a series of coils. Although tendrils may be modified leaves or other parts of a plant, many are very slender stems. These are very sensitive to contact, also. After they are attached, mechanical tissues develop within, thus increasing their

strength. The twisting, or twining, is due to unequal growth on the two sides. This draws the twining stem or the tendril close to the support.

C. Response to Light—Phototropism.—Stems usually react positively to light. The bending of a stem toward light is due to an unequal growth, the growth on the side next to the light probably being checked.

V. Stems of Unusual Form and Function

Certain stems may differ widely in form and functions from most of those that are familiar.

A. Unusual Aerial Stems.—1. CLIMBING STEMS exhibit various modifications for resting upon, or attaching themselves to, a support. The simplest example is a certain rose that rests upon the tops of other plants. It may or may not possess thorns that help it to stick to its support. Another example (Fig. 67*B*) is the *English ivy*, which possesses *adventitious roots* (L. *adventicius*, superadded) that attach the plant to its support. The Boston ivy develops adhesive disks. Tendrils may be modified leaves, as in the pea plant; they may, however, be modified stems, such as those of the grape. Many stems twine around their support, as is true of morning-glories.

Fig. 77.—"Hen and chickens" (Sempervivum). An example of a plant which sends out offsets which will root and produce new plants. (B. Shamos.)

2. CREEPING STEMS trail along the surface of the ground. Watermelon or pumpkin vines are good examples. Strawberry plants send out runners, or *stolons*, that take root at the tip. Other plants may send out offshoots such as the "hen-and-chickens" (*Sempervivum*) (Fig. 77). This is a short branch with a cluster of leaves at the tip that will strike root and produce a new plant.

3. OTHER MODIFIED AERIAL STEMS are the *bulblets* formed in the axils of tiger-lily leaves, and the unusually short stems of so-called *stemless* plants like the dandelion and carrot or beet. In desert and other dry situations, leaves may be reduced to mere spines, and the stem, as noted previously, then becomes the chief photosynthetic organ of the plant. Stems may also be stout and fleshy and may serve as organs for the storage of food and water (Fig. 101*A*, the cactus). Finally, stems may be *thorn-like*. Leaves may become modified into thorns, but honey-locust thorns are modified stems.

B. Stems of Water Plants.—Water plants may (1) float (duckweed) or (2) be rooted (water lily). Such plants possess large air cavities, and their water-vascular systems are not so well developed as are those of

land plants. The air helps buoy up the stems so that mechanical tissue for support is reduced in quantity.

C. Underground Stems.—Figure 78 illustrates four types of underground stems. In all these, the leaves are colorless and are reduced to scales.

1. Rootstock or Rhizome.—Figure 78*A* is that of a *rhizome*, or rootstock, of Solomon's-seal. The rootstock of the common iris is of this

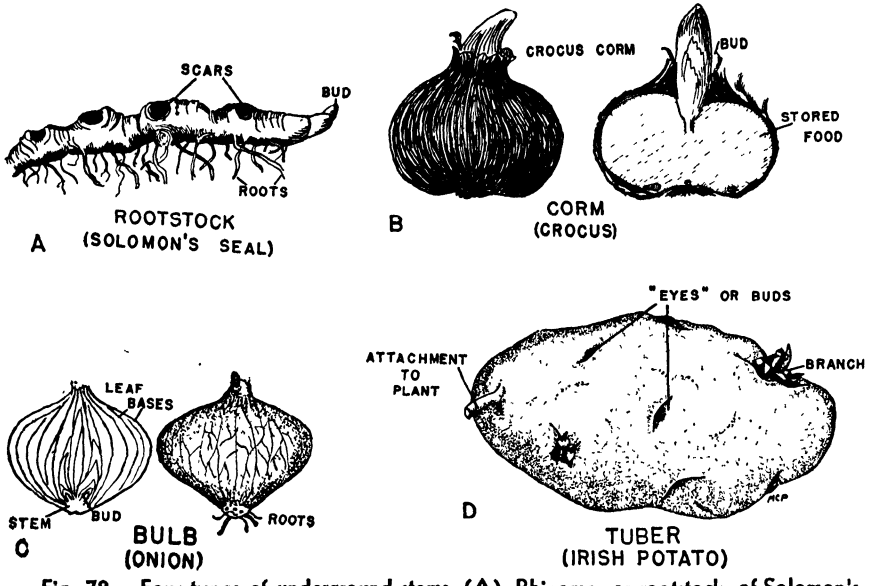


Fig. 78.—Four types of underground stems. (A). Rhizome, or rootstock, of Solomon's seal showing scars (seals) left by stems. (B). Corm of the crocus, a short, stout stem or thick rhizome. (C). Bulb of an onion consisting of a much shortened, stem-bearing, thick, fleshy leaf base, in which food is stored. (D). Tuber of the Irish potato. Each " eye" is capable of producing a new plant. Potatoes are cut into pieces, each piece containing a bud, and planted.

type. They represent horizontally growing stems from which aerial stems arise. One feature that distinguishes rootstocks from roots is the presence of nodes. Johnson grass is a troublesome weed in the South on account of the very rapid growth of its rootstocks. However, this habit is useful in "binding the soil"; for example, the sand-reed grass has been planted in Europe and America to keep sand from drifting from place to place. A rootstock also acts as a place of food storage.

2. Corm.—A corm is a short, upright thick rootstock that contains a large amount of food (Fig. 78*B*). Corms may develop lateral buds. Often they are the only part of the plant that survives the winter. They may also serve as organs of reproduction.

3. BULBS.—These are familiar to all. Their stems are much shortened and bear thick, fleshy leaves in which food is stored (Fig. 78*C*). Common examples are onion, hyacinth, tulip, and jonquil bulbs.

4. TUBERS are horizontal, thickened portions of rootstocks. They are represented by the ordinary Irish potato. Observation of the "eye" of the potato shows that the leaves are so reduced as to be only ridges and that the bud is reduced to a point. A potato can be cut into many pieces, and a new plant will grow from each piece that contains an "eye." Potato tubers are borne on the ends of underground stems (Fig. 78*D*). They are important sources of food for man.

Questions

1. How does the method of growth account for the difference in shape of a fir and an elm tree?
2. What are the main functions of stems?
3. Define the following terms as related to stems: *lenticel, epidermis, cortex, stele, translocation, rootstock, corm, bulb, tuber.*
4. Plants submerged in water usually have weak stems. Why?
5. In what ways may the epidermis of plants be modified? Does the environment affect certain of these modifications?
6. Compare the structure of a monocot and a dicot stem.
7. What is a vascular bundle? What part of the bundle is concerned with transfer of water? Translocation of food?
8. How is water lifted in stems?
9. How does plant food move from leaves to stems?
10. Explain why there is a difference between spring sap and the sap at other seasons. Why is maple sap collected in spring?
11. In tapping a sugar maple, how far in is it necessary to insert the tap for collection of the sap?
12. How does a wire wound tightly around a stem cause injury? Will a girdled tree live a long time?
13. What is sapwood? Heartwood? Why is it possible for a hollow tree to live and grow? How is grafting done?
14. What are annual rings? Why may they be used to indicate the approximate age of a tree?
15. Do all stems respond in the same way to gravity? Light? Contact?
16. Name some stems of unusual form. What are some advantages and disadvantages of each special type?
17. What are some functions of specialized stems?

Suggested References

EAMES, A. J., and MCDANIEL, L. H.: "An Introduction to Plant Anatomy," The McGraw-Hill Book Company, Inc., 1935.

GLOCK, W. S.: The Language of Tree Rings, *Scientific Monthly*, Vol. 38, pp. 501–510, 1934

CHAPTER XI

STRUCTURE AND ACTIVITIES OF LEAVES

Leaves have their time to fall,
And flowers to wither at the northwind's breath
And stars to fall. . . .

—HEMANS.

Leaves are important and remarkable structures, for in them are carried on the activities that are essential to the life of the plant. It is difficult to think of green leaves as factories, yet quietly and efficiently, using raw materials that they get from the air and soil and the energy that they get from the sun, they manufacture food. Their method of manufacturing food is called *photosynthesis* (Gr. *phos*, light; *synthesis*, putting together), a term that means literally "put together with light." The activity of photosynthesis is carried on in all green cells, but the leaf is the center of the process (see below).

Most of the water lost from plants through *transpiration* (L. *trans*, through; *spiro*, to breathe) is lost through the leaves, though this process may take place in other parts of the plant. To understand these processes as well as respiration and excretion, it is necessary to know something of the structure of leaves.

I. The Structure of a Leaf

A. External Structure.—Leaves are borne on stems; that part of the stem to which they are attached is a *node;* the space between two nodes is an *internode* (Fig. 79). *Axillary buds* arise in the upper angle between the leaf and the stem, the *axil.*

Leaves vary greatly in size; they may be almost microscopic or may be more than 20 ft. long. In general, they arise in buds. A complete leaf consists of three parts: (1) the expanded portion, the blade or *lamina;* (2) the leafstalk or *petiole* (L. *petiolus*, a little foot); and (3) the *stipules* (L. *stipula*, a stalk, stem). If a leaf lacks any of these parts, it is said to be incomplete.

1. THE BLADE.—This is usually expanded into a thin sheet of green tissue. Imbedded in this is a system of veins. These veins help support the softer tissue of the blade and are connected with the *transportation* system of the stems and roots. It is by means of the veins that water and salts are brought to all parts of the leaf and that food manufactured in the leaf is distributed to all parts of the plant.

2. The Veins.—The pattern of the veins, *i.e.*, the *veination*, may be either (1) parallel (Fig. 80*A*) or (2) netted (Fig. 80*B*). The word *parallel* here means just what it does ordinarily. The main veins in this type of leaf are approximately parallel. Connecting the principal veins are

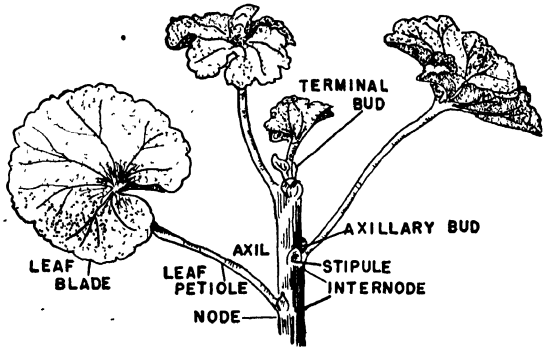


Fig. 79.—Portion of a geranium plant showing the relation of the leaf and buds to the stem. (B. Shamos.)

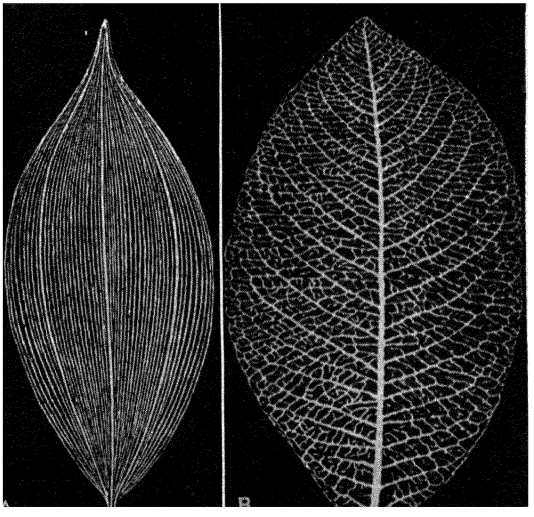


Fig. 80.—Types of leaf veination (Ettinghausen.) (A) Parallel veins of the leaf of the lily of the valley .(B) Net veins of the willow leaf. (From Leavitt, Outlines of Botany, The American Book Company.)

smaller veins, usually invisible. The parallel veins may run up and down the leaf as in the lily of the valley, or they may run crosswise as in the banana. This type of veination is characteristic of the monocotyledons.

A second type of veination includes several varieties, but in all of them the veins form a complete network. If there are one large main vein,

or midrib, running through the center and smaller veins branching off from it on either side, it is called *pinnate* (L. *pinna*, a feather), because the arrangement of the veins suggests the structure of a feather (Fig. 81*A* and *B*). If there are several veins, or ribs, of equal prominence that

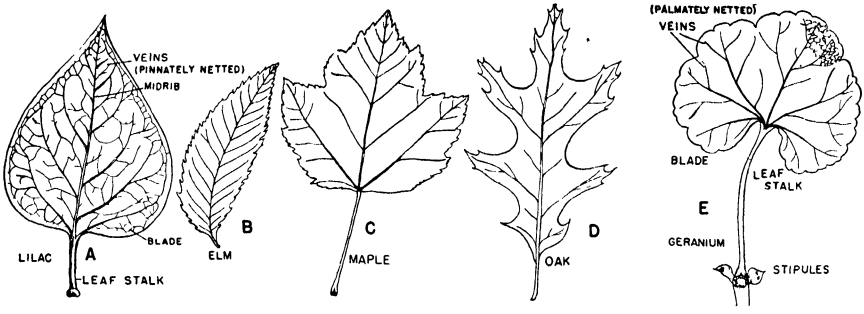


Fig. 81.—Some types of dicot leaves showing differences in general form, leaf margins, veining, etc. (L. Runyon.)

begin at the base of the leaf and spread out like a fan, the type of veination is *palmate* (L. *palma*, palm of the hand) (Fig. 81*C*). Net-veined leaves are, in general, characteristic of the dicotyledons (Fig. 148).

3. The Margins.—Figure 82 gives an idea of some types of leaf margins, of which there are a wide variety.

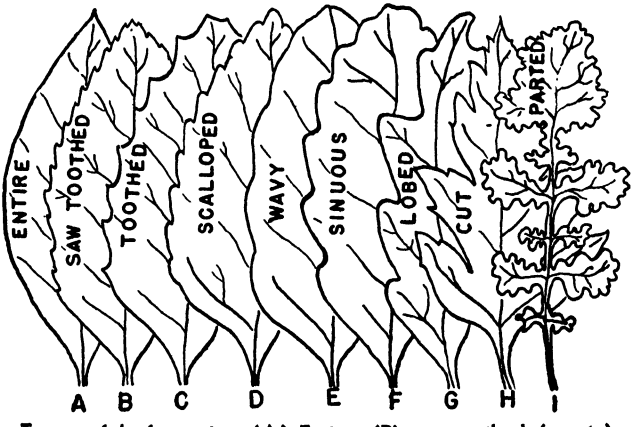


Fig. 82.—Types of leaf margins. (A) Entire; (B) saw-toothed (serrate); (C) toothed (dentate); (D) scalloped (crenate); (E) wavy (repand, undulate); (F) sinuous (sinuate); (G) lobed; (H) cut (incised, jagged); (I) parted. (L. Runyon.)

4. Leafstalk, or Petiole.—This joins the leaf blade to the stem and is usually stem-like. Through it materials pass to and fro from the leaf blade and the stem. In some way, the blade has control over the growth of the petiole. By the bending and twisting of the petiole the leaf is placed in the position most favorable with regard to light from the sun,

which is necessary for photosynthesis. Sometimes the petiole is absent; the leaf is then said to be *sessile* (L. *sessilis*, sitting). In many plants, such as corn and other grasses, the base of the leaf forms a sheath around the stem (Fig. 83).

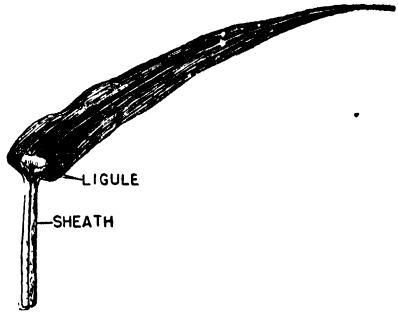


Fig. 83.—A monocot leaf of the grass family. The ligule is a membranous upgrowth which seems to prevent rain water from running into the sheath. (L. Runyon.)

5. STIPULES.—These are appendages that may or may not be present. If present, they are located at the base of the petiole, one on either side. They may be small (Fig. 81*E*) as in the geranium, or large (Fig. 84*B*), as in the pea. In some cases, they may protect buds, as in the tulip tree. When they are green, the manufacture of food goes on in them as it does in the green tissue of the blade. They may become transformed into spines (Fig. 84*D*), as in the black locust. In some species of smilax, they are modified into tendrils (Fr. *tendrillon*, tender branch or sprig).

B. Simple and Compound Leaves.—Simple leaves are those with the blade all in one piece, such as those of the oak, maple, etc. (Fig. 81);

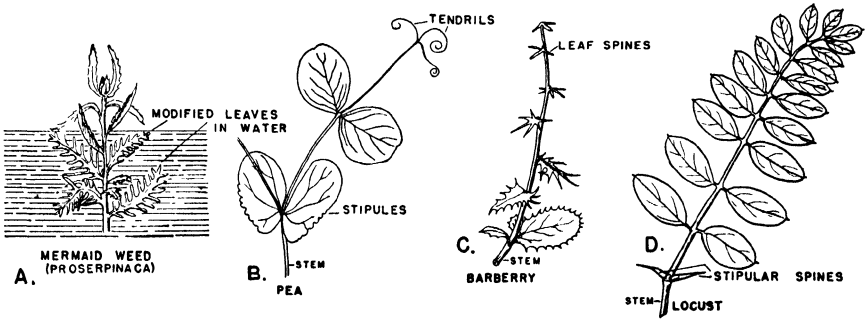


Fig. 84.—Leaves of unusual form and function. (A) Leaves of the "mermaid weed" (Proserpinaca), which has divided leaves under water and leaves with flat blades above the water. (B) Leaves of the pea modified as tendrils. (C) Leaves of the barberry (Berberis) modified as spines. (D) Stipules of the locust (Robinia) modified as spines. (L. Runyon.)

compound leaves possess blades divided into parts called *leaflets* (Fig. 85). If the leaflets arise in pairs along the continuation of the petiole (rachis), it is *pinnately compound*, as in the rose (Fig. 85*A*); if the leaflets are attached at one point, it is *palmately compound*, as in buckeye and clover (Fig. 85*B* and *C*). Sometimes compound leaves are mistaken for leafy branches. They may be distinguished from each other, since there are no buds in the axils of the leaflets. Another characteristic is that, although

the leaflets may fall from the plant separately, as the leaves do, in the autumn the entire structure, leaflets and rachis, falls away; branches usually do not fall.

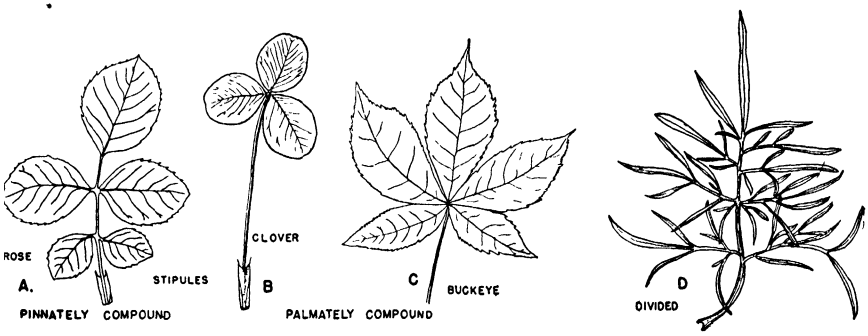


Fig. 85.—Types of compound leaves. (L. Runyon.)

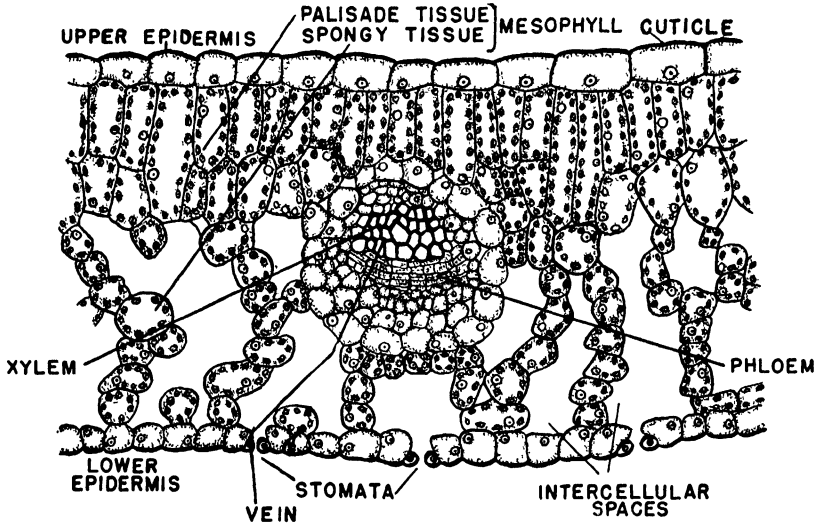


Fig. 86.—Cross section of a leaf, showing structure and the relation of the stomata to air spaces. (From Haupt, Fundamentals of Biology.)

C. The Internal Structure of a Leaf.—A section cut through the blade of a leaf and placed under the microscope will show that a leaf consists of a complicated arrangement of cells (Fig. 86). Both sides of the leaf, as well as the whole plant when young, are covered with a compact layer

of cells. This is the *epidermis* (Gr. *epi*, upon; *derma*, skin). In the epidermis are a number of very minute openings called *stomata* (Gr. *stoma*, mouth). Usually many more stomata (sing., stoma) occur on the undersurface than on the upper surface of horizontal leaves. In vertical leaves, stomata are present on both sides; in floating leaves they are only on the upper surface.

If one strips off the epidermis with a knife and examines it under the microscope, he will find that these minute openings have crescent-shaped cells on each side (Fig. 87). These are the *guard cells*, whose function is to

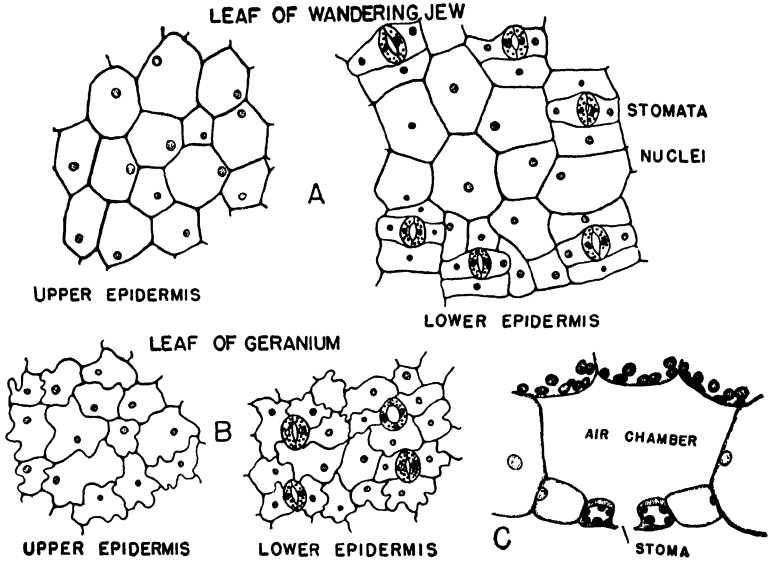


Fig. 87.—Structure and distribution of stomata on leaves. (A) Leaf of wandering jew (Zebrina). (B) Geranium leaf (Pelargonium). (C) Diagram of a stoma (much enlarged), showing its relation to an air chamber. (L. Runyon.)

control the opening and closing of the stomata. In this way, they regulate the exchange of gases between the surrounding atmosphere and the internal atmosphere and tissues of the leaf. The guard cells contain chloroplasts, whereas the rest of the epidermis is colorless.

On the upper side of a horizontal leaf, and to a lesser extent on the underside, the outermost portion of the epidermis consists of a substance called *cutin* (L. *cutis*, skin). This protects the leaf from injury and prevents the drying out of the tissues underneath. In many plants, hairs of various types grow out of the epidermal cells. These may be dead in the mature leaf; they may be stinging hairs, as in the nettle, or some other type.

The middle part of the leaf, or mesophyll (Gr. *mesos*, middle *phyllon*, leaf) is green. The green cells, or *chloroplasts*, contain the chlorophyll.

Next to the upper epidermis are one or more layers of elongated, compact cells that contain chloroplasts, they form what is known as *palisade* (L *palus*, a stake) tissue Any chlorenchyma cell (*palisade*, or other) has a large central vacuole as well as chloroplasts, cytoplasm, and nucleus The three latter make a thin layer next to the cellulose wall One definition of palisade is "a fence of stakes set firmly in the ground to enclose or defend " Figure 86 explains why this is called *palisade tissue* Below the palisade tissue are irregular, loosely arranged cells, the spongy *mesophyll* The numerous air spaces between these cells are in direct communication with the stomata These spaces also reach up to and in between the

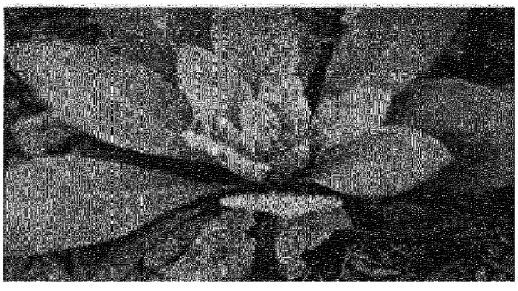


Fig 88 —Leaf arrangement, a rosette The mullein plant grows as a rosette the first year, storing up food with which it produces flowers and seeds the second year (biennial habit) (Dr E H Runyon)

palisade cells This important arrangement allows the taking in and giving off of gases, as will be seen later. The cell walls of the mesophyll contain *cellulose*

Veins or *fibrovascular bundles* run through the blade The fibrovascular bundles form the conductive system of the plant They are made up of water-conducting tissue, or *xylem* (Gr *xylon*, wood) and food-conducting tissue, or *phloem* (Gr *phloos*, bark) Figure 86 will make the relationship of xylem and phloem clear

II. Leaf Arrangement

Leaves are arranged in many ways in order to secure for themselves the light they need In most plants, the leaves are on vertical stems In these, as well as in rosettes (Fig 88), the lower petioles are increasingly longer from the tip to the base of the stem This allows the lower leaves a better light exposure

A. Definite Leaf Arrangements—Phyllotaxy —Leaves are usually attached to the stem in a definite system, or arrangement, called *phyllotaxy* (Gr *phyllon*, *leaf*, *taxis*, arrangement) They are not placed on the stem helter-skelter but as follows.

1. Opposite.—Leaves may be placed on the stem opposite each other; in this case, there are but two leaves, one on each side of the stem, at the joint or node. When the leaves are opposite on an erect shoot, the second pair usually stands at right angles to the first pair, the third pair the same way as the first pair, the same as the second, etc. (Fig. 89*C*).

2. Whorled.—If there are more than two leaves at a node, there will be a cycle or whorl (Fig. 89*E*). This type of arrangement is shown in the hardy *Catalpa*. The leaves of any whorl are in the spaces between the leaves of the whorl next above or below.

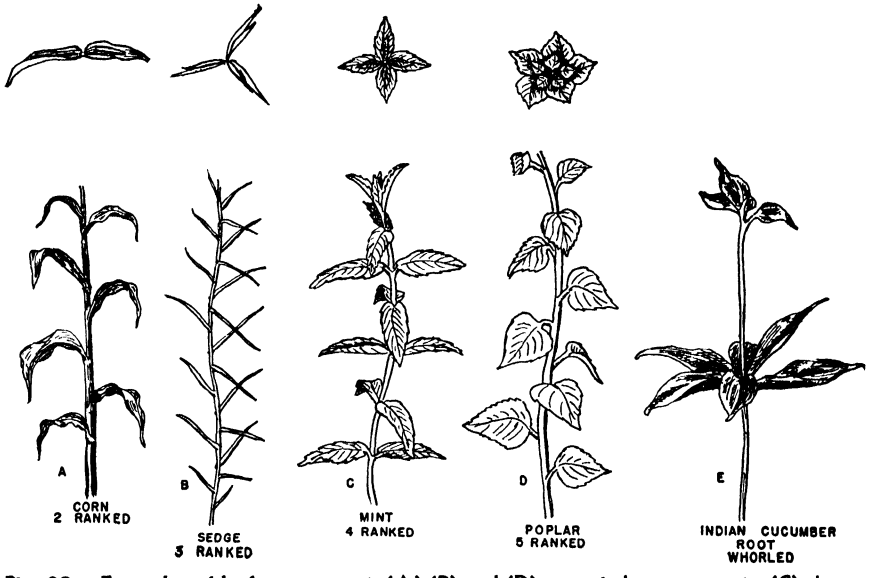


Fig. 89.—Examples of leaf arrangement. (A) (B) and (D) are spiral arrangements; (C) shows arrangement spoken of as opposite; (E) whorled arrangement. (B. Shamos.)

3. Alternate, or Spiral.—If there is one leaf at a node, the arrangement is *alternate* and results in a spiral arrangement of leaves on a stem. In the simplest case of spiral arrangement, the third leaf is directly over the first. This is the one-two type, which is commonly written 1/2. The numerator refers to the number of turns around the stem before a leaf is met with that is exactly over the first leaf; the denominator refers to the number of leaves in the spiral. Following this system, plants will be found with leaf arrangement of 1/2, 1/3, 2/5, 3/8, 5/13, etc. Higher arrangements, such as 21/55, are shown by the scales on a pine cone.

B. Special Leaf Displays.—Plants show many arrangements of leaves with reference to light. The longer petioles on the lower leaves of rosettes and other shoots have already been referred to.

1. Mosaics.—If one walks under a maple, or other shade tree, it can be noted that the leaves have their upper sides spread out to the light

and form a canopy. The leaves are more abundant toward the ends of the branches, and the lower leaves have longer petioles (Fig. 90*A*). A vine

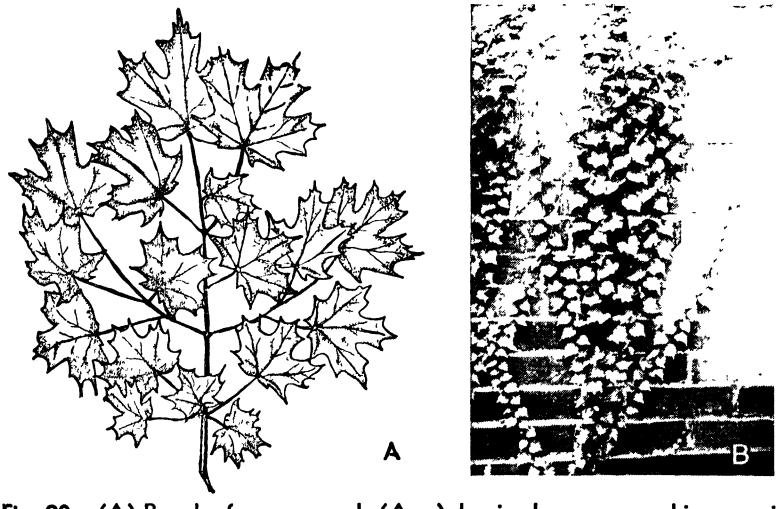


Fig. 90.—(A) Branch of a sugar maple (Acer) showing leaves arranged in a mosaic. (B) Parthenocissus tricuspidata growing on a wall. In both of these examples the leaves are arranged to get the best possible light. (Z. Wells.)

Fig. 91.—Position of leaves with reference to the light. (A) Leaves in an upright position (Iris). (Courtesy of Hastings Seed Company.) (B) Horizontal floating leaves (water lily). (H. A. Carter.) Different types of plants have different light requirements.

growing on the wall will have its leaves so arranged that there will be very little shading. This is called the *mosaic arrangement.* English ivy and Japanese or Boston ivy show this arrangement (Fig. 90*B*).

2. Erect and Edgewise Positions of Leaves.—The usual position of leaves is with the broad upper surface toward the light, but there are exceptions. Such plants as grasses, irises, etc., possess blades that are nearly erect (Fig. 91). Many bear their leaves edgewise, as wild lettuce (Fig. 92). These may be more sensitive to light than are common leaves

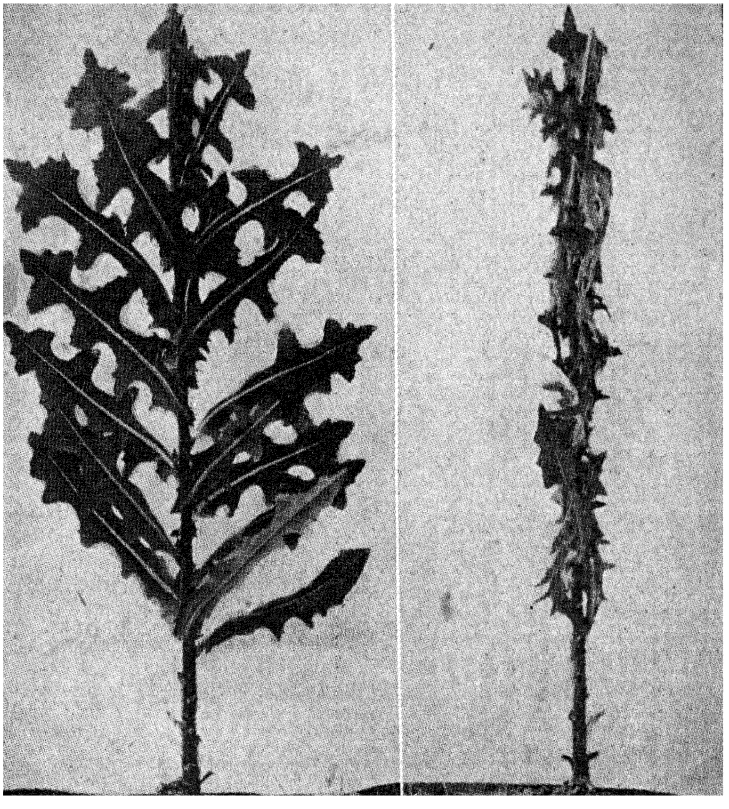


Fig. 92.—Position of leaves with reference to the light. The prickly lettuce is sometimes called the "compass plant" because its leaves are arranged in a north and south direction. It is well lighted in the early morning and late afternoon but escapes the intense light of midday. The leaves may be more sensitive to light than some others. (From Strasbaugh and Weimer, General Biology, John Wiley & Sons, Inc.)

(page 134). But even in the majority of plants, young leaves emerging from buds are usually erect. They assume their usual position when their cells mature.

3. Changed Arrangements Due to Light.—Light may cause a change in leaf arrangement. For example, Fig. 93*K* shows a horizontal branch from a honeysuckle bush having leaves opposite each other, with two ranks, whereas Fig. 93*B* shows an upright branch with leaves opposite

each other, with four ranks. In the horizontal branch, the petioles of the leaves have twisted so as to place the blades in a more favorable light. Thus, on the same bush, there are horizontal branches with a two-ranked arrangement and upright branches with four ranks. The leaves

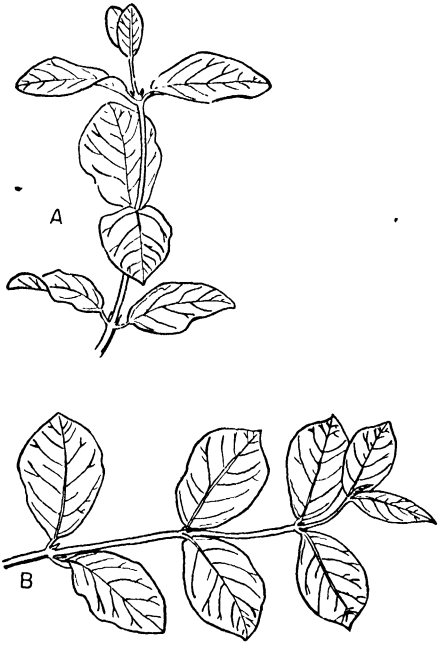


Fig. 93.—The relation of plants to light. (A) Upright branch from a honeysuckle (Lonicera fragrantissima) with leaves illuminated from all sides. (B) Horizontal branch from the same bush. Position of the leaves due to one-sided illumination. (F. Crane.)

originate in positions that are perfectly definite, but under the influence of light the petioles bend, and the blades are brought into various positions.

III. The Fall of Leaves

A. Deciduous Plants.—Many plants in the temperate zone shed their leaves regularly in the autumn. Long before the leaves fall, these plants develop a special layer of cells at the base of the leaf petiole, an *abscission* (L. *abscissio; ab*, from; *scindere*, to cut) layer (Fig. 94). The cells in the abscission layer are special cells having the peculiar property of becoming soft so that they separate from each other. This leaves the leaf fastened to the stem only by the vascular bundles. Soon the strands of the vascular bundles break and the leaf falls. A layer of corky cells formed just underneath the abscission layer heals the scar and protects

the stem. Plants that regularly shed their leaves are known as *deciduous* (L. *de*, down; *cado*, fall).

1. ADVANTAGES.—The advantages of the deciduous habit are: (*a*) The trees can better withstand the winter drought. (*b*) New leaves every year furnish the plant with more efficient organs for food manufacture. (*c*) Food can be manufactured more readily in leaves with less cuticle.

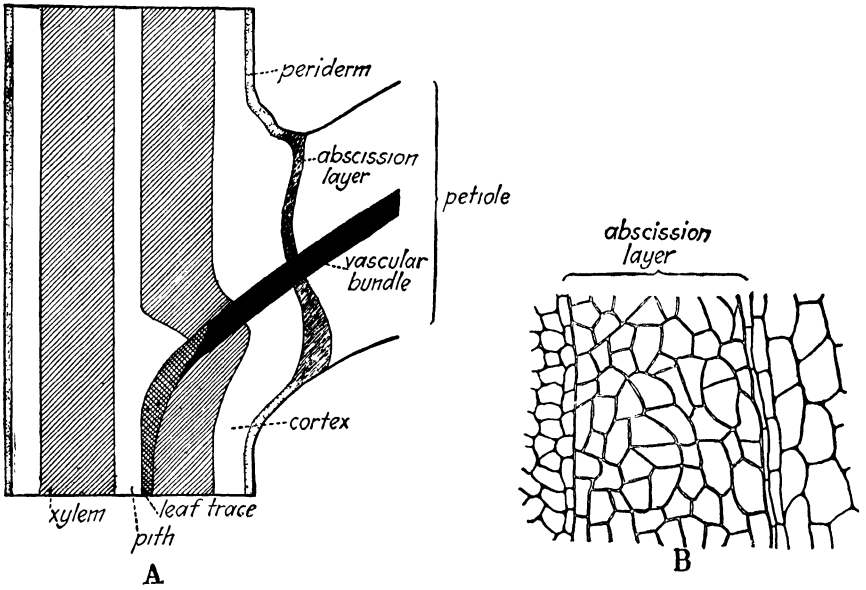


Fig. 94.—(A) diagram to show leaf abscission layer; radial section through twig and leaf base in Juglans cinerea. The abscission layer extends through the vascular bundle only in parenchyma cells; all other cells are broken mechanically. (B) detail of cellular structure of a small part of the layer three weeks before leaf fall. (From Eames and McDaniel, Introduction to Plant Anatomy.)

2. DISADVANTAGES.—Certain disadvantages are (*a*) the large amount of food materials necessary each year to produce an entirely new set of leaves and (*b*) the shorter food-manufacturing season, only 5 to 8 months.

B. Evergreens.—Plants that seem not to shed their leaves are the *evergreens*. These do shed their leaves but not all at once; some of the leaves may live to be several years old. Evergreen leaves are characteristically stiff and are protected by a very thick cuticle.

1. ADVANTAGES.—The advantages of the evergreen habit are: (*a*) The leaves are constructed to conserve water and so stand dry conditions of winter. (*b*) Food can be manufactured even when the temperature is low. (*c*) The tree does not use so much *material* each year in growing an entirely new crop of leaves.

2. DISADVANTAGES.—Some of the disadvantages are: (*a*) Food cannot be manufactured rapidly in compact leaves with heavy cuticle such as are borne by evergreens. (*b*) Rapid growth cannot take place without rapid food manufacture. (*c*) Leaves that have a longer working life are not so efficient in food manufacture as the new leaves of a deciduous tree.

B. Plants Either Deciduous or Evergreen.—Some trees that are deciduous in one part of the country are evergreen in other places. For example, one species of holly, *Ilex decidua*, has the deciduous habit in the North but is an evergreen in the South. There are other plants like this, which indicates that leaf habits are affected not only by heredity but also by environment. The factors in the environment that—in part, at least—affect leaf habits are temperature and moisture.

IV. The Work of Leaves

A. The Food Factories of the World. 1. MANUFACTURE OF CARBOHYDRATES.—Through the stomata (Fig. 87), carbon dioxide enters the leaf from the air; water enters the roots of the plant from the soil and is brought to the leaf through the fibrovascular bundles. With these materials, the chlorophyll in the chloroplasts, with the aid of energy from the sun, is able to manufacture sugar or glucose. This is *photosynthesis* (page 116). Interest in this process deepens when it is considered that in all the world (outside a chemistry laboratory), organic compounds are formed from inorganic raw materials solely in green plants and by photosynthesis. Animals and colorless plants are powerless to do this. They are dependent upon green plants for their food and other requirements of organic materials. Just how chlorophyll, with the energy from absorbed light, is able to break up carbon dioxide and water and recombine them into a different compound is not known. The process may be represented as follows:

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{light}}{\text{energy}} \rightarrow \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

The process by which this is brought about is not simple or well understood, but the result is known. There are probably other steps in the reaction before the final result is arrived at as shown above. This reaction means that carbon dioxide and water, plus energy from sunlight, are transformed into glucose and that oxygen is given off as a by-product. In most plants, sugar is transformed into and stored as starch, a substance that is insoluble. Starch constitutes a reserve source of food for use at any time that the sugar supply becomes low.

2. PROTEINS.—Plants are able to construct a variety of complex foods from glucose and mineral salts. Proteins all contain *nitrogen* and many of them, *sulphur* and *phosphorus*. These elements, in the form of nitrates,

phosphates, sulphates, enter the plants dissolved in the water from the soil. The plant is able to use them together with the simple sugar in manufacturing proteins. They are stored in seeds and in other parts of the plant and are used for building up protoplasm.

3. Fats contain the same elements as carbohydrates, C, H, and O, but the *proportions* are different. Less oxygen is present in proportion to carbon and hydrogen than in the carbohydrates. Animals and colorless plants, as noted above, are unable to synthesize food from inorganic

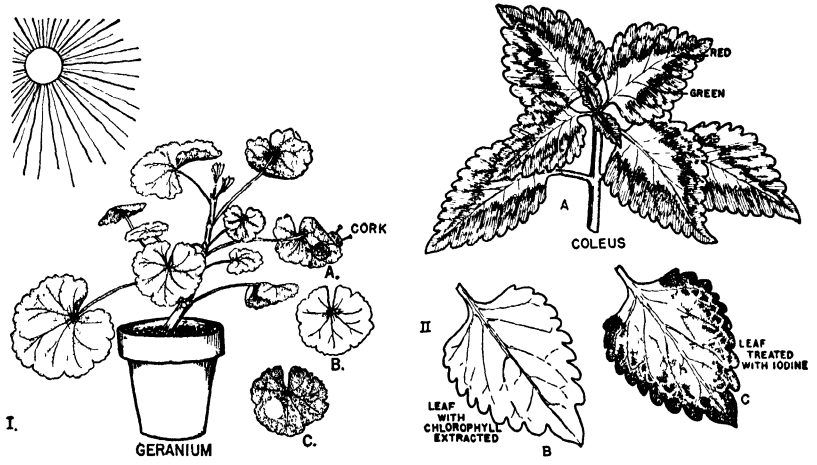


Fig. 95—(I)—Experiment to prove that green plants manufacture starch.
(A) Cork placed over a portion of the leaf to exclude light
(B) Chlorophyll removed from the leaf by boiling in alcohol
(C) The leaf treated with a weak solution of iodine which colors starch blue. The blue color appears in the parts of the leaf which were exposed to the light.
(II)—Some coleus leaves have little or no chlorophyll in the center of their leaves as in this variety. For this reason no starch is found in that region. (B. F. Fountain.)

materials. Animals may obtain food by eating other animals, but the animals they eat have used plants for food; so the saying that *green plants are the food factories of the world* is justified. The manufacture of proteins and fats can go on in either light or darkness, but for photosynthesis, or the manufacture of carbohydrates, light is necessary.

4. Simple Experiments to Prove Photosynthesis.—It can easily be demonstrated that plants manufacture starch. It is necessary only to cover a part of a leaf and set the plant in the sun (Fig. 95*I*). After about an hour has elapsed, the leaf is removed from the plant and the chlorophyll extracted. This can be done by boiling the leaf in alcohol. All the chlorophyll, or green color, will come out. The leaf is then placed in a dilute solution of iodine. The iodine will react with the starch, and the starch will become blue in color. Reference to Fig. 95*I–C* shows that

the part of the leaf that was covered so that the sunlight did not strike it remains without color after the treatment with iodine.

Often red pigment masks chlorophyll. In many of the *Coleus* plants, however, or in leaves like snow-on-the-mountain, the red or white spots that give these leaves their showy character do not cover up chlorophyll, and the process of food manufacture does not take place in these areas. This can easily be demonstrated by taking a leaf from one of these plants

Fig. 96.—Dependence of plants upon light. The lower portion of this yellow cosmos plant was exposed to light for 10 hours each day, while the upper portion received no light. (From the J. Agr. Research.)

that has been in the sunlight (Fig. 95*I*) and treating it exactly as in the experiment with the geranium. After extracting the chlorophyll with alcohol and treating the leaf with the dilute solution of iodine, the area that was green is now blue, whereas the red or white part of the leaf remains colorless, showing that no starch was manufactured in the portion of the leaf where the green chlorophyll was absent.

That green plants cannot live without light is shown by the picture in Fig. 96 of the weak portion of the plant above and the vigorous healthy portion below. To be healthy, the plant must have light for at

least a part of the day; otherwise, there is not enough food manufactured to take care of the life processes of the plant.

The need of energy for all activities of the plant and what the source of that energy is have been discussed (page 140). It is important tc keep this information in mind. When the plant manufactures food by the process of photosynthesis, it is also storing up energy.

B. Respiration.—As has been pointed out, respiration goes on in *all living cells*, and the fundamental process is the same in all organisms.

1. RESPIRATION IN PLANTS.—In many respects, this process is the reverse of photosynthesis. Oxygen is used to break down, or oxidize, food substances in the cell in order that there may be energy to carry on the work of the plant. In this process, carbon dioxide and water are given off. If chemical shorthand is used to express this reaction, it will appear to be the exact reverse of that used for photosynthesis:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \rightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \underset{\text{heat or ability to move}}{\text{energy}}$$

2. RESPIRATION AND PHOTOSYNTHESIS.—It will perhaps make things clearer to contrast these two processes.

Photosynthesis	*Respiration*
Oxygen is given off	Oxygen is absorbed
Water and carbon dioxide are raw materials.	Carbon dioxide and water are waste materials
Carbohydrates are built up	Carbohydrates are used up
Energy is stored	Energy is set free
Weight is increased	Weight is decreased
Goes on only in cells containing chlorophyll and only in the presence of light.	Goes on at all times in all living cells.

C. Demonstrations Relating to Photosynthesis and Respiration.

1. TO PROVE THAT PLANTS GIVE OFF OXYGEN IN PHOTOSYNTHESIS.—Some green plants (*Elodea* is a good type) are put in a jar and covered with a funnel as shown in Fig. 97. If the tube over the funnel is filled with water before it is inverted over the end of the funnel, the oxygen bubbles will displace the water if the plant is placed in the sunlight. That the gas collected is oxygen may be tested by thrusting a lighted stick into the tube. It will burn much more brightly if oxygen is present. The liberation of oxygen in the light demonstrates the important fact that photosynthetic liberation of O_2 greatly exceeds the simultaneous utilization of O_2 and respiration.

For a control, another experiment is set up exactly like the first and covered with a bucket or corrugated paper box to keep out the light or is just set in the dark. No oxygen is given off. Indeed, any oxygen present dissolved in water would be used up in respiration.

2. The Role of Carbon Dioxide.—Carbon dioxide is necessary to the health of the plant. If experiments are set up as shown in Fig. 98, it will be found that the plants growing in the atmosphere from which carbon dioxide has been removed form no starch. The sodium hydroxide in *B* will absorb the carbon dioxide so that the plant will be deprived of one of the "raw materials" used in food manufacture.

The test for carbon dioxide is simple. Since carbon dioxide will dissolve in water, it will not appear in the form of bubbles, as oxygen does.

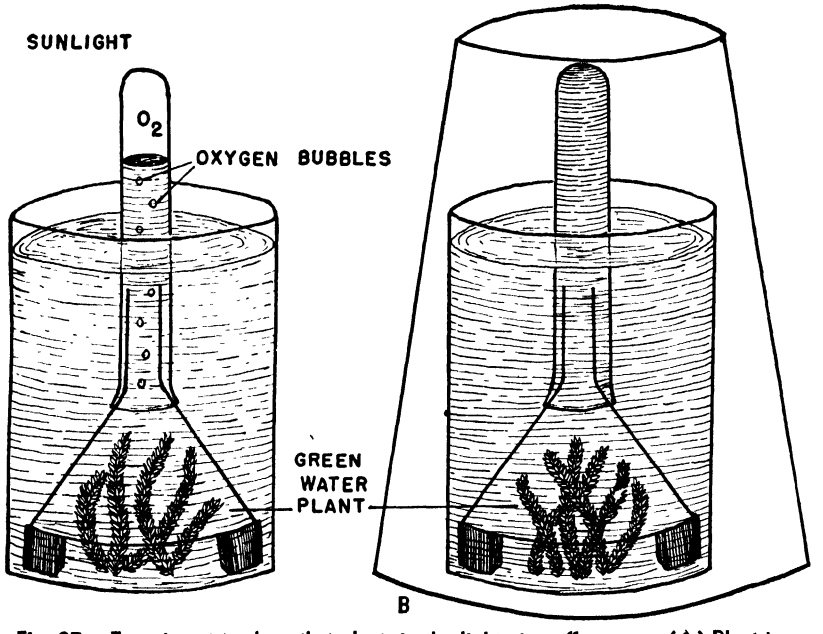


Fig. 97.—Experiment to show that plants in the light give off oxygen. (A) Plant in sunlight. Note bubbles of oxygen. (B) Plant in the dark. Note absence of oxygen bubbles. (L. Runyon.)

The oxygen will dissolve, too, to some extent, but carbon dioxide dissolves in water more readily than oxygen. *Elodea*, or another plant, is placed in a jar and left in the dark for some hours or overnight. Then a small amount of the water in which the plants have been is removed and shaken up with a little lime water. If carbon dioxide is present, it will turn the lime water milky.

D. Water Loss.—1. Transpiration.—This may take place in any part of the exposed plant but occurs mainly in the leaves, on account of their position and structure.

a. Role of the Stomata in Transpiration.—It has been seen that the stomata, in general, open in the daylight and close to some extent at night. They make possible the exchange (*diffusion*) of gases between the

atmosphere and the plant, and it is through the stomata that most of the water is lost as water vapor.

b. Amount of Water Given Off in Transpiration.—Only a small portion of the water absorbed by the roots and carried to the leaves is needed for photosynthesis. Many things influence the amount of water given off, such as the kind of plant, the temperature, the amount of water vapor in the air (*humidity*), etc. It has been estimated that an active sunflower

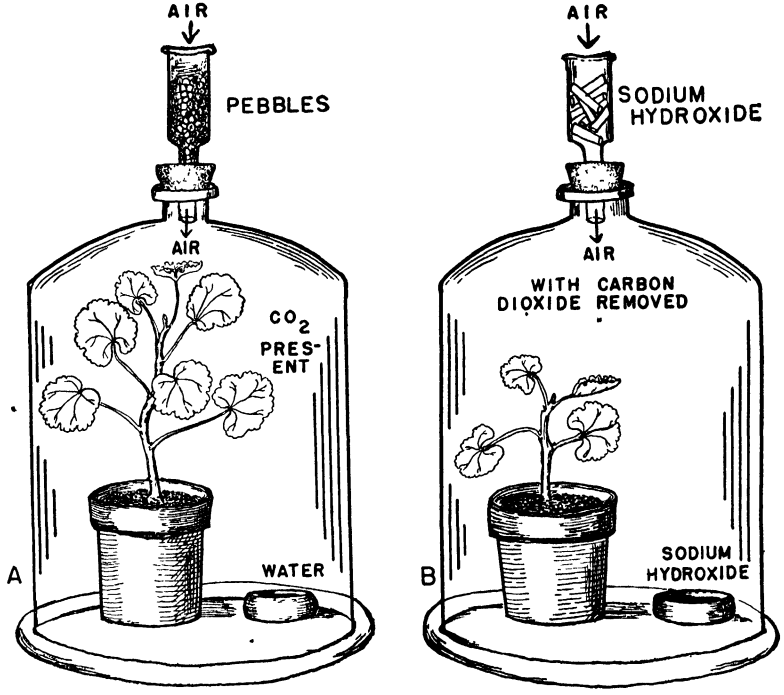


Fig. 98.—Experiment to show that plants need carbon dioxide. (A) The air supply containing carbon dioxide filters through pebbles only. (B) The air supply filters through sodium hydroxide which will remove the carbon dioxide. The geraniums were approximately the same size when placed under the bell jars. (L. Runyon.)

plant of moderate size will lose a quart of water a day, whereas a tree will give off 90 to 100 gal., depending upon the number and size of the leaves. The amount of water that is lost by transpiration by 1 acre of growing grass has been estimated at 6½ tons a day during the summer.

c. Significance of Transpiration.—If transpiration exceeds water absorption, plants suffer from lack of water. Transpiration is, therefore, always a dangerous process for a plant with limited water supply. Plants cannot walk away from the dry, hot soil and get a drink like an animal when thirsty, yet transpiration is inevitable: for if stomata are open—and they must be for the entry of carbon dioxide for photosynthesis—nothing

can prevent the evaporation of water. Thus transpiration is a necessary and dangerous accompaniment of photosynthesis. Many have supposed transpiration to be beneficial to the plant, but none of the theories is well substantiated.

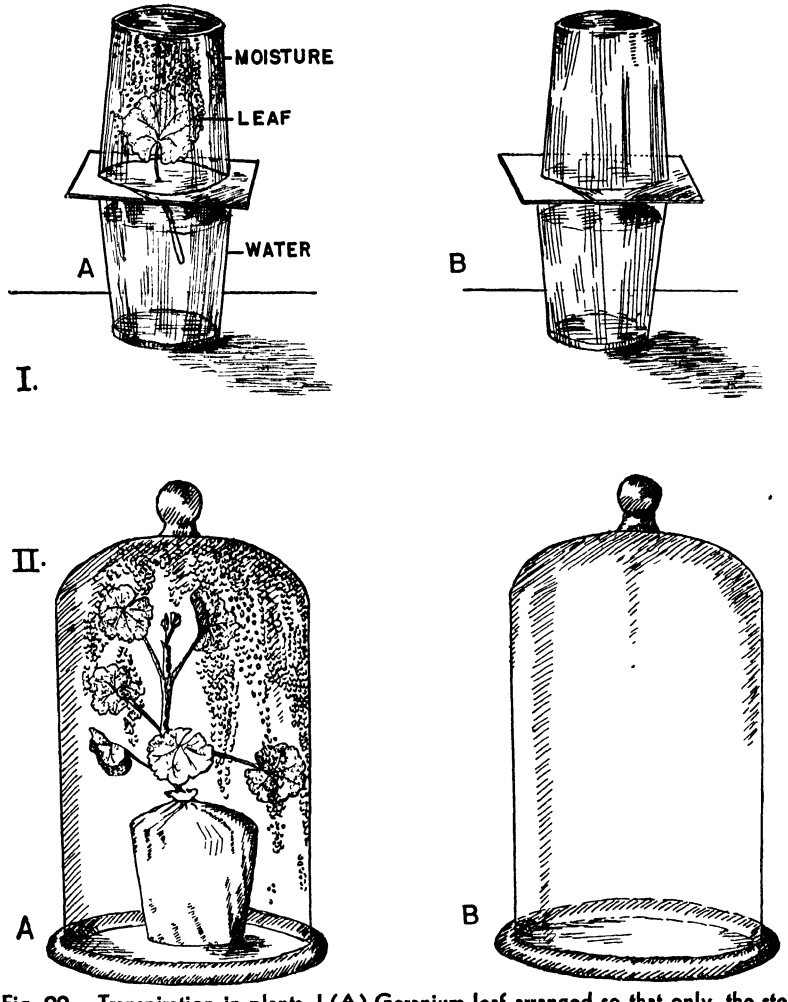


Fig. 99.—Transpiration in plants. I (A) Geranium leaf arranged so that only the stem is in water and so that no evaporation of water can reach the inverted glass through the cardboard. (B) Control. II (A) Pot in which a geranium is growing is covered with rubber sheeting to prevent evaporation from the soil. (B) Control. (L. Runyon.)

d. Factors Limiting Transpiration.—In most plants, the stomata are open in the daylight and closed at night so that the stomata modify the rate of transpiration. They usually close when leaves wilt, though there are some exceptions to this rule.

Some structures modify transpiration for example, the cuticle of leaves and other parts of the plant, the "bloom," which consists of finely divided wax particles scattered over the surface of leaves and fruits, small leaves, compact leaves, and the presence of such substances as resins and waxes

The resurrection plant is able to withstand a remarkable amount of drying Its branches will turn in until the plant becomes the shape of a ball In this condition it may remain dormant for weeks or months When wet weather returns, the plant will open out and begin to grow A few other plants can withstand this drying-out process, but the great majority will die if water is absent for too long a period of time

e Demonstration of Transpiration —Transpiration is readily demonstrated by thrusting a geranium leaf through a piece of cardboard and

Fig 100 —Water of guttation Poppy leaves showing water at the ends of veins The water is excreted because the plant has absorbed more than it needs It is found in the early morning and is often mistaken for dew

placing the stem in water If the stem does not fit tightly in the hole in the cardboard, it should be sealed in with wax or cotton A glass is inverted over the leaf, and soon drops of water collect inside (Fig 99.1) Transpiration and its importance will be discussed further in the study of stems.

Another method of demonstrating the same thing is to cover with rubber the pot in which a geranium is growing If a bell jar is inverted over this pot, the moisture will soon collect on the inside of the bell jar (Fig 110.1) That the moisture does not come from the air is easy to demonstrate by placing an empty bell jar in the same situation (Fig 99*B*)

2 GUTTATION (L *gutta*, drop) —Transpiration has been described as water loss, and that is what it is, but the form of water that is lost is water vapor Water is sometimes lost also in liquid form In certain plants, especially on cool, humid nights following hot days, water can be found along the edges, or tips, of leaves (Fig 100) in the form of drops Such water is often mistaken for dew This is called the *water of guttation* The

process of guttation is not fully understood The water of guttation leaves the plant through special pores connected with the veins

V. Leaves of Unusual Form and Function

Certain leaves are so modified that they are difficult to recognize as leaves Some of these will be described more fully later, here attention will be called only to the fact that they are modified leaves The plant mermaid weed shows some of these modified leaves (Fig 84*A*) It will be seen in *A* that the part of the plant under water bears divided leaves, whereas in the part above the water each leaf consists of one piece The

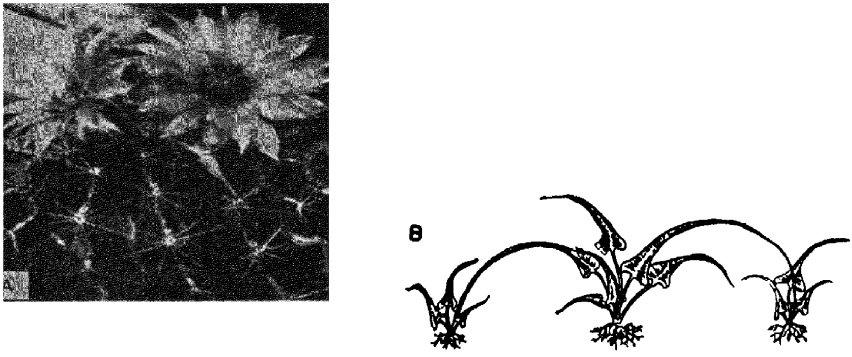


Fig 101 —Modified leaves (A) Cactus (Echinocactus) showing modification of leaves into spines The stem is modified for food manufacture and storage (Dr E H Runyon) (B) "Walking fern" (Camptosorus) with leaves modified as reproductive organs If the leaves touch the ground, they send out roots and new plants are thus produced (B Shamos)

divided condition is especially characteristic of submerged aquatic plants Such leaves offer less resistance to small currents of water

A. Tendrils.—Tendrils are slender, thread-like structures, interesting in their variety and in the ways in which they support the plant by adhering, or twining, around supports Not all tendrils are modified leaves, some are modified stems Tendrils that are modified leaves occur on the pea plant (Fig 94*B*)

B. Spines and Thorns - In some cacti, all the leaves are transformed into spines, and the stem becomes the expanded green part of the plant (Fig 101*A*) The barberry exhibits all gradations of transition from leaves to spines (Fig 84*C*) In the black locust, the spines are modified stipules (Fig 97*D*) Not all spines are modified leaves Those of the honey locust are modified stems, whereas those of the rose are simply outgrowths of the epidermis and cortex

C. Bud Scales.—If the outer scales of a bud are peeled off, they will be found, in many cases, to be small and thick and often to contain a sticky substance, such as resin, and sometimes to appear downy or hairy. All these features are connected with the protection of the tender bud. Bud scales are modified leaves or parts of leaves.

D. Storage.—Unless one knows better, the onion is usually believed to be a root but really is a collection of leaf bases containing stored food. The green plant above the ground manufactures the food, and this is stored in the fleshy lower parts of leaves below the ground. This stored food is used by the young plant while it is developing and until it can manufacture its own food in its green tissue. Later, the food storage in seed leaves will be described (page 178).

E. Vegetative Reproductive Organs.—Certain leaves of the walking fern (Fig. 101*B*) will take root at their tips and form new plants. Leaves of the "life plant" *Bryophyllum* will bud at the leaf notches and form new plants, even if not placed on the soil (Fig. 55). These leaves thus serve as vegetative reproductive organs.

F. Insect Traps.—The highly specialized leaves of carnivorous plants such as sundews and pitcher plants will be described later (pages 154, 155).

Questions

1. Define: node, lamina, petiole, stipule, vein, rachis, cutin.
2. Compare simple and compound leaves.
3. How are leaves arranged on the stem? Are there any variations in the position of leaves with reference to light? Explain why the petioles of leaves on the same plant are often of different lengths.
4. What are the tissues of a typical leaf? How are they arranged? Explain how this arrangement is favorable for the main work of the leaf, the manufacture of sugar.
5. What are the raw materials necessary for photosynthesis? Where is the energy necessary for this work obtained? Why are green plants called the *food factories of the world*?
6. What other foods besides sugar are manufactured by plants? Is sunlight necessary for the making of these foods?
7. What is the role of the stomata? How do the guard cells function? How could smoke and dust injure plants?
8. Compare the processes of respiration and photosynthesis in plants.
9. What is transpiration? Guttation? In what ways is transpiration important for the life of the plant?
10. Plants are said to grow faster at night, yet photosynthesis goes on only in the daylight. Explain why.
11. Why prune trees which are to be transplanted in summer? What season of the year is most favorable for transplanting plants? Give reasons for your answer. Why cannot a wilted plant carry on normal functions well?
12. What protection to the plant is wilting? Why will cut flowers stay fresh longer if the stems are cut every day?
13. What are some advantages and disadvantages of the deciduous habit of some plants? The evergreen habit? Does the climate ever affect these habits?
14. Compare the leaves of desert plants with those of temperate zones.

15. Why are divided leaves advantageous to under water plants?
16. Name some structures that are modified leaves.

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CHAPTER XII

PROBLEMS AND ACTIVITIES OF THE PLANT AS A WHOLE; GROWTH

I. Metabolism

The power of manufacture, transformation, and assimilation of foods is characteristic of living protoplasm and is termed *metabolism* (page 8). The constructive phase, anabolism, is concerned with the construction of simple carbohydrates and from these the more complex plant foods, including fats and proteins. It is also concerned with the storage of these foods and their assimilation into living protoplasm. Growth of new tissue is thus made possible. The destructive phase, *katabolism*, is concerned with the breaking down of protoplasm and its inclusions. This leads to a production of wastes as well as a liberation of energy necessary for the activities of living organisms.

A. The Building-up Phase—Anabolism.—This includes the manufacture, or *synthesis* (Gr. *syn*, together; *tithenai*, place) of (1) foods, (2) protoplasm, and (3) cell walls and other nonliving substances.

1. MANUFACTURE OF CARBOHYDRATES.—Photosynthesis takes place in the green tissues of the plant, especially the leaves (page 140; Fig. 102). It is the process by which the chlorophyll of plants, with carbon dioxide and water as raw materials, synthesizes carbohydrates with the aid of energy from light. Energy from the light is stored up as a result of this process. Carbohydrates, *i.e.*, starches and sugars, are made up of carbon, hydrogen, and oxygen. From simple sugars are elaborated all the other foods upon which both plants and animals depend. The other two classes of foods produced by the plants are *proteins* and *fats*.

2. SYNTHESIS OF PROTEINS AND FATS.—Proteins contain the same substances as the carbohydrates and, in addition, water, nitrogen, and often sulphur and other substances. Minerals are added to a carbohydrate (glucose) to form *amino acids*, which are the building units of the proteins. Some of the glucose is transformed into fatty acid and glycerin, which are the building units of fats. Fats also possess the same chemical elements as carbohydrates, namely, carbon, hydrogen, and oxygen. The carbohydrates and fats are used by the plant as a source of energy; the proteins are used for repair and building processes. They may be modified into enzymes and secretions. All types of food are involved in the formation of protoplasm

3. Assimilation —The changing of food into living substance is assimilation. In the process of assimilation, nonliving substance becomes organized into living protoplasm. Energy is necessary for the building of

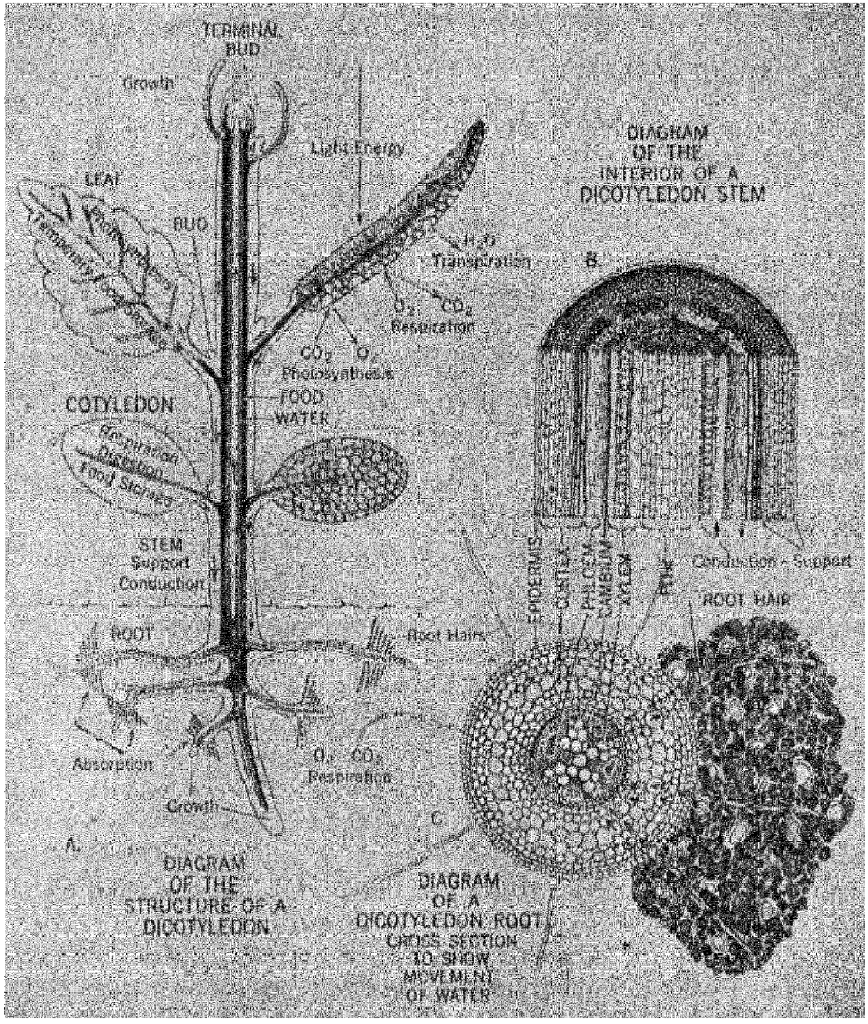


Fig 102 —Three diagrams to illustrate the chief physiological activities of a plant (L Runyon)

living substance, and this is obtained through a process of respiration (katabolic phase). The anabolic and katabolic processes go on at the same time

Just as some of the conditions necessary for photosynthesis are known, so some of the conditions necessary for assimilation are known Some of

the conditions that must precede assimilation may be summarized as follows:

a. A substance to be assimilated must be in soluble form.

b. It must be transported to regions where assimilation is taking place, such as the growing part of a plant.

c. Stored food that is insoluble cannot be assimilated until it is broken down or changed into a soluble form.

B. The Destructive Phase—Katabolism.—The main katabolic processes are digestion, respiration, and fermentation.

1. DIGESTION.—Foods must be in a soluble form before they can be transported in the plant.

a. Role of Enzymes.—The change of materials from an insoluble to a soluble form is brought about through the agency of enzymes; the process is called *digestion.* It is a chemical process. *Enzymes* (Gr. en, in; zyme, leaven) (page 193) were, formerly called *ferments,* because the fermentation of solutions in which yeast cells were growing was one of the first cases in which enzyme action was observed. What happens is that enzymes bring about chemical changes without themselves taking part in the process. Any agent that is able to act in this manner is called a *catalyst* (Gr. *kata,* down; *lysis,* loosening). Enzymes are found in both plant and animal cells. A very interesting characteristic regarding the nature of enzymes is that of specificity of action; *i.e.,* each enzyme acts on only one specific substance. Some examples of plant enzymes are amylase, which changes starch to maltose, and maltase, which changes maltose to glucose. Diastase is a mixture of these two enzymes. Many seeds are rich in fats; hence there must be an enzyme present in them that will aid in the digestion of fats; this enzyme is lipase. Proteins are changed from an insoluble to a soluble condition by a group of enzymes called *proteases,* or *proteinases.*

In digestion, complex food substances are split up into simpler substances. For example, carbohydrates are changed into sugars; fats are split up into fatty acids and glycerin; proteins are split up into amino acids and other substances. All these processes involve the addition of water. A very minute amount of the *enzyme* is all that is necessary. Since foods are digested outside the body if the proper enzymes are employed, digestion need not be carried on directly by the protoplasm.

Another interesting property of enzymes is that the reactions in which they are involved are reversible; *i.e.,* they work both ways. An example will make this clear.

$$\text{Fat} + \text{enzyme} \rightleftarrows \text{fatty acid} + \text{glycerol} + \text{enzyme}$$

From all this, it can be seen that the processes of building up and the processes of tearing down go hand in hand. The building-up processes,

or anabolism, include the synthesis of food and the making of protoplasm. The tearing-down process, or katabolism, includes (1) the conversion of foods into usable forms, which involves the splitting up of complex substances into simpler substances, and (2) the oxidation of foods for the purpose of releasing energy needed by the plant to carry on its life

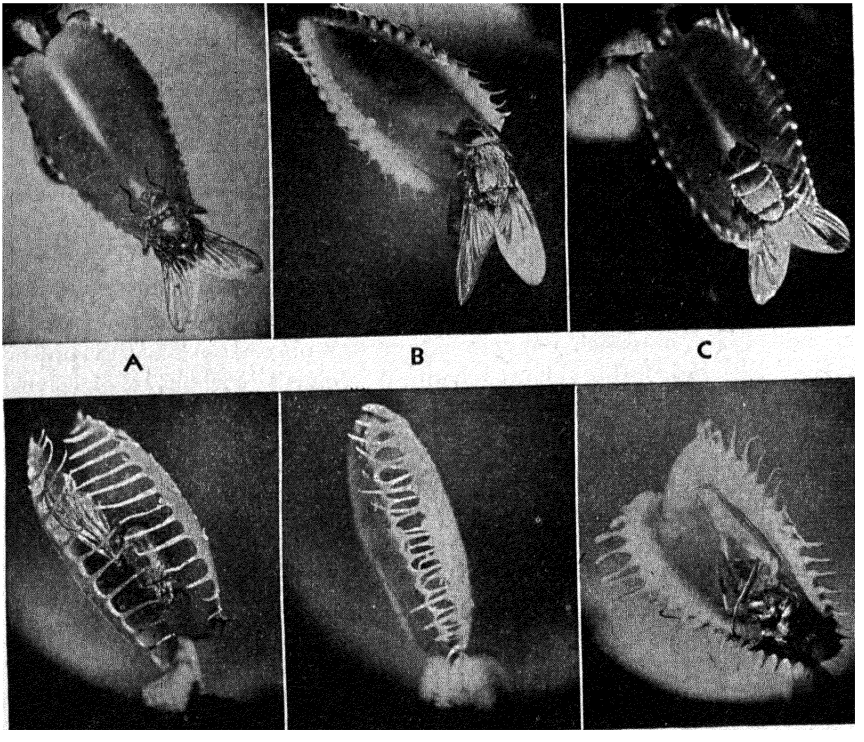


Fig. 103.—Venus's-flytrap (Dionaea) catching a fly. (A) Housefly steps upon a leaf of Venus's-flytrap. (B) Moves in further. (C) Steps on sensitive hairs. (D) Leaf closes; fly captured. (E) The fly dies and is partially digested by the leaf. (F) The leaf opens and the indigestible portions of the fly fall out. (Courtesy of the General Biological Supply Company.)

activities. There is no anabolism without katabolism; the two go hand in hand.

b. Where Digestion Takes Place. (1) DIGESTION IN CELLS.—Higher animals are provided with elaborate digestive systems in which food is digested. This digested food is absorbed and carried to every part of the animal body by the circulatory system. Plants do not possess such systems as these. Digestion may take place inside any cell (intracellular digestion), though it occurs chiefly in places where food has been stored.

(2) DIGESTION OUTSIDE CELLS. (*a*) Digestion in Carnivorous Plants. We have said that digestion may occur in any cell. Digestion may also

occur outside the cell, for example, in the carnivorous plants. Here, when the plant "catches" an insect, digestive juices are poured over the insect, and the products of digestion are then absorbed by the plant (Fig. 103).

(*b*) Digestion in Plants Lacking Chlorophyll.—The bacteria and Fungi use *extracellular* as well as *intracellular* methods of digestion. The

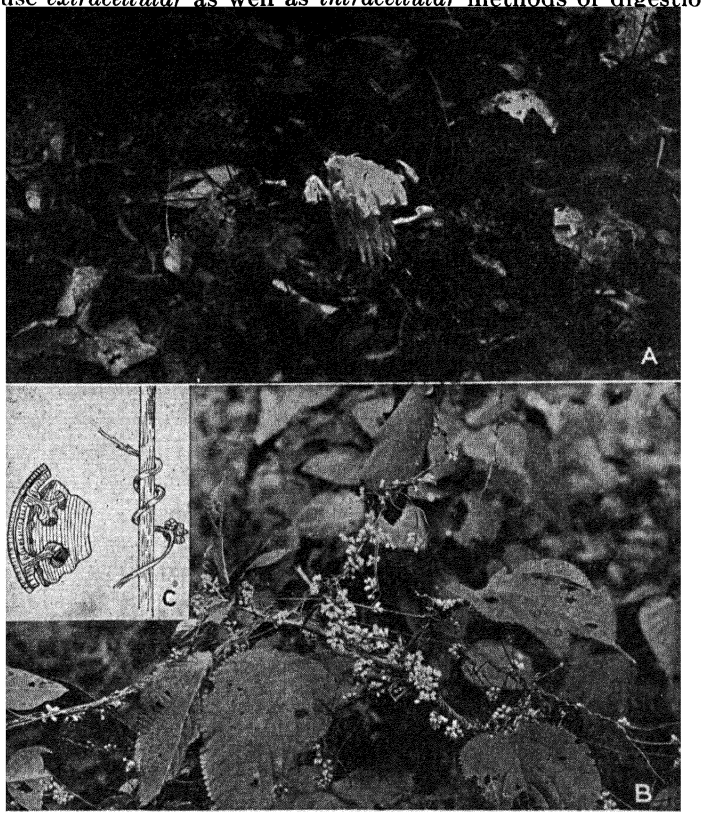


Fig. 104.—Dependent seed plants. (A) Indian pipes (Monotropa). (Mrs. Totten.) (B) Dodder (Cuscuta) in bloom. (Courtesy of The Wild Flower Preservation Society.) (C) Modified roots of dodder. (diagrammatic)

extracellular process is carried on outside the plants, and the products are then absorbed. Such plants are known as *saprophytes* and *parasites*. The saprophytic and parasitic (page 189) habits are also exhibited by certain seed plants. The Indian pipe, for example, is a seed plant that is saprophytic, securing its food from dead organic matter, and the dodder is a parasite that secures its food from the host on which it lives (Fig. 104).

c. The Fate of the Digested Food.—Plants and animals need food in order to carry on living processes; it is the fuel that keeps the living

organism alive and working. In summary, we may say that digested foods may be used as follows: (1) They may be oxidized and thus release energy. This process of respiration is carried on by every living cell. The energy released is needed for the work the plant has to do in maintaining itself, in growing, and in reproducing. (2) They may be transformed into substances suitable for storage. This involves a change to an insoluble form such as starch. (3) They may be carried to other parts of the plant, *i.e.*, translocated (Fig. 102). (4) They may be used for building up protoplasm. This is the process of assimilation. (5) They may be used to synthesize the many compounds that occur in plants.

2. RESPIRATION AND FERMENTATION.—There are two types of respiration, aerobic and anaerobic.

a. Aerobic (Gr. *aer*, air; *bios*, life).—*Respiration* is essentially an oxidation process. It is carried on in every living cell. Animals possess special respiratory organs. These are concerned with the exchange of gases; strictly speaking, such organs are for breathing and not for respiration. The plant is not provided with anything resembling a "lung," but some of its structures are concerned with the exchange of gases. These structures are the stomata, lenticels, and intercellular spaces (Fig. 102). For the part of the plant above the earth, oxygen is obtained from the air; for the root system, oxygen is obtained from the air that is dissolved in the water. In the process of respiration, oxygen is consumed, and carbon dioxide is given off. An example will make this clear.

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \rightarrow \underset{\text{water}}{6H_2O} + \underset{\text{carbon dioxide}}{6CO_2} + \text{energy}$$

Glucose is used as an example here, because it is the most common material available to the plant. Plants are able to use other substances as a source of energy, namely, stored fats and proteins; in cases of starvation, even protoplasm itself may be consumed for food.

The most important fact about respiration is that it provides energy for the use of the plant. Plants probably never use all the energy that they are provided with as a result of the process of respiration. Some of the energy escapes in the form of heat, and, in the case of certain bacteria that are luminescent, in the form of light.

Not all substances yield the same amount of energy. A gram of carbohydrate, when burned outside the body, will yield less energy than will a gram of either protein or fat. Many things affect respiration, such as the amount of food and water present, the light relations, the temperature, and the quantity of oxygen available.

b. Anaerobic Respiration or Fermentation.—In the study of yeasts (page 193), fermentation is described as a respiratory process of the yeast

plants. In these plants and in certain other plants that are deprived of free oxygen, evidence of respiration persists in the giving off of carbon dioxide. Such plants secure their energy through the agency of enzymes. For example, the sugar that is present may be split, forming alcohol as a result and giving off carbon dioxide as a gas. When such a chemical reaction takes place, energy is released that the plant uses for all its life activities.

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \text{enzyme} \rightarrow \underset{\substack{\text{ethyl}\\\text{alcohol}}}{2C_2H_5OH} + \underset{\substack{\text{carbon}\\\text{dioxide}}}{2CO_2} + \underset{\text{heat}}{\text{energy}}$$

It is important to note that certain species of bacteria and Fungi not only do not need free oxygen but die when it is present. They use the anaerobic type of respiration altogether. A good example of an anaerobe is the organism that produces the dread disease known as *lockjaw*. This minute plant does not require free oxygen in order to develop to do its deadly work. It is unable to persist in superficial wounds because of the presence of oxygen. Many parasites are anaerobes.

II. Growth in Plants

The first problem that presents itself to the young embryo is the problem of growth. Plants grow in two ways, in length and in breadth. Growth is not a simple problem, however, since it involves far more than the mere increase in size or in weight. As is well known, a bean seed can increase in size and weight in a very short time by the absorption of water, but this process is not growth. Growth is irreversible; *i.e.*, the plant cannot "return" to its original condition. Growth takes place through the activity of protoplasm; it can occur in no other way. True growth is, therefore, possible only in living things. A crystal or snowball may increase in size by the addition of layers on the outside (accretion), but this is not growth in the sense in which a plant grows, because these added layers may be taken off; *i.e.*, growth in this case is reversible.

Growth is usually measured by determining the increase in size or weight. Growth occurs in two ways: (1) by the increase in the size of cells already present and (2) by increase in the number of cells through cell division (page 35). In the first case, true growth occurs by the addition of new protoplasm to that already present in the cells: growth by *intussusception*. After the cells have increased in numbers, they increase in size by the building up of more protoplasm.

A. External Factors Affecting Growth.—Many factors affect growth. They may be external factors in the environment. These external factors, to be effective, must rest on the effect they may have on internal factors. Some important external factors are temperature, moisture, type of soil, and supply of carbon dioxide, inorganic salts, and oxygen.

B. Internal Factors Affecting Growth.—Factors in growth may also be internal. Briefly, it may be said that a plant is tall or short because its parents were tall or short; in other words, its heredity determines its potentialities. Many factors may affect the plant in spite of its inheritance. There may be minute quantities of substances, vitamins and hormones, that are capable of producing profound physiological effects (pages 618–626). Then there is the question of general *nutritional balance*, *i.e.*, the proper proportion of foods, and, finally, the correlation of plant parts. As is well known, the removal of a part of a plant affects the growth of other parts. For example, removal of the terminal bud will stimulate the growth of lateral buds, etc. But whether the factors are internal or external, one factor cannot be separated from the other. The factors work together.

Questions

1. Discuss the two phases of metabolism in plants.
2. How are proteins and fats synthesized in plants?
3. Why are proteins necessary for construction of living substance in the plant?
4. What are some events that must take place before foods can be assimilated in plants? Why is starch a more suitable form than sugar for storage of carbohydrates? How are starches changed back to sugars before digestion? Is the action reversible? Explain.
5. Why are enzymes called *catalysts*? Name some plant enzymes. Is a specific enzyme capable of changing more than one substance?
6. Where does digestion take place in plants?
7. Do all substances yield the same amount of energy upon digestion? Explain.
8. Compare aerobic and anaerobic respiration. What is fermentation?
9. What are some plants that do not need free oxygen?
10. How does an insectivorous plant like the Venus's-flytrap digest its food?
11. How is it possible for delicate Fungi to penetrate woody tissues?
12. Why are young vegetables like corn, peas, and parsnips sweeter when young than when mature?
13. How does the plant get energy for photosynthesis? For carrying on the processes of metabolism?
14. Why is an excretory system, such as is found in animals, not necessary for plants?
15. Why do plants grow better in unglazed pots?

Suggested References

MILLER, E. C.: "Plant Physiology," Chaps. VII–IX, The McGraw-Hill Book Company, Inc., 1938.

CHAPTER XIII

FLOWERS, FRUITS, SEEDS, AND SEEDLINGS

Flower in the crannied wall
I pick you out of the crannies,
I hold you here, root and all, in my hand
Little flower—but if I could understand
What you are, root and all, and all in all,
I should know what God and man is.
—TENNYSON.

Flowers are among the most beautiful objects in nature. They are specialized branches of the shoot concerned with reproduction of the plant. The vegetative structures and activities of the plant center around the root, the stem, the leaves; the reproductive structures and activities center around the flower, fruit, and seed. It has been pointed out that the vegetative parts of the plant carry on the activities essential to the life of the individual plants. But the individuals, even the long-lived trees, eventually die, and means must be provided for reproduction.

There are two types of reproduction, *asexual* and *sexual*. Asexual, or vegetative reproduction, occurs when a part of the plant, a branch, root, rosette, leaf, or other part will produce new plants when separated from the parent; sexual reproduction occurs when two special bodies, the *gametes* (Gr. *gamos*, marriage) unite and from this union a new individual arises. It is in the flowers of the higher plants that these gametes are produced. Flowers are concerned, then, with sexual reproduction. From the fertilized egg cell will develop the seeds that are constructed for certain definite purposes in the life history of the plant. How they originate, how they are dispersed over the earth, and how the young plant develops from them are fascinating subjects.

I. The Flower

A. The Flower and Flower Cluster.—The flower is a shoot specialized for a particular purpose. In this specialized shoot, pollination and fertilization lead to the production of seeds. Flowers are usually thought of as the familiar, brightly colored blooms that are enjoyed in the fields and gardens and as decorations at home. But many plants such as grasses, poplars, etc. possess flowers that are inconspicuous, yet these are true flowers for all that.

It has been seen that leaves are arranged on stems according to a definite plan; so, too, flowers exhibit definite types of arrangement. Figure 105 shows some of the types of flower clusters. As an aid to identification, it is desirable to know something of the types of arrangement. Botanical keys describe flowers as solitary or having the arrangement of a head or other type of cluster.

1. The Parts of a Flower.—Aside from knowing something about the organization that exists in the make-up of a flower cluster, a knowledge of the parts of a flower is useful in determining new species. Botanical keys use a description of parts of a flower as one means of identification of plants.

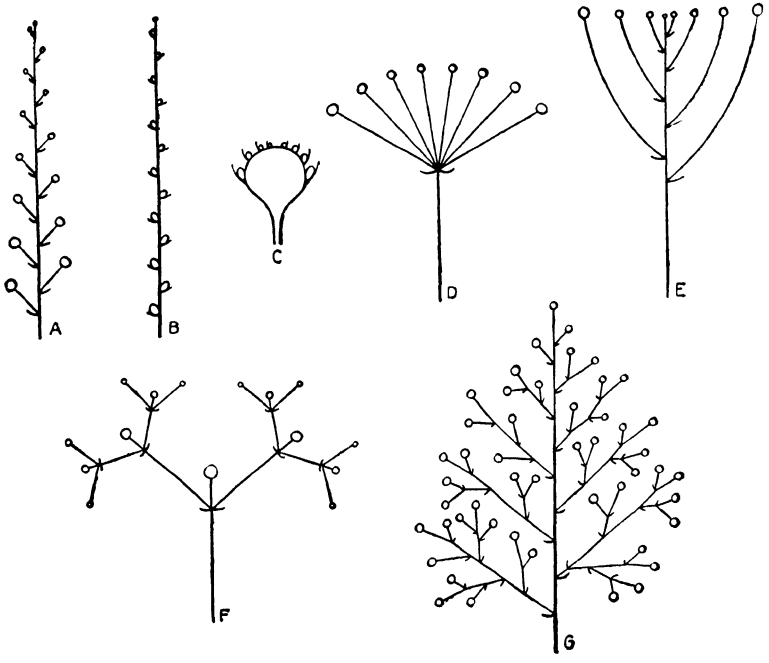


Fig. 105.—Diagram showing the arrangement of flowers in the most common types of inflorescence. (A) Raceme; (B) spike; (C) head; (D) umbel; (E) corymb; (F) cyme; (G) panicle. (From Sinnott, Botany, Principles and Problems.)

Figure 106 represents a complete analysis of the parts of a flax flower. This flower was chosen because all its parts are present.

a. The Calyx and Sepals.—Beginning with the outside of the flower, it is observed that the "cup" or *calyx* (Gr. *kalyx*, a cup), is usually, but not always, colored green. In the tulip, for example, the calyx has the same color as the petals. The separate parts of the calyx are leaf-like; these are called *sepals* (Gr. *skepe*, a covering). In the bud stages, the calyx may completely enclose the flower.

b. The Receptacle.—The top of the flower stalk is the *receptacle.*

c. Corolla and Petals.—Next to the calyx is the *corolla* (diminutive of *corona,* crown). This is the brightly colored part of the flower with which everyone is familiar. But the conspicuous part of the flower may not be the petals of the corolla but may consist of modified leaves, as in the dogwood. The flowers of the dogwood are the small inconspicuous

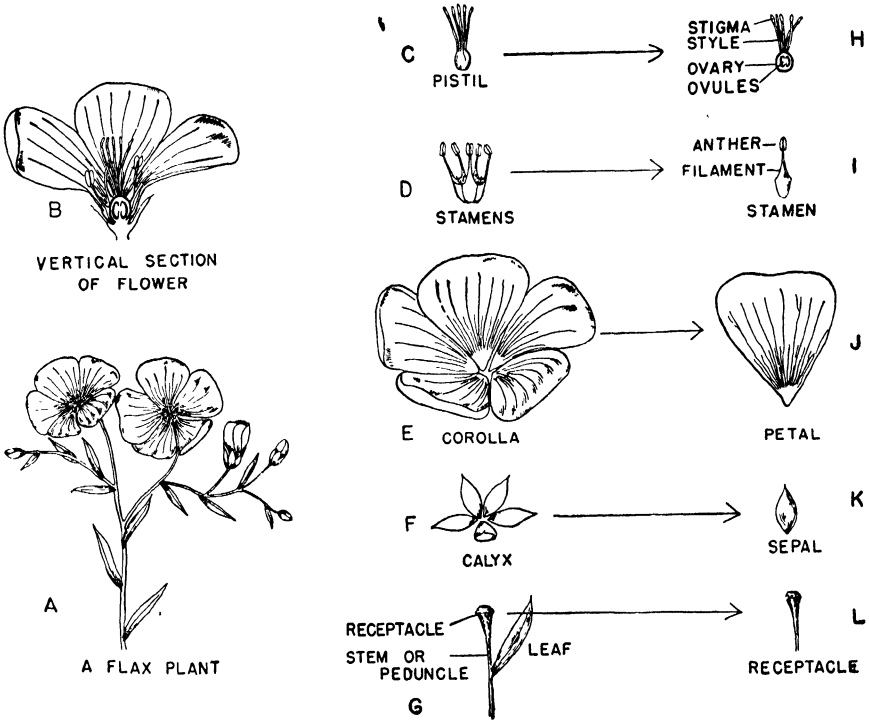


Fig. 106.—(A) Flax plant (Linum). (B) Vertical section of the flax flower showing the relation of the floral parts to each other. (C to G) The floral organs. (H to L) The parts of a flower. (L. Runyon.)

structures in the center. *Odors* of flowers may be due to special secretion cells of the petals or other parts. If nectar glands are present, they are often at the base of the petals. Flower colors and odors may attract insects that effect pollination.

d. The Perianth.—The sepals and petals (or the sepals alone) make up the floral envelope, or *perianth* (Gr. *peri,* around; *anthos,* flower). The perianth parts are not necessary to seed formation and so are sometimes spoken of as accessory flower parts.

e. The Stamens.—Just inside the perianth are the *stamens* (Gr. *stemon,* warp or thread). Each stamen possesses a *filament* (L. *filare,* to

spin) at the top of which is an *anther* (Gr. *anthos*, flower); inside the anther are the *pollen grains* (L. *pollen*, fine dust); these are also known as *microspores* (Gr. *mikros*, small; *spora*, seed).

f. The Pistil.—Inside the circle of the stamens is the *pistil* (L. *pistilum*, a pestle), which is made up of one or more *carpels* (Gr. *karpos*,

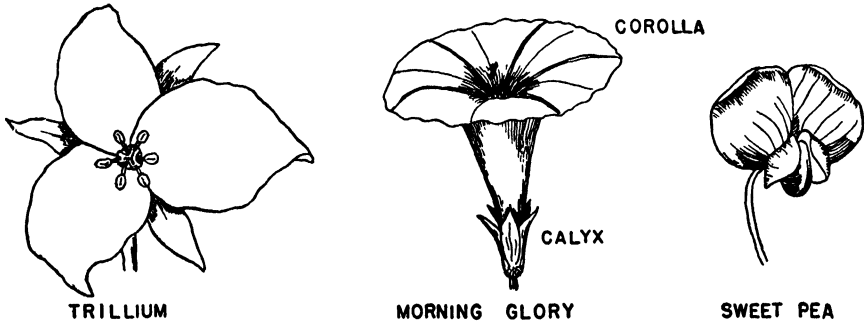


Fig. 107.—Types of flowers. The petals in the corolla of the trillium are separate while those of the morning-glory are fused together. The sweet pea is irregular. (L. Runyon.)

fruit). At the base of the pistil is the *ovary* (L. *ovum*, egg), and inside that is the *ovule*. The egg, surrounded by the embryo sac, is inside the ovule (Fig. 110). The *style* extends upward from the ovary, and the *stigma* is on top of the style.

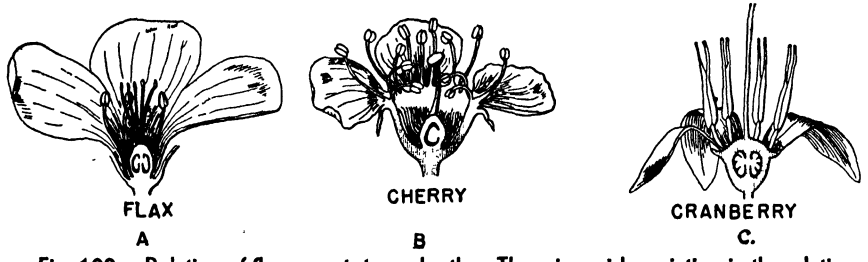


Fig. 108.—Relation of flower parts to each other. There is a wide variation in the relationship of the parts of flowers to each other. (A) Superior ovary. (B) Half-inferior ovary. (C) Inferior ovary. (Redrawn by L. Runyon from Gray, School and Field Botany, The American Book Company.)

Each flower has a definite role to play in pollination, fertilization, or other reproductive processes of the plant that lead to the formation of seeds.

2. Relation of the Parts of a Flower to Each Other.—Great variation exists among plants with respect to these parts as well as the way they are related to each other. In Fig. 108, three distinct types of ovaries are illustrated: (1) superior, (2) inferior, (3) half inferior ovaries. In *Trillium*, the petals are separate; in the morning-glory, they are fused

together; in the sweet pea, the flower is irregular (Fig. 107). In Fig. 108, it can be seen that in the flowers of flax, cherry, and cranberry different arrangements exist in the relations of the parts to one another. An ovary entirely free from the calyx is called a *superior ovary* (Fig. 108*A*); if the receptacle encloses, and is fused with, the ovary and the floral parts appear to be above the ovary, it is said to be an inferior ovary (Fig. 108*C*). The type halfway between these two is a half inferior ovary (Fig. 108*B*).

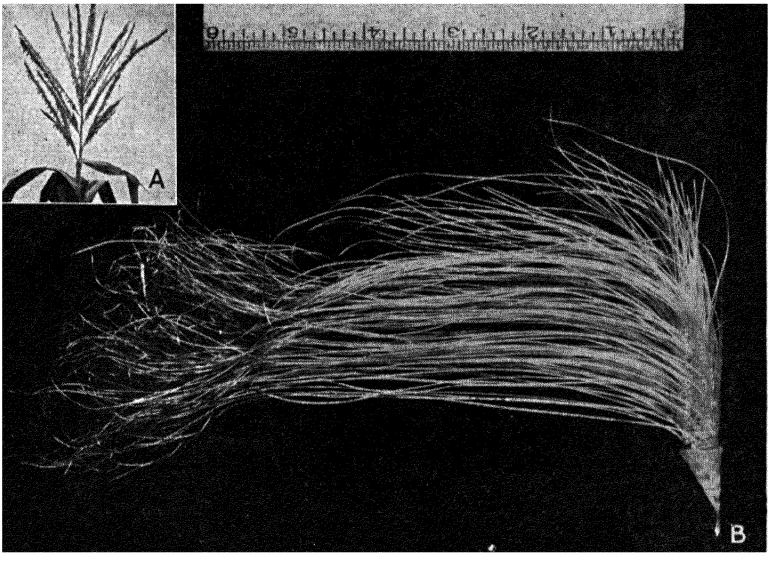


Fig. 109.—(A) Corn tassel. The male or staminate flowers are produced in the tassel which is a panicle at the top of the corn stalk. (Courtesy of Hastings Seed Company.) (B) Young ear of corn. The husks are removed to show the development of the silk from the tip of each ovary. Each silk must receive pollen if the corn grain to which it is attached is to develop. (From the Yearbook, U.S. Department of Agriculture, 1936.)

3. Types of Flowers. *a. Complete and Incomplete Flowers.*—If a flower contains all four sets of organs—*i.e.*, calyx, corolla, stamens, and pistil—it is said to be *complete*. If any one of these sets is lacking, the flower is said to be *incomplete*. If the petals are lacking, the flower is said to be *apetalous*. In the *Clematis*, the petals are lacking, but the sepals have become colored and resemble the petals. If the sepals are lacking, it is designated *asepalous*. Sometimes both are lacking, as in the blue ash.

b. Perfect and Imperfect Flowers.—Two other terms, perfect and imperfect, are often used. A perfect flower is one that has both stamens and pistils. It makes no difference whether the other organs are present or not, because the flower is perfect so far as structures necessary for reproduction are concerned. An imperfect flower is one that lacks either

stamens or a pistil. All complete flowers are perfect, but incomplete flowers may be either perfect or imperfect. A good example of an imperfect flower is that of the holly plant. Certain holly trees bear flowers with stamens (staminate) but no pistils, and other trees bear flowers with pistils but no stamens. The *Begonia* may possess both pistillate flowers and staminate flowers on the same plant. This is also true of the corn plant, where the staminate flowers occur on the tassel and the pistillate flowers are borne on what becomes the ear (Fig. 109).

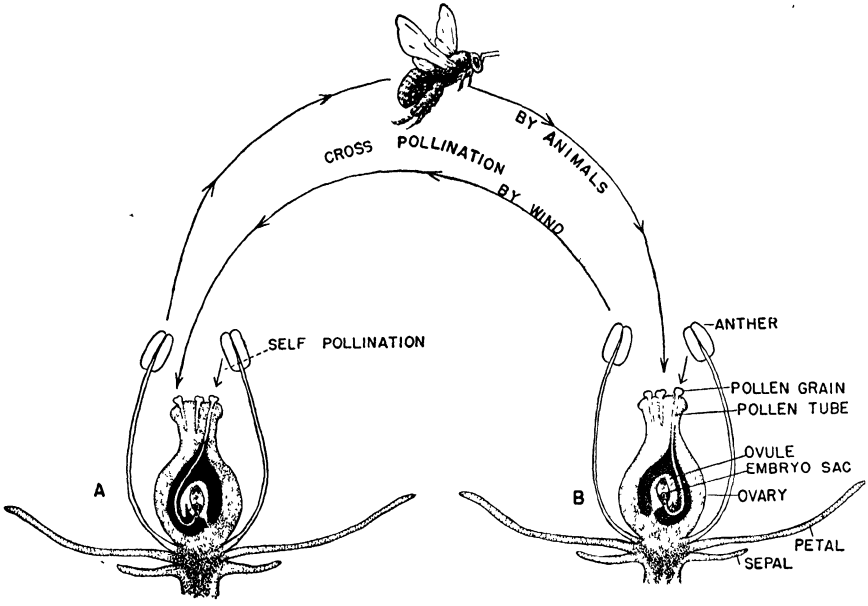


Fig. 110.—Diagram to illustrate cross- and self-pollination in flowers. (B. F. Edwards.)

4. POLLINATION.—Pollen is the yellow, dust-like material shed from the anther. Under the microscope, it is seen to consist of multitudes of granules that may vary greatly in size and shape. The transfer of the pollen to the stigma of the pistil is called *pollination* (Fig. 110).

a. Agencies for Cross-pollination.—Pollen may be carried to the flower by the wind or by insects or by other animals. Hummingbirds transfer pollen from flower to flower as they visit them in search of nectar. Bees seek nectar and pollen from flowers. From the nectar they make honey; the pollen they use as food for the larvae, which will later develop into bees. While they are about their own business of collecting nectar and pollen, the pollen sticks to various parts of their bodies and is "dusted on" the stigmas that they happen to touch. Plants possess a great variety of devices for attracting insect visitors and thus securing cross-pollination. It is a question whether insects can distinguish bright

egg. Then, mounting to the top of the stigma, she forces some of the pollen she has brought with her into the tube of the stigma. The yucca flower is pollinated in no other way, and the race of yucca plants would soon die out if it were not for this little moth.

Plants whose pollen is carried by the wind produce great quantities of pollen. In some types, such as pecans, oaks, etc., the catkins swing about in the breezes and broadcast their pollen far and wide (Fig. 112).

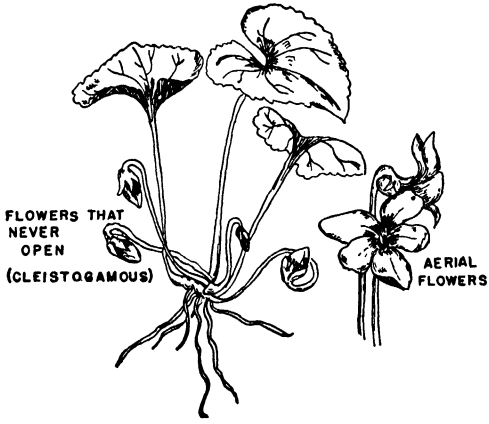


Fig. 113.—The violet, aerial and cleistogamous flowers. Cleistogamous flowers may be subterranean and colorless and may appear some time after the aerial flowers. Since they never open, cross pollination is impossible. (L. Runyon.)

In the spring, when the pollen is ripe, under these trees the ground is yellow with the pollen shed from their catkins.

b. Self- or Close Pollination.—Cross-pollination is not universal. Figure 110 shows that a plant may receive pollen from its own anthers. This is, as the name implies, self-pollination. The garden pea is normally self-pollinated. Some flowers guard against cross-pollination by remaining always closed. This is true of one type of violet (Fig. 113). Some plants bear two types of flowers (many violets), the usual type that is cross-pollinated and another type that never opens [*cleistogamous* (Gr. *kleistos*, closed; *gamos*, marriage)].

5. Fertilization.—As soon as the pollen falls on the stigma, it is stimulated to germinate and sends a tube down into the ovary. Examination of Fig. 114 shows that several pollen grains have germinated but that only one tube has reached the ovary. In the same figure, the location of an egg in the embryo sac may be seen. *B* of the same figure shows the pollen tube, after it has developed, containing two sperm nuclei. One of these will fuse with the egg to form the fertilized egg, or zygote (page 167), and from this will develop the embryo. The other will fuse with the two polar nuclei, so called because they have come from the ends or poles

of the embryo sac. From this fusion nucleus, by repeated divisions, is formed a mass of tissue known as the *endosperm.* The function of the endosperm is the nourishment of the young embryo and the seedling in the early stages. These are the events of *fertilization.* Fertilization is an orderly process and has far-reaching consequences. Each step prepares

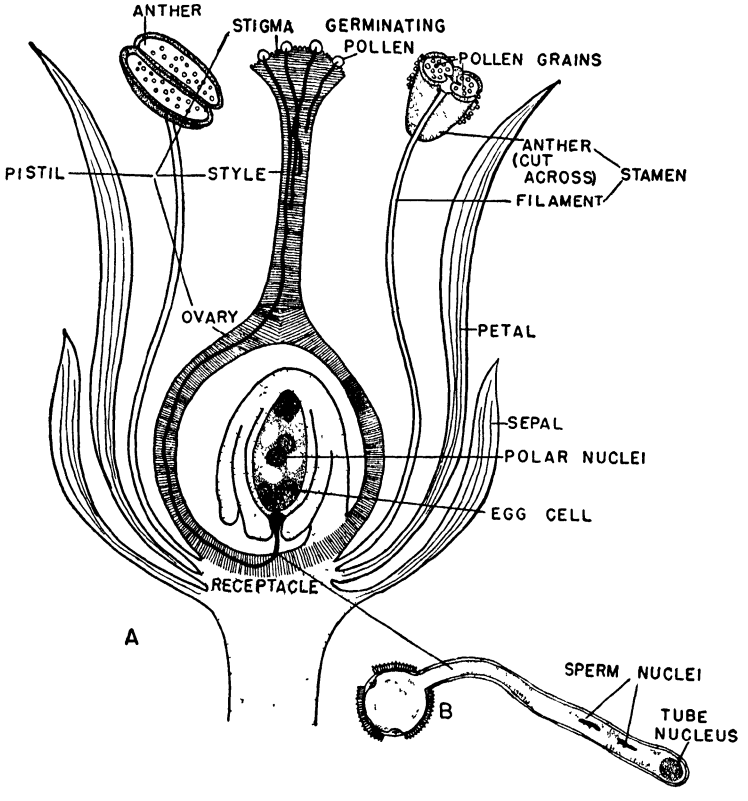


Fig. 114.—(A) Fertilization. Diagram of a flower showing method of fertilization of the egg. In the figure, several pollen grains have germinated but only one has reached the egg. (B) Pollen grain that has germinated. (L. Runyon.)

the way for the next event. There are fundamental similarities in the steps of fertilization common to all types of sexually reproducing organisms. The differences are merely details and interesting variations exhibited by different species.

II. Fruits

A. What a Fruit Is.—Sometimes to a layman a fruit means only the fleshy fruits one buys in the market. To a botanist, however, the word *fruit* has a different meaning. The fruit contains the seeds. A simple fruit

is a ripened ovary and its contents. Sometimes other parts of the flower develop into parts of the fruit as well. A good example is the apple (Fig. 115*B*). Here the base of the receptacle grows up around the ovary, and the juicy apple pulp that is good to eat is developed from this. The five-celled ovary and the ovary wall can be seen in an apple that has been cut. Various other parts of the flower may enter into the development of a fruit.

The place of attachment of the ovules to the ovary is known as the *placenta*. As shown in Fig. 116, there are various types of placentae.

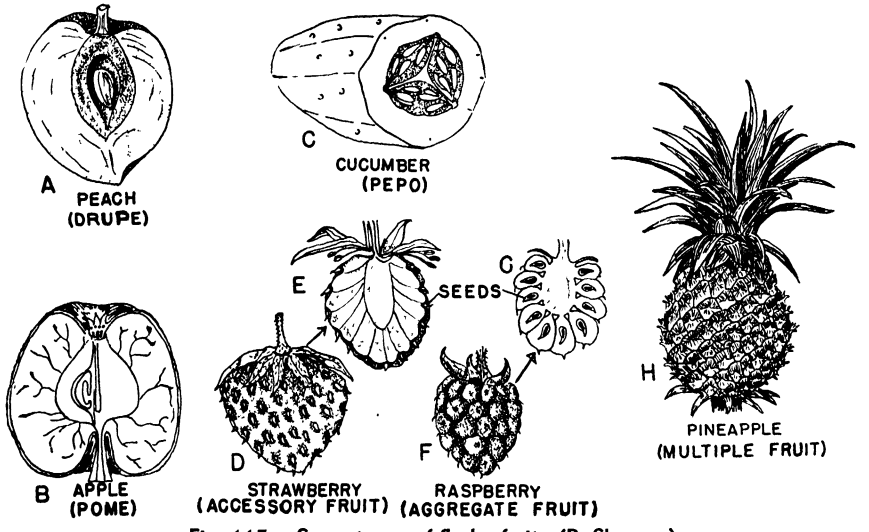


Fig. 115.—Some types of fleshy fruits. (B. Shamos.)

B. Types of Fruits.—There are so many kinds of fruits that it will be impossible to mention all of them here. However, there are two principal kinds, dry and fleshy, and the nut and apple represent these two groups. In the nut, the ovary wall, which, when mature, is called the *pericarp*, is dry; in the apple it is not dry but fleshy.

1. Dry Fruits.—There are many varieties of these included in two divisions, those that split their walls when mature, or dehiscent fruits, and those that do not, indehiscent fruits.

a. Dehiscent Fruits.—These include several characteristic types.

(1) The legume.—One of the most characteristic dry fruits is the *legume* of the pea family. This develops from a simple pistil, and, when mature, it opens along both dorsal and ventral sutures (Fig. 117*C*).

(2) The follicle.—The *follicle* develops from a single carpel and when mature dehisces along one suture. Examples are the larkspur and the milkweed fruits.

(3) THE CAPSULE.—This is a type that develops from a compound ovary with two or more carpels, each containing several seeds when mature, as in the capsules of the Jimson weed (*Datura*) (Fig. 117*A*), the violet (Fig. 117*B*), and the poppy (Fig. 118*E*).

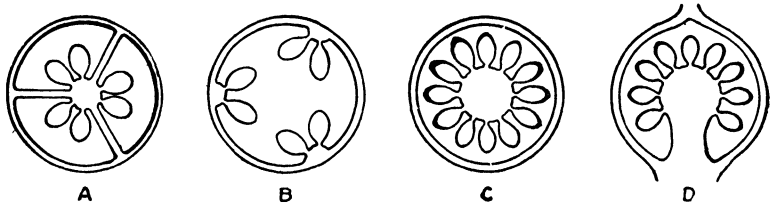


Fig. 116.—Types of placentation. (A) axile. (B) Parietal. (C) Central. (D) Free central (From Sinnott, Botany, Principles and Problems.)

b. Indehiscent Fruits. (1) THE AKENES are small one-seeded fruits, characteristic of the sunflower, dandelion (Fig. 118*C*), and other plants.

(2) GRAINS.—These are much like the akenes, except that the seed coat is fused with that of the ovary wall characteristic of the grass family.

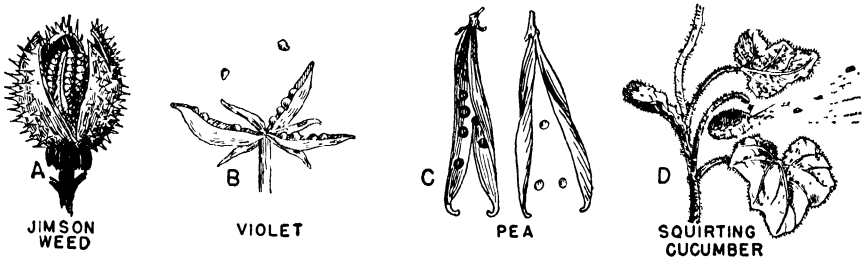


Fig. 117.—Seed dispersal. Some seeds are scattered by the action of the seeds themselves. (B. Shamos.)

(3) KEY FRUIT OR THE SAMARA.—This is an akene-like fruit that is winged. Sometimes it is one-seeded, as elm and ash (Fig. 118*B* and *F*) or two-seeded, as the maple (Fig. 118*G*).

(4) SCHIZOCARPS are characteristic of the carrot family. This fruit develops from a bicarpellary ovary, and, when mature, each of the two one-seeded indehiscent carpels separates from the common partition.

(5) THE NUTS.—The nut is a hard-shelled fruit formed from the entire ovary. Figure 119 shows various types of nuts.

2. FLESHY FRUITS.—These may be simple, aggregate, or multiple, according to the method of origin.

a. Simple fleshy fruits are so named because they develop from a single ovary and with, or without, certain other parts of the flower. Figure 115 illustrates various types of fleshy fruits.

(1) THE DRUPE, OR STONE FRUIT (Fig. 115*A*).—Examples of these are peaches and pears. The outside of the fruit is fleshy; on the inside is found the familiar peach "stone," in the case of the peach. The seed is inside the "stone." Other examples are the cherry and the olive.

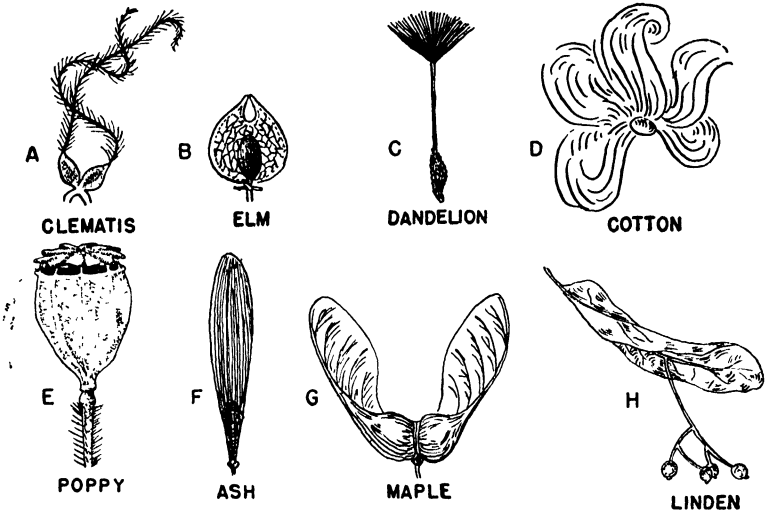


Fig. 118.—Seed dispersal. Some types of seeds scattered or transported by the wind. (B. Shamos.)

(2) THE BERRY.—Many fruits called *berries* are not true berries. Cranberries and gooseberries are true berries, and the tomato, grape, and many others belong to this group. The cucumber is a modified berry called a *pepo* (Fig. 115*C*). It has a hard outer rind. The orange is also a

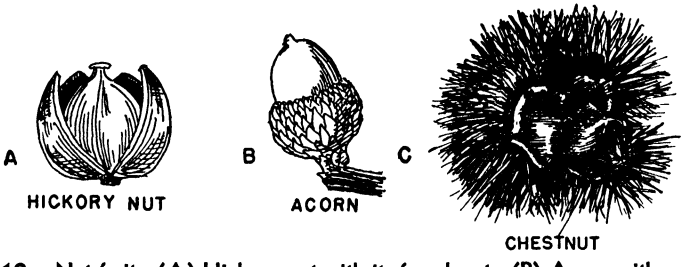


Fig. 119.—Nut fruits. (A) Hickory nut with its four bracts. (B) Acorn with cup formed from many bracts. (C) Chestnut, with a bristly bur which corresponds to the cup of the acorn. (B. Shamos.)

modified berry with a leathery rind, easily separable from the rest of the fruit. It is called a *hesperidum.*

(3) THE POME (Fig. 115*B*).—As has been said, the apple is a familiar example of this type of fruit. In this case, the much enlarged receptacle surrounds the ovary and forms the fleshy part of the fruit.

b. Aggregate Fruits.—Examples of these are the raspberries and the blackberries (Fig. 115*F*). They are formed by the ripening of a number of separate pistils, all belonging to a single flower.

c. Accessory Fruits.—An accessory fruit is one in which the larger part of the fruit does not develop from the ovary. This is the case in the apple (*pome*) and the strawberry (Fig. 115*D*).

d. Multiple Fruits.—These are developed from several, or many, flowers united in compact inflorescence, the whole forming a single fleshy mass. One example is the pineapple (Fig. 115*H*). Each of the units on the surface of the pineapple represents a separate flower. There are no seeds in pineapple fruits. Other examples are the mulberry and the fig.

3. Functions of Fruits.—Fruits have two important functions: (1) to protect the developing seed and (2) to aid in seed dispersal.

III. Seeds

A. The Development of a Seed.—After the egg has been fertilized, the petals and stamens of the flower often drop off. But inside the ovule, great changes now take place. The forerunner of the future plant, the embryo, must develop from the fertilized egg. And in order that the embryo may obtain nourishment until it becomes a self-supporting plant, food must be manufactured and stored up for the future. The endosperm is formed from the endosperm nucleus, and the food for the embryo comes from the endosperm and the mother plant. In some cases, the endosperm is used up before the maturing of the seed, as in the bean. In this case, food for the embryo is stored in the embryo itself. Or the endosperm may be wrapped around the embryo, as in the corn.

The outside of the ovule changes into a hard coat, the "seed coat." Thus the ovule is transformed into a seed that stops growing until conditions are proper for its further development. If either peas or beans are soaked for a while, the seed coat can be removed easily. It is then readily observed that the seed contains only one structure, the embryo. Most of the food in this case is in the cotyledons.

B. Seed Dispersal.—Seeds must obviously find a favorable place for germination and for the growth of the plant. Many curious modifications are present in the structure of seeds and fruits that aid in their dispersal. In addition to this, various agencies take part in scattering seeds and fruits over the earth.

1. Agencies for Seed Dispersal. *a. Wind, Water, Animals.*—The two principal agencies are wind and animals, although water is also of considerable importance. Animals aid in seed dispersal by eating fleshy fruits but not the seeds or by eating the seeds themselves, which may pass through the digestive tract unharmed. In certain places where birds come

to rest, such as fence rows, a variety of plants spring up that grow from seeds deposited there in bird droppings. Seeds are often carried long distances on the feet of birds, especially on those of wading and water birds.

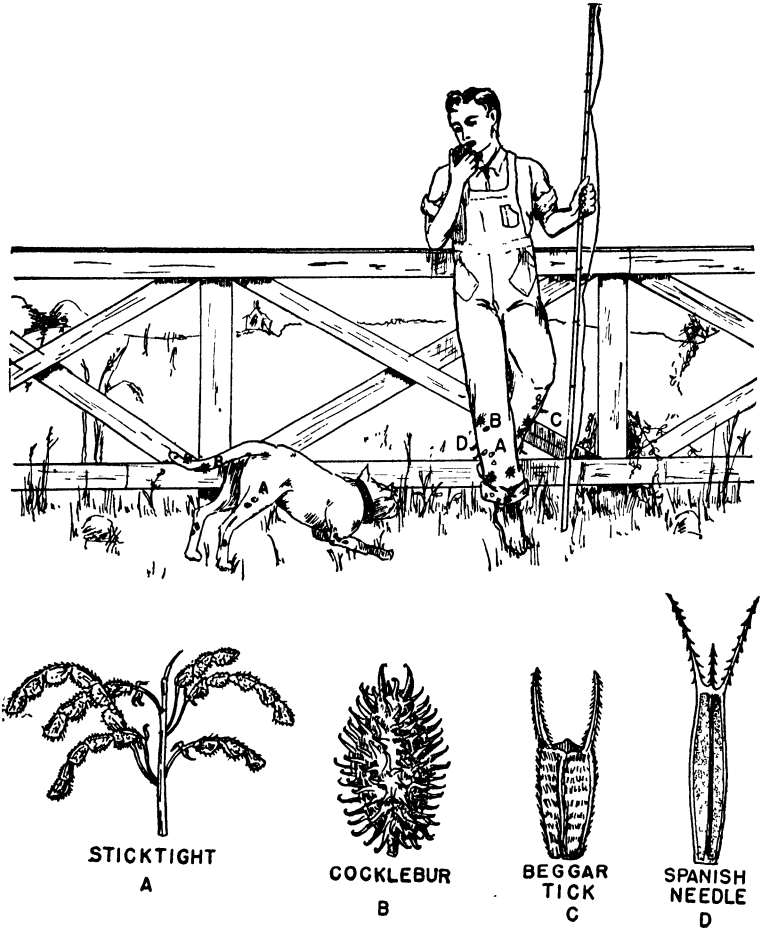


Fig. 120.—Distribution of fruits by animals. Hooks, barbs, hairs, etc., of some fruits cause them to stick to any passing object. (B. F. Edwards.)

b. Special Devices.—Figures 117, 118, 120, and 121 illustrate various devices that enable the seed to "get around." These include structures that enable the seed to float (dandelion and cotton seeds), the "parachute" principle employed by the ash, maple, or linden, and the "sifter" principle of the poppy fruit. In the poppy capsule, open pores are present at the top when the fruit is ripe; the wind shakes the capsule, and the minute seeds "sift" out. In Fig. 120, hairs, hooks, and barbs may be seen

that enable certain kinds of seeds or fruits to stick to passing animals, including man, that may chance to brush against them. Interesting structures are produced by certain water plants that enable their seeds to float on or near the surface for long distances. Coconuts are light because of the air they contain (Fig. 121). The material of which the husk is composed is said to be resistant to salt water. Also, in Fig. 121, the curious "raft" of the lotus plant may be seen.

c. Dispersal of Seeds by the Action of the Fruits.—Figure 117 gives some idea of the "explosive" action of fruits. Various fruits open with such force as to scatter the seeds far and wide. The "squirting cucumber," for example, "shoots" its seeds into the air. When the cucumber is ripe, it drops from the stem, and the seeds are forcibly ejected through the place

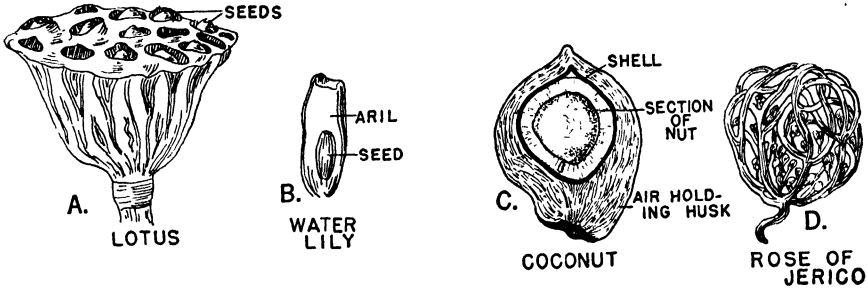


Fig. 121.—Distribution of fruits by water. Fruits of this kind have various devices which adapt them to float in water. (Redrawn by B. Shamos from Ganong, A Textbook of Botany, The Macmillan Company.)

formerly "plugged" by the stem (Fig. 117*D*). Only a few of the various types of structures that aid in the dispersal of fruits and seeds have been mentioned. Many other methods occur by which seeds "find their way around." Many of these ways may be observed on walks through the woods.

C. How Seeds Wake Up—Germination.—As has been said, a fully developed seed remains dormant until conditions are favorable for it to develop further. The embryo is already present in the seed together with a certain amount of stored food (endosperm) for its use.

1. Time Necessary for Germination.—Some seeds will not germinate until they have passed through a "rest period." This is particularly true of wild seeds. On the other hand, some seeds will germinate as soon as they become mature, even without waiting to be planted. Some of the cereals, such as wheat, oats, etc., will germinate in the shocks in the fields if the weather is very wet and thus ruin the crop. The germination of seeds as soon as they are mature is characteristic of many cultivated plants. This has probably resulted from the fact that man has selected for his use plants whose seeds germinate readily.

Sometimes seeds will not develop for a time even when conditions that favor germination are present. This may be due to the character of the seed coat, which may not be permeable to water or oxygen, both of which the seed must have. In nature, freezing or the action of bacteria and of other plants may aid in cracking or destroying the seed coat, thereby making it more porous. Another cause of delayed germination is the condition of the embryo itself, which may not be mature when the seed is ripe or may require certain chemical changes before it germinates. The dormancy of seeds may also be prolonged by external conditions, such as temperature and dryness.

2. CONDITIONS NECESSARY FOR GERMINATION. *a. Water* must be absorbed in great quantities before germination takes place, yet there must not be too much water, since that would exclude the oxygen.

b. Oxygen is necessary for respiration. All living things respire; *i.e.*, oxygen is taken in and used in oxidation, and carbon dioxide and water are given off. Oxygen is thus needed for the "burning," or oxidation, of the food. In the process, energy is liberated in addition to carbon dioxide and water. A simple experiment will illustrate the giving off of carbon dioxide and heat that represents excess respiratory energy. A small beaker of lime water is placed in a vessel containing germinating seeds. After a time, the lime water will become milky, showing that the carbon dioxide has entered into a chemical reaction:

$$\underset{\text{calcium hydroxide (lime water)}}{Ca(OH)_2} + \underset{\text{carbon dioxide}}{CO_2} \rightarrow \underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{water}}{H_2O}$$

The milky precipitate is calcium carbonate. If a thermometer is placed in a bottle containing germinating seeds, it will register a rise in the temperature. If seeds are buried too deeply in the soil, they will not germinate because of lack of oxygen.

c. Temperature.—The third factor necessary for the germination of seeds is a proper temperature. Seeds vary in their requirements in this respect, as they do in everything else, but the majority react most favorably in temperatures ranging from 25 to 30°C.

3. LENGTH OF LIFE OF SEEDS.—Seeds vary greatly in length of life. Experiments have been conducted that prove that some seeds will germinate after a hundred years, but most seeds cease to live after a few years. The stories of seeds supposed to have germinated after being in the tombs of Egyptian mummies for thousands of years appear to be untrue.

IV. The Seedling

It has been observed that the germination of a seed involves processes that are very complex; water is absorbed, digestion of stored food begins, and the seed increases greatly in size.

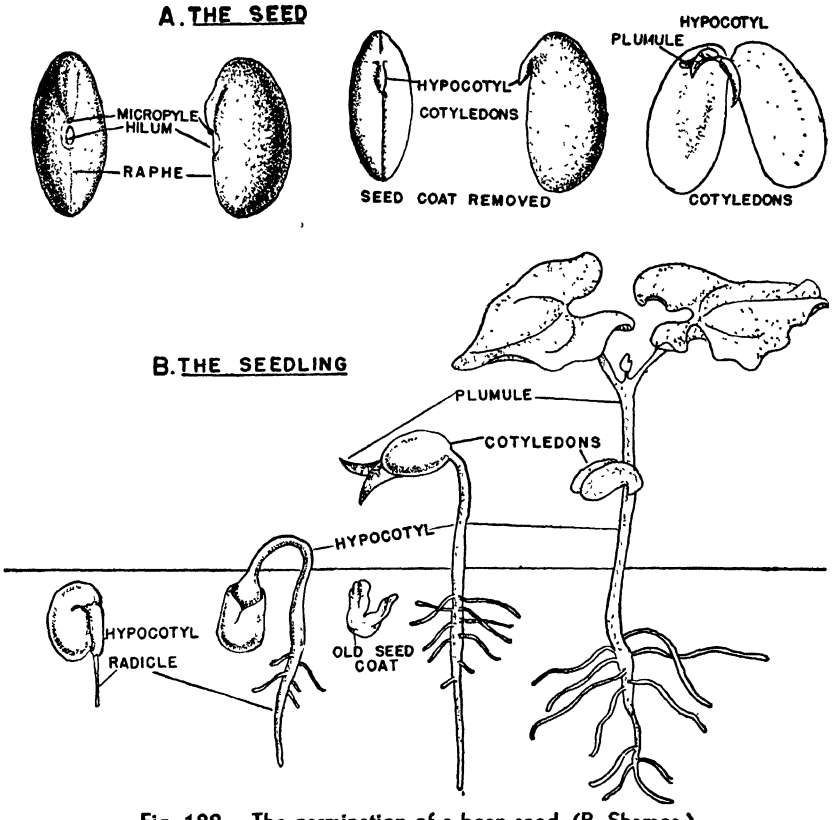
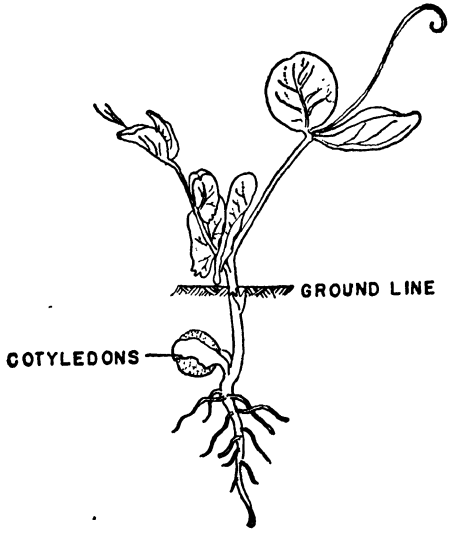


Fig. 122.—The germination of a bean seed. (B. Shamos.)



A. Growth of Embryo and Seedling. 1. CHANGES IN THE STORED FOOD.—Before the young plant comes out of the seed, even partially, many changes must take place within. The food, mentioned so often, is

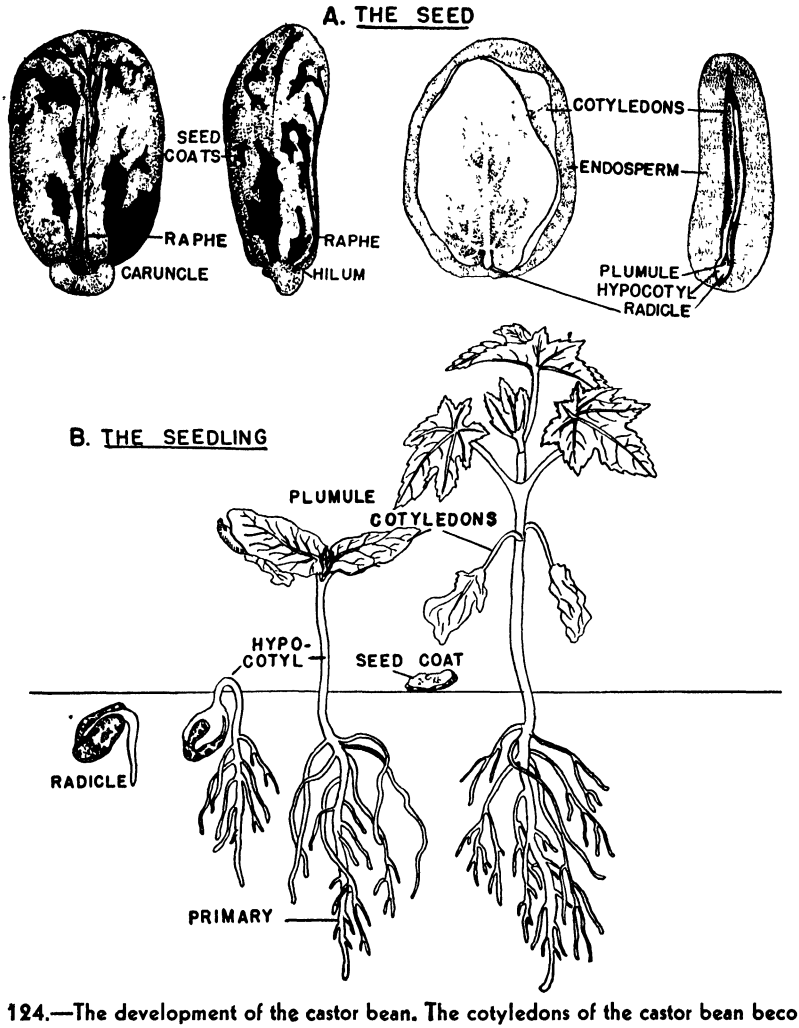


Fig. 124.—The development of the castor bean. The cotyledons of the castor bean become green. (B. Shamos.)

usually stored by the plant in the form of starch. Starch is a remarkable substance that possesses many qualities enabling it to serve the plant efficiently. Energy must be reserved, and starch is a compact substance in which it may be stored. But starch is practically insoluble; hence it must be converted into a soluble form before it can be utilized by the embryo; in other words, it must be digested. This is made possible by

enzymes that, as has been said, are substances produced in living cells (page 23). Minute quantities of enzymes can do a great deal of work; they bring about the changing of starch to sugar without being used up

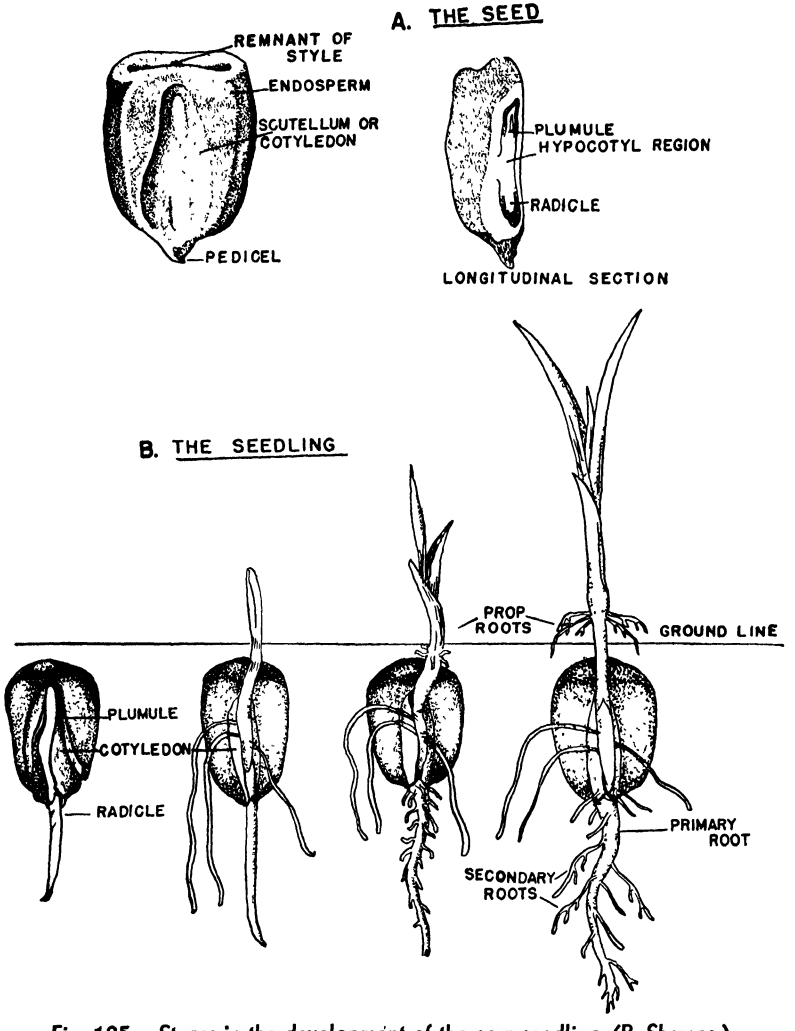


Fig. 125.—Stages in the development of the corn seedling. (B. Shamos.)

themselves. The special enzyme in plants that changes starch to sugar is diastase. Diastase is said to be a combination of several enzymes.

2. THE YOUNG SEEDLING. *a. The Radicle.*—The first structure to appear outside the seed is the *radicle* (L. *radicula*, *dim.* of *radix*, root) or root (Fig. 122). This radicle is one of the fastest growing parts of the young plant. It thrusts itself into the soil and becomes the primary root.

As soon as it becomes established, it begins to branch out and to take in mineral salts and water from the soil. These are transferred through the beginnings of the vascular system to the other developing parts of the young plant.

b. The Cotyledons and the Foliage Leaves.—As already pointed out, in some plants, such as the bean and pea, food is stored in the cotyledons. The two cotyledons of the bean "pull" out of the old seed coat and are lifted above the ground (Fig. 122); in the case of the pea, the cotyledons remain under the surface of the soil (Fig. 123). The next thing that happens is the appearance of the *plumule* (L. dim. of *pluma*, a feather) or bud. The plumule is the part of the young plant above the cotyledons. It is a bud, consisting of leaves and a stem. After the cotyledons are lifted above the ground, they become somewhat green, as in the bean and castor bean (Fig. 124), but, in all cases, they eventually shrivel and drop off. Foliage leaves develop in the meantime, and the plant can now manufacture its own food, being no longer dependent on food in the seed. Up to the time when the foliage leaves develop, the plant must depend for nourishment upon the food stored in the seed.

Young corn seedlings develop differently on account of the way food is stored in the corn grains and because they are monocots and possess, therefore, only one cotyledon (Fig. 125). When a corn grain germinates, the future root, or radicle, appears first as in the bean, but the one cotyledon never leaves grain or seed. It acts as an absorbing organ, since it is closely applied to the food around the embryo (contained in the endosperm).

Questions

1. Are the relations of the parts of a flower to each other the same in all types of flowers?
2. Aside from general interest, what useful purpose is served in knowing types of flowers and the relationship of flower parts to each other?
3. What parts of a flower are essential for reproduction?
4. What is a perfect flower? An imperfect flower? Do you think these are good names? Explain why an incomplete flower may be a perfect flower.
5. What is the most common color for flowers that bloom at night?
6. Define: sepal; petal; stamen; ovary; placenta; stigma; style; calyx; corolla; pistil; receptacle.
7. What are some of the differences between a dicot and a monocot flower?
8. Are the showy parts of a dogwood or poinsettia flower petals? Explain.
9. Compare sexual and asexual reproduction in plants. Name the types of asexual reproduction.
10. What advantages and disadvantages are there in wind pollination?
11. What are the advantages and the disadvantages of insect pollination?
12. Do you know any flowers constructed to receive some types of insect visitors and not others?
13. How do some flowers provide for cross-pollination? Self-pollination? What is the usual method? Do any flowers guard against cross-pollination? Self-pollination? Give a "running account" of fertilization. What are some consequences of fertilization?

14. What parts of a flower develop into the fruit?
15. How would you distinguish between a fruit and a seed?
16. The grape, currant, and tomato are berries. The orange, cucumber, squash, and melon are modified berries. What features do they all have in common?
17. How are seeds dispersed?
18. Give examples of various structures that aid in seed dispersal.
19. How is seed dispersal accomplished by various types of plants?
20. Why do you think that weeds are able to maintain themselves so well?
21. How do you know that seeds are alive?
22. Is the dormant period of seeds of value to the plant? Explain. At what season of the year do most seeds ripen? What are some of the reasons why some seeds have a dormant period and others do not?
23. What common plants are self-pollinated? Are there any advantages in this type of fertilization? Disadvantages?
24. What are some advantages and disadvantages in cross-pollination?
25. Explain why, if the stamens are removed from some flowers as soon as the bud opens, the flower may remain in bloom longer?
26. Give a full account of fertilization of a flower. Include in your account a statement of the role of each part of the flower.
27. What is a fruit?
28. Give examples not mentioned in the list of the following: capsule, pod, achene, nut, grain, berry, pepo, drupe, pome.
29. Name some common types of seed dispersal, giving examples.
30. Why is it an advantage to the dandelion for its flower stalks to elongate after the seeds are ripe?
31. Cracking or chipping the shell of a hard seed or fruit often hastens its germination when the seed is planted. Why?
32. What are the parts of a mature seed? What types of food may be found stored in seeds? How is this food used? What part of the seed develops into the new plant?
33. Where is the food stored in the seeds of the bean? In the seeds of corn? Of castor bean?
34. Give an account of how seeds "wake up" or germinate. What are some necessary factors for this awakening? How is the stored food made available to the young plant?
35. A cold, wet spring causes planted seeds to rot. Why?
36. Compare the early development of the young seedlings of the bean, the pea, and the castor bean. To what conditions in the seed are these differences in development due?

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B. THE PLANT GROUPS; MORPHOLOGY AND PHYSIOLOGY OF REPRESENTATIVE TYPES

CHAPTER XIV

THE SIMPLEST PLANTS; THALLOPHYTA

To the true scientist, there is no natural object
Unimportant or trifling. From the least of
Nature's work he may learn the greatest lessons.
—Sir John Herschel.

I. The Thallus Plants, Thallophyta

The thallophytes include the smallest and simplest plants, and some of these are the most important of all plants. They are the bacteria, several types of Algae, diatoms, yeasts, molds, mushrooms, rusts, slime molds, and lichens. All these plants are interesting in themselves alone, but many of them serve as food for man or are related more or less intimately to the formation of food stuffs with which man is concerned. Some of them are poisonous, and others are the agents responsible for devastating diseases in man and animals as well as in other plants.

A. Classification.—The thallophytes are divided into two great divisions, or subphyla, one with chlorophyll, the Algae, and one without chlorophyll, the Fungi.

Phylum. **Thallophyta** (Gr. *thallos*, young shoot; *phyton*, plant). Plants without roots, stems or leaves. Plant body is called a *thallus*.

Subphylum *A.* **Algae** (L. *alga*, seaweed). Thallus plants that contain chlorophyll.

Class I. Myxophyceae (Gr. *myxa*, slime; *phykos*, seaweed), or Cyanophyceae (Gr. *cyanos*, a dark blue substance; *phykos*). The blue-green Algae. Probably the most primitive of plants; no distinct nucleus; plant body may be single-celled or of cells adhering to form masses or filaments; *Glœocapsa*, *Oscillatoria* (Fig. 126).

Class II. Chlorophyceae (Gr. *chloros*, green; *phykos*). The green Algae. Cells have definite nuclei; single cells or cells adhering to form masses or filaments; *Protococcus* *Spirogyra*. *Ulothrix*, *Vaucheria* (Figs. 127 and 128).

Class III. Phaeophyceae (Gr. *phaios*, brown; *pykos*). The brown marine Algae. May become very large as *Laminaria* (160 ft.); no single-celled type known; *Fucus* (Fig. 129).

Class IV. Rhodophyceae (Gr. *rhodon*, rose; *phykos*). The red seaweed. Mostly marine; body is multicellular and may be simple or feathery; *Polysiphonia*.

Class V. Bacillariaceae (L. *bacillum*, a small rod) or Diatomaceae (Gr. *di*, two; *tome*, to cut). Classification uncertain; often included in other groups of Algae; plants have two similar parts or valves; silica present in plant body; the diatoms (Fig. 130).

Subphylum *B.* Fungi (*L. fungus*, a mushroom). Plants without chlorophyll.

Class I. SCHIZOMYCETES (Gr. *schizein*, to split; *mycetos*, Fungus). Classification uncertain; exhibit both plant and animal characteristics; fission Fungi include bacteria (Fig. 131).

Class II. MYXOMYCETES. (Gr. *myxa*, slime; *mycetos*, Fungus). The slime molds. Classification uncertain; plant body a mass of protoplasm containing nuclei but not divided into cells; a *plasmodium;* slime molds (Fig. 140).

Class III. PHYCOMYCETES (Gr. *phykos*, seaweed; *mycetos*, fungus). Alga-like Fungi. Plant body without cross walls and consisting of fine filaments (hyphae) that are multinucleate, without cross walls, *i. e.*, not divided into cells; bread mold, (*Rhizopus nigricans*, Fig. 134); the downy mildews, the water molds.

Class IV. ASCOMYCETES (Gr. *askos*, bladder; *mycetos*, fungus). The sac Fungi. Spores are produced in a sac (ascus); largest group of the Fungi; yeasts, powdery mildews, cup Fungi, the fungal component of most Lichens.

Class V. BASIDIOMYCETES (L. *basidium*, a club; *mycetos*, fungus). The club Fungi. Spores grow in club-shaped body called a *basidium;* mushrooms, puffballs, rusts, and shelf Fungi (Fig. 138).

Class VI. IMPERFECT FUNGI. A group whose relationships are uncertain.

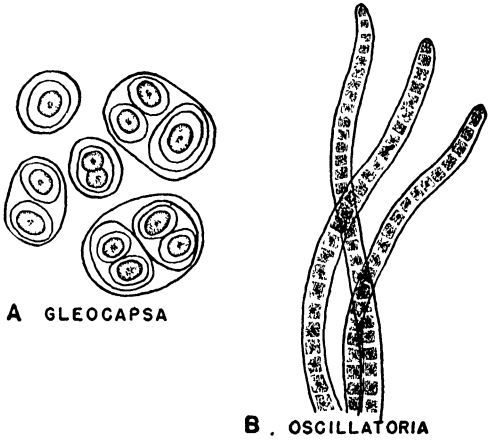

Fig. 126.—Representative blue-green algae. (L. Runyon.)

B. The Algae.—There are four great groups of the Algae, which are typically found in water or damp situations. Some of them form the familiar green stains on trees, walls, and other damp places; others produce the scums on quiet waters or the felt-like growths that cover wet stones; still others are the seaweeds, green, brown, and red.

1. THE BLUE-GREEN ALGAE, MYXOPHYCEAE, are often called *Cyanophyceae.*

a. General Features.—These are simple plants with a blue-green color. No nucleus is present in them, but chromatin grains are scattered through the cytoplasm. They may be single cells, like *Gleocapsa* (Fig. 126*A*), or may be united into filaments, like *Oscillatoria* (Fig. 126*B*). Many colonial types occur.

Since the blue-green Algae contain chlorophyll, they are able to manufacture their own food by the process of photosynthesis (page 140). Carbon dioxide is obtained from the water or from the air; a certain amount of carbon dioxide is dissolved in the water in which the plants grow. They also absorb water by osmosis (page 39). Reproduction is by asexual means only.

b. Gleocapsa.—In the unicellular forms, such as *Gleocapsa*, binary cell division is the method of multiplication. In *Gleocapsa*, the cells are surrounded by a gelatinous sheath that keeps them from drying out. Although each cell is a separate plant, the cells usually remain together after cell division and form loose colonies.

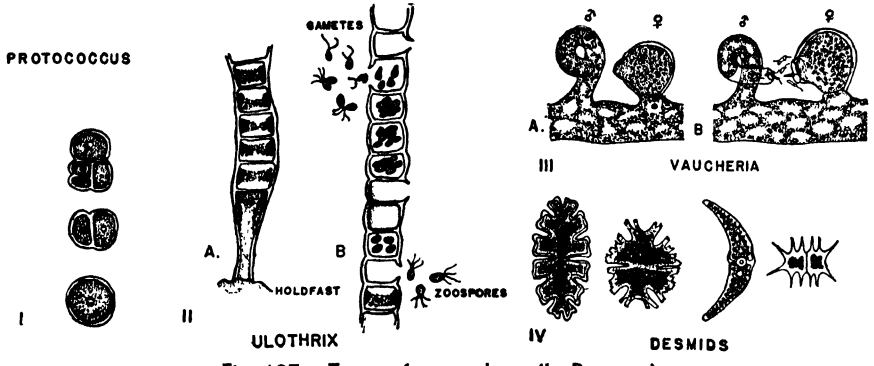

Fig. 127.—Types of green algae. (L. Runyon.)

c. Oscillatoria (L. *oscillare*, to swing).—A common representative of a filamentous type of blue-green alga is *Oscillatoria*. This plant gets its name from the fact that it moves in an oscillatory manner. A gelatinous sheath is present, as in *Gleocapsa*. It is interesting to note that the filamentous condition of *Oscillatoria* is due in part to the method of reproduction. Transverse division occurs, and the daughter cells remain attached end to end. The filaments often break, but the cells go on dividing, and the fragments broken off continue to grow in length. Another interesting feature ensures that the filament will break or fragment; certain of the cells die, thus creating a breaking point. Certain species of blue-green Algae form resting cells with heavy walls; these are fitted to withstand unfavorable conditions.

d. Summary.—The blue-green Algae, then, are simple plants that live in water or in damp situations. They reproduce by asexual methods only *i.e.*, by cell division, by fragmentation, and by the formation of resting cells. Although they are more complex than the bacteria, they are among the simplest plants. They sometimes pollute water supplies and cause disagreeable odors. This odor comes from certain oils in the plant body. Copper sulphate in very small quantities will kill these plants.

2. The Green Algae, Chlorophyceae.—This large group of plants is more varied than the preceding one.

a. General Features.—In this group are one-celled forms such as *Protococcus*, sometimes called *Pleurococcus* (Fig. 127*I*). Filamentous forms, such as *Spirogyra*, and colonial forms, such as *Volvox*, also occur. Green Algae have well defined nuclei and chloroplasts. Four examples will illustrate the advances in the complexity of the green Algae over the blue-green Algae.

b. Protococcus (Gr. *protos*, first; *kokkus*, a grain, seed). This form is found on stone walls, fences, trees, and other damp places. Large numbers of these plants together produce a sort of green stain. It is a single-celled

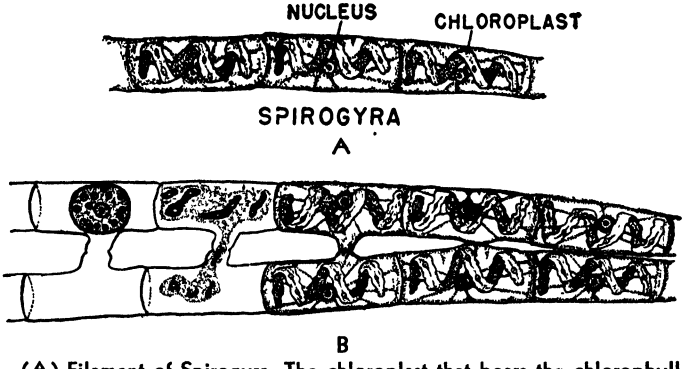

Fig. 128.—(A) Filament of Spirogyra. The chloroplast that bears the chlorophyll is in the form of a spiral band. (B) Stages in the conjugation of Spirogyra. (L. Runyon.)

plant, but the cells often remain together after dividing, giving the appearance of colonies. Since it reproduces by cell division only, it may be considered as a simple plant.

c. Spirogyra (Gr. *spira*, coil; *gyros*, ring) (1) The plant body. Spirogyra is an example of a filamentous form. It is one of the common pond scums but nevertheless a very beautiful plant, as will be seen if it is examined under a microscope. Each chloroplast in *Spirogyra* is in the form of a spiral band (Fig. 128*A*). The nucleus lies at about the center of the cell, and radiating from it are strands of cytoplasm.

(2) Reproduction. (*a*) Asexual reproduction.—The cells divide in one direction only and so form filaments. These filaments often break at the junction of the cells, and thus multiplication of filaments occurs by fragmentation.

(*b*) Conjugation.—Conjugation occurs in the following manner (Fig. 128*B*). Two filaments lie side by side, touching at various points; short tubes grow out from cells that are opposite each other; these push the filaments apart, but the ends of the tubes remain attached together, and

the walls between them break down, thus leaving a pathway. The conjugation tube is formed in this way. The contents of one of the two cells migrate through the conjugation tube and fuse with the contents of the opposite cell. The migrating cell is considered the *male* and the stationary cells, the *female*. The single cell (zygote) produced by this union possesses a heavy wall and passes through a resting period before germinating and producing a new filament. In this way, the plants can survive periods during which conditions are unfavorable for growth.

d. Ulothrix (Gr. *oulos*, woolly; *trichos*, hair).—(1) THE PLANT BODY. This is another filamentous type that grows on stones to which it is attached by holdfast cells (Fig. 127*II*). This attachment enables the plant to grow in moving water without being washed away.

(2) REPRODUCTION. (*a*) Asexual.—The type of reproduction characteristic of this plant is more complex than that in *Spirogyra*. Asexual reproduction takes place by the formation of zoospores. The protoplasm of certain cells in the filament divides from 2 to 32 times. The minute cells resulting from these divisions are called *zoospores*. These zoospores escape when the cell wall ruptures. Since they are provided with four flagella, they are able to swim about for a time; then they settle down, lose their flagella, and grow into a new plant. There are two advantages in this type of reproduction: (1) increase in numbers and (2) a wide distribution due to the swimming ability of the zoospores.

(*b*) Sexual.—Other cells in the filament of *Ulothrix* form reproductive cells (gametes) by repeated divisions of the cell contents. In this case, instead of 32 small bodies, 64 or more may be formed. These are smaller than the zoospores; each possesses two flagella. They escape from the cell in which they are formed but seem to be incapable of producing new filaments independently. Their fate is to fuse in pairs to form zygotes. After a period of rest, which usually lasts through the winter, each zygote divides to form four zoospores. A new plant develops from each zoospore. In this alga, there is no visible distinction between male and female gametes.

e. Vaucheria (named for the Swiss botanist J. E. E. Vaucher).—This alga also exhibits a complicated sexual process of reproduction. It is mentioned here because of the formation of special side branches that are really sex organs, in which are differentiated sperm and eggs. The two kinds of sex organs may be on separate plants or both on the same plant (Fig. 127III). The female sex organ is called the *oogonium* and the male sex organ, the *antheridium*. When the oogonium is mature, the ends of the beak open slightly, and a single sperm, which has escaped from an antheridium, enters (Fig. 127III, *B*). Thus fertilization is accomplished. The sperm is a minute, flagellated cell that may swim widely before finding a mature, unfertilized egg; the egg is a large nonmotile cell.

f. Summary.—Four plants belonging to the green Algae have now been examined, each exhibiting an increase in complexity over the one before in its method of sexual reproduction. For example, in *Protococcus*, there is no sexual reproduction; in *Spirogyra*, conjugation takes place; in *Ulothrix*, the swimming gametes unite in pairs to form the zygote; and in *Vaucheria*, definite sex organs and differentiated male and female gametes are formed.

Many animal-like forms such as *Euglena*, *Volvox*, etc., are sometimes classed here. These "borderline" organisms will be discussed with the Protozoa. Here, too, are included the beautiful desmids (Fig. 127IV).

3. The Brown Algae: Phaeophyceae. *a. General Features.*—As the name implies, most of the plants in this large group are brown in color. All of them are marine in habit. No single-celled forms are known. Brown Algae vary in size from those that are almost microscopic to the giant kelps that are as long as very tall trees are high. Some of the larger brown Algae may reach a length of 160 ft. Usually the plant is anchored by a strong holdfast at the base (Fig. 129). At high tide, the expanded portions float on the water. This is due to the presence of hollow stems or air bladders. Some of the brown Algae are simple, whereas others possess structures that resemble those of the higher plants.

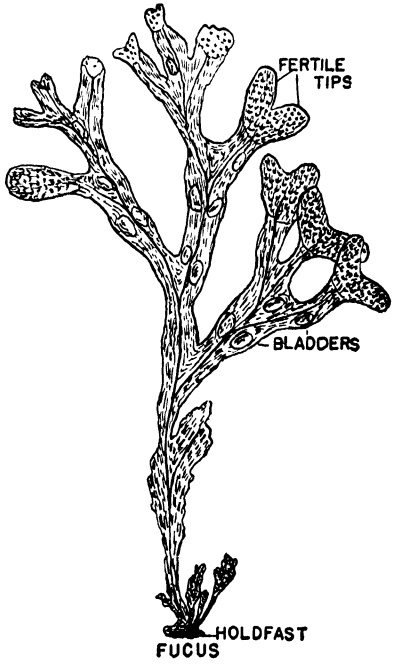

Fig. 129.—Rockweed (Fucus), a brown alga. (B. Shamos.)

b. Fucus.—The rockweed, *Fucus* (Gr. *phykos*, seaweed), is a good representative of the brown Algae. The body of *Fucus* is a ribbon-like thallus. This common brown seaweed has a ribbon-like thallus, branched *dichotomously* (Gr. *dicha*, in two). It is provided with air bladders that enable it to float in the water and is anchored by a holdfast. Sex organs are also present. These occur on the tips of the branches (Fig. 129). The female oogonium and the male antheridium may be on separate plants, or both may be on the same plant, depending upon the species. Sex cells, eggs and sperm, are not of the same size, the sperm being much smaller. When the eggs are mature, they are set free into the water but are nonmotile. The motile sperms, which are also set free, surround them.

One sperm fuses with each egg, and thus the zygotes are formed. These develop immediately into new plants.

4. The Red Algae—Rhodophyceae.—These beautiful plants are the most complex of all the thallophytes. All of them consist of more than a single cell. They live in warmer and more quiet waters than do the brown Algae. They resemble the brown Algae in being attached to the rocks near the shore. Their red color masks the green chlorophyll.

Both asexual and sexual reproduction occur but the processes are too complicated to be considered here. One peculiarity of the red Algae should be mentioned; they exhibit a *definite alternation of generations; i.e.*, an asexual generation alternates with a sexual generation. Agar, which is used in making up artificial culture media for growing bacteria and is also used in medicine, is an extract of red seaweed.

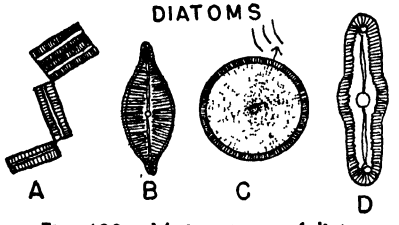

Fig. 130.—Various types of diatoms. Note fissure down the center of each plant. In (C), the "pill-box" type, the fissure is on the edge. (B. Shamos.)

5. The Diatomaceae (page 180). Diatoms occur almost everywhere. They may be found in vast numbers in both fresh and salt water and serve as food for countless other organisms. One of their distinguishing characteristics is the presence of a silicious shell. These shells, examined under the microscope, are seen to be beautifully sculptured (Fig. 130). They persist after the protoplasm within has died, and in some places, such as at the bottom of ponds and on the ocean floor, diatom shells have accumulated in such vast quantities as to form what is called *diatomaceous earth*. This type of "earth" is used as an abrasive in scouring soaps, as insulating material, etc.

Sometimes diatoms are classified with the brown Algae on account of their color; or with the green Algae on account of the fact that their reproductive processes somewhat resemble those of the desmids.

C. The Fungi.—The Fungi comprise a large and varied group of plants that are exceedingly important to man. To this group belong thallus plants that do not have chlorophyll. About 70,000 have been described. Included in this large group are not only the mushrooms and toadstools but also the mildews, molds, and rusts, so important because many of them destroy crop plants.

Fungi are classified as thallophytes on account of the character of their tissues and because their methods of reproduction are similar to those of the Algae.

All Fungi are either *parasitic* or *saprophytic*.

1. The Bacteria; the Schizomycetes.—The simplest plants are the bacteria and the blue-green Algae. These are sometimes classed together as the *fission plants*. Bacteria do not possess chlorophyll and are

like the Fungi is this respect. For this reason, they are often classed with the Fungi.

a. Discovery of Bacteria.—The first person really to see bacteria was a Dutch dry-goods merchant named Leeuwenhoek. In 1683, he examined the tartar from his teeth and saw some rod-shaped bodies that are now called bacteria. The great Pasteur proved in 1864 that boiled (and hence sterilized) fruit juices would remain free of bacteria if kept free from contamination. Pasteur's work was questioned at first, but he lived to see it accepted.

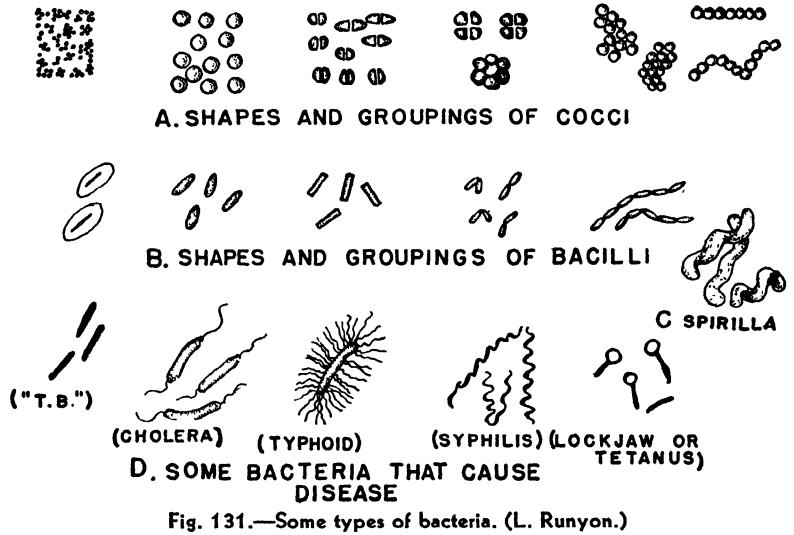

Fig. 131.—Some types of bacteria. (L. Runyon.)

Another great discovery was that of Robert Koch, in Germany, who first saw, in 1882, the bacteria that cause the "great white plague," tuberculosis. Since this chapter is concerned with bacteria as living organisms, further discussion of bacteria in relation to disease, industry, etc., will be left until later (pages 806, and 847–849).

b. The General Characteristics of Bacteria.[1] (1) WHAT THEY ARE.—Bacteria exist almost everywhere. They are often spoken of as "germs" or "microbes." These terms are used in a loose way, however, and include plants, such as yeasts, as well as certain other plants and one-celled animals. They may be responsible for serious trouble or may be harmless or may be almost indispensable. If it is possible to state that anything living is simple, it may be said that the bacteria are simple plants.

(2) SIZE.—Bacteria are the smallest living things that can be seen with the most powerful microscopes. Many of them are too small to be

[1] A widely distributed bacteria-destroying agent, *bacteriophage*, is normally present in blood, urine, intestinal tract, etc., of man. Though its real nature is unknown, it is usually considered to be a virus.

seen with the usual compound microscope; the point of a pin will hold thousands of them. The largest is about $\frac{1}{250}$ in. long; the smallest *known* is only about $\frac{1}{250,000}$ in. long.

(3) FORMS.—Three principal types may be recognized (Fig. 131): (1) Spherical or *coccus* forms. These may be single, in pairs, *diplococci*, in chains, *streptococci*, or in clumps, *staphylococci;* (2) *bacilli*, which are rod-shaped and which may be single, or in chains, *streptobacilli;* some of these may have a gelatinous covering that makes the solution containing them slimy; (3) *curved forms*, or *spirilla*. Certain bacteria possess flagella that enable them to swim in a liquid medium.

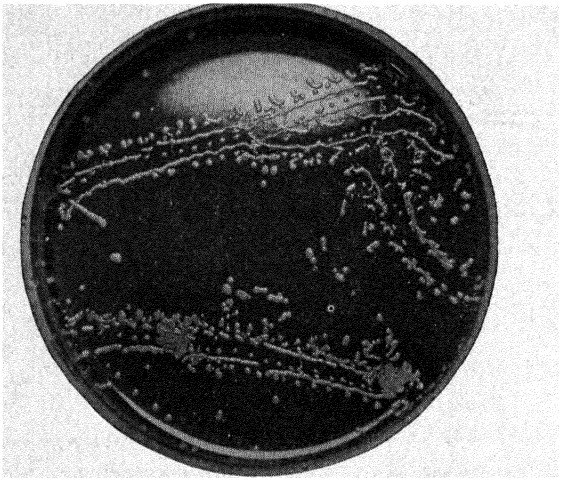

Fig. 132.—A fly walked across a sterile agar plate, then the plate was placed in an incubator overnight. Colonies of bacteria appeared wherever the foot of the fly touched the plate. (Dr. E. Gambrell.)

c. Identification.—In addition to studying bacteria with the aid of a microscope, one of the best ways of identifying them is to culture them. Some of them form characteristic colonies on sterile culture media; others form gases, etc. An expert bacteriologist can identify many bacteria by the way they affect the culture media in which they are growing.

d. Reproduction in Bacteria. (1) BY CELL DIVISION.—*Bacteria* do not reproduce by a sexual process. The usual method of multiplication is by *cell division*. Certain forms may divide as often as every 20 to 30 minutes; hence multiplication is very rapid. If all the descendants of a single bacterium lived and reproduced at the same rate, in 24 hours there would be 17 million and in two days, 281 million. Fortunately, various agencies check this prolific reproduction; the food supply gives out, or an accumulation of their own wastes in the medium in which they are

growing retards growth and reproduction. If a fly is allowed to walk across a sterile culture plate and the plate is then placed in an incubator for 24 hours, the result will be as shown in Fig. 132. This experiment demonstrates two things: (1) the foot of a fly carries bacteria, and (2) bacteria multiply rapidly.

(2) By spores.—Under certain conditions, bacteria form spores. These can withstand drying and high temperatures, and ordinary methods

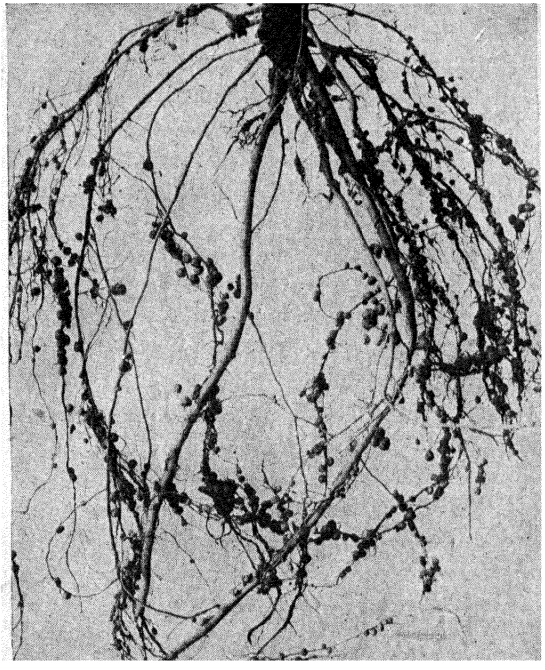

Fig. 133.—Roots of a soybean (Glycine) plant showing abundant development of nodules formed by nitrogen-fixing bacteria. (Farmer's Bulletin 1520, U.S. Department of Agriculture.)

of sterilization do not kill them. Some of these spores can withstand boiling for 16 hours and afterward, when conditions become favorable, are able to grow and reproduce.

e. Methods of Getting Food.—Bacteria do not possess chlorophyll. On this account, like certain plants and most animals, they must obtain their food from organic matter, which may be living or dead. Those that feed on living organisms are parasites; those which feed on dead organic matter are *saprophytes* (Gr. *sapios*, rotten; *phyton*, plant). To be absorbed by any living organism, food must be in such simple form as to pass through membranes. In bacteria, the membrane is the cell wall of the plant. Food is transformed and liquidified through the agency of enzymes, which the

bacteria secrete and pour out on the food to be absorbed. This explains why the parasitic bacteria that feed on living hosts cause so much damage. A few bacteria are known that, like green plants, can build up protoplasm from purely inorganic materials. An example of this is one of the sulphur bacteria. Such an organism is simpler than the simplest green plant.

f. Relation of Bacteria to Soil.—It has been known since the time of the Romans that peas, beans, and other leguminous plants cause enrichment of the soil. The reason for this was not known. The fact is that roots of such plants contain nodules (Fig. 133) in which live special types of bacteria. These are called the *symbiotic nitrogen* fixers. They enter the plant through the root hairs. Symbiosis may be defined as the living together of two organisms to the mutual benefit of both (page 54). The nitrogen fixers are able to take the nitrogen from the air that is present between the soil particles and build it into proteins or other compounds available to the plant.

g. Role of Bacteria in Decay.—The role of bacteria as scavengers is very important. When an organism dies, it "returns to the earth from whence it came." Many raw materials are used in the building up of protoplasm; these are returned to the earth again to be used in building the protoplasm of other living things. This process, which is commonly called *decay*, is largely the work of bacteria. No matter whether accident or disease "turned out the light," bacteria are present and begin the work of decomposition immediately after death occurs.

The decay of certain products, such as ice cream and fish, may give rise to poisonous substances known as *ptomaines* (Gr. *ptoma*, deadly body). Ptomaine poisoning, however, is rather rare, most supposed cases being botulism or, still more common, food-borne infection.

Bacteria play an important part in the maintenance of the carbon and nitrogen cycles (Figs. 36 and 37). From this it naturally follows that they are important in the interrelations of plants and animals.

h. The Economic Importance of Bacteria.—Bacteria play an important role in industries; for example, in the making of liquors, wines, and vinegar, as well as the souring of milk, in the ripening of cheese, in the making of sauerkraut, in the "curing" of tobacco, in the separation of the fibers of hemp and flax from other parts of the plant (*retting*), and in the tanning of hides, etc. In solving the problems of sanitation, sewage disposal, and disease control, a knowledge of bacteria and their ways is indispensable.

i. Bacteria in Relation to Disease.—It is common knowledge that bacteria cause many diseases of both plants and animals. Indeed, the scope of their activities is so great that a large part of the science of bacteriology is devoted to the study of this class of bacteria, the *pathogenic* (Gr. *pathos*, suffering; *genesis*, to produce) bacteria. Problems of

sanitation, sterilization of drinking water, pasteurization of milk, and many other sanitary measures have to do with control and spread of disease. Before the relation of bacteria to infection was discovered, there

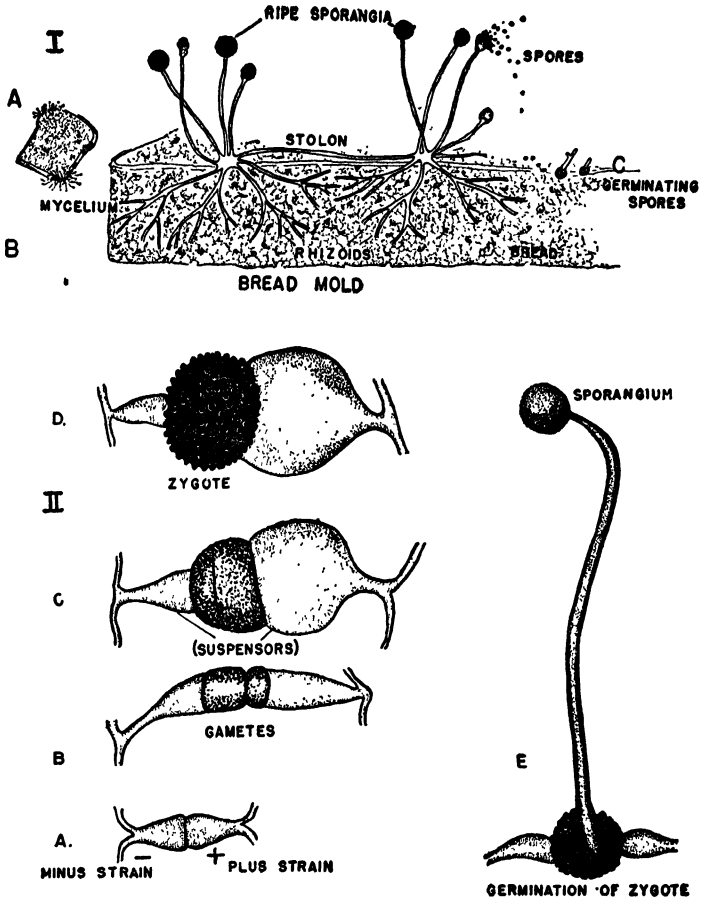

Fig. 134.—(I) Bread mold (Rhizopus nigricans). (A) Bread mold growing on bread. (B) Enlarged portion of mature plant showing plant body and sporangia. (II) Sexual cycle in the bread mold. If plus and minus strains grow in the same situation, the tips of the aerial hyphae will come together, fuse, and form a zygote. When mature, the zygote germinates and a new plant begins its growth. (L. Runyon.)

was very high mortality in surgical cases. Some of the most common diseases caused by bacteria are typhoid fever, tuberculosis, pneumonia, tetanus, and many others (see Chap. XLVIII).

2. Algae-like Fungi, Phycomycetes, the Filamentous Fungi. *a. General Characteristics.*—Although this group of Fungi resembles the Algae in some ways, Fungi have no chlorophyll. Examples of this group

are the bread mold (Fig 134) and water mold (Fig 135). There are about 330 species

The individual branches of the plant body, or filaments, are called *hyphae* (sing *hypha*, from Gr *hyphe*, a web) A group of hyphae form a *mycelium* (Gr *mykes*, fungus) or plant body Root-like structures called *rhizoids* attach these plants to the substratum.

b. Bread Mold—A good example of the life cycle of this group is found in the bread mold, *Rhizopus nigricans* Examination of Fig 134 illustrates the life cycle of the bread mold This saprophyte is easily obtained for study by exposing a damp piece of bread to the air So many spores of the bread mold are floating about in the air that a white felt-like growth soon appears on the bread that has been exposed After a few days, the mycelium produces erect branches At the tip of each branch a swelling appears These are white at first but soon turn black The swellings are the sporangia or spore cases; in them spores are formed. When the spores become mature, the walls of the sporangia rupture, and the light spores are carried away by air currents If these spores chance to encounter a favorable medium, they germinate, and new plants are produced This is the asexual generation

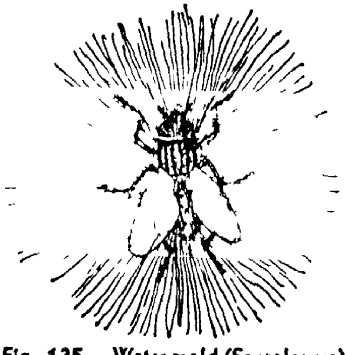

Fig. 135—Water mold (Saprolegnia) growing on a dead fly (B Shamos)

Rhizopus plants may differ from one another, some are said to be *minus* and other *plus* strains The hyphae of these two types of strains may conjugate, thus beginning a sexual process Such a conjugation results in the formation of a body known as a *zygospore* This zygospore (Gr *zygos*, united, *sporos*, seed) possesses a thick wall, goes through a resting stage, and then, when conditions are favorable, germinates to form a new plant (Fig 134*II*) The asexual type of plant continues to live and grow indefinitely, as long as conditions are favorable The sexual generation does not appear unless plus and minus strains, which may be compared to male and female, conjugate

3. Sac (or "Cup") Fungi, the Ascomycetes—This is a large group of about 20,000 species They include such common forms as *yeasts*, true *molds*, *mildews*, and *blights*

a General Features—The spores of these plants are borne in sacs or asci It is an important group, because it includes many plants that cause diseases of plants that are economically important Many of them are useful to man, however, the molds in the making of cheeses, the yeasts in fermentation, etc.

b. Yeasts.—Yeasts are small one-celled plants. Reproduction among yeasts is by budding. Sometimes these buds remain together, forming chains that appear to branch (Fig. 136). Each of the cells can lead an independent existence, however. Yeast cells cause *fermentation.* This is a part of the respiratory process due to the presence of enzymes produced by the yeast cells (Fig. 137). In breadmaking, the *yeast* cells develop in all parts of the dough. They cause fermentation of the sugars in the dough through the agency of enzymes. What happens is that the enzymes oxidize a part of the sugar present into carbon dioxide and alcohol. In this way, the yeast obtains the energy that it needs. The alcohol formed is vaporized and driven off by the heat. The carbon dioxide is also driven off by the heat, but it accumulates in bubbles and "raises" the bread as it is making its escape (Fig. 137*C*). High temperatures kill the yeast plants and also change some of the starch to dextrin, which is more digestible than starch. Sometimes yeast added to the dough contains acid-forming bacteria. These change part of the alcohol to acetic acid, and sour bread is the result.

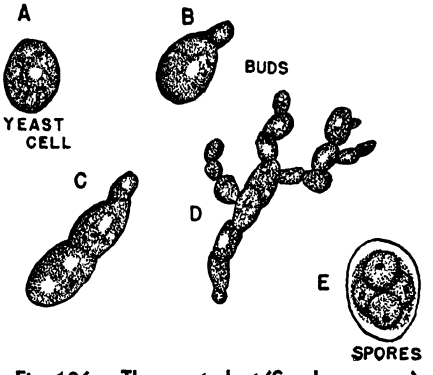

Fig. 136.—The yeast plant (Saccharomyces). (A) Single cell. (B and C) Budding yeast cells. (D) Filament formed by budding, the resulting cells remaining attached to each other. (E) Spores in a single cell. (B. Shamos.)

Yeasts are the agents that cause fermentation in solutions containing carbohydrates and so are used in the manufacture of beer from sprouted barley, wine from fruit juices, and cider from apples. Bacteria and Fungi may also cause fermentation.

c. Lichens.—A lichen is a combination of an alga and an ascomycete fungus. They are usually to be found growing on rocks, trees, etc. The fungus forms the plant body within which the alga cells are enclosed and kept more or less moist. The result is a plant that is grayish green in color (Fig. 31). The alga can utilize sunlight for the manufacture of food by photosynthesis, and the fungus keeps the green alga moist by enclosing it in its body. In this way, lichens can grow in places where neither plant could grow alone. The alga is able to grow alone if conditions are favorable, *i.e.*, if moisture and light are present; and the fungus is able to grow alone if the proper food is available. From the alga, the fungus obtains organic materials that it cannot synthesize for itself.

Lichens multiply in a peculiar manner. Small bits break away from the plant and are blown about by the wind or distributed by insects and

other animals. These pieces produce new plants if they encounter favorable conditions.

Lichens often cover rocky surfaces. The acids they produce dissolve away the rock; then the plant dies, adding its body to the crumbled rock and thus forming a tiny patch of shallow soil.

The manna mentioned in the Bible (Exodus, 16–35 and Numbers, 11: 6–9) is supposed to have been one of the lichens (*Lecanora esculenta*).

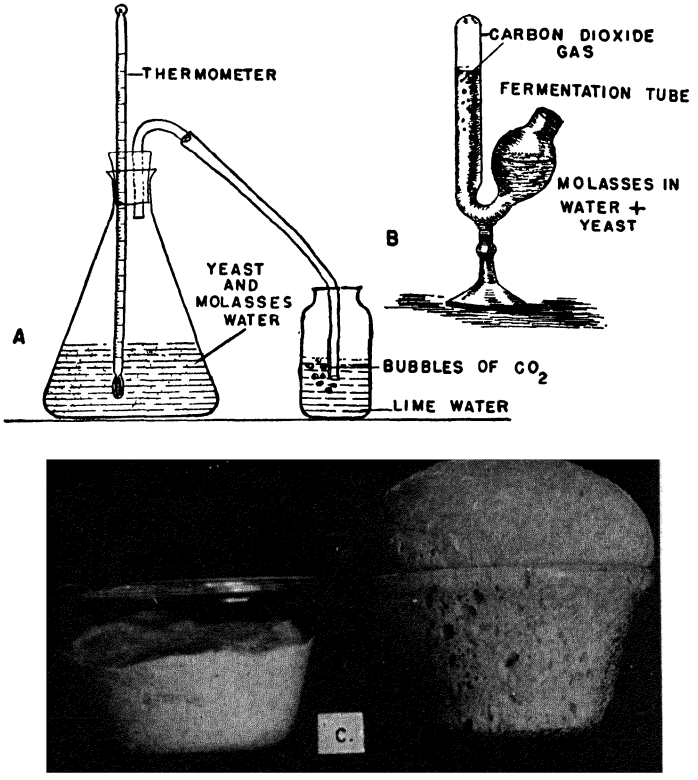

Fig. 137.—Experiments to demonstrate fermentation. (A and B) Growing yeast gives off both carbon dioxide and heat. (C) Yeast has not been added to the dough on the left while it has been added to the dish on the right. (Dr. E. H. Runyon.)

This species grows on rocks in wrinkled masses. It may be distributed either by being broken away and carried off by the wind or by being washed into depressions by heavy rains.

4. Club Fungi; Basidiomycetes.—This, also, is a large group including about 20,000 species.

a. General Features.—The spores, instead of being borne in a sac or ascus, are borne in a club-shaped body, the *basidium*. In this group are found the mushrooms, puffballs, etc.

b. Mushrooms are of special interest because some of them are used for food and others are deadly poison. For a long time France was the center for growing mushrooms, but of late years quite an industry has grown up in the United States. From 15 to 20 million pounds are raised in and around Philadelphia yearly. Often one hears of people being poisoned as a result of eating one of the poisonous varieties of mushroom. Most of the poisonous varieties belong to the genus *Amanita.*

Figure 138 represents the development of a mushroom. Spores are shed from the gills. These fall to the ground, where they germinate, forming a thread-like mycelium. As the mushroom grows, the veil that

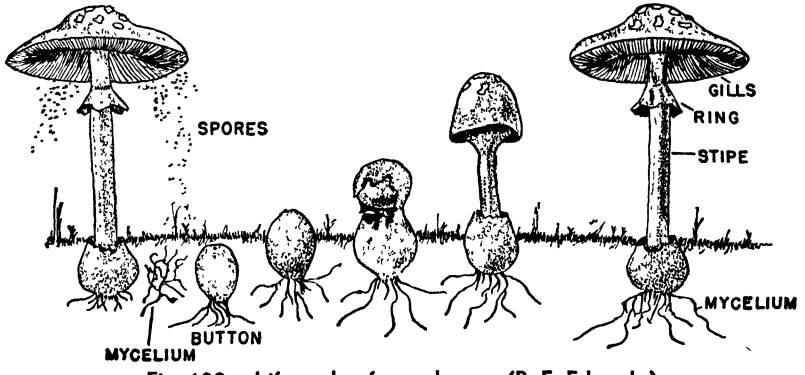

Fig. 138.—Life cycle of a mushroom. (B. F. Edwards.)

encloses the plant breaks; and the stem with the cap emerges and grows to maturity.

c. The Wheat Rust (*Puccinia graminis tritici*).—The stages in the complicated life cycle of this plant are illustrated in Fig. 139. It is interesting to note that the rust grows on such different plants as the barberry and the wheat, and that different stages occur on each plant. The name wheat rust comes from the color of the summer spores. The life cycle of many parasites is quite complex and often difficult to unravel. That of the wheat rust is an excellent example. Beginning with the blotches on the barberry, it has been found that these blotches are *cups*, produced by the rust, that contain many *cluster cup spores* (*aecidiospores*). Some of these spores may be carried by the wind or by insects to wheat fields, where they germinate, sending their mycelia through the stomata and into the leaves and stems. The rust plant grows inside the wheat plant. When mature, it produces *summer spores* (*uredospores*), which are rusty in color. These spores appear when the leaves crack open and infect other wheat plants. The resulting mycelia produce other *uredospores*, and this cycle may be repeated many times. As a result, millions of

wheat plants may be injured. Late in the summer, the wheat-rust plant produces another type of spore, the *winter* (*teleutospore*, or *teliospore*) spore. These spores are black and consist of two cells. They remain dormant all winter on the stems of the wheat stubble. In the spring, each of the two cells germinates to produce still another type of spore

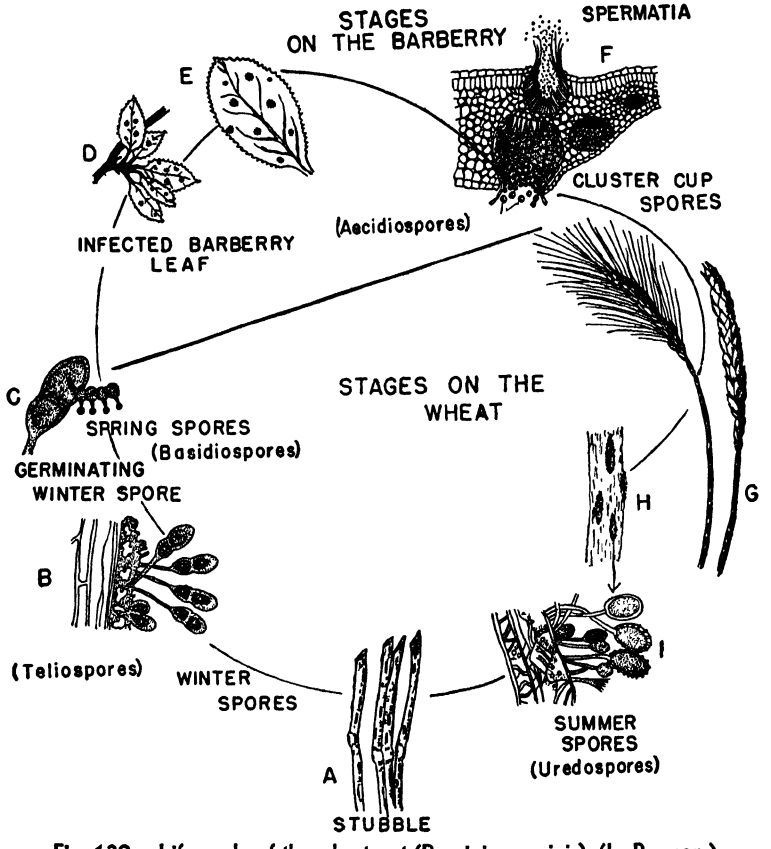

Fig. 139.—Life cycle of the wheat rust (Puccinia graminis). (L. Runyon.)

(*basidiospore*), which infects the young leaves of the barberry. Here a type of sexual union occurs that produces binucleate hyphae. *Cluster cup* (binucleate) spores are produced by the binucleate hyphae. These are the *aecidiospores*, which infect the wheat, and so the cycle begins over again.

5. The Slime Molds; Myxomycetes.—The slime molds (Fig. 140) are very difficult to classify, because they have both plant and animal characteristics. They are very similar in many ways to *Amoeba* (page 270). Instead of one nucleus, they contain many nuclei. The body is capable of movement and may respond to certain stimuli by flowing

around and engulfing foreign particles. Slime molds resemble plants in their methods of reproduction. They produce spores as plants do. Most of them are saprophytes.

6. The Imperfect Fungi.—In addition to the recognized classes of the Fungi, there are a large number whose relationships are obscure. They are called imperfect, because many of the stages in their life cycles

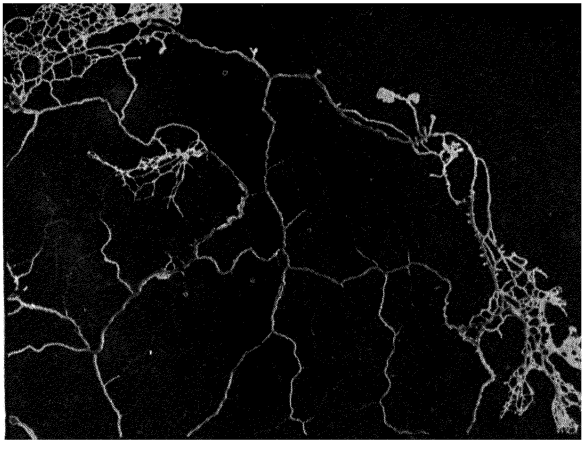

Fig. 140.—A slime mold. (Dr. E. H. Kunyon.)

have not been found as yet. They may, or may not, have these stages. Many of the imperfect Fungi are pathogenic.

II. Biological Principles and Problems Illustrated by the Thallophyta

A. Independent and Dependent Plants.—It has been pointed out several times that the Algae manufacture their own food and are, therefore, independent and that Fungi are *saprophytes* (page 190). It seems reasonable to suppose that first plants must have been independent, something like the types of bacteria capable of synthesizing their own food (*autropic*) and that dependent plants arose by adaptation to their mode of life.

B. Saprophytes.—Most of the saprophytic plants (page 155), or dependent plants, belong to the Fungi. An exception is the Indian pipe (Fig. 104).

C. Symbiosis.—Whether symbiosis and parasitism are degrees of the same principle or not, a beautiful example of symbiosis is furnished by the lichens (page 193). Here the alga is protected from drying out and is held in place. It gives to the fungus the organic substances that it needs but that it cannot manufacture for itself.

D. Parasites.—The parasitic mode of life is common among the bacteria molds, mildews, rusts. As is the case with animal parasites, many parasitic forms have very complicated life histories, involving more than one host, as the wheat rust.

Questions

1. What are the three main types of bacteria?
2. How do bacteria obtain the oxygen that they need?
3. How do the bacteria reproduce? What hinders indefinite multiplication?
4. Some bacteria, even after being boiled, may develop in foods and in solutions. Why?
5. Why do not dried fruits, vegetables, and meats decay? What is meant by "smoking" meat?
6. What conditions favor the development of bacteria?
7. Why are fruits and vegetables shipped in refrigerated cars?
8. How does yeast cause bread to "rise"? Why is bread put in a warm place to "rise"? Is bread dough usually mixed with warm or cold water or milk? Explain.
9. What are some of the products of fermentation? Explain just what fermentation is. Are yeast plants the only plants that cause fermentation? Will fermentation, once started, continue indefinitely?
10. Sugar is often added to bread dough. Is there any method by which sugar may be formed in the dough?
11. What products of fermentation are driven off when bread is baked? In what form are they?
12. What vitamins are present in yeast?
13. Branches of the mycelium of the bread mold penetrate moist bread; how must the solid foods of the bread be changed before this fungus can absorb them? How does the bread mold bring about this change? If the bread were dry, could this change take place?
14. What is meant by "plus" and "minus" strains of bread mold?
15. Compare *Spirogyra* and bread mold with respect to their manner of obtaining food.
16. Why do we think that the green Algae are a higher type of plant than the blue-green Algae?
17. Describe conjugation in *Spirogyra*. Which gamete may be considered the male? Which the female?
18. What is the difference between the type of sexual reproduction of *Ulothrix* and that of *Vaucheria*?
19. What products are obtained from brown seaweeds?
20. What is a spore? What is the difference between a spore and a seed?
21. Give an account of the life cycle of a common mushroom. The bread mold. The wheat rust.
22. What are slime molds? Why are they called *borderline organisms*?
23. No Algae live at great depths in water. Why?
24. What are lichens? What is the role of each of the partners in this combination?
25. Why are the blue-green Algae sometimes classed with the bacteria? Why are the bacteria often classed with the Fungi?
26. What are some problems connected with the three modes of life: saprophytic, symbiotic, parasitic?

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CHAPTER XV

BRYOPHYTA AND TRACHAEOPHYTA

The Night is mother of the Day
The Winter of the Spring
And ever upon old Decay
The greenest mosses cling.
—WHITTIER.

I. Liverworts and Mosses; Bryophyta

This is the second of the great plant groups. They are low, green plants found in many kinds of situations. There are two large groups, the *liverworts*, usually delicate plants, which require moist environments, and the true mosses, which form the familiar carpets of our woods.

A. Classification.

Phylum **Bryophyta** (Gr. *bryon*, moss; *phyton*, plant). No true vascular system.

Class I. HEPATICAE (L. *hepar*, liver). The liverworts. Thallus bodies, so named from fancied resemblance to the liver; *Marchantia* (Fig. 141).

Class II. MUSCI (L. *muscus*, moss). The true mosses. Gametophyte has erect stem and spirally arranged leaves; no true roots; mosses (Fig. 143).

B. Liverworts; Hepaticae.—The liverworts were so named because the plant body was supposed to resemble the liver in form. In olden times, plants were often named after the parts of the body they were supposed to resemble.

1. MARCHANTIA.—*Marchantia*, a good example of the liverworts, grows in damp, shady places.

a. The Plant Body.—The body is flat and is notched at the ends (Fig. 141). These notches represent growing points. Each growing point may fork or branch, but the plant usually grows to be only from 2 to 3 in. long. No true roots are present, but the thallus-like body is attached to the earth by means of rhizoids. The upper surface of the plant is covered with an epidermis in which are pores, or openings, that, like the stomata of the higher plants, provide for ventilation.

b. Reproduction. (1) VEGETATIVE REPRODUCTION.—Two types of *Marchantia* plants occur, male and female. Both types bear cupules in which are to be found asexual reproductive bodies (gemmae) (Fig. 141). When these gemmae, or buds, fall on soil that is favorable for their growth, new plants develop from them.

(2) SEXUAL REPRODUCTION; THE GAMETOPHYTE.—Figure 142*A* and *D* shows the difference between the "umbrellas" that grow on each plant. On the underside of the "umbrella" (gametophore) on the female plant are the female sex organs, or *archegonia* (sing. *archegonium*, Gr., *arche-*

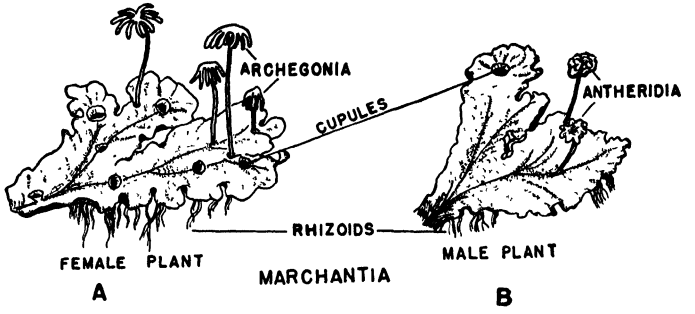

Fig. 141.—Male and female plants of Marchantia. Special asexual reproductive bodies (gemmae) are in the cupules. (L. Runyon.)

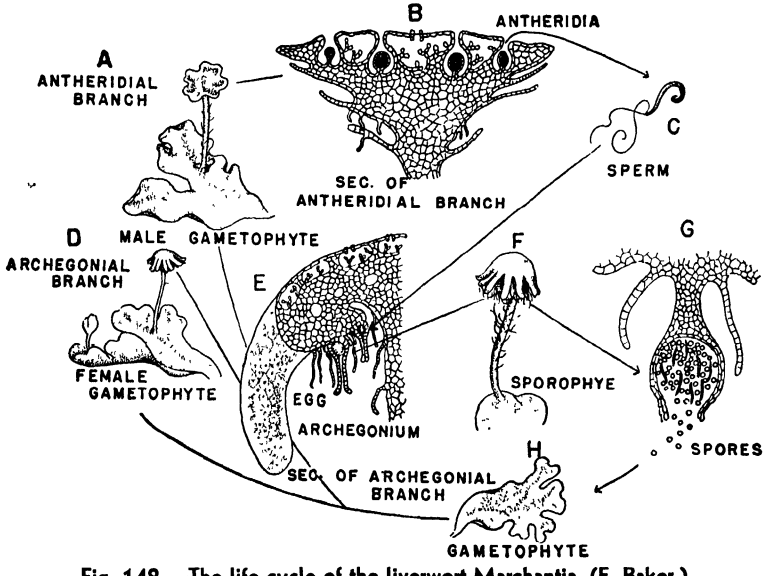

Fig. 142.—The life cycle of the liverwort Marchantia. (F. Baker.)

gonos, the first of a race). In the archegonium is an egg. In the "umbrella" (gametophore) on the upper side of the male plant are the male sex organs, the *antheridia* (sing. *antheridium*, L. diminutive of *anther*, flower), and in the antheridia the male sex cells, the sperm, are formed. Thus it will be seen that gametophytes bear the *gametes*, or sex cells, whereas sporophytes produce *spores*. In this case, the plant that we know as *Marchantia* is the gametophyte generation.

(3) THE SPOROPHYTE; SPORE FORMATION.—After the sperm has fertilized the egg, which is still on the underside of the female gametophore, the fertilized egg, or zygote, remains in place and begins to divide. Soon a sporophyte develops. This is an inconspicuous structure consisting of little more than a stalk bearing a spore capsule that contains the spores.

The sporophyte is entirely dependent upon the old plant for food. When the spores are ripe, they fall to the ground, and each one is capable of producing a new plant that grows into a gametophyte. If it is borne in mind that a sporophyte produces spores and a gametophyte produces gametes, or sex cells, the two generations will not be confused. In *Marchantia*, the sporophyte is small and inconspicuous. Among the higher plants, the sporophyte is the familiar tree, or flowering plant; the gametophytes are small, and are never seen without the aid of a microscope.

C. Mosses, Musci.—Mosses are near relatives of the liverworts. They tend to grow in moist places, although some of them live in fairly dry situations.

1. THE PLANT BODY.—In mosses, the "leafy" plant is part of the gametophyte. Separate plants bearing male and female sex organs, as in the life cycle shown in Fig. 143, do not occur in all mosses. Plants that bear both female sex organs (archegonia) and male sex organs (antheridia) are known as *hermaphrodites* (Gr. *Hermaphroditus*, a Greek mythological character). This is the condition of many species of plants and animals.

2. LIFE CYCLE OF A TYPICAL MOSS.—The life cycles of the mosses and liverworts are quite similar.

a. Reproduction. (1) VEGETATIVE REPRODUCTION.—Mosses multiply freely by vegetative means, almost any fragment being capable of producing a new plant. "Brood bodies," or special reproductive buds, occur on leaves or rhizoids of some species. Adventitious protonema may also develop from almost any part of the plant in some species.

(2) THE GAMETOPHYTE; SEXUAL REPRODUCTION.—When the minute spores produced by the *moss* (Fig. 143) fall to the ground, a thread-like plant develops from them. Such a plant is called a *protonema* (Gr. *protos*, first; *nema*, a thread). These thread-like green plants, which are rarely recognized except by botanists, spread over the soil for some distance. After a time, numerous buds appear; these give rise to the erect, "leafy" moss plant. The moss plant, together with the protonema, form the gametophyte. Since the buds are very close together, it is evident why the moss plants form the familiar compact "carpets" in our woods. At the tips of these gametophytes, the archegonia and antheridia develop (Fig. 143). Only a film of dew, or a raindrop, is necessary to enable the

sperm produced in the antheridia to swim to the eggs that lie in the archegonia. When a sperm and an egg have fused in the process of fertilization, the zygote thus formed begins to divide and soon develops into a young *sporophyte* (Fig. 143).

(3) THE SPOROPHYTE; SPORE FORMATION.—The sporophyte sends a "foot" down into the tissues of the gametophyte and remains anchored

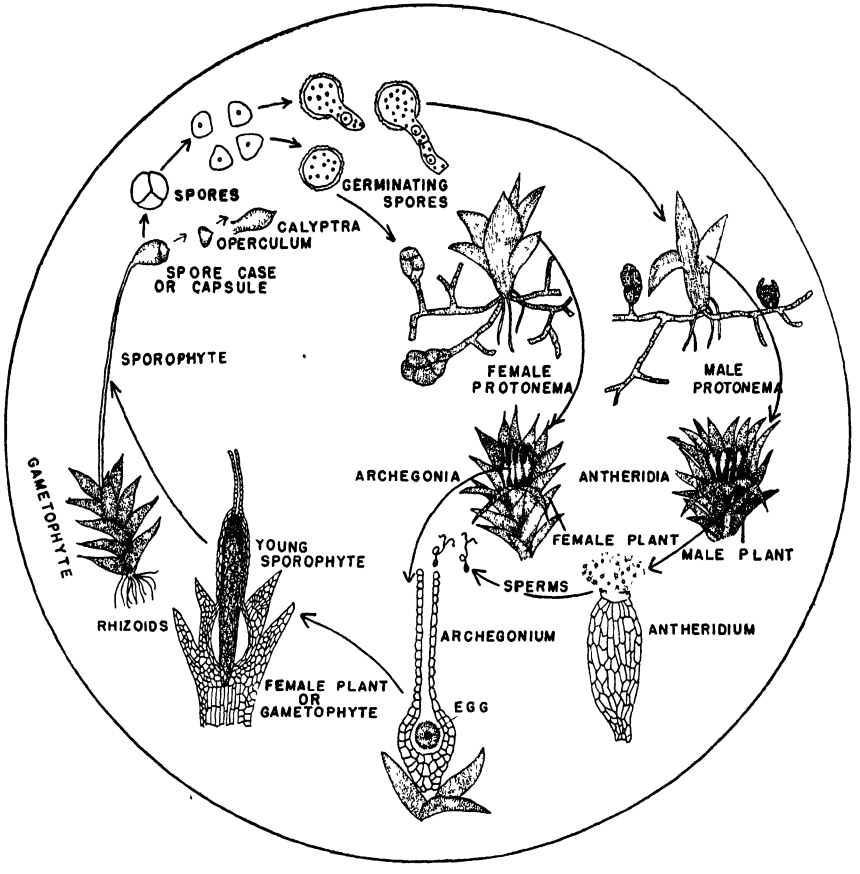

Fig. 143.—The life cycle of a moss. In some mosses the male and female sex organs are borne on the same plant. (L. Runyon.)

there. A spore case full of spores is now produced by the sporophyte, and for a time this spore case is surrounded by the *calyptra* (Gr. *kalyptra*, a covering for the head), which is the remnants of the old archegonium. The end of the capsule is covered by a lid called an *operculum* (L. *operculum*, lid). If the calyptra is removed, or falls off, the operculum may be displaced. It falls off naturally when the spores are mature. The spores

then fall to the ground, and, if the situation is favorable, new protonemata develop, and the cycle is repeated.

This alternation of generations is in a more pronounced form than that in *Marchantia*. The sporophyte is more prominent, but the gametophyte is still the more conspicuous, being the erect plant familiar to everyone as moss.

3. Economic Uses of Mosses. *a. Peat.*—Mosses of the genus *Sphagnum* are responsible for the formation of peat. They grow in cool, damp places, as well as in standing water, and often form dense cushions in marshes. On top of these cushions other plants may grow; in this way, "quaking bogs" arise. These bogs may appear to be solid ground, but when one walks over them, the whole mass moves more or less. Often the lower part of the *Sphagnum* plants may die and the upper part continue to live. On this account, the plants may become very old. Since the upper portion of the plant continues to grow, the dead portions underneath are pressed down; this results in the formation of peat. The water in which these mosses flourish contains acid; this prevents the dead mosses and other organic matter from completely decaying. In the course of time, extensive deposits of peat are formed. Some of the peat now being used in northern Europe may be millions of years old. Blocks of it are cut out, dried, and used as fuel.

b. Surgical Dressings.—Some types of *Sphagnum* are capable of absorbing from 15 to 20 times their own weight in water. For this reason, and because their acidity inhibits bacterial growth, they were used as surgical dressings in the place of cotton to some extent during the First World War.

c. Packing.—*Sphagnum* is often used to pack live plants that are to be shipped, since it serves to keep them moist. This type of moss may also be mixed with the soil to keep the ground moist or to make it acid. It is also an excellent material for mulching.

II. Vascular Plants

Formerly club mosses, horsetails, and ferns were grouped together as Pteridophyta (Gr. *pteris*, fern; *phyton*, plant). More recently Sinnott has proposed a new classification, grouping some primitive plants, mostly extinct, the old pteridophytes and the spermatophytes (seed plants) in one group of vascular plants, the Tracheophyta. The pteridophytes are the most highly organized of the seedless plants. They possess a vascular system; true roots, stems, and leaves. Without the development of a vascular system, there could not have been large land plants. The ferns and their relatives represent a very old group of plants. During the Carboniferous period of the Paleozoic Age, they were the dominant group of plants.

A. Classification of the Vascular Plants.

Phylum **Tracheophyta** (Gr. *tracheia*, windpipe; *phyton*, plant).

Subphylum *A.* **Psilopsida** (Gr. *psilos*, bare; *opsis*, appearance). Primitive vascular plants most of which are extinct.

Subphylum *B.* **Lycopsida** (Gr. *lykos*, wolf; *opsis*, appearance). Club mosses or ground pines.

Subphylum *C.* **Sphenopsida** (Gr. *sphen*, wedge or wedge-shaped; *opsis*, appearance). Horsetails or scouring rushes. Survivors of what was a great group in the Coal Age; silica present in walls of the plant; horsetail (*Equisetum*).

Subphylum *D.* **Pteropsida** (Gr. *pteris*, *pteridos*, a fern; *opsis*, appearance). Ferns and seed plants.

Class I. FILICINAE (L. *felix*, fern). Familiar fern plants; underground stems bearing numerous leaves or fronds; gametophyte, inconspicuous; sporophyte, the fern plant; bracken fern, *Pteris*.

Class II. GYMNOSPERMAE[1] (Gr. *gymnos*, naked; *sperma*, seed). Plants with naked seeds; cycads, conifers.

Class III. ANGIOSPERMAE (Gr. *angio*, covered or enclosed; *sperma*). Seeds are enclosed in case.

Subclass 1. DICOTYLEDONEAE (Gr. *di*, two; *kotyledon*, embryonic leaf). Plants with two seed leaves; netted veined leaves; flower parts in fours, fives, or more; violet, rose, oak, *maple*.

Subclass 2. MONOCOTYLEDONEAE (Gr. *mono*, one; *kotyledon*). Plants with one seed leaf; parallel veined leaves; flower parts usually in threes or multiples of three; grasses, lillies, etc.

B. Club Mosses; Lycopsida.—The club mosses are the descendants of an ancient group of plants. Their modern representatives are small and insignificant compared with the giant forests of those plants that existed in Carboniferous times. Delicate herbaceous plants also existed then (Fig. 47). Living representatives of this group are the *ground pines*, which are used as Christmas decorations, and *Selaginella*, "the little club moss."

C. Horsetails; Sphenopsida.—The *scouring rushes*, or *horsetails*, were once a mighty group of plants. In Carboniferous times, their relatives, the *Calamites*, grew into great and noble forests. Some of the trees in these forests were 30 ft. in diameter and 90 ft. in height. Most of the modern representatives of the horsetail group are small in size.

Certain of the stems of the horsetails are horizontal and subterranean (Fig. 47); from these two types of shoots arise, (1) vegetative and (2) spore-bearing. In some species, whorls of branches occur at each node that give the plant the appearance of a brush or horsetail. The cells of horsetails contain silica. For this reason, the plants are called *scouring rushes*. The early settlers used them for scrubbing purposes. *Equisetum* is a common example of the horsetails.

[1] Seed plants are often grouped together as Spermatophyta (Gr. *sperma*, seed; *phyton*, plant).

D. Ferns; Pteropsida; Class, Filicinae.—These are the familiar Fern plants of the woods and their relatives.

1. HABITAT.—Ferns grow in many types of environments. Some float in water; others are rooted in mud and are partly covered with water; some grow on tree trunks, such as the so-called *resurrection plant*, and are capable of being thoroughly dried; still others are the tree ferns of the tropics. But the ferns that are most familiar are those found in moist, shady woods in temperate climates.

2. THE PLANT BODY.—The stems of ferns are in most cases horizontal. They either lie on the ground or extend under the surface of the soil. forming rootstocks. The leaves arise from the stem and uncoil as they develop. The tree ferns may attain a height of from 30 to 40 ft. Fern leaves are large and compound, being divided into leaflets.

3. THE LIFE CYCLE. *a. Reproduction.* (1) VEGETATIVE REPRODUCTION.—Ferns may reproduce themselves both asexually and sexually. The rootstock may branch and "take root." Stems are often seen extending over the edges of pots in which ferns are growing. The tips of the leaves of the walking fern may take root where they touch the earth and a new plant develop there (Fig. 101*B*). Fern plants may reproduce themselves indefinitely by one or the other of these types of vegetative reproduction.

(2) SEXUAL REPRODUCTION; THE GAMETOPHYTE.—The life cycle of a type of fern that exhibits an alternation of generations is illustrated in Fig. 144. As in mosses, the sporophyte and gametophyte generations are present. The gametophyte generation bears the sex organs that produce the gametes, or sex cells, and the sporophyte generation bears the spores. The two generations are more independent of each other in ferns than they are in mosses. In ferns, the gametophyte takes the form of a very heart-shaped plant that is not usually seen unless it is looked for especially. Both types of sex organs are borne on the underside of this small plant, the archegonia being nearer the top and the antheridia nearer the bottom (Fig. 144). The sperm escape from the antheridia and swim in a thin film of water to the egg, which is fertilized during the time it is within the archegonium. The zygote begins development while still attached to the old gametophyte (Fig. 144). The plant that arises from the zygote is a *sporophyte.* This sporophyte soon develops roots and leaves and becomes the familiar fern plant.

(3) THE SPOROPHYTE; SPORE FORMATION.—As has been observed, the sporophyte begins its development while still attached to the gametophyte. The spores are usually formed in spore cases (sporangia) on the underside of the leaves, although some forms (*cinnamon fern* and others) produce specialized fruiting, or fertile, leaves. A group of sporangia is called a *sorus.* When young, each sorus may be covered by a membrane

(indusium). The method of escape of the spores from the sporangia is interesting. The heavy walled cells on the outside of the sporangium form a ring, the *annulus* (Fig. 145). This ring does not quite enclose the spore case. When mature, the annulus slowly bends backward; then it snaps forward again, throwing the spores into the air. If the

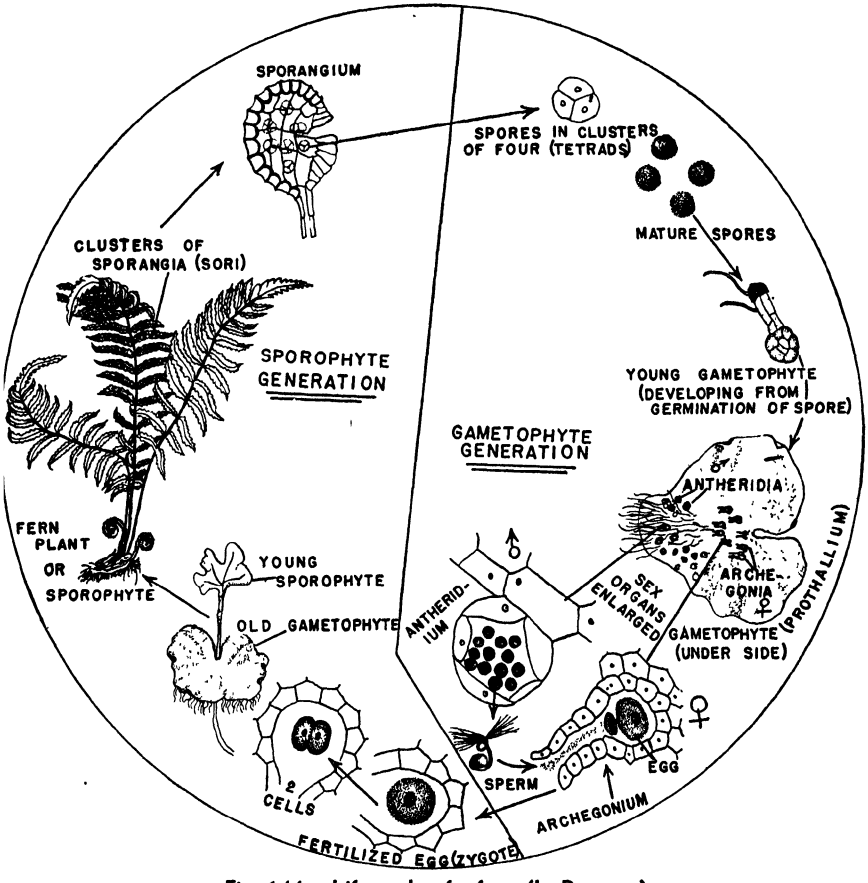

Fig. 144.—Life cycle of a fern. (L. Runyon.)

spores fall upon damp ground in a shady place, they germinate and produce the heart-shaped *gametophyte*, and thus the cycle is repeated.

E. Significance of the Alternation of Generations.—Alternation of generations aid the plants in the bryophyte-pteridophyte groups to solve two problems: (1) *dispersal* and (2) *sexual reproduction* involving cross-fertilization, the process by which new individuals are produced by reassortment of the chromosomes. In the Algae, these problems are largely solved by living in water. This medium serves for distribution

of the zygotes; in it, also, the motile germ cells may swim, and so fertilization is effected.

Land plants must solve these problems in other ways. The sporophyte generation in liverworts, mosses, and ferns produces minute spores easily borne by the wind, or other agencies, and the gametophyte provides for sexual reproduction and cross-fertilization. Water, though it may be only a film of dew, is still necessary for the union of gametes.

The two generations differ in many ways, the most fundamental being that the nuclei in the cells of the sporophytes contain a *diploid* (page 42) number of chromosomes, whereas the nuclei in the cells of the gametophyte contain a haploid (page 42) number of chromosomes. Meiosis in these plants differs somewhat from the preliminary description

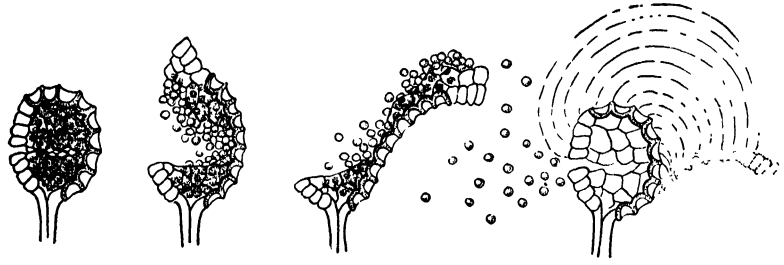

Fig. 145.—Discharge of spores from the sporangium of a fern. (Redrawn by F. Baker from Coulter, Plant Life and Its Uses, The American Book Company.)

of the process described on page 42. Here the reduction division, *i.e.*, the halving of the number of chromosomes, takes place when the spores are formed by the sporophyte. Since the sporophyte will develop from the zygote, the nuclei of all its cells will have the diploid number of chromosomes.[1]

By alternation of generations, then, a division of labor occurs, the sporophyte ensuring distribution by producing minute spores easily borne by the wind or other agencies and the gametophyte providing for sexual reproduction, involving cross-fertilization. This cross-fertilization provides for variation by the reassortment of chromosomes in those individuals that have come from the fertilized egg.

F. The Formation of Coal.—The fern group played an important part in the formation of coal. In early geological times, a large part of the earth was covered with marshes, and these marshes supported a very luxuriant vegetation. When conditions changed, great masses of vegetation were buried under mud, rocks, and water (Fig. 517). Very little oxygen was present; hence very little decay took place, and vegetation was changed slowly by chemical reactions. Gases, such as carbon dioxide

[1] For a more detailed discussion of haploid and diploid numbers of chromosomes, see p. 702.

and marsh gas, were given off. The residue became coal deposits. When one considers the important uses of coal in the modern industrial world, it is difficult to overestimate its value.

Questions

1. In what ways do the liverworts resemble the Algae?
2. Can you suggest a reason for the fact that whereas mosses can grow in both dry and moist places, liverworts do not thrive except in moist situations?
3. Define the following terms as related to liverworts: prothallus, male gametophyte, female gametophyte, archegonium, antheridium, gemmae cupules.
4. Give a "running account" of the life history of *Marchantia*.
5. Define the following terms as related to mosses: seta, calyptra, operculum rhizoid, protonema, gametophyte, sporophyte.
6. Give the life history of a typical moss.
7. How is peat formed? What is a "quaking bog"?
8. What characteristic possessed by *Sphagnum* moss makes it valuable as a packing in shipping plants a long distance? What other uses has this moss?
9. Define the following terms as related to the pteridophytes: indusium, annulus, strobilus, prothallus.
10. Compare the three classes of the pteridophytes as to general features.
11. How many ferns reproduce themselves asexually?
12. Give the life history of a typical fern.
13. Why are the pteridophytes and the seed plants called *vascular plants?*
14. Why would you say that the ferns are the most highly organized of the seedless plants?
15. What is the probable history of coal formation?
16. Compare the gametophyte of a moss with that of a fern; the sporophyte.
17. Give an account of the significance of alternation of generations.
18. Describe the processes of fertilization in liverworts; in mosses; in ferns.

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CHAPTER XVI

TRACHEOPHYTA *(Continued)* THE SEED PLANTS

June reared that bunch of flowers you carry
From seeds of April's sowing.
—BROWNING.

I. Seed Plants (Spermatophyta)

A. Seeds Plants in General.—Because of their large size and abundance, as well as their usefulness to man, the seed plants are more familiar than any other plants. Included in this group are the great majority of herbs, bushes, and trees that exist on earth. The "cone bearers" (*gymnosperms*) bear seeds that are freely exposed to the air (naked); the flowering

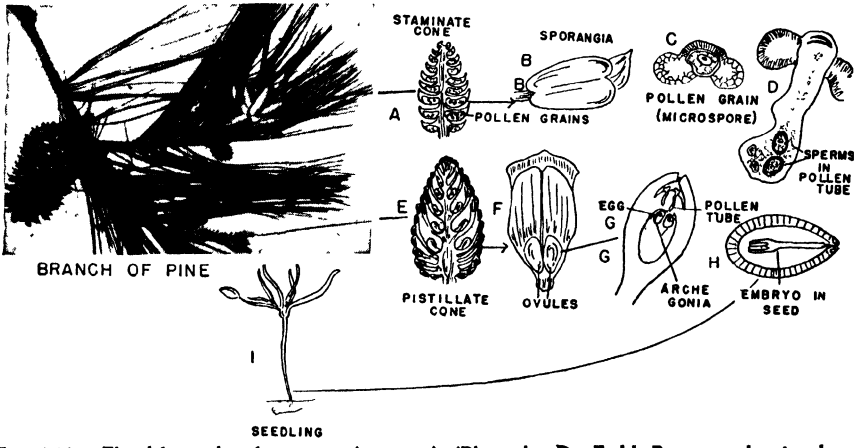


Fig. 146.—The life cycle of the pine (see text). (Photo by Dr. E. H. Runyon, drawing by B. Shamos.)

plants (*angiosperms*) bear seeds enclosed in an ovary. Chapters VII to XII are devoted to a study of the organization and structure of a typical *angiosperm*. It is necessary here to describe a representative of the gymnosperms such as the pine (Fig. 146).

B. Classification.—The classification of the seed plants is shown on page 205. The older classifications place them in the phylum Spermatophyta, with two subphyla, Gymnospermae (with naked seeds) and Angiospermae (seeds enclosed). More recent classifications include the seed plants, together with the ferns, in the phylum Tracheophyta

(subphylum Pteropsida) (page 205). The classes Gymnospermae and Angiospermae are called *divisions* by some authors.

C. Gymnospermae.—Gymnosperms are of ancient lineage. In ancient times, they were a dominant plant group, but relatively few of them—only about 500 species—are alive today. Fossil records demonstrate that

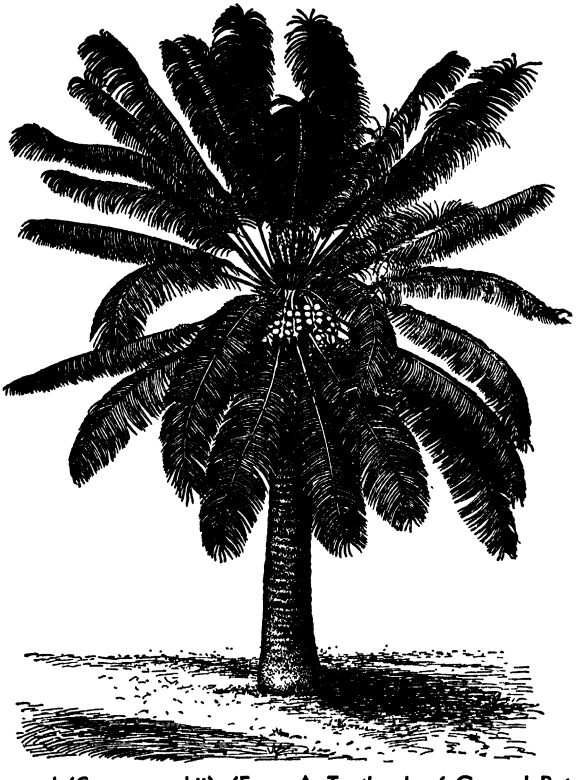


Fig. 147.—A cycad (Cycas rumphii). (From A Textbook of General Botany by W. H. Brown, Ginn and Company.)

many kinds that formerly existed are now extinct. Some of the fossil gymnosperms are so well preserved that we can study even their cell structure with the aid of a microscope.

The living gymnosperms are classed in four orders: (1) *Cycadales*, a somewhat palm-like group with about 90 species; (2) *Ginkgoales*, with one living representative, the ginkgo, or maidenhair, tree; (3) the *Coniferales*, the cone-bearing plants, of which there are about 350 species; (4) *Gnetales*, a small group with only about 50 species.

1. CYCADALES.—The cycads are very ancient seed plants (Fig. 147) that resemble palms closely. A familiar example is the "sago palm," used often to decorate churches on Palm Sunday.

2. GINKGOALES.—This group of *gymnosperms* contains only one living species, the *Ginkgo biloba,* often called the *maidenhair tree* because its leaves suggest the leaves of the maidenhair fern. Because of the large number of fossil remains of this species and because of certain primitive features, especially in its method of reproduction, it has been called a *living fossil.* The ginkgo is a native of China but it is much cultivated in this country for ornamental purposes.

3. THE GNETALES.—Most of the plants in this group are leafless shrubs, trees, or vines in the desert. Some live in moist tropical forests.

4. THE CONIFERALES.—By far the most important group of gymnosperms are the Coniferales. Representatives of the group are pines, firs, hemlocks, cypresses, and tamaracks.

a. General Features.—These plants have typically excurrent stems (page 117) and bear evergreen leaves that remain on the tree from 3 to 5 years. However, certain members of the conifer groups, such as tamarack and bald cypress, shed all their leaves in the fall and are, therefore, deciduous.

b. The Pine.—As a representative of the life cycle of the gymnosperms, the pine may be used. This familiar tree has a stem that is straight and continuous from the base to the top (excurrent). The branches usually grow in whorls, the lower ones being longest. This gives the tree the cone shape characteristic of the conifers.

(1) SPOROPHYTE AND GAMETOPHYTE.—Pine cones are of two types; *staminate,* which produce pollen, or *microspores* (page 162), which produce the male gametophyte, and carpellate (page 162) cones, which bear the *megaspores* (Gr. *megas,* large; *spora,* seed) which produce the female gametophyte. The pine tree that bears cones represents the *sporophyte* generation. The gametophytes of the pine have the same function as all other gametophytes, *i.e.,* the production of gametes, or sex cells. In the pine, however, the male gametophyte is reduced to a few cells that arise inside the microspores, or pollen, but it is here that the male gametes, or sperm cells are produced. The female gametophyte is a small mass of tissue that arises inside the megasporangium (nucellus).

Reduction division in the gymnosperms occurs during meiosis (page 705) at the time of spore formation by the sporophyte. The gametophytes, therefore, have the haploid number of chromosomes. When the egg and sperm unite, the diploid number is restored, and the cells of the sporophyte, which develop from the zygote, contain a diploid number. This provides for cross-fertilization and all that this implies, *i.e.,* a reassortment of chromosomes which brings about variation, etc. (page 716).

(2) POLLINATION AND FERTILIZATION.—It is not necessary to describe in detail the complicated phases of the reproduction of the pine. The events in the life cycle, however, are interesting. Figure 146*F* shows the

position of the ovules in the carpellate cone. When the gametes are ripe, the pollen, carried by the wind, falls on the ovulate cone. At this time, the scales of the cone are slightly spread apart, and the ovules have secreted a little sticky, resinous material. Into this the pollen grains fall. When the ovulate cones are ready for the reception of the pollen, they occupy an erect position at the ends of the twigs. This is a favorable position, since the pollen slides easily down between the scales until it reaches the sticky ovule at their base. The scales now "close up" *i.e.*, they fit over each other tightly; then the cone turns downward. From 1 to 2 years is required for the seeds to develop. In certain species of conifers, the seeds become mature in a single year; in others, as is the case with most pines, 2 years are necessary. During this period, the male and female gametophytes develop in the microspores, or pollen, and in the megaspores in the ovules; male and female gametes (the sperm and eggs) are produced by the gametophytes; and finally fertilization takes place.

(3) SEED DISPERSAL AND GERMINATION.—When the seeds are mature, or ripe, the cone dies. As it dries, the scales curl back, and the seeds drop out. The seeds number two to each scale. Each seed is provided with a "wing" (Fig. 146) that aids it in "flying" to a new location some distance away from the mother tree. Usually a prolonged rest period ensues before the seeds germinate. A sporophyte develops from the seed.

SUMMARY OF THE LIFE CYCLE OF THE PINE

In outline form, the life cycle of the pine is as follows (Fig. 146):

1. Microspores and pollen are formed in the microsporangia of the staminate cone.
2. Two sperms are developed in the pollen grains.
3. Pollen grains are liberated from microsporangia (by dehiscence).
4. Megaspores are formed in the megasporangia, or ovules, of the carpellate (ovulate) cone.
5. The female gametophyte is developed from the megaspore within the ovule.
6. Archegonia are formed; each contains an egg cell.
7. Pollination occurs; the pollen tube grows into the archegonium.
8. Fertilization occurs; zygote is formed from union of egg and sperm.
9. Embryo develops from fertilized egg.
10. "Endosperm" (not the same thing as endosperm of the angiosperms) develops further.
11. Seed coats develop from ovule coats.

5. ADVANCES OF THE GYMNOSPERMS OVER THE PTERIDOPHYTES.—In comparing the differences between a fern and a pine, it will be recognized that the pine has a greatly enlarged root structure and larger stems. The vascular systems of the pine are more highly developed. But the greatest advance of the gymnosperms over the fern group is the ability of the gymnosperms to produce seeds.

D. Angiospermae.—These are the flowering plants that are most familiar. There is a great diversity in the flowers in size, color, and forms.

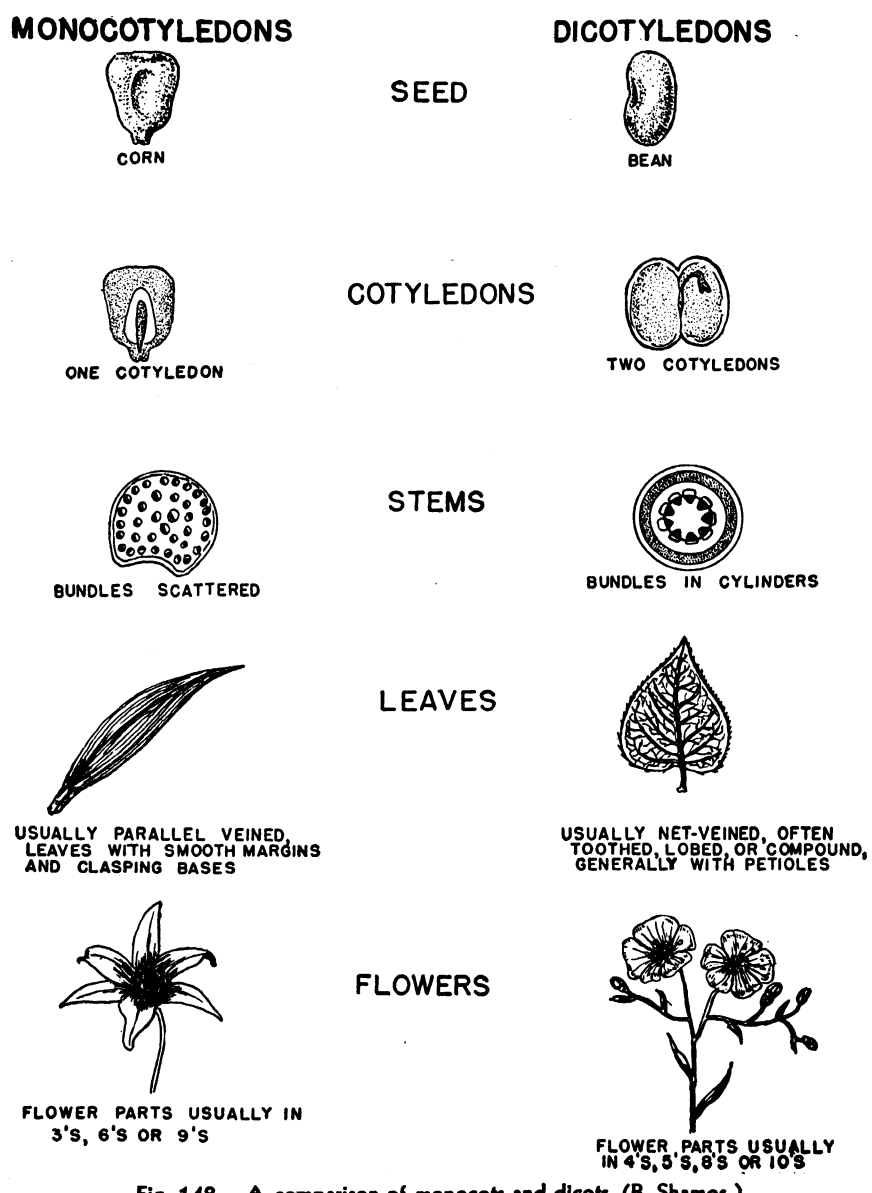


Fig. 148.—A comparison of monocots and dicots. (B. Shamos.)

As has been pointed out, the plants range in size from small plants like duckweed, floating on the water, to gigantic trees 300 or more feet tall Some are very short-lived, the life span being only a few weeks, others live for several centuries The seeds are borne in closed structures, the ovaries

The structures of a flowering plant have already been described (page 99) and need not be repeated here It is desirable that the student review these chapters, especially the structures of flowers and their relationship to each other

The angiosperms are subdivided into two great subclasses, the Monocotyledoneae and the Dicotyledoneae The differences between the two subclasses are illustrated in Fig. 148

Characters	Monocots	Dicots
Number of leaves produced by the seed	1	2
Vascular bundles in stem	Often scattered (cambium absent)	In cylinders (cambium present)
Veination in leaves	Usually parallel	Usually netted
Leaf margins	Usually smooth	Often tooth-lobed
Number of sepals, petals, etc	Usually 3 or 6	Commonly 4 or 5

There are, naturally, other differences.

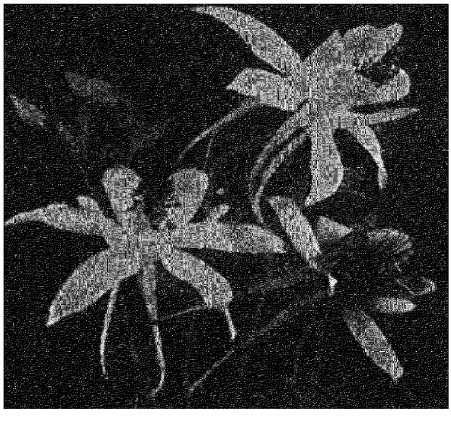


Fig 149 —Columbine (Aquilegia) Ranunculaceae (buttercup or crowfoot) family (Hastings Seed Company)

1 DICOTYLEDONEAE (page 205) —The dicots constitute the largest group of seed plants, including many forest trees, such as oaks and maples

and most of our fruit trees. The sporophyte is the conspicuous plant, the gametophytes being even more reduced than they are in the gymnosperms.

A few of the most important families are briefly described below:

a. The Buttercup Family; Ranunculaceae (L. *ranunculus*, medicinal plant).—Mostly herbaceous plants, *Clematis* being an exception; in general, pollinated by insects; flowers mostly symmetrical and perfect; buttercups, anemones, hepaticas, marsh marigold, columbines (Fig. 149).

b. The Rose Family; Rosaceae (L. *rosa*, a rose).—Distinguished from the buttercup family by the fact that the receptacle grows up around or is fused with the ovary;

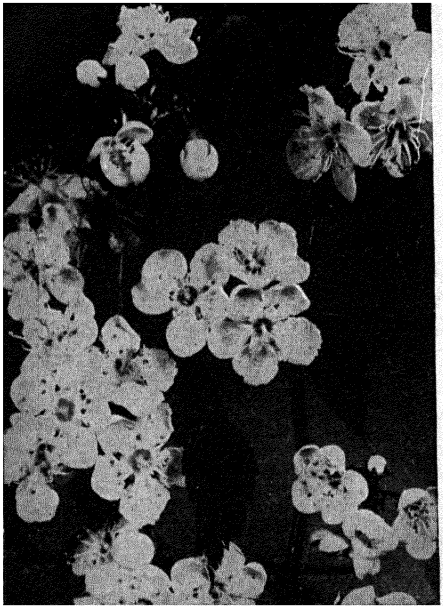


Fig. 150.

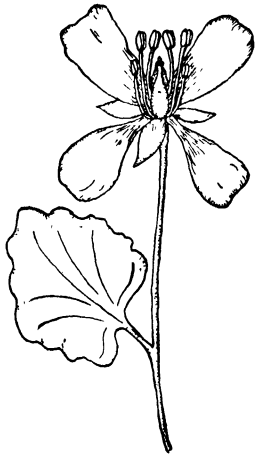


Fig. 151.

Fig. 150.—Hawthorn (Crataegus) Rosaceae (rose) family. (Dr. E. H. Runyon.)

Fig. 151.—Cress or Cardamine. The flowers in this family get their name from the arrangement of the four petals of the flowers in the form of a Maltese cross. Cruciferae (mustard) family. (L. Runyon.)

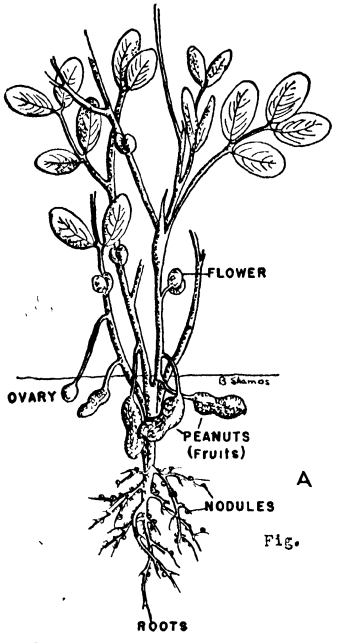
five petals are usually present and are separate from each other; familiar rose plants, cinquefoil, strawberry, spireas, hawthorn (Fig. 150), crab apple, wild cherry, apple, peach, etc.

c. The Mustard Family; Cruciferae (L. *crus*, a cross).—Four petals arranged so that they resemble a Maltese cross; hence the name; four petals, four sepals, and six stamens, of which four are longer than the other two; petals arranged alternately with sepals; candytuft, wall flower, alyssum, cabbage, water cress (Fig. 151), radish, Brussels sprouts, etc.

d. The Pea Family; Leguminosae (L. *legere*, to gather).—Cultivated by man since ancient times; fruit is a pod that develops from a single carpel:

most pods split open at maturity, but a few do not (*peanut*) (Fig. 152*A*); flowers usually irregular, perfect and complete; a few poisonous, *e.g.*, *loco weeds* (Fig. 152*B*), which are poisonous to livestock; some of great economic importance, as peas, beans, lentils, peanuts, clover, vetch, and alfalfa; ornamental types, sweet peas, wisteria, Judas tree or redbud; black locust and other types used for timber.

e. The Carrot Family; Umbelliferae (L. *umbella*, dim. of *umba*, shade).—Shape of the umbel suggests an umbrella (Fig. 105*D*); flowers may be in simple or compound umbels; individual flowers, yellow or white,



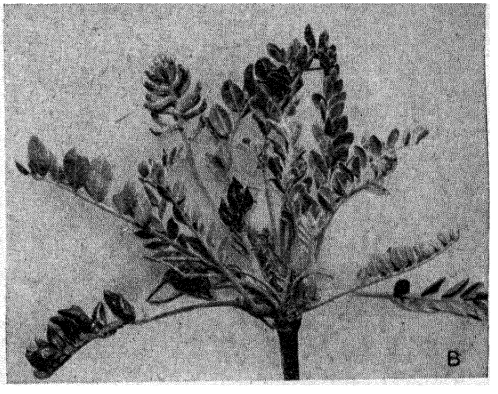


Fig. 152.—(A) Peanut plant (Arachis hypogea). After the stamens and corolla drop off, the flower stalk elongates and carries the developing ovary into the ground where the peanuts develop. (B) "Loco weed" (Astragalus molissismus). Cattle which eat this weed behave peculiarly and are said to be "loco." Leguminosae (pea) family.

are small and inconspicuous; herbaceous annuals or biennials; Queen Anne's lace, garden carrot, celery, parsley, dill; harmful species, poison hemlock.

f. The Mint Family; Labiatae (L. *labium*, lip).—Flowers irregular and two-lipped; four-sided stem; leaves simple and opposite; spearmint, peppermint, thyme, and sage furnish flavors; salvia, catnip.

g. The Potato Family; Solanaceae (L. *solanum*, nightshade).—Flowers five-parted; petals and calyx usually fused to form a tube; fruit ripens into a berry, sometimes quite large as eggplant and tomato, or into a dry capsule, as in the Jimson weed and tobacco; drugs obtained from many members of this family—solanin, belladonna, nicotine, capsicum, atropine (henbane, Fig. 153); important to man are potato, pepper, etc.; ornamental types, petunia, bittersweet; troublesome weeds, horse nettle, buffalo bur, nightshade.

h. The Figwort Family; Scrophulariaceae (so called because it was reputed to be a remedy for scrofula, or from its knotty root).—Annuals or biennials; flowers more or less irregular, some having two-lipped corollas (snapdragon), and produced in racemes (Fig. 105*A*); ovary consists of two coalesced carpels, which matures into a dry capsule; foxglove (Fig. 154), mullein, toadflax, figwort.

i. The Sunflower Family; Compositae (L. *compositus*, made up of parts).—Largest group in the plant kingdom; flowers are small and

Fig. 153.—Henbane (Hyoscyamus niger). A drug from this plant is used in certain types of indigestion. Solonaceae (potato) family. (College of Pharmacy, University of Minnesota.)

grow into a "head," which is usually called the *flower;* anthers form a tube or sheath around the style; flowers irregular (Fig. 155): troublesome weeds, ragweed, cocklebur, burdock, Spanish needle, all true thistles, and goldenrod; ornamental plants, chrysanthemums, zinnias, dahlias, asters, marigolds; best known food plants, artichokes and lettuce.

j. The Amentiferae (L. *amentum*, thong, strap).—A group of families that cannot be discussed here in detail; all members of these families are trees or shrubs; flowers borne in catkins (aments); the beech family (Fagaceae), beeches, oaks, chestnuts; the birch family (Betulaceae), *alders, birches* and *hazelnuts;* the walnut family (Juglandaceae), walnuts and hickories; the willow family (Salicaceae), willows, aspens, poplars.

2. MONOCOTYLEDONEAE (page 205).—Although the monocotyledons are a much smaller group that the dicotyledons, they are of great importance to man; they include important crop plants, wheat barley, oats, corn, etc., as well as some of the most prized flowers, as lilies, tulips, and orchids; all have one seed leaf.

Some important families of the monocots are the following:

a. The Lily Family; Liliaceae (L. *lilium*, lily).—Leaves usually parallel-veined; exceptions to this as in Trillium; calyx and corolla look alike; hyacinths, tulips, lilies, trilliums, onions (Fig. 158).

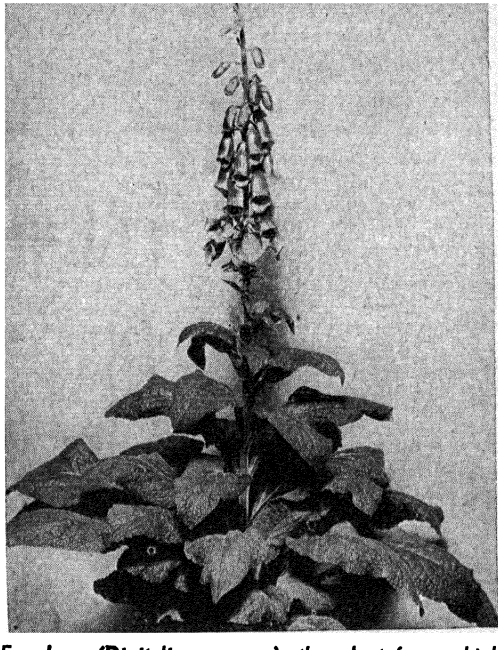


Fig. 154.—Foxglove (Digitalis purpurea), the plant from which is obtained the drug digitalis used in the treatment of heart troubles. Figwort family. (College of Pharmacy of the University of Minnesota.)

b. The Orchid Family; Orchidaceae (Gr. *orchis*, testicle).—Grow best in moist tropics; aerial roots that enable plants to absorb moisture from the atmosphere; much-prized beautiful irregular flowers; lady's-slipper.

c. The Grass Family; Gramineae (L. *gramen, graminis*, grass).—One of the most important families; flowers of grasses borne in spikes or panicle-like clusters; difficult to identify because parts of flowers are small and much reduced in number; no true sepals or petals present; harmful examples, Johnson grass and sand bur, which crowd out desirable plants; useful crop plants, corn, wheat, oats, rye, rice, millet, sorghums, sugar cane.

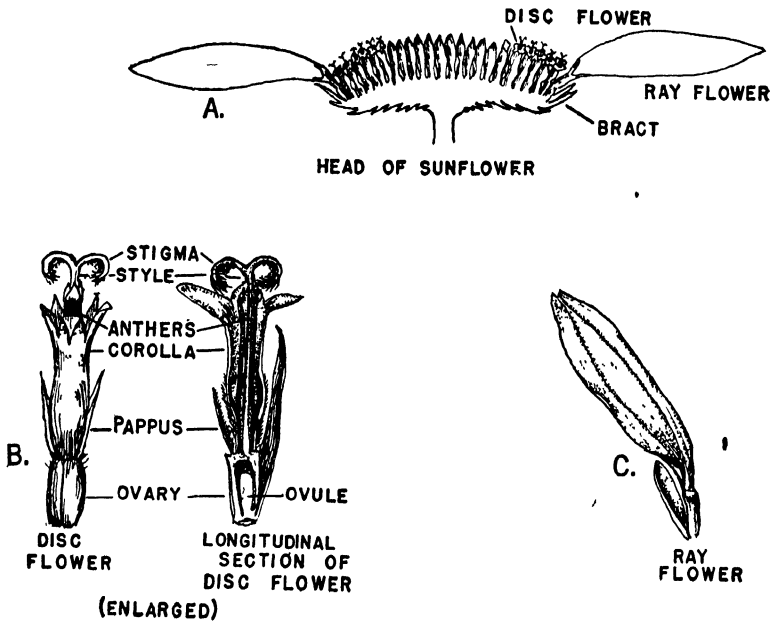


Fig. 155.—(A) Diagram of the head of a sunflower. (B) Disc flowers, much enlarged. These flowers are capable of reproduction. (C) Ray flower, a sterile flower. In a mature sunflower "head," one seed is formed in each disc flower. Composite family. (L. Runyon.)

Fig. 156.—Mountain laurel (Kalmia). The anthers are held in little pockets but they will snap up if a bee or other insect alights upon it thus covering it with pollen. Heath family. (Dr. E. H. Runyon.)

d. The Cattail Family; Typhaceae (Gr. *typhe*, a plant used for stuffing beds).—Small family with 9 of 10 species that grow in wet, marshy places; interesting flowers, dense spike with staminate flowers above and pistillate flowers below; after flowering, staminate flowers fall

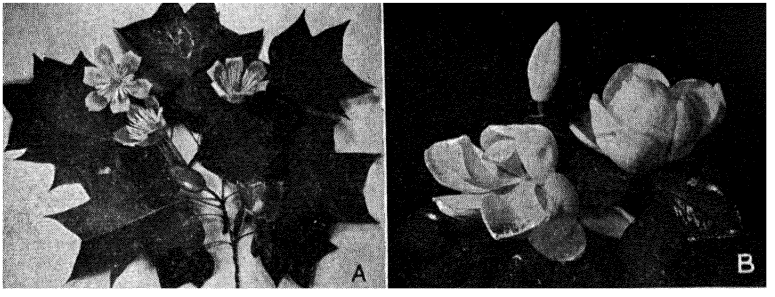


Fig. 157.—Representatives of the magnolia family. (A) Relatively simple flowers of the tulip tree (Liriodendron tulipifera). (B) Flowers of the magnolia tree (Magnolia grandiflora). (Dr. E. H. Runyon.)

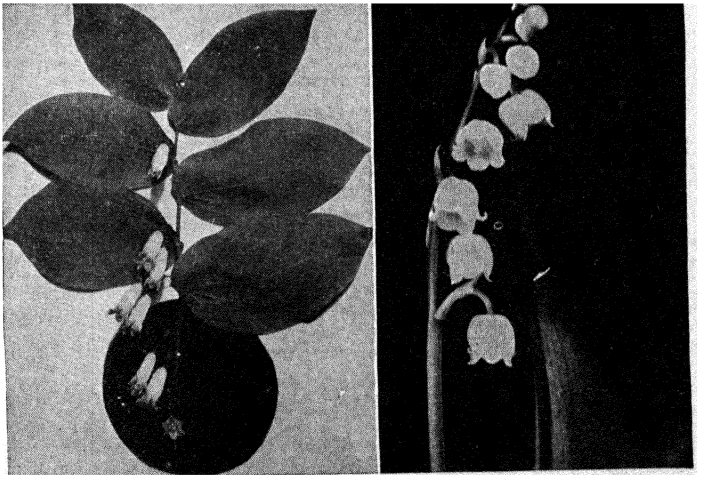


Fig. 158.—Representatives of the lily and lily of the valley families. (A) Solomon's sea (Polygonatum). (A. Furman.) (B) Lily of the valley (Convallaria). (Dr. E. H. Runyon.)

off, leaving axis above pistillate portion bare; as fruits ripen, the spike becomes dark brown.

II. Gametophytes and Sporophytes in the Plant Kingdom

A. Definitions.—A *gametophyte* bears the gametes or sex cells; i begins with a spore and ends with the fusion of gametes. A *sporophyt* bears spores; it begins with a fertilized egg or zygote and ends in th formation of spores.

B. Chromosome Constitution.—The cells of the gametophyte contain the haploid number of chromosomes (page 702); the cells of the sporophyte contain the diploid number of chromosomes (page 702). The reduction division occurs when the spores are formed. The endosperm of the angiosperms is formed from the fusion of three nuclei (page 705) and has, therefore, a triploid number, or three haploid sets, of chromosomes. The so-called *endosperm* of gymnosperms is not homologous with the endosperm of angiosperms. It is gametophyte tissue that develops from the megaspore and contains the haploid number of chromosomes. The endosperm of the angiosperms is neither gametophyte nor sporophyte but is called *xeniophyte* (Gr. *xenophyes*, strange in shape or nature).

C. Dependent and Independent Phases.—The gametophyte is the most conspicuous phase of most Algae, liverworts, and mosses, the sporophytes in these plants being partially dependent upon the gametophytes; in ferns, the sporophyte is the conspicuous phase, though both the sporophyte and the obscure gametophyte are independent plants; the sporophyte is the conspicuous phase in the brown seaweeds and in the seed plants. In these the gametophytes are reduced to a few cells and in seed plants are dependent upon the sporophyte.

III. The Economic Importance of Plants

The importance of plants to man is discussed in Chaps. XLVIII and XLIX. It is sufficient here to point out that a nation must produce the food it needs or perish. The whole science of agriculture is bound up with the economy of the nations. In addition to the use of plants as food, plant products, such as lumber, cotton, and other fibers, oils, drugs, and many others (page 807) are of value beyond calculation to man. On the other side of the picture, many plant and animal diseases are caused by bacteria and other Fungi, and these affect our health and crops (pages 806 and 849).

Questions

1. What is the chief difference between the gymnosperms and the angiosperms?
2. What kinds of plants are in the gymnosperm group? What is meant by "a living fossil"?
3. Give a summary of the life cycle of a pine.
4. Contrast the characteristics of the monocots and the dicots. Which of these two groups probably represents the latest development in the plant kingdom?
5. Trace the evolution of the sporophyte and the gametophyte from the liverworts, through all the plant groups, to the angiosperms.

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Part III
ANIMALS

A. Morphology and Physiology of a Typical Vertebrate, the Frog
B. The Animal Groups; Morphology and Physiology of Representative Types

A. MORPHOLOGY AND PHYSIOLOGY OF A TYPICAL VERTEBRATE

CHAPTER XVII

THE ORGANIZATION OF A VERTEBRATE; THE FROG

Of all the funny things that live, in
Woodland, marsh or bog
That creep the ground or fly the air, the
Funniest thing's a frog.

—ANONYMOUS.

The frog is an intermediate form in the vertebrate series; it is, therefore, a good form with which to introduce a study of the vertebrates, or animals, in general, for that matter. The frog has similarities in structure with the animals below it in the scale of life as well as with those above it, including man. Frogs are easy to obtain and easier to handle in making a study than many of the larger animals.

There are many species of frogs, but the two most commonly used for study in the laboratories are the leopard frog (*Rana pipiens*) and the Bullfrog (*R. catesbiana*) (Fig. 159). The descriptions below apply to the leopard or grass frog, except where noted.

A. Habitat.—The frog belongs to the class Amphibia (Gr. *amphibios*, living a double life). The *leopard frog*, so named because of its mottled appearance, is also called the *grass frog*, because it is often found in the wet grass. It frequents streams and ponds but does not stay so close to the water as the bullfrog does.

B. External Features. 1. SYMMETRY.—The frog is bilaterally symmetrical; *i.e.*, the two sides are alike. There is nothing to indicate the boundary between the head and the trunk.

2. LIMBS.—Four legs are present, the anterior pair being short and the long, powerful hind legs being folded when the animal is at rest. The forelegs possess four short digits or fingers (II–V) and a rudiment of the first (I), the *thumb;* the five digits of the hind limbs are joined together by a web.

3. THE SKIN OR INTEGUMENT.—A frog is slippery and difficult to hold in the hand because of the smooth, moist, scaleless skin. This covers the body loosely and is covered with mucus secreted by mucus glands. Other glands in the skin secrete a fluid irritating to the skin. More of these glands are found in the toad than in the frog. The skin of

the frog has also black pigment spots, and, according to some authorities, green spots are present. These pigment spots are capable of contracting and expanding, thus enabling the frog to change its color. When the black pigment cells are expanded, the frog is dark; when they are contracted, they are light. Some frogs, especially tree frogs (*Hyla versicolor*), are able to change color rapidly. This enables them to match the background to some extent and so escape their enemies. Other functions of the skin are the protection of the underlying tissues from mechanical injury, prevention of the entry of bacteria, and protection from loss of water. The skin also serves the frog as an organ of respiration.

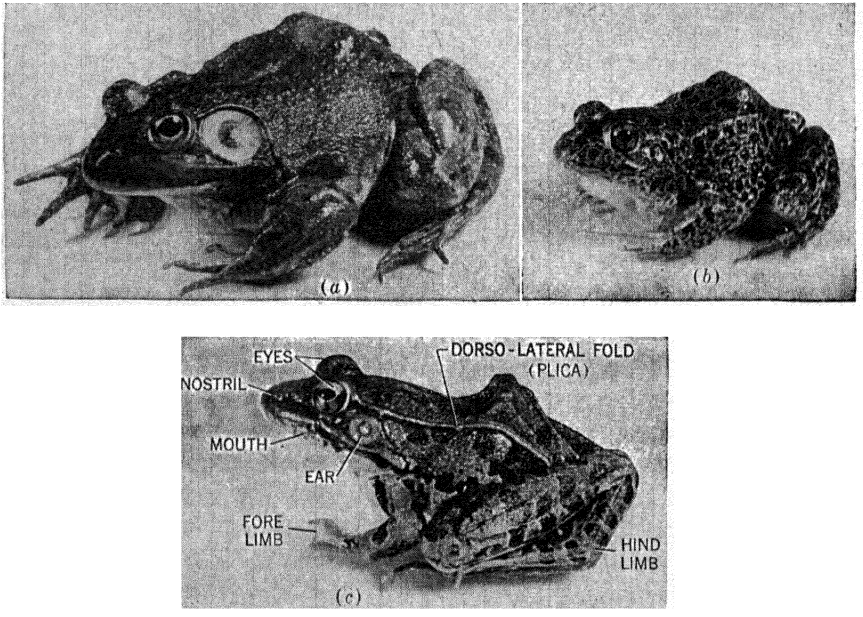

Fig. 159.—Three common frogs, Reelfoot Lake, Tenn. (a) Bullfrog, Rana catesbiana. (b) Northern gopher frog, Rana areolata. (c) Grass frog, Rana pipiens. (Dr. C. L. Baker)

4. Eyes and Ears.—The eyes of the frog are prominent and protrude a little, but they are withdrawn into their sockets when they are closed. A *nictitating membrane*, or third eyelid, can be drawn up over the eyeball from below. Birds and crocodiles possess a similar membrane in addition to the two eyelids. In man, this membrane is represented by a small fold in the corner of the eye next to the nose.

Behind the eye is a tightly stretched membrane, the *tympanum* (L. *tympanum*, a drum). This is the external ear. All these features can be found on any of the three frogs illustrated in Fig. 159. Between the eyes is the brow spot (see below).

5. External Openings.—The mouth extends across the anterior end. Near the anterior end will be found also a pair of external nares. At the posterior end is the anus, or vent, which is the posterior opening of the alimentary canal.

C. The Skeleton.—A catalogue of the bones in a frog's skeleton would be out of place here. Only the main bones will be mentioned in order to give an idea of the construction of the vertebrate skeleton. The skeleton largely determines the form of the body, furnishes support and protection for the softer parts, and serves as a framework for the attachment of muscles.

The frog skeleton is made up of bones and cartilages and is, as is every part of the body, supplied with blood vessels and nerves. The skeleton is composed of two main parts: (1) an axial skeleton, including the head (skull, jaws, etc.) and the vertebral column, and (2) the *appendicular skeleton*, which is made up of the forelimbs with the pectoral girdle, and the hind limbs with the pelvic girdle. The bones are joined together by connective tissue in such a way as to allow movement between them, in some cases at the *articulations* or *joints;* in other cases, especially in the skull, the method of articulation allows for no movement; in still other cases—for example, between the vertebrae—there is limited movement.

1. The Axial Skeleton. *a. The Skull.*—The skull is composed of bones and cartilage. Figure 160 shows the principal bones in the skull of a frog. The skull protects the brain and sense organs. In the central portion is the *cranium*, a small elongated box, and between the cranium and the upper jaw are the capsules for the organs of special sense, the nose, the eye, the ear. The nasal *capsules*, near the anterior end, enclose the nasal cavities. Into these cavities open the external nostrils from the outside and the internal nostrils from the mouth cavity. The eyeballs are lodged in the orbits, one on each side of the cranium. The internal ears are lodged in the auditory capsules posteriorly on each side of the cranium. The *foramen magnum* (L. *foramen*, an opening; *magnum*, large) is a large opening in the posterior part of the cranium through which the spinal cord passes to join the brain stem. Ventral to the foramen magnum is a pair of rounded projections, the *occipital condyles* (L. *occiput*, back of the head; Gr. *condylos*, joint, knob) by which the skull articulates with the vertebral column.

b. The Visceral Skeleton.—A part of the axial skeleton, made up of the jaws and the hyoid arch, is known as the *visceral skeleton*. The jaws are attached to the cranium by a suspensory mechanism composed of three bones on each side—the *squamosal*, the *pterygoid*, and the *palatine*.

c. The Vertebral Column.—The frog has 9 vertebrae and an elongated posterior bone, the *urostyle;* man has 33 vertebrae (including those fused to form the sacrum and coccyx). Each vertebra consists of a cylindrical

solid centrum, dorsal to which is the neural arch enclosing the nerve cord. From the neural arch project three processes for muscle attachment, a dorsal neural spine and two lateral transverse processes. Between the vertebrae are pads of cartilage. The *atlas* is the first vertebra and is without transverse processes. It has, however, a pair of oval facets for the articulation of the skull. The frog lacks ribs, which in many other verte-

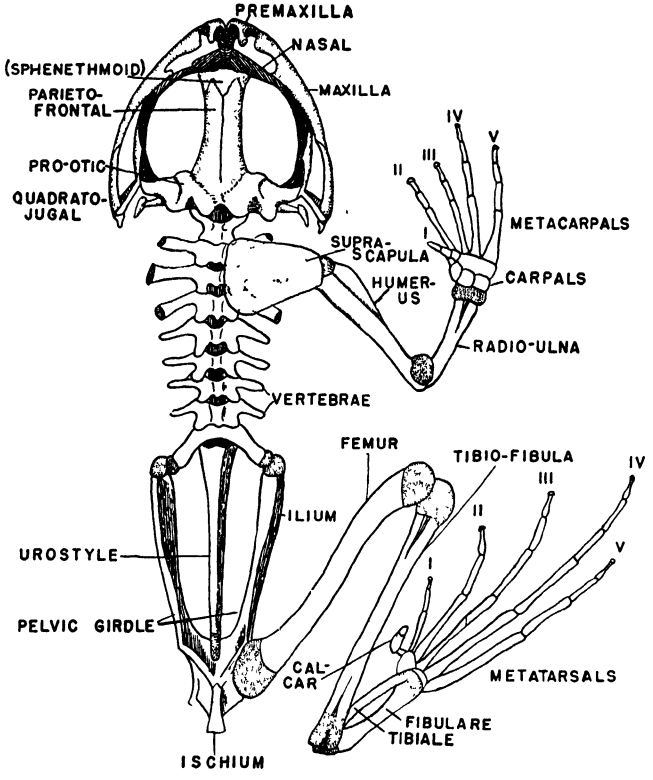

Fig. 160.—The skeleton of a frog. (L. Runyon.)

brates form an important part of the framework of the body; man has 12 pairs of ribs.

2. The Appendicular Skeleton. *a. The Pectoral Girdle and Sternum.*—These form the anterior portion of the appendicular skeleton and furnish protection for the heart, lungs, and other organs in the anterior part of the body. They also serve as support for the weight of the body, as shock absorbers, and as a place of attachment for the fore-limbs and muscles. There is no direct connection with the vertebral column. For the names of the bones in the pectoral girdle and their relations to each other, see Fig. 161.

b. The Forelimbs.—The bones of the forelimbs are the *humerus,* which articulates with the glenoid fossa (Fig. 160) of the pectoral girdle at its proximal end and the radio-ulna at its distal end; the fused bones of the forearm, the *radio-ulna;* the six bones of the wrist, the carpals arranged in two rows of three bones each; the five *metacarpals* in the hand, the thumb being rudimentary and represented by the small metacarpal only; four complete digits, or fingers, each extending from a metacarpal bone. In digits II and III are two *phalanges;* in digits IV and V are three phalanges.

c. The Pelvic Girdle.—The pelvic girdle supports the hind limbs and furnishes a place for their attachment. It also serves as a place of attachment for muscles. It consists of two sets of three bones each, the ilium, the ischium, and pubis (Fig. 160). The anterior end of each ilium is attached to one of the transverse processes of the ninth vertebra. Where

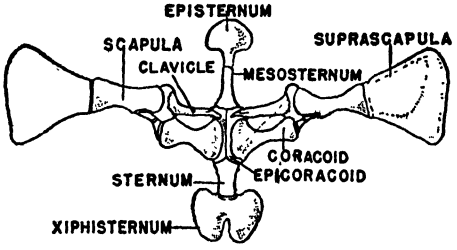

Fig. 161.—The pectoral girdle of a frog. (B. Shamos.)

the parts of each half of the pelvic girdle unite, there is a depression, the *acetabulum,* in which the long leg bone, the *femur,* lies.

d. The Hind Limbs.—The large leg bone, or femur, joins the girdle at the socket-like acetabulum. The distal end of the femur articulates with the *tibiofibula* (fused tibia and fibula), and the distal end of the tibiofibula articulates with the *tarsus,* or ankle. The ankle is elongated to give additional leverage for jumping. It is composed of two long bones, the *tibiale* and *fibulare,** enclosing an oval space between them (Fig. 160), and two very small tarsal bones. Distal to the *tarsals* are five long metatarsals and, following these, five complete digits. In digits I and II are two *phalanges;* in digits III and V, three phalanges; in digit IV, four phalanges. A remnant of a sixth toe, the *prehallux,* or *calcar,* is situated in the inside of the foot. All these bones and their relations to each other are shown in Fig. 160.

D. Motion and Locomotion.—In the frog, as in all except the lowest animals, movements, as well as position of the body, are brought about by contracting and relaxing of muscular tissue. In the frog, the muscular system is well developed, especially in the hind legs. In studying action

* The *astragalus* and *calcaneus* of the higher vertebrates.

of muscles in laboratories, a nerve-muscle preparation of the *gastronemius* muscle and the sciatic nerve from the leg of a frog is often used.

1. Functions of Muscles.—The functions of the muscles are (1) to move the parts of the body as in walking, leaping, breathing, etc., (2) to help the bones enclose the body cavities and thus protect the

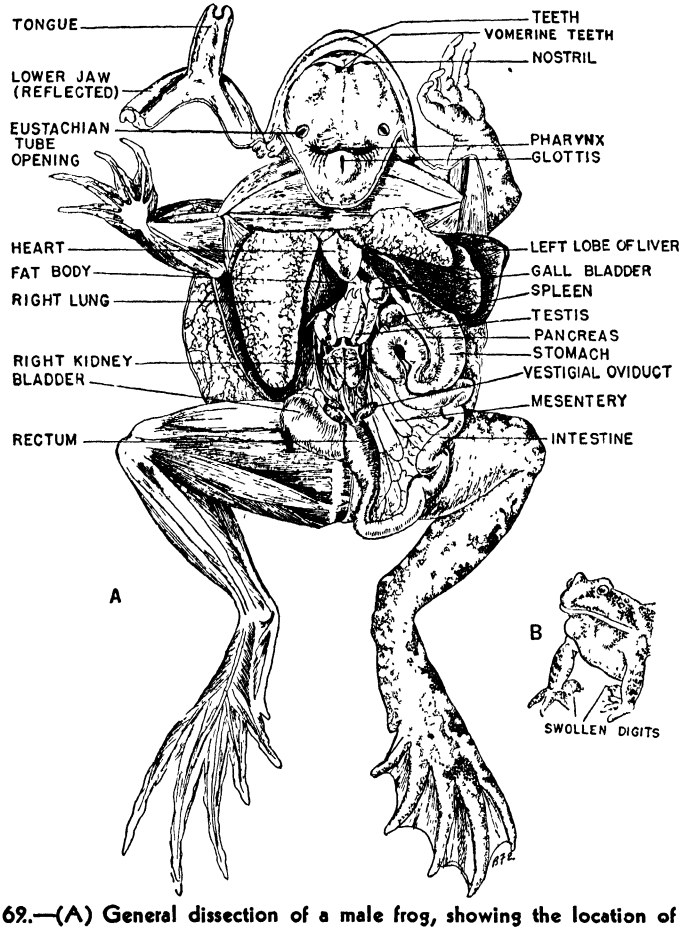

Fig. 162.—(A) General dissection of a male frog, showing the location of the main organs. (B) Swollen digits on the forelimbs. (Adapted by B. F. Edwards. From Denoyer-Geppert Co.)

delicate organs within, and (3) to assist the ligaments in binding the skeleton together.

2. Types of Muscles.—As shown by histological structure, there are three types of muscles: (1) *smooth muscles*, sometimes called *involuntary* muscles, because they occur in the walls of such organs as the

stomach, the intestines, etc., which are not under control of the will; (2) *striated muscles*, which are under the control of the will and are sometimes called *skeletal muscles*, because many of them are attached to the skeleton; and (3) *heart* or *cardiac muscles*, which are also striated but which differ in cell structure from the skeletal muscles. The structure of skeletal muscle is shown in Fig. 24.

3. Muscle Arrangement and Structure.—Muscle fibers are usually arranged in bundles enclosed in a sheath. The muscles themselves are usually arranged in pairs, and in these pairs one muscle "works against" the other or is said to be antagonistic. For example, if a muscle in the front of an arm contracts, the arm is bent; if on the other side of the arm another muscle contracts, the arm becomes straight again. Special terms are employed to indicate these two types of muscles; *flexor*, for bending, and *extensor*, for straightening. Other terms used for muscles to indicate movements performed by them are: *adductor*, one that draws the limb to the mid-ventral line of the body, and *abductor*, one that draws the limb away from the mid-ventral side of the body; *levator*, one that raises a part, as the lower jaw; *depressor*, one that lowers a part, as the lower jaw; *rotator*, one that rotates a part on another, as muscles at the wrist.

The end of a voluntary muscle that is attached to a relatively fixed and immovable part is called the *origin;* the end that is attached to that part which moves is called the *insertion*. The parts of a typical striated muscle are (1) the *tendons* attached at its ends, (2) the *membrane* surrounding the muscle, the *fascia*, and (3) the fleshy part of the muscle, the *belly*.

There are many muscles, several hundred in the higher animals, and a detailed description of them would be out of place here. Reference to Fig. 162 will show the general arrangement of muscles in bands on the fore- and hind limbs.

E. The Mouth Cavity. 1. Lining of the Mouth.—The frog has a wide mouth cavity, which is lined by mucous membrane. This is ciliated, except on the tongue.

2. The Tongue.—Small projections, or *papillae*, on the tongue are thought to be organs of taste. The tongue is fastened to the floor of the mouth at the anterior end. The posterior end of the tongue is notched and free. It is covered with a sticky mucus and can be thrown out to a considerable distance with lightning-like rapidity (Fig. 163). Any insect that is touched by this sticky tongue is certain to be caught! The tongue is then withdrawn to its proper position and the prey, insect, earthworm, or other animal small enough to be swallowed, is delivered to the animal's throat, where it is swallowed whole. The frog will eat almost anything that moves and is small enough to be swallowed.

3. The Teeth.—The food is held in position by the teeth. Two types of teeth are present, the *maxillary* teeth along the edges of the upper jaw and the two groups of *vomerine* teeth in the roof of the mouth near the anterior end (Fig. 162).

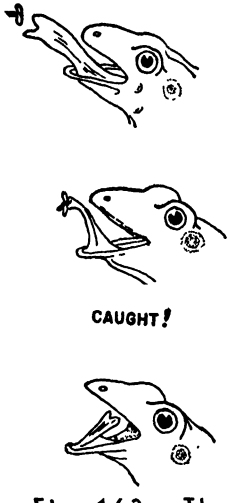

Fig. 163.—The tongue of a frog is useful in catching insects. (B. F. Edwards.)

4. Openings in the Mouth.—On the roof of the mouth, near the anterior end, are two openings for the *posterior nares*, or nostrils. Further back are the two apertures for the *Eustachian tubes*, which connect the mouth cavity with the middle ears. In the back of the mouth is a small raised area with a longitudinal slit, the *glottis*, through which the air passes to the lungs. In the posterior end of the *pharynx*, behind the glottis, the mouth leads through the pharynx to the *esophagus*. The location of all these openings is seen in Fig. 162. In the male, openings to the air sacs are present. The position of these varies with the species of frog (Fig. 164).

F. The Body Cavity and Its Contents.—If a longitudinal incision be made in the ventral wall of the frog, the internal organs, or *viscera*, in the body cavity will be exposed. The body cavity is called the *coelom* (Gr. *koilos*, hollow).

1. The Heart and Lungs.—The heart may beat some time after the frog has been chloroformed, even though its head has been cut off.

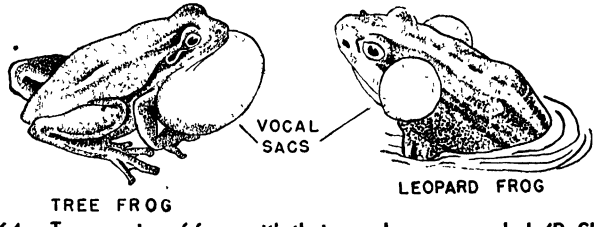

Fig. 164.—Two species of frogs with their vocal sacs expanded. (B. Shamos.)

It lies in the *pericardial* (Gr. *peri*, around; *kardia*, heart) *cavity* and is enclosed in a thin membranous sac, the *pericardium*. On either side of the heart will be seen the two lungs. The windpipe, or *trachea*, runs from the larynx to the lungs. The trachea bifurcates near the lungs to send a branch to each lung. Unless the lungs are inflated, they will be concealed by other structures.

2. Organs in the Abdominal Region.—In the frog, there is no partition separating the cavity containing the heart and lungs from the

a. Excretory Organs and Associated Structures.—In Fig. 162, which is a diagram of a general dissection, only the tips of the kidneys can be seen, but their position is indicated. They are a pair of flattened, elongated bodies, reddish brown in color, attached to the rear dorsal wall of the body cavity. On the ventral surface of each kidney is a yellowish, longitudinal strip crossed by many blood vessels. This is the *adrenal gland.* It is not concerned with either reproduction or excretion but produces adrenalin, a substance necessary to the life of the frog (see Endocrine System, page 626.)

The frog has the *mesonephric* (Gr. *mesos*, middle; *nephros*, kidney) type of kidney, more advanced than the more primitive kidney (*pronephros*) and not so highly advanced as the type characteristic of the higher animals (*metanephros*). The ducts of the frog's kidney are usually spoken of as the *ureters*, but, strictly speaking, they are mesonephric ducts. They can be seen easily on the outer margins of each kidney (Fig. 165) as small white tubes. They run posteriorly and enter the dorsal wall of the cloaca (Fig. 165*C* and *D*) opposite the opening for the *bladder.* The bladder is a thin-walled, bilobed structure that lies in front of the cloaca and the large intestine. From the foregoing, it can be seen that the urine from the kidney enters the cloaca by way of the ureters and then passes to the bladder for temporary storage. When filled, the bladder contracts and forces the urine back into the cloaca and to the outside through the anus. Some authorities say that a part of the urine may be expelled from the cloaca without passing into the bladder. It is estimated that the frog excretes about one-third of its weight per day in urine, whereas man excretes only about one-fiftieth of his weight in the same period of time.

b. Structure of the Kidney.—In the frog, the kidney is made up of a large number of tubules. At one end of the tubule is the *renal corpuscle* or *Malpighian body* (Fig. 172). This is made up of a thin double-walled capsule, the *Bowman's capsule*, enclosing a knot of blood vessels, the *glomerulus* (L. *glomus*, a ball). The renal corpuscle is joined on to a tubule, which, after several turns or convolutions, joins larger collecting tubules, and these, in turn, empty into the mesonephric ducts extending along the border of each kidney.

On the ventral surface of the kidney of the frog are numerous ciliated funnels called *nephrostomes* (Gr. *nephros*, kidney; *stoma*, opening). The expanded ends of these open into the coelom and the other ends into the renal veins. The beating of the cilia creates a current of lymph from the body cavity into the blood. The wastes in the fluid thus forced into the branches of the renal veins are then eliminated by the kidney.

c. Functions of the Kidney.—The chief function of the kidney is the elimination of metabolic wastes. In addition, it plays a role in maintaining

a constant level of body fluids and salts. In its tubules it may reabsorb glucose and some other substances and reintroduce them into the blood stream.

There is a difference of opinion as to just how the kidney does its work. According to one view, water and dissolved salts filter through the walls of the glomerulus and the capsule and into the tubule; at the same time, certain other substances are being removed from the blood in the capillaries surrounding the tubule and brought into the tubule through the

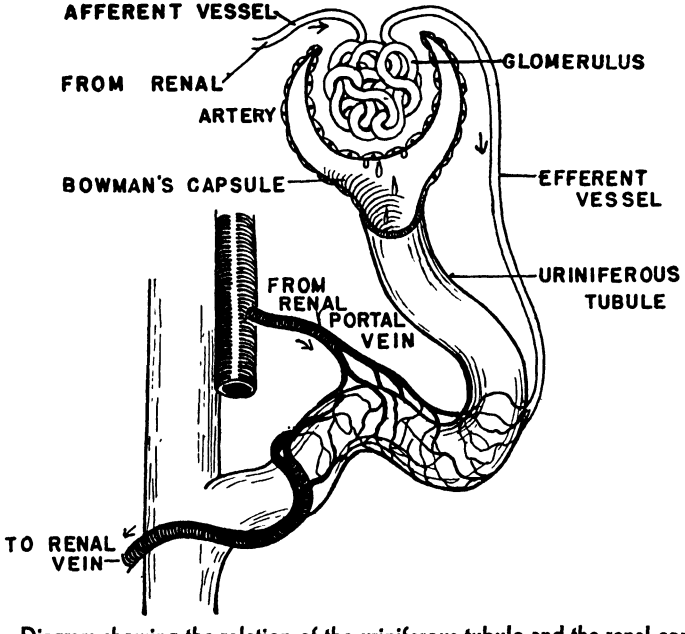

Fig. 172.—Diagram showing the relation of the uriniferous tubule and the renal corpuscle to the blood vessels. (F. Baker.)

action of the epithelial cells of the tubules, a process of true secretion. Some authorities think that sugar and other substances are reabsorbed from the tubule and pass into the blood.

By whatever method it is accomplished, the selective secretion and resorption action of the kidneys makes possible the maintenance of a fairly constant level of fluids and salts in the body. *Urea*, $(NH_2)_2CO$, is an end product of protein metabolism and is the principal constituent of the urine. It is built up in the liver and is carried by the blood to the kidneys, where it is excreted.

d. Fat Bodies.—These are located at the anterior end of each kidney in front of the gonads. They consist of tufts of yellowish finger-like processes (Fig. 165). Their function is that of a reserve food supply to be

used in the development of eggs and sperm and during hibernation. They reach their maximum size in the fall. They are said to decrease in size just before and during the breeding season in the spring, after which they begin to increase again.

K. Coordination; the Nervous Mechanism.—In all animals, there may be some coordinating mechanism in order that the parts may work together. In the frog, as in all but the lowest animals, the main coordinating mechanism is the nervous system. The distinguishing characteristics of the nervous system of chordates is that they are dorsal in position and tubular in form.

In the developing vertebrate embryo, the central nervous system arises as a long groove on the dorsal side. Because of the folding over of the edges of the groove, it later become a tube with a central cavity (Fig. 177*I*). The cavity is much reduced later, especially in the spinal cord, but in the brain it is expanded to form the ventricles.

Although the nervous system is continuous, it is convenient to study it in three divisions: (1) the *central nervous system*, consisting of the brain and spinal cord; (2) the *peripheral nervous system*, consisting of nerves that connect the brain and spinal cord with all parts of the body; and (3) the *autonomic system*, often called the *sympathetic*, made up of a large number of ganglia, two rows of which are on each side of the vertebral column.

1. The Central Nervous System.—This is made up of the brain and the spinal cord, and their branches; it is often designated the cerebrospinal system.

a. The Brain.—In the developing embryo, there appear in an early stage three enlargements at the anterior end of the nerve tube, which are called *fore-*, *mid-*, and *hindbrains*. Later in development, constrictions appear in the fore- and hindbrains, so that there are five primary divisions as follows:

From the forebrain or prosencephalon
- I. Telencephalon
- II. Diencephalon

From the midbrain
- III. Mesencephalon

From the hindbrain or rhombencephalon
- IV. Metencephalon
- V. Myelencephalon

The term *cephalon* (Gr. *kephale*, head) is the term applied to the brain as a whole; *tel* = end; *di* = between; *mes* = middle; *met* = after; *myel* = spinal cord (relation to); *pros* = fore; *rhomb* = spinning top (shape).

The brain of the frog is more highly developed than that of fish but not so highly developed as that of the higher animals.

(1) MEMBRANES.—Two membranes cover the brain; one next to the skull, the *dura mater*, a pigmented layer that adheres very closely to the skull, and an inside membrane, *pia mater*, that adheres closely to the brain itself. It has some pigment and is more delicate than the dura mater. The human brain has three membranes. In addition to the dura mater and pia mater, there is a delicate middle layer, the *arachnoid membrane.*

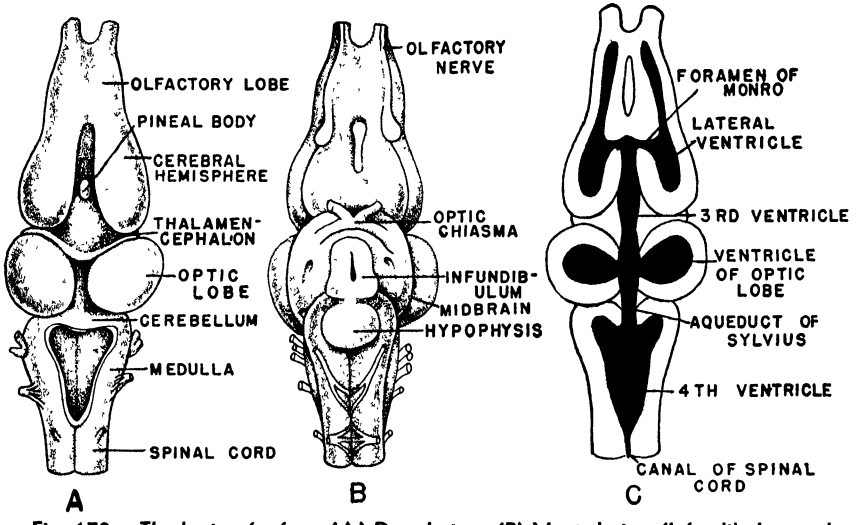

Fig. 173.—The brain of a frog. (A) Dorsal view. (B) Ventral view (Infundibulum + hypophysis = pituitary). (C) Section to show ventricles of the brain. (Adapted mainly from Wiedersheim and Ecker by F. Baker.)

(2) THE FOREBRAIN.—(*a*) *Telencephalon.* On the dorsal surface of the forebrain, there are two cerebral hemispheres making up the *cerebrum.* This is small in the frog, and its removal is not fatal to the life of the animal. As the scale of complexity ascends to the higher animals, the cerebral hemispheres are increasingly well developed. In them is the center for voluntary motion; it is the seat of the mind, and other important centers are located there.

In front of the cerebral hemispheres, separated from them by a small constriction, are the *olfactory lobes*, which are concerned with the sense of smell (Fig. 173). Nerves go from these lobes to the *nostrils.*

(*b*) The *diencephalon* is a depressed region that has on its surface a small projection, the *pineal gland.* This is of special interest, because in the *Sphenodon* (page 469) it is connected with a simple eye. In the frog,

it is only a vestige. It may be located by the *brow spot* on the skin of the head between the eyes.

In front of the *pineal stalk* is a region rich in blood vessels, the *anterior choroid plexus*. The blood in these vessels serves to bring nourishment to this region and to take away wastes.

On the ventral surface of the diencephalon is the *optic chiasma* (two lines placed crosswise) formed by the crossing of the optic nerves (Fig. 173*B*). A short distance behind this is the *infundibulum* and connected with it is the *hypophysis*. These two are collectively known as the *pituitary* (L. *pituita*, phlegm) *body*, so called because it was formerly supposed to secrete the mucus of the nose. In the higher animals, the two parts are more closely united than in the frog (page 623). The gland has many important functions connected with growth, besides other functions.

(3) THE MIDBRAIN.—The *optic lobes*, which are hollow, form the dorsal part of the midbrain. They are large rounded bodies located just in front of the cerebellum. Below the optic lobes are the *crura cerebri*, a pair of fiber tracts, which form the floor of the midbrain.

(4) THE HINDBRAIN.—(*a*) *Metencephalon*. Behind the optic lobes of the midbrain is the *cerebellum* (L. dim. of *cerebrum*, or "little brain"). It is regarded as an important center for coordination of muscular activity. The cerebellum is quite small in the frog and forms the roof of the metencephalon.

(*b*) *Myelencephalon*. This part of the hindbrain connects the brain with the spinal cord. Its thick floor and sides make up the *medulla oblongata*, in which are the centers for the control of the vital processes of the body, such as breathing, etc. It is a pathway between the brain and spinal cord and contains the roots of most of the 10 pairs of cranial nerves. Man has 12 pairs of cranial nerves. The medulla is also an important center for reflex action.

The *posterior choroid plexus* forms a thin roof over the myelencephalon. This is richly supplied with blood vessels, and the blood in these vessels serves the region in bringing nourishment and taking away wastes.

(5) CAVITIES OF THE BRAIN.—As stated above, the cavities in the nerve tube of the embryo are formed by the folding over of the ectoderm to form a nerve tube. At first the cavities are large, but as the nervous system develops they become much reduced, especially in the spinal cord. In the brain, there are four *ventricles* or cavities. These are connected with one another by openings or *foramina*. The first ventricle is in the right cerebral hemisphere, the second in the left, the third in the diencephalon, the fourth in the medulla. There is a T-shaped canal connecting the first and second ventricles with that of the third, the *foramen of Monro* (Fig. 173*C*). The *aqueduct of Sylvius* is a tiny canal connecting the third and fourth ventricles. This aqueduct also connects

the fourth ventricle with the cavities in the optic lobes (optic ventricles). The fourth ventricle is connected with the very small canal, the *neurocoele*, in the spinal cord. This runs the length of the spinal cord.

b. The Spinal Cord.—The spinal cord joins the medulla. It is covered by two membranes, an outside membrane, the *dura mater*, and an inside

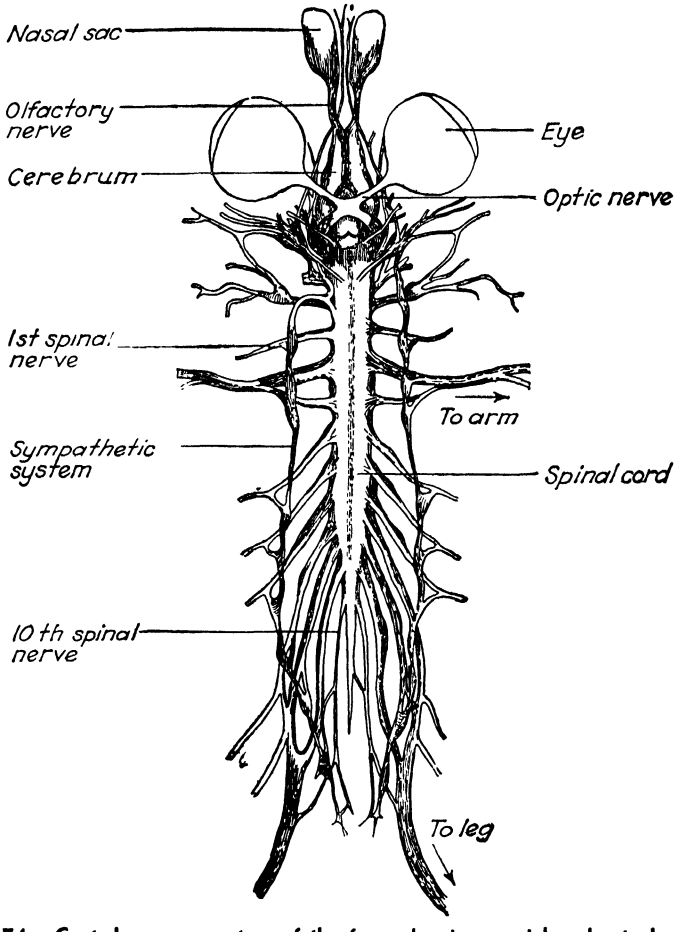

Fig. 174.—Central nervous system of the frog, showing cranial and spinal nerves and sympathetic nervous system, ventral view. (After Ecker, from Haupt, Fundamentals of Biology.)

membrane, the *pia mater*. It is somewhat flattened, and a median fissure occurs on both the dorsal and ventral surfaces. A small canal, the *neurocoele*, mentioned above, runs the length of the canal. The cord consists of a central mass of gray matter, which is composed chiefly of nerve-cell bodies and an outer mass of white matter made up chiefly of nerve fibers.

2. The Peripheral Nervous System.—This consists of 10 pairs of cranial nerves and 10 pairs of spinal nerves (Fig. 174).

a. The Cranial Nerves.[1]—These arise in the brain, and all except the tenth go to sense organs. The tenth pair sends branches to the viscera.

b. The Spinal Nerves.—One pair of spinal nerves arises from the junction of each of the vertebrae, 10 pairs in all. They can be seen as white strands running out from between the vertebrae. Each nerve has two roots, a *sensory root*, entering the dorsal surface of the spinal cord, and a *motor root*, entering the ventral surface of the spinal cord. The cell bodies of the *sensory neurons* are in the spinal ganglia on the dorsal root, and the cell bodies of the *motor neurons* are in the ventral horn of the spinal cord. The sensory neurons take impulses to the spinal cord, and the motor neurons carry the impulses from the spinal cord to the tissues. When the impulses from the sensory neurons enter the spinal cord, they are carried to and from the brain by association neurons. Most of these ascending and descending nerve paths cross over before they reach their destination.

c. Brachial and Sciatic Plexuses.—A plexus is a place at which branches of several nerves come together to form a sort of network. There are two plexuses connected with the nervous system of the frog: (1) a *brachial plexus*, formed by branches of the first, second, and third spinal nerves, and (2) the *sciatic plexus*, formed by the branches from the seventh, eighth, and ninth spinal nerves. The sciatic nerve is a large nerve going from the plexus down the leg of the frog (Fig. 174).

3. The Autonomic or Sympathetic System.—The *autonomic* (Gr. *auto*, self; *nemo*, distribute) system regulates the heartbeat, the movements of the involuntary muscles, the muscles of the blood vessels, the visceral organs, the glandular activities, and the like. It is made up of two strands of *ganglia*, one on either side of the vertebral column (Fig. 174). These ganglia connect with the spinal nerves along the course of the strands.

4. Reflex Action.—The spinal cord is the center for simple reflex action. A reflex may be defined as an action that follows a stimulus reflexly, *i.e.*, that is performed without volition on the part of an animal. If a piece of filter paper is moistened with a weak acetic acid solution and placed on the ventral surface of a frog's body, the frog will wipe it off with its legs. The mechanism by which this is carried out is shown in Fig. 175. If the stimulus is sufficient, a more complex type of reaction will follow. This will involve other parts of the central nervous system,

[1] The names of the 10 cranial nerves of the frog are, beginning with the first near the anterior end of the brain: (1) olfactory, (2) optic, (3) oculomotor, (4) trochlear, (5) trigeminal, (6) abducens, (7) facial, (8) auditory, (9) glossopharyngeal, and (10) vagus or pneumogastric.

i.e., parts of the brain. Complex reflex action will be described in Chap. XXXIX.

5. Effects of Removal of Parts of the Brain.—Attempts have been made to learn the functions of the nervous system by removing various parts of it. In work of this kind, care is exercised to avoid the effects of shock.

Removal of the cerebrum seems to make little difference in the behavior of the frog. Spontaneity of action is not lost. The animals will snap at food, move about, and bury themselves at the approach of winter. According to some authorities, however, the decerebrate frogs lose a sense of fear and cannot learn even a simple path to the water; they lose the *power of associative memory* that is located in the cerebrum of the higher animals.

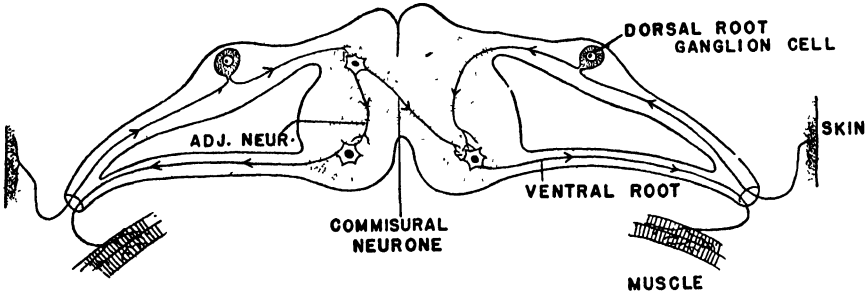

Fig. 175.—Diagram to represent a simple reflex arc. One adjuster (Adj. neur.) or internuncial neurone and one commissural neurone are shown.

Removal of the midbrain, the thalamencephalon, and the optic lobes results in an almost complete loss of spontaneous movements. Since the optic nerves enter the midbrain, blindness follows the removal of this part of the brain. There is some response to direct stimuli after the midbrain is removed. Removal of the optic lobes increases the irritability of the spinal cord.

The cerebellum is small in the frog, and its function is uncertain. It may have some coordinating function, though the evidence is conflicting.

The medulla oblongata is an important reflex center for vital activities such as swallowing, breathing, shooting out the tongue, and many other activities. After all the brain is removed except the medulla, the frog will still snap at food brought into contact with its jaws; it can also breathe, swim, and leap. With the removal of the medulla, life ceases, proving that the vital centers are in the medulla.

6. Segmental Character of the Nervous System.—The nervous system of the frog is segmental or metameric. Even in the brain, there is a linear series of centers, and the different levels of the cord control limited

portions of musculature and other parts. The nervous system of the frog thus illustrates the essentially segmental organization of the vertebrates.

L. The Sense Organs.—The organs of special sense are concerned with sight, hearing, touch, temperature, and the like. They are *receptors* for stimuli in the environment, which are able to select certain types of stimuli from many kinds of changes in the environment. For example, the eye is sensitive to light rays, the ear to sound waves, etc. The stimulus received by a sense organ is transformed into a nervous impulse, which is transmitted by a sensory nerve to a group of nerve cells in the brain and spinal cord. No matter how the auditory nerve is stimulated, it will not give the sensation of sight nor will the optic nerve give a sensation of hearing.

The sense organs of the frog are not, in general, highly developed. Since the types of sense organs in the higher animals are discussed later, only a brief mention of these organs in the frog will be made here.

1. The Nares.—These were mentioned in connection with respiration. Between the external and the internal nares is an enlargement known as the *olfactory chamber*. The lining of this chamber contains sensory ciliated cells. These are the special olfactory cells concerned with the sense of *smell*.

2. Taste Buds.—Along the surface of the tongue are small projections, or papillae, which are thought to be taste buds having the function of taste.

3. The Eyes.—The eyes of a frog are prominently situated on each side of its head. From their position, it is seen that each eye covers entirely different fields. Frogs have little, if any, binocular vision. The eyes are well developed, and their plan of construction may be likened to that of a camera, the eyeball forming a light-tight compartment. Each eye lies in an orbit, or socket, in which it is freely movable and into which it can be withdrawn and covered with the *eyelids*. The eyelids are of peculiar interest, inasmuch as the upper eyelid can be drawn down only slightly, whereas the lower eyelid can be drawn up to cover the eye completely. The lower eyelid is in reality two portions, the lower eyelid proper, which is the thicker lower part, and the *nictitating membrane*, a thinner part that is separated from the lower eyelid by a shallow groove. This third eyelid, or nictitating membrane, is important in many of the lower vertebrates, including the birds; in man, it is reduced to a vestige in the inner corner of the eye.

The outside coat of the eye is the white of the eye, the *sclera* (sclerotic coat), which is continued over the iris as a transparent membrane, the *cornea*. Inside the sclera is the *chorioid coat*, a vascular pigmented coat, and within this is the *retina*. The retina, which is connected with the brain by the *optic nerve*, is composed of two layers, an outer layer of

pigmented cells and an inner, much thicker layer, which is the sensitive portion.

In the center of the eye is a dark oval, the *pupil*, and surrounding this is the *iris*, an iridescent ring. Just behind the iris is the transparent crystalline *lens*, nearly spherical. This is made up of concentric coats, like an onion, and is surrounded by a delicate capsule. The capsule is attached along the margin to the ciliary body of fibers. Between the cornea and the lens is the large internal chamber filled with jelly-like *vitreous humor*.

The eye of the frog has no power of accommodation, as the human eye has, for viewing near and far objects. The mechanism of seeing is better explained in the discussion of the eye of man (page 634 *et seq.*).

4. The Ears.—The frog lacks the outer ears characteristic of mammals, including man. The *tympanum*, or eardrums, have already been referred to in describing the external features of a frog. They may be seen as tightly stretched membranes on either side of the head behind the eyes. The *middle ear* is under the tympanum and is an air-filled cavity. Air pressure in this cavity is regulated by the *Eustachian tubes*, which connect with the mouth (Fig. 162). Extending across this chamber, attached to the tympanum near the middle, is a rod-shaped bone, the *columella*. This joins a small cartilage lying over and closing the small aperture to the inner ear, the *fenestra ovalis*. The fenestra ovalis is on the outside wall of the *auditory capsule*. Sound waves received by the tympanum are transmitted over the columella to the cartilage, closing the fenestra ovalis (stapes), and thence to the inner ear.

The inner ear is between the middle ear and the cranium. It lies in the auditory capsule and is composed of a membranous labyrinth, a complicated thin-walled sac that contains a fluid, the *endolymph*. Surrounding the sac is another fluid, the *perilymph*, which fills the space between the labyrinth and the wall of the auditory capsule. The membranous labyrinth is divided into two portions, the *sacculus*, a lower portion concerned chiefly with hearing, and the upper portion, the *utriculus*. Connected with the utriculus are three *semicircular canals*, which lie in planes approximately at right angles to each other. At one end, each canal is enlarged to form the *ampulla*, well supplied with sense cells similar to those in the sacculus and also connected with the auditory nerve. The function of the semicircular canals is to maintain the sense of equilibrium. When the position of the head is changed, the fluid in these canals changes its level and stimulates the sensory hairs, thus giving the sense of *change in position*.

5. End Organs for Touch, Temperature, Pain, Etc.—In the skin of the frog are the special end organs, or nerve ends, the so-called *touch corpuscles*. These lie in the corium under small papillae in the

epidermis. Experiments seem to show that the skin of the frog very probably has sense organs also for heat and cold. The behavior of the animal under different conditions of the atmosphere indicates that the skin is also sensitive to changes in the moisture content of the air.

M. Behavior. 1. HABIT FORMATION.—Yerkes found that a frog could go through a labyrinth after about a hundred trials, showing that there is some power of formation of habits in this animal. The grade of intelligence is very low, however, and the behavior of the frog is mainly instinctive. It performs many complicated movements and also responds to various stimuli in its environment. All this is possible because the nervous system receives stimuli, coordinates and transfers the impulses. A low degree of intelligence is mentioned above. Intelligence implies an ability to profit by former experiences.

2. RESPONSE TO STIMULI.—Although reaction to light is somewhat influenced by temperature, the frog seeks the shade if possible. However, another response to the stimulus of light is one of *orientation; i.e.*, the frog faces the light. It seems, therefore, that this animal has two distinct responses to light.

Frogs tend to crawl into crevices and under objects, thus exhibiting a response to *contact* (*thigmotropism*).

There is no mechanism in frogs to regulate the temperature of the body. It is at the mercy of the surrounding environment. The body temperature may be greatly reduced, the body may even be frozen, if gradually done, for a time, but it is said that if the tissues of the frog are completely frozen, it cannot survive. Temperatures above 30°C. are unfavorable, and movements become irregular. Exposure to temperatures of 39 and 40°C. is fatal.

The *clasping reflex* at the time of mating is noted below.

3. HYPNOTISM.—If a frog is laid upon its back and held in that position for a few minutes, it will remain motionless for a considerable time (Fig. 176). This is probably not a true *hypnosis*. The same result may often be obtained by rubbing the back and sides.

N. The Reproductive System and Reproduction.—As has been stated, the excretory system and the reproductive system are so closely associated that the two together are usually known as the *urinogenital system*. The reproductive organs are called *gonads* (Gr. *gone*, that which generates).

1. THE MALE REPRODUCTIVE ORGANS.—Male and female frogs are very much alike externally. During the mating season, however, the *thumb* of the male is thicker than that of the female (Fig. 162). This thickening is useful in holding the female at the time of mating. The male clasps the female, and, as the eggs are laid, he spreads the sperm over them, and so fertilization is external. The clasping of the female appears

to be a reflex. It is said that the head of the male may be cut off at this time, yet his hold on the female is not loosened until quite a while afterward.

The pair of ovoid *testes* (sing., testis) are attached to the kidneys by a fold of peritoneum. In this peritoneum run several ducts that carry the sperm to the collecting tubules of the kidneys. In Fig. 165, one of the testes has been pulled away from the kidney in order to show these ducts, which are called *vasa efferentia* (L. *vasa*, vessels; *effero*, to bring out). The sperm go from the collecting tubules of the kidney to the *mesonephric ducts* and through them to the cloaca. From the cloaca, they are expelled to the outside at the time the eggs are laid. In the grass frog, the male has two rudimentary oviducts. These are lacking in the bullfrog.

Fig. 176.—A "hypnotized" frog. If a frog be stroked gently, it will pretend to be dead. Sometimes this is called hypnosis but it probably does not correspond to that state in man. (Dr. E. H. Runyon.)

2. Female Reproductive Organs.—The female reproductive organs are also associated with the kidneys. There is a *pair of ovaries*, which, during the breeding season, become much enlarged with their burden of eggs. In fact, during this season, when one opens up a female frog, the egg masses are the most prominent things to be seen and must be lifted out of the way in order to observe the other organs. The *oviduct* for each ovary is a much-coiled tube with a funnel-shaped opening, or mouth. The oviducts are not connected in any way with the ovaries and are located near the anterior end of the body cavity. When the eggs are mature, they break out of the ovary into the body cavity. They then find their way to the mouth of the oviduct through the action of a current created by the cilia of the *ostium*, or opening of the oviduct. As they pass down the ciliated oviduct, gland cells in the wall of this duct secrete a sort of jelly that is deposited around the eggs. Near the cloaca, the

oviduct is expanded to form a *uterus*. In the higher animals, further development occurs here, but in the frog, the uterus serves only as a temporary storage place for the eggs. When the eggs are to be laid, the male clasps the female, and the eggs are fertilized by the sperm as they leave the body of the female. As soon as the eggs reach the water, the jelly around them begins to swell, and the egg mass becomes much larger. An egg mass from one female may contain 500 or more eggs.

The mating of frogs takes place in the spring. Masses of frogs' eggs are a familiar sight in pools and streams in the spring. The eggs are black above and white below. The jelly serves several functions, protection to some extent from changes in *temperature* and protection from *injury*. It also holds the eggs apart and so allows oxygen to diffuse to the center of the cluster, at the same time allowing waste products to escape.

After the egg is fertilized, it begins to develop by a series of cell divisions. Development continues until there is a free-swimming tadpole, which later metamorphoses into a frog.

O. Development of the Frog.—The origin of the germ cells, the behavior of the chromosomes, and related problems in development are discussed in Chap. XLIV. It is well here, however, to follow a brief description of the *cleavage* of the fertilized frog egg.

1. THE FERTILIZATION MEMBRANE.—It was stated above that the eggs were fertilized as laid. As soon as the sperm enters the egg, the membrane surrounding the egg is raised from the protoplasm underneath, leaving a fluid-filled space. This prevents other sperm from entering. The membrane is called the *fertilization membrane*.

2. CLEAVAGE.—The division of the fertilized egg by mitosis is called *cleavage*. There are several types of cleavage. If the division plane cuts all the way through the egg, the type of cleavage is *holoblastic* (Gr. *holos*, complete; *blastos*, sprout) and may be equal or unequal; in *meroblastic* or *discoidal* (Gr. *meros*, part, fraction; *blastos*, sprout), the plane cuts only a part of the way through, as in birds' eggs with large yolks; in *superficial* cleavage, the nuclei, after dividing, migrate to the periphery and, as their walls form, surround the central mass, as in insects' eggs (page 403). The frog egg exhibits *holoblastic* cleavage (Fig. 177).

The parts of the divided egg are *blastomeres* (Gr. *blastos*, sprout; *meros*, fraction). As division proceeds in holoblastic eggs, the cells at the animal or pigmented pole become slightly smaller. This is because they are more active than the cells at the vegetal pole. The accumulation of yolk at the vegetal pole nourishes the developing tadpole until it can shift for itself.

3. THE BLASTULA (Gr. *blastos*, sprout).—As the cells divide, they form a hollow sphere, the blastula. The cavity is filled with fluid and is called the *cleavage cavity*, or *blastocoele*.

4. The Gastrula (Gr. *gaster*, stomach).—In *Amphioxus* (page 684) and in the starfish (Fig. 246), the gastrula is formed by the inpushing of the ectoderm to form a two-layered sac, the outside layer being the ectoderm and the inside layer being the entoderm. The two lips of the

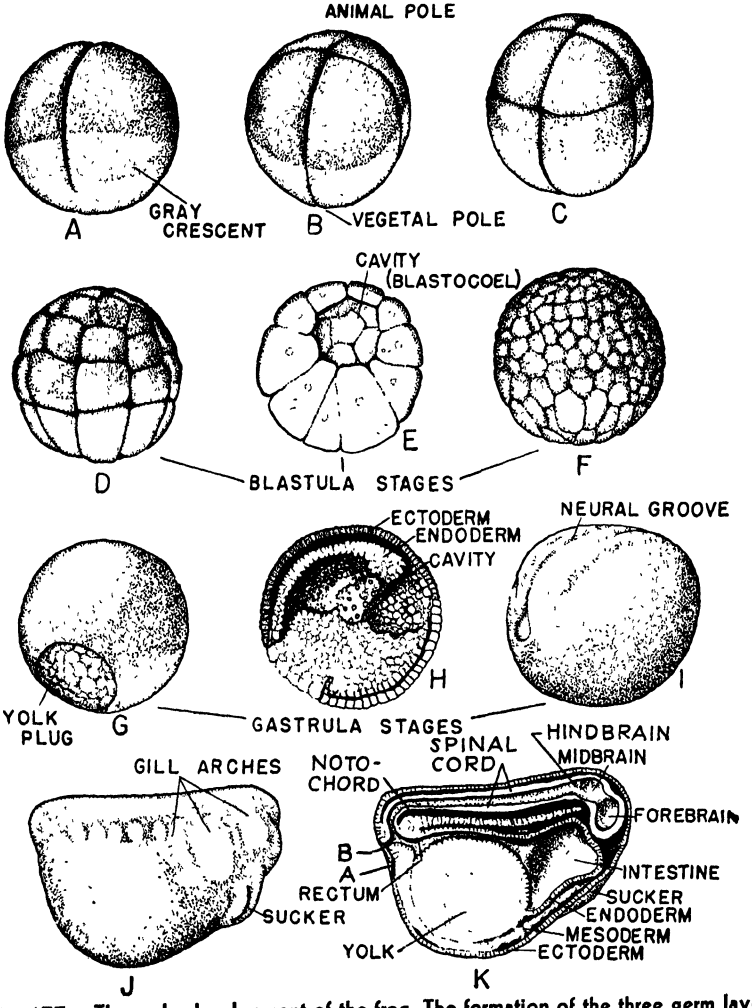

Fig. 177.—The early development of the frog. The formation of the three germ layers is a little more complicated than the same stages in the starfish (p. 246) and the Amphioxus (p. 684) but the general plan is the same. (B) Blastopore. (A) Anal pit.

sac bound the *blastopore*, and the cavity of the gastrula is the primitive gut or *archenteron* (Gr. *arche*, beginning; *enteron*, intestine). These processes are somewhat modified in the frog because the vegetal pole cells are so massive that simple invagination is difficult. The archenteron is

produced by a flat infolding just below the pigmented area. A crescentic crease left on the surface is the blastopore (Fig. 177).

5. MESODERM FORMATION.—The details of the formation of the mesoderm differ somewhat in different animals. In any case, this layer of cells grows out between the ectoderm and the endoderm. For further information on mesoderm formation, see Chap. XLIII.

6. DERIVATIVES OF THE GERM LAYERS.—All adult structures are derived from the three germ layers, the ectoderm, the mesoderm, and the endoderm. In general outline, these are as follows:

Ectoderm

Nervous system
Eyes, ears, and nasal cavities
Epidermis of the skin
Lining of the proctodeum and the stomodeum

Mesoderm

Dermis of the skin
Skeletal system
Walls of the digestive tract, except the lining
Muscular system
Circulatory system
Excretory system
Reproductive system
Lining of the coelom

Endoderm

Lining of the digestive system, except in the region of the stomodeum and proctodeum
Lining of the lungs and air tubes
Parts of the liver and pancreas
Lining of the urinary bladder

7. THE LARVA.—When the egg hatches, the larva is somewhat fish-like in appearance. Two pairs of branching external gills are present, and the mouth is ventral. This mouth is purely a larval feeding organ, being surrounded by a chitinous rim used for scraping matter from the surfaces of water plants. Soon the external gills disappear, and internal gills, something like those of a fish, appear. These are covered with a fold of skin, the operculum, which has a single opening on the left side, the *spiracle*. Water passes from the gill slits through the spiracle to the outside. The hind limbs appear first, then the forelimbs.

8. METAMORPHOSIS.—It is difficult to separate the larval phase from the phase of metamorphosis as one phase blends into the other. The tail is resorbed toward the end of the larval period:

> And funny tadpoles that are fish
> When in the stream they swim and swish
> Take off their tails and climb a log
> When it is time to be a frog!
>
> —J. PRESTON.

Other changes are the shortening of the long, spirally coiled intestine (typically a vegetarian organ) and the resorption of internal gills. The lungs develop, and the tadpole now comes to the surface for air. Shortly after this, the tadpole becomes a frog.

Some frogs complete their metamorphosis in a few weeks; others require several months; a bullfrog may take two, three, or four years, a longer time being required in colder than in warm climates.

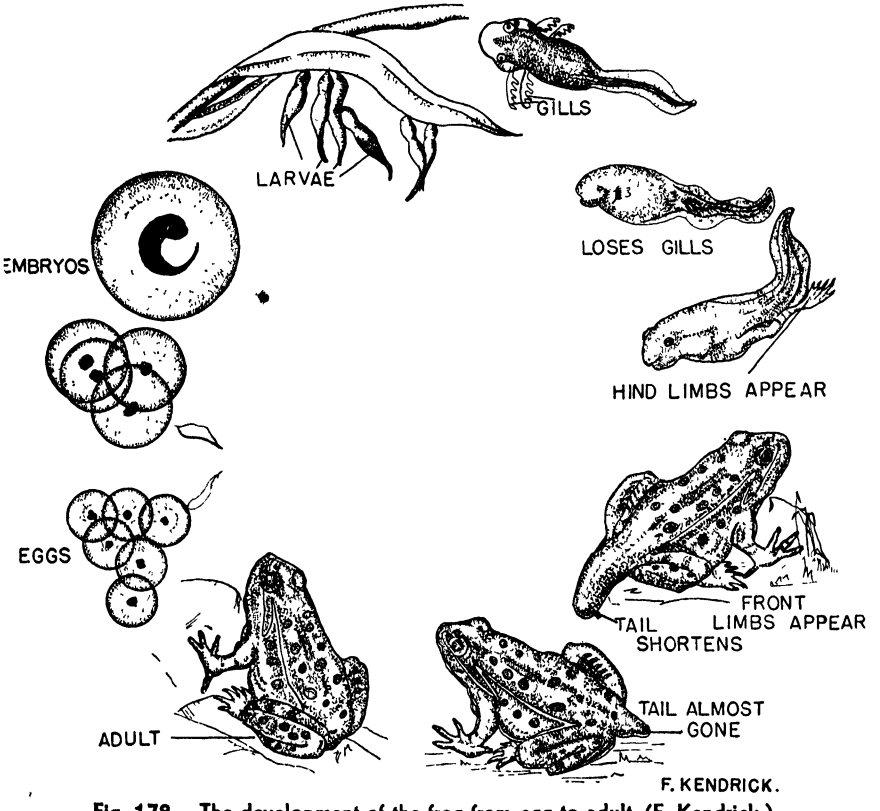

Fig. 178.—The development of the frog from egg to adult. (F. Kendrick.)

9. Adolescence.—The young frog takes some time to mature. At first, the skeleton is cartilagenous; then it becomes ossified. Other changes are the relative proportion of parts. The final change is when the animals become sexually mature and the reproductive organs produce germ cells, the male producing sperm, the female, eggs. Figure 178 shows the events in the development of a frog from the egg.

P. The Endocrines.—In addition to the complicated nervous system, the frog and all the higher animals possess ductless or *endocrine* (Gr. *endon*, within; *krinein*, separate) glands, which may be spoken of as

agents of chemical coordination. Endocrine glands have no special ducts; their secretions are absorbed directly into the blood stream and carried to all parts of the body. These secretions are called *hormones* (Gr. *hormon*, to arouse or excite). Mention has been made of the pineal and adrenal glands.

It will be more convenient to study endocrine glands in a later section (page 619), since more of the experimental work done to demonstrate their function has been done on the higher animals. However, some interesting work has been done with tadpoles and frogs.

1. The Thyroid.—It was discovered by Guternatsch that if thyroid is fed to tadpoles, they are transformed into miniature frogs very quickly; in other words, their metamorphosis and development speeded up. On the other hand, it was found by Allen that if the thyroid is removed from young tadpoles, they never metamorphose; *i.e.*, they never become frogs. If, however, a small amount of thyroid extract is dropped in the water in which these tadpoles are, they will begin development and, in a short time, become frogs.

2. The Pituitary.—If the pituitary gland of tadpoles is removed, they lose their natural dark color, becoming silvery in appearance, and they are unable to alter their coloration. It has been determined, also, that if the eyes are covered with an opaque material, the color changes do not take place. This suggests that the pituitary plays a role in those animals that are able to change their colors in different surroundings; the stimuli enter the eyes, pass along the optic nerve to the brain, and probably some of them are sidetracked to the pituitary (Fig. 173*B*). For a general discussion of the endocrines, see page 619.

Q. Hibernation (page 506).—In the late fall, frogs bury themselves in mud and lie in a dormant condition until the next spring; *i.e.*, they hibernate. During this time, vital activities are reduced to a minimum. No food is taken in winter, but in summer the frog feeds voraciously and stores up food in the tissues to be used during hibernation.

Questions

1. Describe the external features of a frog.
2. What are some interesting features of the skin of a frog?
3. Compare the pectoral and pelvic girdles, stating the functions of each.
4. Name the functions of the skeleton.
5. Describe the three types of muscles and the functions of each type. How are muscles arranged on the skeleton?
6. How does the frog use its teeth?
7. Describe the interior of a frog's mouth.
8. What are the organs of digestion? Give a running account of the events of digestion in the frog. Include in this account a statement of the structures and enzymes involved.
9. What are the types of blood corpuscles in the blood of a frog and the function of each type? What is one difference between the red corpuscles of the frog and those of man?

10. What is the blood plasma? The lymph? What is the function of the lymph?
11. Give an account of how the blood enters and leaves the heart. How does the structure of the heart prevent much mixing of oxygenated and nonoxygenated blood?
12. By what two paths may blood return from the hind legs of the frog to the heart?
13. What is the particular role of the hepatic portal system?
14. What are the three ways in which the blood of the frog may be oxygenated?
15. The frog is an air-breathing animal, yet it can remain under water for a long time. Explain.
16. Discuss the functions of the blood.
17. What is the difference between an artery, a vein, and a capillary?
18. Describe the divisions of a frog's brain, stating the functions of each division.
19. What is the result of the removal of the cerebrum? The midbrain? The cerebellum? The medulla oblongata?
20. Describe the cavities in the brain and spinal cord.
21. Describe the peripheral nervous system and the autonomic nervous system.
22. How many cranial nerves has the frog? How many spinal nerves?
23. Describe a reflex arc and a simple reflex.
24. Where are the brachial and sciatic nerve plexuses?
25. What are the types of metabolic wastes, and how are they eliminated?
26. Where is urea built up, and how is it eliminated? Describe the excretory system of the frog.
27. Compare the male and female reproductive systems of the frog.
28. Give an account of the fertilization and early development of the frog egg.
29. What is the blastula? The gastrula?
30. Describe the metamorphosis of the frog. What is meant by the adolescent period?
31. What is the result upon the development of the frog of the removal of the thyroid gland? What is the function of the pituitary gland?
32. Define: occipital condyle, urostyle, neural arch, tendon, fascia, Bowman's capsule, mesentery, duodenum, ileum, cloaca, mucosa, villus, goblet cell, diastole, systole, sinus, optic chiasma, infundibulum, hypophysis.

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B. THE ANIMAL GROUPS; MORPHOLOGY AND PHYSIOLOGY OF REPRESENTATIVE TYPES

CHAPTER XVIII

THE PROTOZOA

Nature is never more perfect than in small things.
—PLINY.

I. Protozoa and Metazoa

The animal kingdom is divided into two great groups, the *Protozoa* (Gr. *protos*, first; *zoon*, animal), which are single-celled animals, and the *Metazoa*, which includes an enormous number of species of animals. These consist of animals without backbones and animals with backbones, as well as some forms not included in these two groups, the lower chordates. Brief mention was made in Chap. VII of representatives of various groups in the very condensed description and classification of the living world. As an introduction to the study of animal biology, the organization of a typical vertebrate, the frog, was described. It is now necessary to select for study a very few key types of the more important animal groups. The morphology and physiology of the types studied will be included as well as a discussion of the important biological principles illustrated by the group to which the types studied belong. Whether this study is made in the laboratory or in the classroom, it will be found an excellent background for the understanding of Part III of this book, the principles of biology.

Protozoa

II. One-celled or Acellular Animals

It is the fashion to call Protozoa "the simplest animals." A little reflection, however, will convince one that a single cell, or a group of single cells, able to perform all the functions of life cannot be simple. Many diseases are caused by them, and a knowledge of the life cycles of pathogenic forms is important in some public-health problems. Further, many biological principles and problems are illustrated very well by the Protozoa.

A. Habitat of Protozoa.—Protozoa live everywhere in the earth, in fresh and salt water, in the bodies of plants and animals, and their spores are in the air.

B. Classification of Protozoa.—Protozoa are classified on the basis of their means of locomotion:

Class I. FLAGELLATA (L. *flagellum*, whip) or *Mastigophora* (Gr. *mastix*, whip; *phoros*, bearing). Protozoa that move by means of flagella; *Euglena* (Fig. 179); *Volvox* (Fig. 180).

Class II. RHIZOPODA (Gr. *rhiza*, root; *pous*, foot) or *Sarcodina* (Gr. *sarx*, flesh). Protozoa that move by means of pseudopodia (false feet); *Amoeba* (Fig. 182); *Difflugia* (Fig. 183*B*).

Class III. SPOROZOA (Gr. *spora*, seed; *zoon*, animal). All members of this group are parasitic, possess no locomotor organs, and reproduce by means of spores; *Plasmodium* (malaria parasite) (Fig. 184); *Coccidium*, *Gregarina*.

Class IV. CILIATA (L. *cilium*, eyelash), or *Infusoria* (L. *infusus*, poured into, crowded). Protozoa that move by means of cilia; *Paramecium*, *Chilodonella*, *Euplotes*, *Vorticelli* (Figs. 185 and 194).

Class V. SUCTORIA (L. *sugere*, to suck). Often classed with ciliates; only larvae have cilia; adults have sucking tentacles; *Podophrya*, *Acineta* (Fig. 194*I*).

C. Flagellates.—Both single and colonial forms are found among the flagellates. *Euglena* and *Volvox* are the forms usually studied.

1. EUGLENA. *a. Habitat.*—This animal is a flagellated protozoan that lives in stagnant pools or along the quiet edges of ponds and streams. In spite of the fact that it can be seen only with the microscope, such numbers may be present as to render the water green in color.

b. Appearance and Structure.—*Euglena* is green in color, containing the same substance, chlorophyll, that gives plants their green color. For this reason, *Euglena* is sometimes called one of the *borderline organisms*, neither plant nor animal, but having characteristics of both. For convenience, *Euglena* is usually included with the Protozoa, although some biologists think it is more plant-like than animal-like.

Euglenae vary greatly in size and shape. *Euglena agilis*, one of the most common species, is more or less cigar-shaped, as shown in Fig. 179. The blunt end is the anterior end and is directed forward when the *Euglena* swims. The outer covering of the body, the *cuticle*, is elastic, making it possible for the animal to change its shape to a certain extent. At the anterior end is a whip-like filament, the *flagellum*, which lashes about and moves the *Euglena* from place to place. At the base of the flagellum is a depression shaped like a funnel; it is the opening to the reservoir, often called the cytosome (Gr. *kytos*, hollow vessel; *stoma*, mouth). This opening leads through a short passageway, the neck of the reservoir, to the spherical reservoir. Next to this is a vacuole into which small contractile vacuoles empty their contents from time to time. A red body, sensitive to light, called an *eyespot*, is located near the anterior end. In the living animal, near the center of the body, may be seen an apparently clear space. This is the nucleus. When *Euglena* is stained, this nucleus appears as a conspicuous oval body.

c. Motion and Locomotion.—Euglena moves from place to place chiefly by swimming. It is able to do this because of movements of the flagella. In most Euglenae, the flagella are short and difficult to see, but some of their relatives possess conspicuous flagella that can be readily observed. A number of these euglena-like species move their flagella with a vibrating motion, whereas others bend them in various ways. The method of moving the flagellum determines the way in which the Euglenae move; some swim—for example, *Peranema*—more smoothly

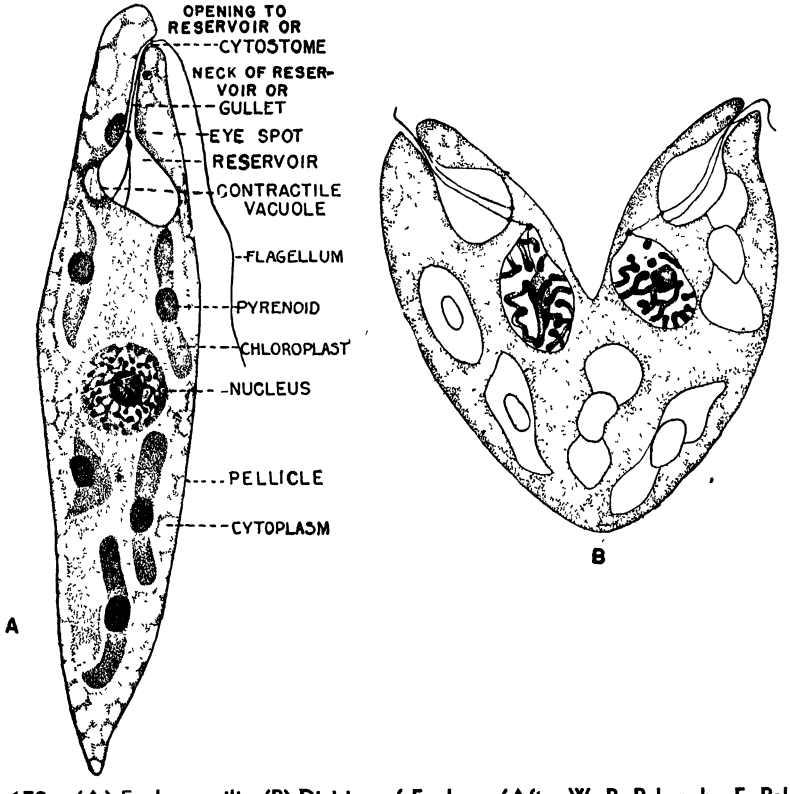

Fig. 179.—(A) Euglena agilis. (B) Division of Euglena. (After W. B. Baker, by F. Baker.)

than others. On account of the fact that *Euglena* is able to contract and twist its body, it is able to "squeeze through" very small spaces that would be impossible for it to manage otherwise.

d. Food and Digestion.—Euglena may absorb food substances that are in solution through its body wall, but it also possesses chlorophyll, and with the aid of sunlight and by absorption of water and mineral substances may manufacture food as the plants do, by photosynthesis (page 140). It produces and stores up a special kind of starch called *paramylum*.

e. Respiration and Excretion.—Respiration in *Euglena* is carried on through the body wall. Since the process of photosynthesis takes place within the *Euglena's* body, it is probable that some of the carbon dioxide produced by the animal is used in some way in this process and that some of the oxygen resulting from photosynthesis is used in the cell for oxidation purposes. Liquid wastes and water collect in the small *contractile vacuoles.* When the vacuoles contract, these wastes are emptied into the *large vacuole,* then into the *reservoir,* and finally into the *cytopharynx,* and from there to the outside.

f. Reaction to Stimuli.—The red "eyespot" mentioned above is sensitive to light, although it is not a real eye. Since photosynthesis is carried on only when light is present, it is of advantage to *Euglena* to be in the light at least a part of the time, yet direct sunlight will kill it. If a dish containing Euglenae is placed in the direct sunlight and one side of it shaded, in about an hour the green masses are concentrated on the shady side of the dish.

g. Reproduction.—*Euglena* reproduces by *longitudinal binary fission.* When the animal is ready for reproduction, the nucleus divides, and then, beginning at the anterior end, the body divides down the middle (Fig. 174*B*) along its longitudinal axis.

When conditions are unfavorable for *Euglena,* the body may become spherical and secrete around itself a sort of envelope. After this envelope has been secreted, *Euglena* loses its flagellum and is then said to be *encysted.* The animal, together with its envelope, is called a *cyst.* While within the cyst, it divides into two or more cells, depending upon the species of *Euglena.* When conditions again become favorable, each cell within the cyst emerges as a young *Euglena.* Cysts of *Euglena* may be found on the sides and bottoms of culture dishes that have stood for some time in the laboratory or are becoming dry. When the cysts are able to withstand drying, they can live in the cyst stage for a long time, becoming active again when the pools fill up with water. This is one of nature's ways of helping the animal tide over unfavorable conditions.

2. Volvox, a Colonial Flagellate.—*Volvox globator* is a colonial flagellate consisting of hundreds or thousands of one-celled individuals that form a sphere shaped like a hollow rubber ball, as illustrated in Fig. 180. The outside of the ball contains a single layer of cells. Each cell is connected with all its neighbors by protoplasmic strands. One remarkable feature of *Volvox,* is the presence of two types of cells, *body cells* and *germ cells.* The body cells carry on all the functions except reproduction. The germ cells are set aside for the single purpose of reproducing other colonies of *Volvox.* This is a *division of labor* among the cells.

Figure 180*a* represents one type of reproductive cell. This grows and divides as shown in (*b*) and (*c*) until it becomes a small asexual colony as in (*d*). This small colony breaks away from the parent colony and grows into a full-sized *Volvox*.

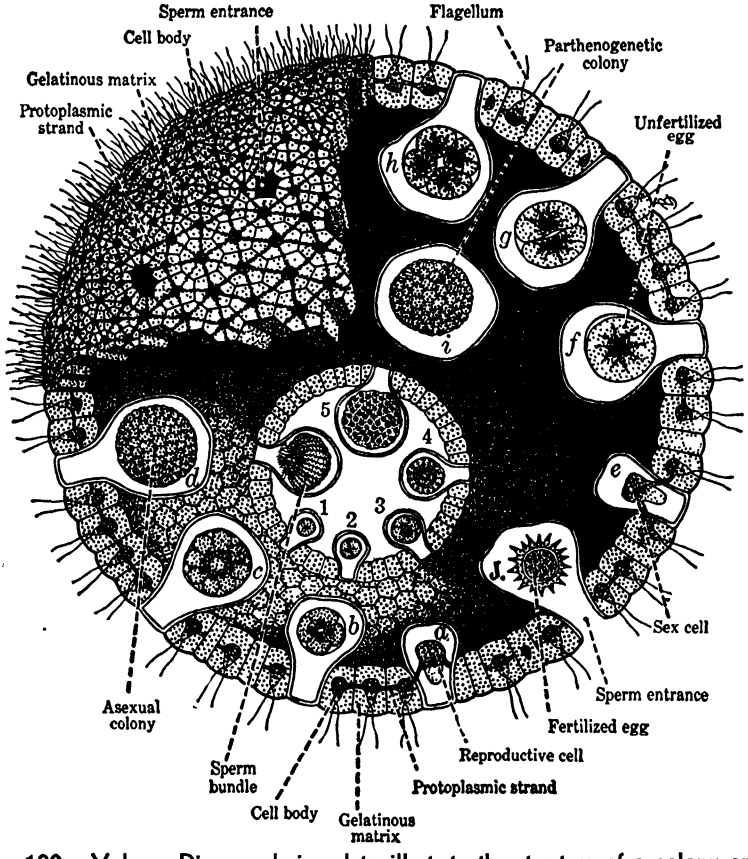

Fig. 180.—Volvox. Diagram designed to illustrate the structure of a colony and the various types of cells. (e) (f) (g) (h) (i) are stages in the development of a parthenogenetic colony. (1) (2) (3) (4) (5) are stages in the development of a sperm bundle. Natural size, about 0.7 mm. in diameter. (Drawn by Bruce Lineburg, from Hegner, College Zoology, The Macmillan Company.)

Another type of reproductive cell is shown at (*e*). This may grow in size, as shown in Fig. 180*f*, *g*, and *h* and forms a *parthenogenetic colony* (Fig. 180*i*).

A third type of reproductive cell, also a sex cell, grows and divides as shown in the figure from 1 to 5; this, then, transforms into a bundle of minute cells, each of which represents a *spermatozoon*. The spermatozoa

break out of the bundle, and each egg is fertilized by one of them. The fertilized egg surrounds itself with a spiny covering as shown in the illustration (Fig. 180*j*). It lives through winter, and when spring comes, develops into a single *Volvox* colony.

3. Other Representative Flagellates.—In Fig. 181 are shown six types of flagellates that are more or less closely related to *Euglena*. They may all be found in fresh-water ponds, and they often occur in cultures of *Euglena*, and other Protozoa.

Gymnodinium is characterized by a groove around the center of the body in which lies a flagellum (Fig. 181*A*). *Trachelomonas hispida* is covered with spines and possesses a long flagellum (Fig. 181*B*). *Dinobryon* is a type that forms a branching colony; each individual is surrounded

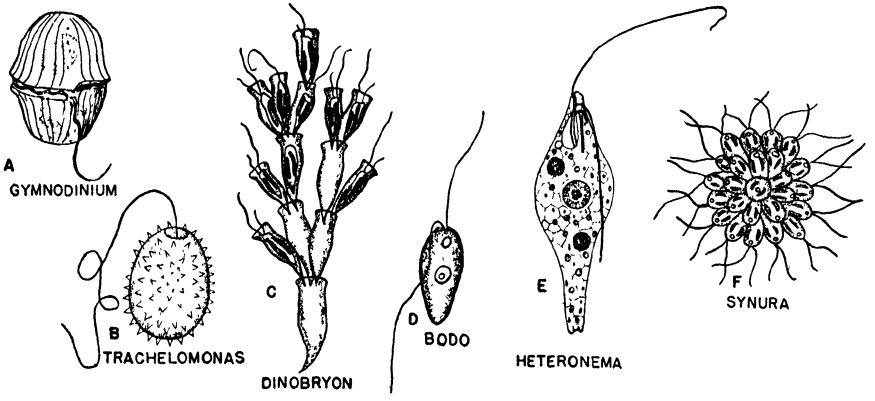

Fig. 181.—Some types of flagellates, Mastigophora. (Heteronema after Rhodes. F. Kendrick.)

by a transparent membrane, shaped somewhat like a collar (Fig. 181*C*). *Bodo* is a minute type with two flagella, one directed forward and the other trailing behind (Fig. 181*D*). *Heteronema* also has two flagella, a long anterior flagellum and a shorter trailer (Fig. 181*E*). *Synura* is a colonial type; the members of the colony are fastened together at their posterior ends to form a sort of ball-like mass (Fig. 181*F*). *Dinobryon* and *Synura* often occur in such numbers in reservoirs as to render the water unfit to drink. *Dinobryon* produces a fishy odor, and *Synura* produces an odor resembling ripe cucumbers and a bitter and spicy taste. Dissolving a very small amount of copper sulphate in the water destroys these noxious Protozoa.

D. Rhizopods. 1. Amoeba Proteus (Fig. 182*A*) is a familiar scientific name. This familiarity is partly due to the fact that it is usually considered to be the most primitive of all the animals and partly because many students study it in high school or college. It is the usual form studied as a representative of the class Rhizopoda.

a. Habitat.—Fresh-water ponds are the favorite habitat of *Amoeba proteus*. Here it may be found creeping about on the underside of lily pads or on dead leaves and sticks on the bottom. It is almost transparent and is too small to be seen with the naked eye; hence scrapings from these objects must be brought into the laboratory and examined under the microscope. It is not always easy to find.

b. Appearance and General Structure.—A living *A. proteus*, when viewed with a microscope, looks like "a minute mass of animated jelly." Within it are a number of *granules*, some of which are food particles. Close observation will reveal a clear bubble-like body that is known as the *contractile vacuole*. This is a little cavity in the protoplasm that fills up with liquid, rises to the surface, and then contracts so as to force its contents to the outside. In addition to the probable functions mentioned below, some authorities consider that the contractile vacuole may be a *hydrostatic* organelle, *i.e.*, that it regulates the amount of water in the body. Another apparently clear space may also be seen; this is the *nucleus*. When killed and stained, the nucleus, contractile vacuole, and food bodies are more easily distinguished.

c. Motion and Locomotion.—*A. proteus* moves with the aid of finger-like processes called *pseudopodia*. These are slowly thrust out from the jelly-like mass, and then the rest of the body flows into them. New pseudopodia are then formed, and a little more progress is made. There is an almost constant streaming of protoplasm in the body.

d. Food Getting.—*A. proteus* is said to practice some food selection. It is especially fond of one of the flagellates, a species known as *Chilomonas paramecium*. It will creep up on a *Chilomonas* and surround it with its pseudopodia, thus engulfing the little flagellate. Other minute plants and Protozoa, as well as organic particles, also serve as food for *A. proteus*.

e. Digestion and Assimilation.—A little water is taken in with the food. The result is a spherical globule of water with the food suspended in it. Thus a *food vacuole* is formed. Digestive juices secreted by the protoplasm go into the food vacuole. After digestion, food is absorbed into the protoplasm; *i.e.*, it is *assimilated*. Undigested wastes are left behind, or *egested*.

f. Circulation, Respiration, and Excretion.—In the body of *A. proteus*, food vacuoles are carried about from place to place by the streaming of the protoplasm. In this way the products of digestion and other materials are distributed and no circulatory system is necessary.

Respiration and excretion take place mainly through the general surface of the body wall. If present, contractile vacuoles may play a part in these processes. Many *Amoebae*, however, especially salt-water forms, do not have contractile vacuoles. The exchange of respiratory gases, *i.e.*, the taking in of oxygen and the giving off of carbon dioxide, corresponds to internal respiration of the higher animals.

g. Response to Stimuli.—If an amoeba is touched with a needle, the response to this type of mechanical stimulus is movement away from the needle. Many investigators have tried to determine why *Amoeba proteus* behaves as it does. They have subjected specimens to all sorts of stimuli, *i.e.*, to all sorts of changes in their environment. They have found that it will move toward food particles but away from such chemicals as sodium chloride and cane sugar; that it will move away from strong light but toward weak light; and that it will move away from hot water.

h. Reproduction.—Only one type of reproduction is known with certainty to occur, though other types have been described; this known

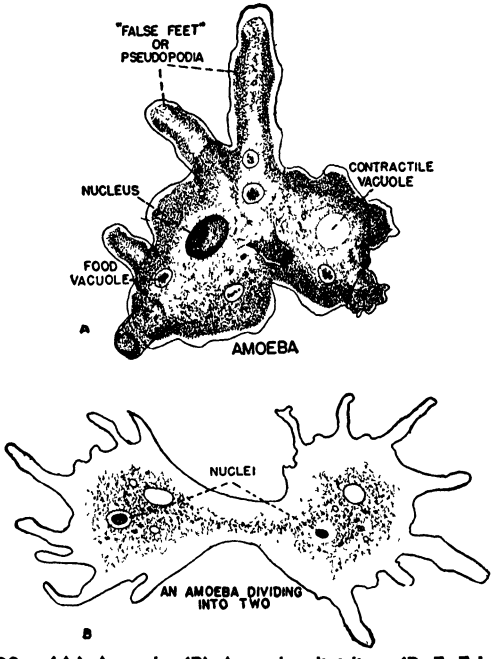

Fig. 182.—(A) Amoeba (B) Amoeba dividing. (B. F. Edwards.)

method is called *binary division*, since the body has divided into two daughter amoebae. The nucleus divides first by a sort of mitosis (page 36), and then the entire body divides, each daughter receiving one-half of the nucleus and one-half of the cytoplasm of the parent (Fig. 182*B*). After a period of growth, the animal divides again. This continues day after day and year after year and probably has been going on for millions of years. If conditions were favorable, amoebae and some other Protozoa would keep on dividing and so live on indefinitely without the intervention of natural death. For this reason, they have been called *the immortals.*

2. Representative Sarcodina.—In Fig. 183 are shown four types of Sarcodina. The first, known as *Arcella* (L. *arca*, box), is a fresh-water

type that resembles an amoeba. The living body of *Arcella* secretes a shell of lifeless matter in which to live. A circular opening is left through which the *Arcella* thrusts its pseudopodia for purposes of moving about and obtaining food.

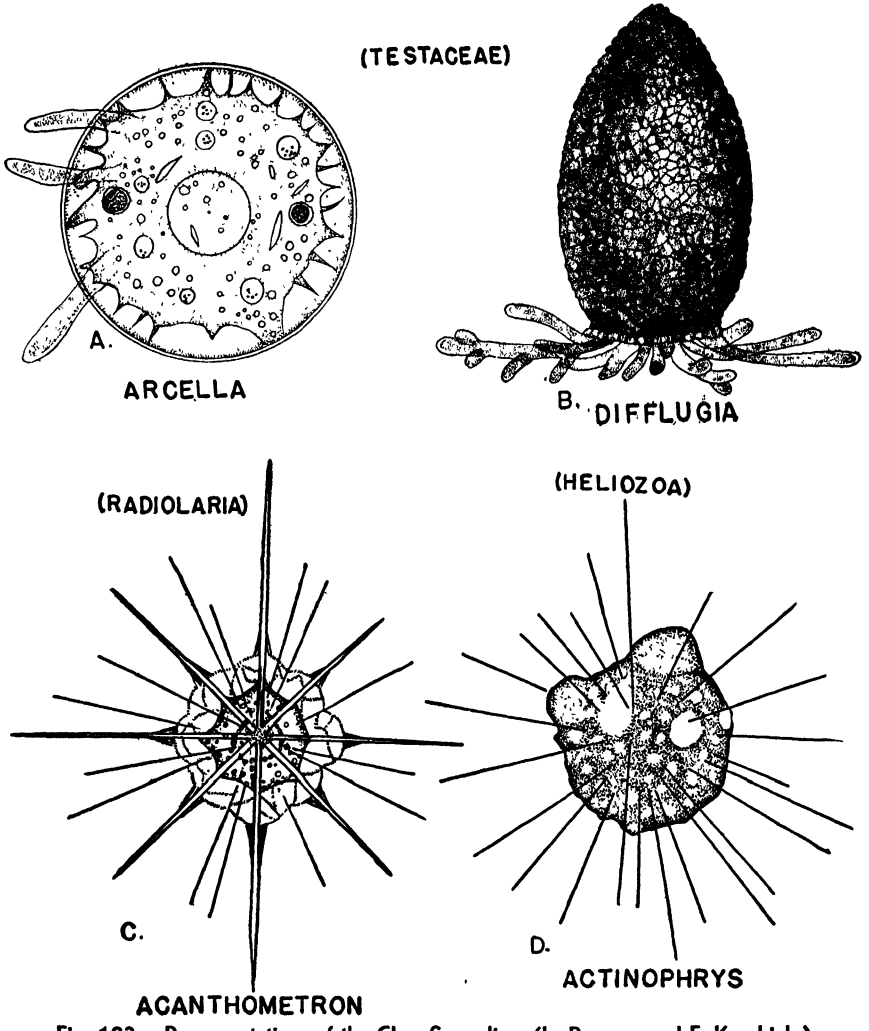

Fig. 183.—Representatives of the Class Sarcodina. (L. Runyon and F. Kendrick.)

Difflugia (L. *diffluere*, to flow apart).—This amoeba-like fresh-water species builds a house or *test* of minute grains of sand (Fig. 183*B*). Like *Arcella*, it leaves an opening for the thrusting out of pseudopodia.

In the sea are vast numbers of Protozoa that may claim *A. proteus* as a relative. Some of these are Radiolaria (L. *radius*, radius), one of which

is shown in Fig. 183*C*. These radiolarians build very elaborate skeletons out of silica.

The sun animalcules, or Heliozoa (Gr. *helios*, the sun; *zoon*, animal), are also relatives of *Amoeba*. They live in fresh water, where they roll about on the ends of their "rays." *Actinophrys sol* is a common form (Fig. 183*D*).

E. Sporozoa.—Some parasitic forms are found in all four groups of the Protozoa, but the Sporozoa are all parasitic. They form a very large group of heterogenous forms without mouth or locomotor organs. Because of their parasitic habit, they have lost the structures necessary for a free life. Because of their mode of life, also, they have very complex life histories that ensure that the parasites shall reach their host or hosts.

1. MONOCYSTIS is a common form of sporozoan living in the seminal vesicles of the earthworm. They are present in most earthworms and are easily recognized by their spindle-shaped bodies.

2. COCCIDIA.—Many species of Coccidia are parasitic in both vertebrates and invertebrates. They attack the cells of the intestine and are the most common cause of death in young rabbits and in poultry (page 814).

3. PLASMODIUM.—The *malarial-fever parasite Plasmodium* is the most important sporozoan that affects man, causing widespread damage in some sections, especially in the south. Other animals besides man also suffer with malaria. For example, wild birds, such as sparrows, robins, etc., are often infected with their own type of malaria. Birds do not become infected with human malaria, and man does not become infected with bird malaria.

Malarial fevers are characterized by periodicity of symptoms, by the deposition of pigment in the tissues of the body, and by the enlargement of the spleen.

a. The Types of Malaria.—Plasmodium has a complicated life history. In 1880, a French doctor, Laveran, discovered *Plasmodium vivax* (benign malaria parasite) in the blood of malaria patients. Later (1891) he suggested that this disease was transmitted by some blood-sucking insect. This was proved by Sir Ronald Ross in 1899.

Three types of human malaria are recognized: (1) *tertian* fever, characterized by an attack every 48 hours and caused by *P. vivax* (this type is also called *benign malaria*), and (2) *quartan fever*, characterized by an attack every 72 hours and caused by *P. malariae*, and *aestivo autumnal* fever, characterized by daily attacks and caused by *P. falciparum*.

b. The Cycle in Man; the Asexual Cycle.—The disease is transmitted by the female *Anopheles* mosquito (Fig. 184). The male does not bite animals but lives on plant juices. When the infected mosquito bites a person, the saliva containing the parasites finds its way into the wound.

The parasite, known at this stage as a *sporozoite*, penetrates red corpuscles (Fig. 184), rounds up, becomes amoeba-like, and develops into a *trophozoite*. In about 50 hours, the trophozoite is full-grown and is known as a *schizont*. This now divides into 15 or 20 cells, the *merozoites*, which are then liberated into the blood stream. At the same time, a brown pigment, *melanin*, which is a waste product of the parasite, is thrown into the blood stream. The *merozoites* immediately enter red blood cells. Some of them become *schizonts*, which repeat the asexual cycle; others develop

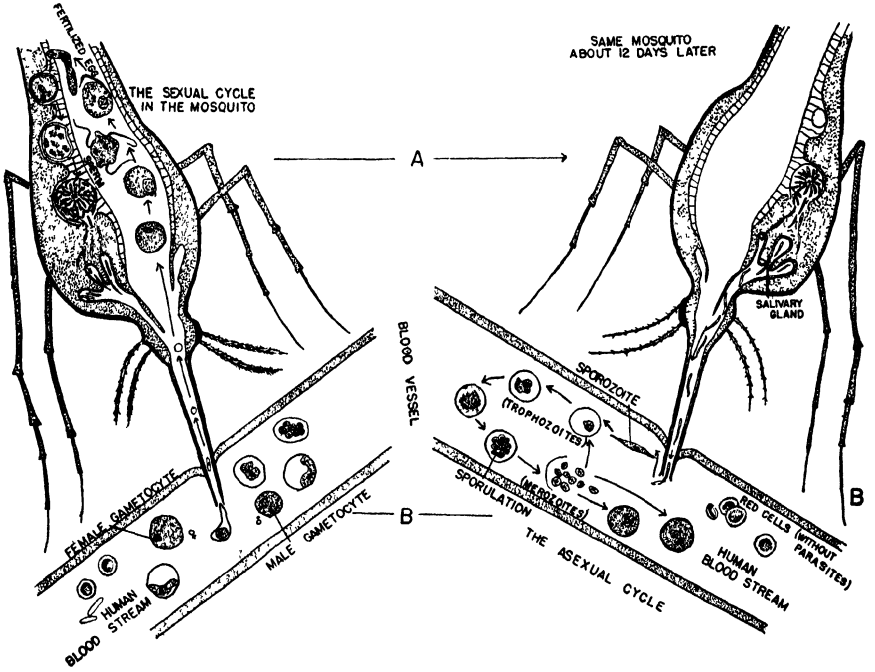

Fig. 184.—Life cycle of the malaria parasite. (A) Cycle in the mosquito. (B) Cycle in man.

into male and female *gametocytes* and remain quiescent until an *Anopheles* mosquito gets them by sucking up the blood. If the common mosquito *Culex* (Fig. 185) sucks up parasites when biting malaria patients, they are digested in her stomach; she does not transmit the disease.

c. The Cycle in the Mosquito; the Sexual Cycle.—When the female mosquito takes the blood containing the parasites from a malaria patient, the gametocytes begin development in the stomach of the mosquito. From the male gametocyte, six to eight flagellate bodies develop, *microgametes*, and the female gametocyte develops into the mature female gamete. One of the microgametes fuses with the female gamete, and fertilization is thus effected in the stomach of the mosquito. From the

zygote an active *ookinete* is formed. This enters the wall of the mosquito's stomach, rounds up into an oocyst, and in 6 or 7 days several hundred spindle shaped sporozoites are produced. These break out into the body

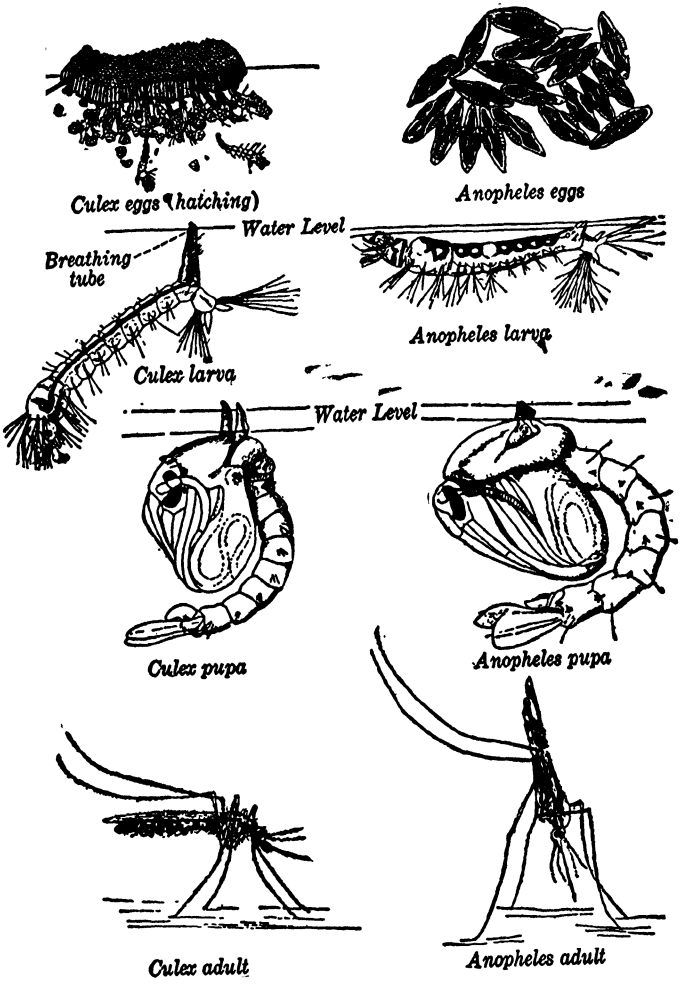

Fig. 185.—Mosquito. Stages in the life cycle of a common house mosquito of the genus Culex at the left and of a malaria mosquito, Anopheles, at the right. (Courtesy of U.S. Bureau of Entomology.)

cavity of the mosquito and find their way to the salivary glands. The mosquito is now ready to infect other human beings.

d. Malaria as a Treatment for General Paralysis (Paresis).—General paralysis is a syphilitic disease due to a minute spiral organism, *Treponema pallida* (a spirochete). Ordinarily, patients suffering from general paralysis

on the sea bottom, they form *radiolarian ooze*. An area of about 2,290,000 sq. miles on the bottom of the Pacific and Indian oceans is covered with this earth-forming ooze. Flint or chert are hardened radiolarian deposits. Abrasive powders for polishing metals made from "Tripoli" stone are largely of radiolarian origin.

3. NOCTILUCA.—The name *Noctiluca* means "night light" and was given to the Roman goddess Luna, whose palace was always lighted at night. The *Noctiluca* is well named, since it is luminescent. Ships may travel for miles through water filled with them, a phenomenon that makes the wake of the ships very beautiful to watch. Many other Protozoa are luminescent.

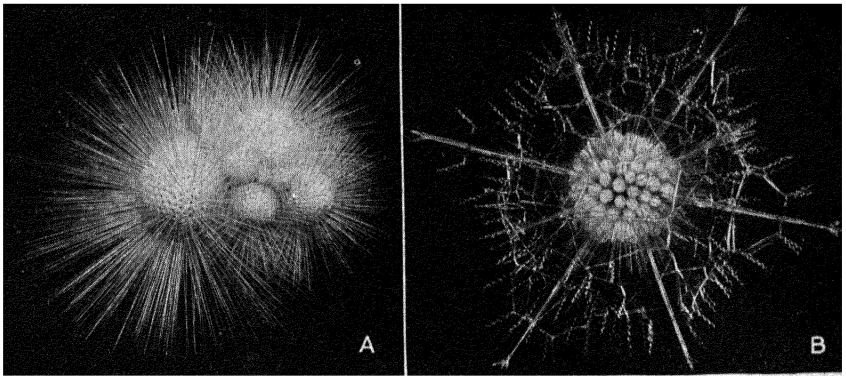

Fig. 196.—(A) Glass model of a Foraminifera, Globigerina. This protozoan has a calcareous skeleton. Millions of the animals die each day, sink to the bottom of the sea and form "Globigerina ooze." (B) Glass model of one of the Radiolarians a beautiful protozoan with a silicious shell. The skeletons of these animals form "Radiolarian ooze" on the floor of the sea. (Courtesy of American Museum of Natural History.)

4. HAEMATOCOCCUS.—This name means "bloodberry," and the animal that bears it is responsible for red snow or "bloody" rain. It can grow and multiply on the tops of snow-capped mountains as well as in rain water.

5. FLAGELLATES IN TERMITES.—If the body of a white ant or termite is crushed in a drop of normal salt solution and then examined under the microscope, many beautiful and interesting protozoa are to be seen. Some of them have many flagella. These flagellates are said to aid the termite in the digestion of the wood upon which it feeds.

III. Biological Principles and Problems Illustrated by the Protozoa

A. Division of Labor.—Protozoa are single-celled animals, yet many forms show colony formation. In these colonies, there is a division of labor. For example, in *Volvox*, certain cells are set aside for reproductive

purposes. The question is raised as to whether this may not be a step the formation of the multicellular animal. The vegetative cells of *Volvo* however, are all alike, and for this reason, it is designated as a colony a not as a multicellular animal.

B. Immortality.—When a protozoan divides, two new individua are formed. This process of division will continue as long as conditio are favorable. For this reason, protozoa are often spoken of as "th immortals." However, even here, in a form like *Volvox*, certain cells ar set aside for reproductive purposes, and the vegetative individual cannot reproduce itself, so its life span is limited.

C. Symbiosis (page 54).—Some Protozoa live *symbiotically*, *e.g.*, the flagellates in white ants. Sometimes organisms live symbiotically in Protozoa. For example, in *Paramecium bursaria*, a one-celled plant (*Chlorella*) lives in symbiotic relationship with *Paramecium*.

D. Parasitism.—The art of parasitism has been developed even in animals of the lowest scale. Parasitic forms are found in every group of Protozoa, and even the Protozoa themselves have parasites. *Endamoeba hystolytica*, causative agent of *Amoebic dysentery* and *Plasmodium*, the parasite causing malaria, are two important protozoan parasites of man.

E. Role in the Formation of Rocks.—In the problems connected with rock formation, certain Protozoa play a part. Through the ages, skelet of the Foraminifera and Radiolaria may become compressed into roc As stated before (page 286), these rocks often form deposits 1,000 thick.

Questions

1. Name the four groups of the Protozoa. What is the basis of classification?
2. Why do we say that Protozoa are not simple?
3. What is the reason colonial forms of Protozoa are not classed with the many-celle animals or Metazoa?
4. Why must *Euglena* be kept in the light?
5. How does *Paramecium* use its trichocysts?
6. Compare *Amoeba*, *Euglena*, and *Paramecium* with regard to general body shape locomotion, food getting and digestion, respiration, excretion, reproduction, an responses to stimuli.
7. After comparing the three types mentioned in Question 6, which do you consider mo specialized? Give reason for your answer.
8. What is the neuromotor system, and what is its probable function?
9. Give a full account of the conjugation of *Paramecium caudatum*? What is the sign cance of conjugation? May paramecia be said to have separate sexes?
10. What is endomixis?
11. Why are the Protozoa called *the immortals*?
12. What is the causative agent of amoebic dysentery?
13. Name at least five interesting Protozoa, and state why they are interesting. Do yo know of others?
14. Why are suctorians classed with the ciliates?
15. Describe the formation of rock by the Foraminifera and the Radiolaria.

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CHAPTER XIX

PORIFERA, COELENTERATA, CTENOPHORA

Today the many-hued anemone
Waving expands within the rock pools green
And swift, transparent creatures of the sea
Dart throu' the feathery sea-fronds scarcely seen.
—Sir Lewis Morris.

Each of the phyla making up the great group of animals without backbones, or the Invertebrata, includes a tremendous number of species of animals, each presenting certain problems. Yet relationships can be shown, and, with few exceptions, each group fits into a general scheme. In order to keep this scheme ever in mind, it will be profitable for the student to refer often to the classification of the animal kingdom in Chap. VII and to the Genealogical Table (Fig. 53).

I. Porifera

A. Sponges in General.—The relationships of the sponges are somewhat obscure, and for this reason, they are not always placed first in the metazoan division of the animal kingdom. Sponges may be described as "loosely put together." This is shown by the fact that certain of these animals may be gently squeezed through fine silk bolting cloth, yet the small groups of cells resulting from this will "rearrange themselves," and a new sponge will grow from these small parts.

The scientific name of sponges, Porifera (Gr. *poros*, pore; L. *fero*, to bear), refers to the fact that the body wall is perforated with small pores that lead through *canals* to the central body cavity. The canals in some species form a complicated system (Fig. 197).

B. Classification.—Sponges are classified on the basis of the type of skeleton they secrete.

Class I. Calcarea (L. *calcarius*, lime). Sponges having skeletons of carbonate of lime. The spicules are embedded in the body walls and may be rods, such as those that surround the osculum, three pronged types that overlap each other (Fig. 199) and support the body wall; *Grantia* (Fig. 198).

Class II. Hexactinellida (Gr. *hex*, six; *actin*, rays). Sponges with skeletons of silicon. The spicules are six-rayed; Venus's-flower-basket (Fig. 200).

Class III. Demospongiae (Gr. *demos*, people; *spongos*, sponge). Sponges with skeletons of spongin, a substance closely related to silk. Some sponges in this group have a combination of spongin and silicious spicules; bath sponge (Fig. 201).

C. Grantia and Other Sponges. 1. HABITAT.—Some sponges grow in fresh water, but most of them live in salt water. For a long time, they were thought to be plants. Most of them grow attached to rocks and other objects in shallow salt water.

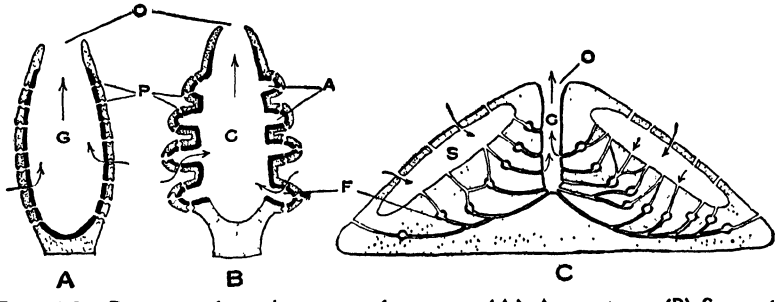

Fig. 197.—Diagrams of canal systems of sponges. (A) Ascon type. (B) Sycon type. (C) Rhagon type. The gastral epithelium is shown by heavy black line, the dermal epithelium by a light line. Arrows show water currents. (O) Osculum. (G) Gastrovascular cavity. (From Wieman, General Zoology.)

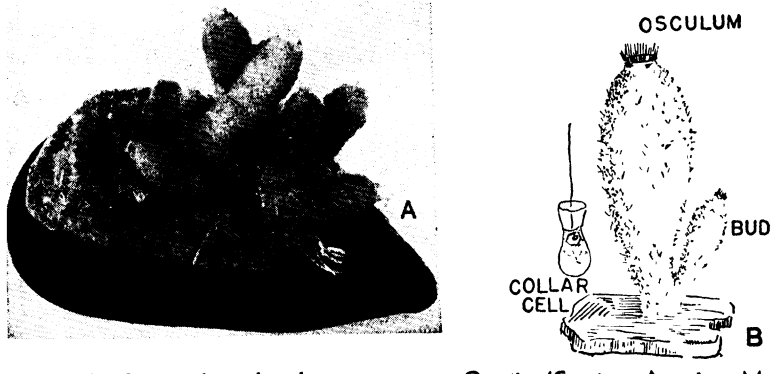

Fig. 198.—(A) Group of simple salt-water sponges, Grantia. (Courtesy American Museum of Natural History.) (B) Grantia with bud. (B. Shamos.)

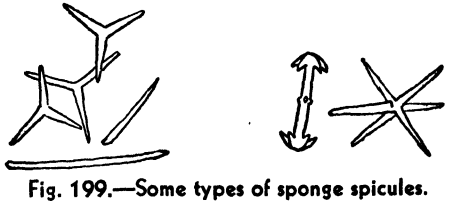

Fig. 199.—Some types of sponge spicules.

2. APPEARANCE AND STRUCTURE.—*Grantia* resembles a hollow cylinder-shaped vase. Its body wall consists of two layers, an external dermal epithelium and an inner, or gastral, epithelium. Between these two is a gelatinous material, the *mesoglea* (Gr. *mesos*, middle; *gloia*, glue), which is noncellular. The dermal epithelium and the gastral epithelium

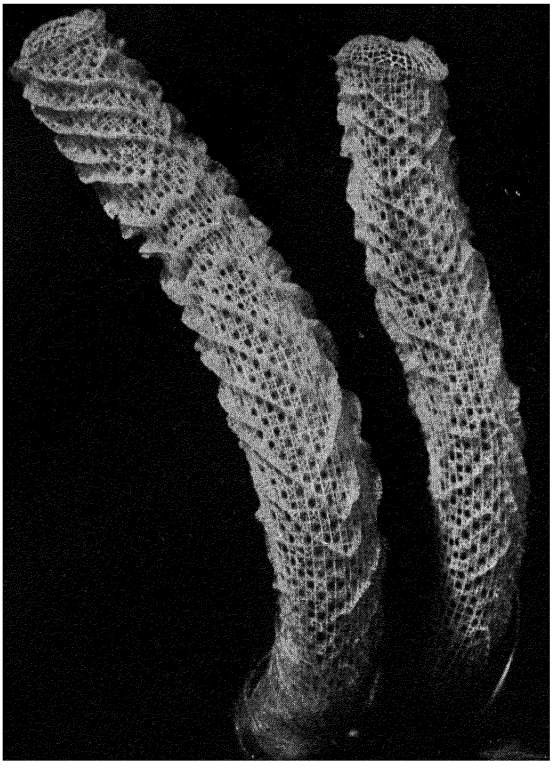

Fig. 200.—Silicious skeletons of Venus's Flower Basket, Euplectella aspergillum. (Courtesy of American Museum of Natural History.)

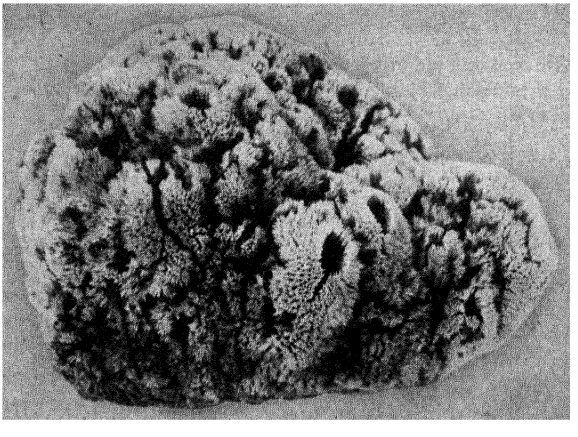

Fig. 201.—Yellow Sponge. The skeleton in this type of sponge is spongin, a substance closely akin to silk. (Courtesy of the U.S. Bureau of Fisheries.)

appear not to be homologous with the ectoderm and endoderm of the higher animals. In early embryological development, what seems to be endoderm comes to lie on the outside of the body and assume the functions characteristic of the ectoderm, whereas what seems to be ectoderm in the embryo appears later to line the internal cavities and thus assumes the functions of the endoderm. This apparent reversal of things has not been satisfactorily explained.

Collar cells line the gastral cavity and certain parts of the canal system. These keep water circulating through the body by a lashing of the flagella. The collar cells remind one of flagellated Protozoa.

3. Skeletons.—For types of skeletons for each of the groups, see above under Classification. The skeletons provide the sponges with rigidity and protect the soft parts.

4. Food and Digestion.—The water is drawn into the canals through the pores by action of the collar cells in creating currents of water contains food for the animals, mostly one-celled creatures. The cells lining the gastral cavity engulf bits of food much as an amoeba does (page 271). Digestion is also quite similar to that of the Protozoa. Products of digestion are then passed on to neighboring cells. Undigested wastes pass out through the osculum (Figs. 197, 198).

5. Other Life Activities.—Respiration and excretion are also carried on by individual cells. There is no circulatory system.

6. Reproduction.—Sponges reproduce themselves both by sexual and asexual means.

a. Asexual.—Two types of asexual reproduction may occur: (1) by budding (Fig. 198) and (2) by the formation of gemmules by internal budding. These are small groups of cells that, usually after a period of rest, grow into new individuals.

b. Sexual.—Sexual reproduction is by the formation of eggs and sperm. After the egg is fertilized, a very small larva develops. This bears cilia at first and is able to swim about. After a time, it settles down, becomes attached, and develops into a full-grown sponge.

D. Biological Problems Illustrated by the Sponges. 1. Organization.—As has been stated, the organization of a sponge appears to be of a simple type, for a whole new sponge will grow from a few cells. Yet sponges are much more complex than the Protozoa. They show a division of labor not achieved by the one-celled creatures, even by the colonial flagellates.

2. Relationship to the Animal Kingdom.—The sponges present a peculiar problem in that their two primary cell layers, the ectoderm and the endoderm, are apparently reversed from those of the higher animals. For this and some other reasons, the sponges are considered as a side branch in the animal kingdom.

For the relation of sponges to human welfare, see page 817.

II. The Coelenterata

A. General Features of the Coelenterates.—The phylum Coelenterata (Gr. *koilos*, hollow; *enteron*, intestine) contains about 5,000 species, and certain members of the group may be studied with profit as illustrating biological principles. The plan of the coelenterate body is that of a *two-layered sac.* For this reason, the animals are said to be *diploblastic* (Gr. *diplos*, double; *blastos*, germ). The outer body layer is the ectoderm and the inner, the endoderm. Between these two, as in the sponges, is a noncellular layer, the *mesoglea.*

Typically, the coelenterates have tentacles around the mouth, and these, as well as the body wall, contain stinging cells, the *nematocysts* (see below).

Many of the coelenterates show an alternation of generations in their life cycles, the *hydroid* (hydra-like) generation alternating with a *medusoid* (medusa-like) generation. Some exceptions to this rule are noted below.

The coelenterates exhibit *radial symmetry, i.e.*, the arrangement of similar parts around a central point like the spokes of a wheel.

B. Classification.

Class I. *Hydrozoa* (Gr. *hydra*, a water serpent; *zoon*, animal). Hydra-like animals; not so highly organized as the other two classes; no true gullet or stomodaeum, as in the sea anemones; sometimes alternation of generations; sometimes not; if medusa is present, it has a membrane, or velum, on undersurface around the margin; sex cells are discharged directly to the exterior; *Hydra, Obelia, Gonionemus, Physalia* (Figs. 202, 208, 210, 212).

Class II. *Scyphozoa* (Gr. *skuphos*, cup; *zoon*, animal). Larger jellyfish; margin of bell lobed, usually with eight notches; medusa without velum; Hydroid stage inconspicuous; gastrovascular cavity held in place by membranous mesenteries; *Aurelia* (Fig. 213).

Class III. *Anthozoa* (Gr. *anthos*, flower; *zoon*, animal). No medusa stage; most polyps produce a colony by budding, though a few are solitary. Coral polyps secrete skeletons that reproduce the great coral formations of the seas; *sea anemones* (Fig. 214) *corals* (Fig. 215) *sea fans, sea pens.*

C. The Hydrozoa.—One of the members of this class, the *Hydra*, is very widely used for study in biology laboratories.

1. Hydra.—This is one of the simplest examples of the multicellular Metazoa.

a. Habitat.—Hydras live in fresh-water pools and streams. They may be seen as small green or brown specks on the underside of leaves or attached to sticks and stones and water plants.

b. External Features.—The body of the *Hydra* is very elastic and may be considerably extended. It usually attaches itself to some object by its *basal disk.* This disk, or foot, may also serve as a locomotor organ. At the anterior, or *distal*, end of the body is a circlet of from 6 to 10 *tentacles.* These are also very extensible, and each is capable of independent move-

ment. They aid the animal in capturing food and in drawing it to the mouth. The tentacles surround a conical elevation, the *hypostome* (Gr. *hypo*, under; *stoma*, mouth). In the center of this is a single opening, which serves as a mouth and also as an excretory pore. The thickened hypostome helps crush the food as it is ingested.

If the hydras are well fed and in good condition, *buds* are usually present in various stages of development (Fig. 202). In the summer or autumn, sex organs are also to be seen; the male organs, *testes*, usually two in number, are near the anterior or distal end of the animal; the single *ovary* is about one-third from the basal disk.

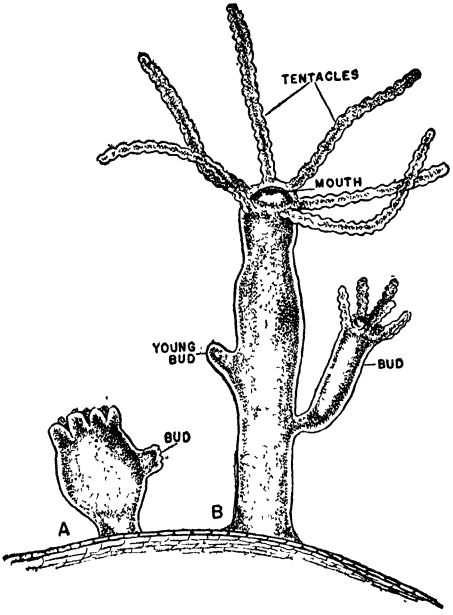

Fig. 202.—(A) Hydra, contracted. (B) Hydra with a bud about to be pinched off and a very young bud.

Hydra is radially symmetrical; *i.e.*, the parts of the body are arranged in a circle about a central point, as the tentacles are arranged around the mouth.

c. Internal Anatomy and Physiology.—The mouth leads into a large gastrovascular cavity that extends into the tentacles. Reference to a longitudinal section of *Hydra* (Fig. 203) shows that the body is essentially a two-layered sac. The outside layer, the ectoderm, is protective and sensory; the inside layer lines the body cavity and is concerned with secretion and digestion. As in the sponges, between these two is a noncellular layer, the *mesoglea*.

The ectoderm contains (1) *muscle cells*, which give the hydra the power to contract and expand or move about, (2) *stinging cells* (described below), which are useful in obtaining food and in defending the hydra from its enemies, and (3) *nerve cells*, which enable the animal to respond to stimuli. Special stains are required to reveal that certain of the cells that line the body possess flagella (Fig. 203*A*).

d. Food Getting.—*Hydra* is aided in capturing small water animals upon which it lives by means of *stinging capsules* (nematocysts). These

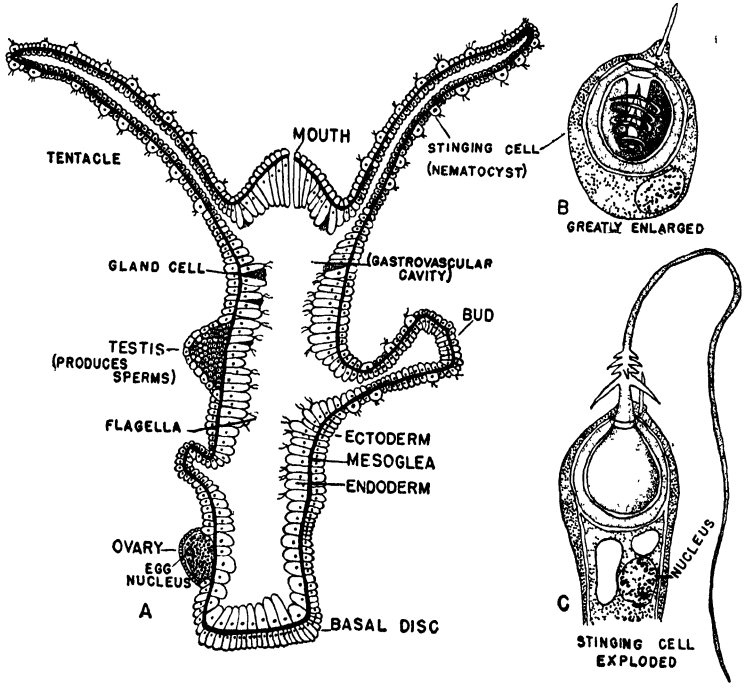

Fig. 203.—(A) Longitudinal section of Hydra, showing general structure. (B) Stinging cell or nematocyst, greatly enlarged. (C) Nematocyst exploded. (L. Runyon.)

are located on the tentacles and distributed about on the body. Each of these is embedded in a cell (Fig. 203*B*). Inside the capsule is a coiled thread, which is shot out when the capsule is exploded. This thread is hollow, and poison is forced through it into the animal. The effect of the poison is to paralyze the prey instantly. The hydra then bends its tentacles toward the mouth, bringing the prey into a position to be swallowed.

e. Digestion.—Digestion takes place principally within the body cavity. Gland cells in the endoderm secrete digestive fluids, which they discharge into this cavity. The digested food is taken up by endoderm cells and is passed on by them to the ectoderm. Certain endoderm cells

engulf food particles, much as an amoeba does, which they digest within themselves Thus *extracellular* (outside the cell) *digestion* occurs within the body cavity and *intracellular* (inside the cell) *digestion*, within the endoderm cells The flagellated cells that line the body cavity keep up a constant current by the movements of their flagella Food that is not digested passes out through the mouth

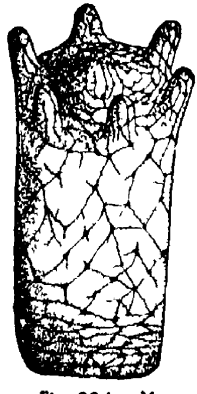

Fig 204 —Young Hydra stained to show network of ectodermal nerve cells and their ring-like arrangement in the foot and hypostome (After Hadzi, from Wolcott, Animal Biology)

f Respiration —In the green hydra, the color is due to the presence of a green one-celled plant (*Chlorella vulgaris*), which grows within the cells of the endoderm The hydra makes use of the oxygen produced by the plant This type of "living together," where the association is mutually beneficial, is called *symbiosis* (page 54) In the process of photosynthesis, green plants give off oxygen in the presence of sunlight (page 140) The plant benefits by its association with *Hydra* not only because it is sheltered within the animal but also because it uses some of the waste products of *Hydra* Green plants must have carbon dioxide, which they usually take from the air *Hydra* gives off carbon dioxide, as do all living things But not all hydras are green; some are brown These secure their oxygen from the water, for water has oxygen dissolved in it They absorb oxygen through the body wall and also excrete the wastes of respiration through the body wall

g. Irritability —*Hydra* possesses a primitive type of nervous system in the form of a network, as shown in Fig 204 This aids the animal to respond to various types of stimuli, such as contact and light, touch, etc The contraction of the body in *Hydra* is illustrated in Fig 202, this specimen had just been touched with a needle

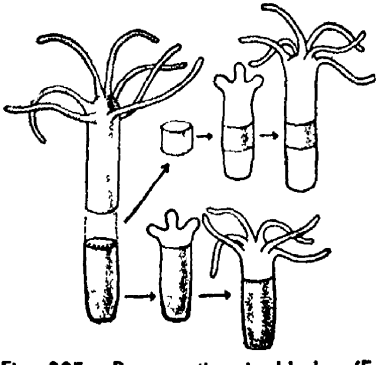

Fig 205 —Regeneration in Hydra (F Baker)

h Regeneration and Grafting — *Hydra* shows remarkable powers of regeneration, *i e*, it can regenerate a complete body from a piece of its body. If pieces are cut from a hydra that are not too small, each will grow into a new hydra (Fig 205) Trembley discovered this about *Hydra* in 1740. If the head end of the animal is split longitudinally,

one can obtain a two-headed hydra. Many other lower animals are capable of regeneration, but the higher animals have lost part of this ability to replace parts that are missing. Even in man, however, cells may grow and divide, as in the healing of cuts, so that the power of regeneration is not lost entirely.

Parts of several hydras will grow together if properly held in place, much as part of one plant may be grafted upon another.

i. Locomotion.—It has already been noted that *Hydra* has the power of moving its tentacles and of contracting its body into a small mass. It may move from place to place in a variety of ways. It may glide about on its basal disk; it may float about in the water like a piece of thread; or it may "stand on its head" by attaching itself by its tentacles, then bend its body until the basal disk is again attached (Fig. 206).

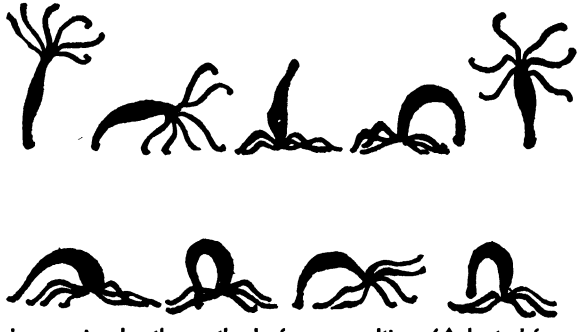

Fig. 206.—Hydra, moving by the method of somersaulting. (Adapted from various authors by B. Shamos.)

When it straightens up, it has traveled a short distance. This is then repeated.

j. Reproduction.—Hydra is especially interesting because of its methods of reproduction. It exhibits two types, asexual and sexual.

(1) ASEXUAL.—One type of asexual reproduction, called *budding*, is of common occurrence. Usually buds are to be found on many of the hydras when they are brought in from the ponds. First a small nodule appears (Fig. 202); this grows gradually larger, develops tentacles, and finally drops off after the formation of a wall between it and the parent. For a time, the cavity of the bud is continuous with the cavity of the parent. Another type of asexual reproduction is by division. Reproduction of this type is rarely observed. This may be either transverse division or longitudinal division.

(2) SEXUAL REPRODUCTION.—At certain times, usually in September or October, certain outgrowths of the body wall appear just below the tentacles and also close to the base of the animal. Those near the tentacles develop into male organs, or testes; these will produce sperm cells,

or spermatozoa (Fig. 203). The outgrowths near the base are the female organs, or ovaries; each of these will produce a single egg, or ovum. Animals that possess both male and female organs in the same body are called *hermaphrodites* (Gr., *Hermaphroditus*, a mythological character) and these animals are said to be hermaphroditic. When the sperm of *Hydra* become ripe they break out of the testes into the water; the egg remains attached to the body. The sperm find the egg, and one of them fuses with it; thus is fertilization accomplished. The egg now divides, and the develop-

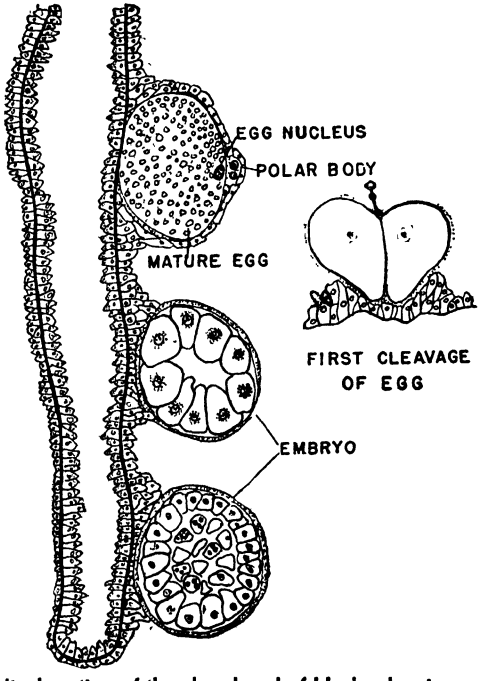

Fig. 207.—Longitudinal section of the aboral end of Hydra showing eggs in different stages of development. (Redrawn by B. Shamos from Tannreuther, Biological Bulletin, Vol. 44.)

ment of an embryo begins (Fig. 207). After a while, the developing egg drops off and falls to the bottom of the pond, where it remains unchanged for a few weeks. After this resting period, the embryo develops into a young hydra.

Although most species of *Hydra* are hermaphroditic (or *monecious*), certain species, as *Hydra oligactis*, have separate sexes, *i.e.*, male and female individuals (*diecious*).

2. Obelia.—The coelenterates appear to be a varied group, yet the fundamental plan of structure of all the members of the group is the same. Many interesting colonial forms are closely related to *Hydra*. One of these is *Obelia*, a form found along the seacoast attached to rocks,

seaweeds, sticks, etc. It is very beautiful, flower-like, and delicate (Fig. 208).

a. Comparison with Hydra.—If the *Hydra* were to bud many times and all the buds remain connected, the resulting colony would resemble the *Obelia* colony somewhat (Fig. 208). The individual vegetative or feeding polyps[1] of *Obelia* possess a greater number of tentacles than

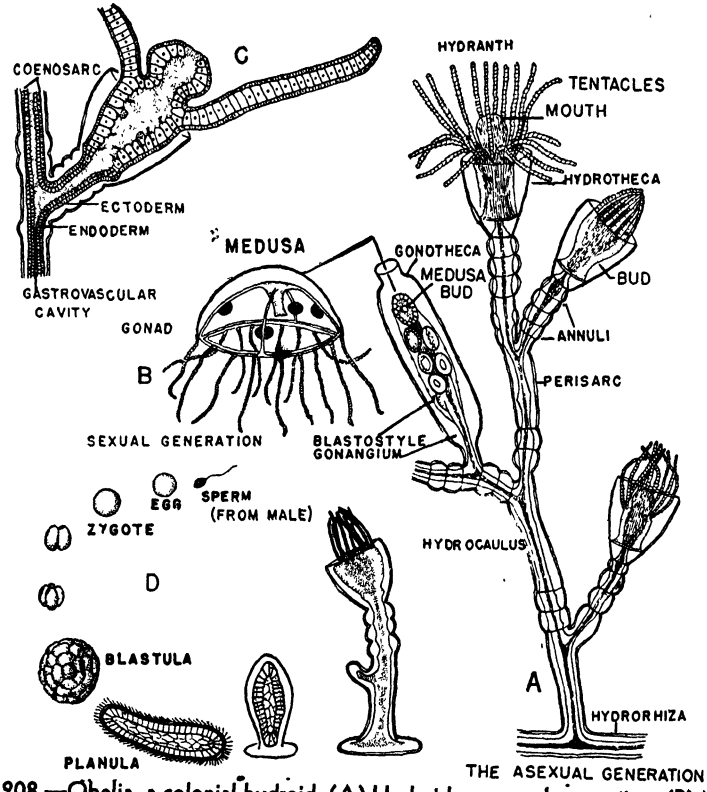

Fig. 208.—Obelia, a colonial hydroid. (A) Hydroid or asexual generation. (B) Medusa, or sexual generation, side view. (C) Medusa, with mouth side up. (D) Fertilization cleavage, blastula, larval (planula) and early developmental stages of the hydroid. (L. Runyon.)

Hydra, and these tentacles differ from those of *Hydra* in being solid. The shape of the mouth is different, and a sheath-like skeleton is present. Nevertheless, the body plan is the same. As in all coelenterates, the symmetry of *Obelia* is radial. The *Obelia* captures its food as does the *Hydra* by use of the tentacles that are armed with the stinging cells. Furthermore, the colony arises from a single hydra-like polyp.[1]

[1] Polyp (Gr. *polypous*, many-footed) is a term used to designate any tubular coelenterate having tentacles.

Hydra is one type of individual, but three types of individuals make up the *Obelia* colony: (1) feeding individuals or *hydranths*, each of which resembles a hydra, (2) nonfeeding individuals that produce *medusae* by budding, and (3) the *medusae* or jellyfishes.

b. Morphology and Physiology.—Although the plan of the zooids or polyps of *Obelia* is hydra-like, the structure of the body is somewhat different. The *Obelia* is attached by a basal stem, the *hydrorhiza* (Gr. *hydra*, water serpent; *rhiza*, root). The basal stem gives off upright branches, the *hydrocauli* (Gr. *hydor*, water; *kaulos*, a stalk). A transparent horny sheath surrounds each part of the colony. This is the *perisarc* (Gr. *peri*, around; *sarx*, flesh) and permits little free movement of the colony. However, rings (*annuli*) occur in some places in the perisarc that surrounds the body, and this allows some movement. The hydra-like polyps inside their cups are able to contract and move their tentacles freely.

Inside the perisarc is the softer part of the animal, the *coenosarc* (Gr. *koinos*, common; *sarx*, flesh). This has the two cellular layers, the ectoderm and the endoderm, as well as the noncellular mesoglea. The coenosarc is tubular, its cavity being *continuous with the cavities* in the various polyps. This continuous cavity makes up the gastrovascular cavity, and it is here that digestion takes place. Intracellular digestion also takes place in the endodermal cells lining the cavity. *Circulation* is effected by beating of the flagella of the cells that line the gastrovascular cavity and by muscular contractions.

The nutritive polyps are borne at the ends of branches and are called *hydranths* (Gr. *hydra*, water serpent; *anthos*, flower). The vase-like modification of the perisarc that surrounds the hydranths is called a *hydrotheca* (Gr. *hydra*, water serpent; *theca*, a case or covering). These polyps have numerous solid tentacles surrounding the mouth. When the polyp is extended, the mouth is funnel-shaped. The animal is able to contract and draw itself inside its cup. The tentacles are well armed with stinging cells or capsules.

The reproductive polyps are borne in the angles between certain of the hydranths and the main stem. These polyps are called *gonangia* (sing. *gonangium*), and each gonangium (Gr. *gonos*, offspring; *angio*, vessel) contains a central stalk, a *blastostyle* (Gr. *blastos*, bud; *stylos*, pillar), which is surrounded by a capsule, the *gonotheca* (Gr. *gonos*, offspring; *theca*, case). On the blastostyle are borne small saucer-like *medusa buds*. When these buds are mature, they escape from their capsule, which ruptures at the end.

c. Reproduction. (1) ASEXUAL.—The hydroid colony, so named because some of its members resemble *Hydra*, arises by budding from a single hydra-like polyp. Further budding and growth produce the

colony. The colony cannot reproduce itself as such. Since, however, the colony comes into being by budding, it is spoken of as the asexual generation. The colony increases in size, of course, as new polyps are budded off and grow. In addition, the stems at the base of the colony grow over the substratum and give off more upright stems, on which other polyps will develop. After a time, the colony may consist of hundreds of individuals.

(2) SEXUAL.—The development of the medusae as buds in gonangia of the hydroid colony has been described. The medusae are either male or female, and so they constitute the sexual generation. In general appearance, they are bell-like and very transparent. For a description of the structure of a medusa, see description of *Gonionemus* below. On the underside of the bell hang the gonads. There are four of these, one on each radial canal (Fig. 208); in the female, these are ovaries, in which the eggs are produced, and in the male, they are testes, in which sperm are produced. When mature, the sex cells are shed into the water. Here the egg is fertilized by the sperm, and in a short time a free-swimming larva, a planula, appears. *Planula* is a general term applied to any *coelenterate* larva. This develops into a hydra-like polyp, which soon settles down and begins to bud. And so the hydroid colony comes into being. From the preceding, it can be seen that the hydroid or asexual generation alternates with the medusoid or sexual generation. This is known as *metagenesis* (Gr. *meta*, over; *genesis*, origin).

d. Comparison of a Medusa and a Hydranth.—Although the medusa seems different from the *Hydra* or other polyp, the two are much the same. If a medusa is inverted and examined histologically, it will be seen to have the same layers, ectoderm, endoderm, and mesoglea (Fig. 209). By using special techniques, it has been demonstrated that the medusa has a more highly developed nervous system, the net being more complex and having a marginal ring of nerve cells, a sort of controlling center.

3. GONIONEMUS.—The medusa of the *Gonionemus* is a form frequently studied in the laboratory. It is common along the Eastern coast of the United States. Being from 1 to 2 cm. in diameter, it is larger than the medusa of the *Obelia* and therefore easier to examine. The hydra-like polyp is quite inconspicuous (Fig. 210).

a. General Features.—The convex surface of the bell is the *exumbrella*, or aboral surface, and the concave surface is the *subumbrella* or adoral surface. Around the margin of the bell, a muscular shelf, the *velum*, projects inward, partly closing the cavity of the bell. Around the rim of the umbrella extend numerous tentacles, armed with stinging cells.

The medusa has the same layers as the other *coelenterates*, *i.e.*, two cellular layers, the outside layer of ectoderm, the inside layer of endoderm, and the noncellular layer of mesoglea between. In the case of the medusa,

the mesoglea is thick, and this gives the animal a jelly-like consistency (Fig. 209).

Hanging from the center of the concave subumbrella is the *manubrium*, at the tip of which is the *mouth*. The mouth leads into a stomach, and this, in turn, leads into four radial canals, which traverse the bell to the

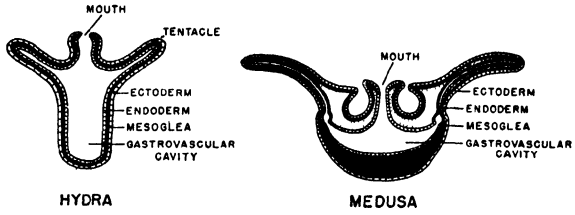

Fig. 209.—Diagram of a Hydra, a polyp, and a medusa, showing the same fundamental body plan. (B. Shamos.)

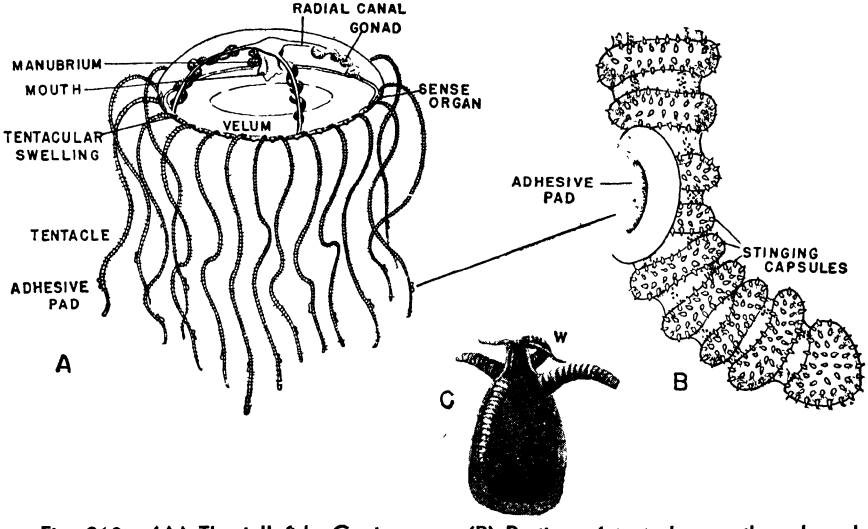

Fig. 210.—(A) The jellyfish, Gonionemus. (B) Portion of tentacle, greatly enlarged. (C) Hydra-like stage of development of Gonionemus. (After Perkins.) One tentacle is carrying a worm (W) to the mouth. Tentacles are in contracted state. (A) and (B) drawn by F. Baker, (C) from Hegner, College Zoology, The Macmillan Company.

margin (Fig. 210*A*), where they join a delicate *circular canal*. The circular canal connects also with cavities in the tentacles. Partly digested food is distributed to all parts of the body through this continuous cavity, which is the *gastrovascular cavity*.

b. Nervous System and Sense Organs.—The nerve net of *Gonionemus* is more developed than in *Hydra*, being connected with a nerve ring around the margin of the bell that coordinates the animal's movements.

Embedded in the jelly between the tentacles are specialized sense organs, probably concerned with controlling and directing swimming movements. In addition, at the bases of the tentacles will be found swellings that contain sensory cells.

c. Locomotion.—*Gonionemus* swims by taking water into the subumbrella and then forcing it out by contracting muscles in the bell and the velum. This drives the animal in a direction opposite to that in which the water is expelled, thus enabling the animal to swim about. When the medusa is at rest, it attaches itself to the bottom of the pool or to some object by the adhesive pads on the tentacles (Fig. 210*B*).

d. Reproduction.—The medusae represent the sexual generation. The sexes are separate; *i.e.*, the medusae are either male or female. The gonads are suspended beneath the radial canals (Fig. 210*A*), as described for the *Obelia* medusae. The sex cells are shed into the water, and there the eggs are fertilized by the sperm. From the fertilized egg a free-swimming larva, a planula, develops, and from this a hydra-like polyp (Fig. 210*C*). Although it is inconspicuous, it serves the same purpose as the hydroid of the *Obelia*. It is, therefore, the asexual generation. After a time, small larvae bud off from the hydra-like polyp, and these develop into the medusae.

From this it will be seen that *Gonionemus* has alternation of generations, also, although the emphasis here is on the medusa and not on the hydroid, as is the case with *Obelia*.

4. HYDRACTINIA.—Another member of the class Hydrozoa is the *Hydractinia*, a complicated colonial form (Fig. 211).

a. General Features.—The beauty of this form can be observed only with a microscope. Specimens are to be found often as a coating on the shells occupied by hermit crabs. Examination shows them to appear as a miniature forest of polyps of three types. The largest of the polyps looks like a *Hydra;* these are the feeding individuals or zooids. A second type is the reproductive zooids. They are short and blunt, and there is a cluster of reproductive organs around the body that reminds one of a group of coconuts. Of particular interest is the third type of polyp; these grow around the edge and are heavily loaded with stinging cells. They twist about actively and protect the colony by use of these stinging cells. The hermit crab is protected also by these stinging polyps. In return, the crab furnishes transportation for the colony. In this association (*commensalism*, page 54), *Hydractinia* also benefits by feeding upon bits of food dropped from the jaws of the crab, which is a wasteful feeder.

b. Polymorphism.—If a colony of coelenterates has two kinds of individuals, it is said to be dimorphic. Since *Obelia* has three, it is said to be trimorphic or polymorphic; *Hydractinia* and others of this group exhibit *polymorphism* (Gr. *poly*, many; *morphe*, form) to a high degree.

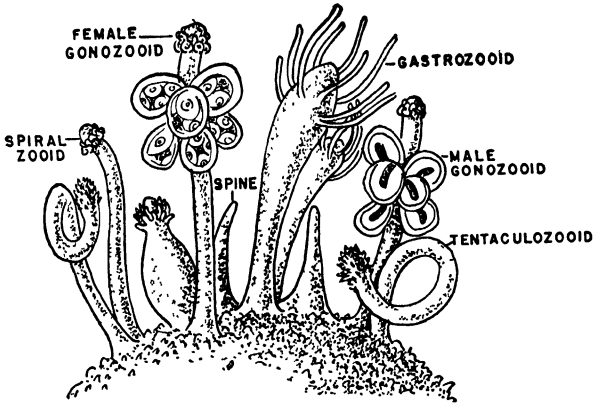

Fig. 211.—Hydractina, a colonial Coelenterate which has several types of zooids.

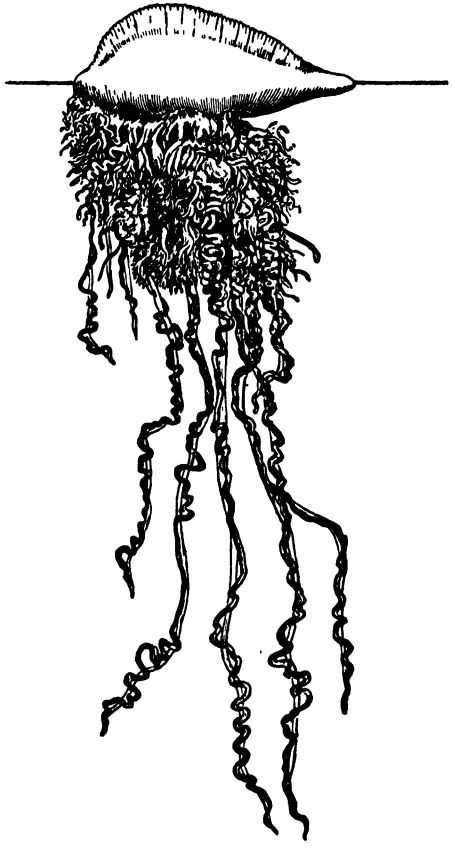

Fig. 212.—Physalia, the Portuguese man-of-war. (After Agassiz, from Packard, Zoology, Henry Holt and Company, Inc.)

5. PHYSALIA, or Portuguese man-of-war (Fig. 212), is also a representative of the class Hydrozoa. Like *Hydractinia*, it has many types of individuals and is, therefore, *polymorphic*. It is not a small animal. The floating part of the colony is a sort of bag filled with gas, having a puckered crest that acts as a sort of sail. Hanging from this, and submerged in water, are long tentacle-like individuals—stinging individuals, feeding individuals, and reproductive individuals. The "sail" is iridescent, and a group of *Physalias* floating on the water is a beautiful sight. Swimmers are often painfully stung by these animals. They are more highly organized than *Hydractinia*.

D. Scyphozoa.—The larger jellyfish are included in this group. *Aurelia* is a common example and is the form often studied. The margin of the bell is lobed, usually having eight notches; no velum is present; the animal has an inturned ectodermal stomodaeum; there is a system of complexly branched radial canals; in the alternation of generations, the polyp form (*scyphistoma*) arises by a type of internal budding (*strobilization*) and is inconspicuous. Many members of this class exist only as jellyfish.

1. AURELIA.—This form is found along our coasts. It is larger than *Gonionemus* and differs from it in not having a velum, in the position and shape of the gonads, in having a more complicated canal system, and in the structure and arrangement of its sense organs.

a. General Features.—The manubrium is very short, and at its tip is the square mouth. From each of the corners of the mouth hangs a trailing mouth lobe. Each of these has a ciliated groove and, in addition, stinging capsules. When small animals are paralyzed by the stinging capsules, they are swept up the ciliated grooves to the cavity in the center of the bell. From each side of the rectangular "stomach" extend four gastric pouches. From the stomach also lead numerous radial canals that branch repeatedly and then join the circular canal at the margin of the bell. Inside the gastric pouches are gastric filaments covered with stinging capsules. These serve to paralyze the prey that may reach the pouches still alive. The entire gastrovascular cavity is lined with flagellated cells. These maintain a current of water that brings in a constant supply of food and oxygen. It also removes wastes from the internal parts of the animal.

b. Sense Organs.—Around the margin of the bell are numerous short tentacles. Eight notches, spaced at equal distances, are found around the margin of the bell. In each of these notches are sense organs, or *tentaculocysts*. According to some authors, they are made up of three parts: (1) a pigmented eyespot sensitive to light, (2) a hollow sac containing hard particles that may be concerned with swimming movements or equilibrium, and, (3) two pits that may be sensitive to food and chemicals.

c. Reproduction.—The gonads lie in the walls of the gastric pouches. When the sex cells mature, they are shed into the gastric pouches and from there pass through the stomach, the gullet, and the mouth to the outside. The fertilized egg develops into a hydra-like individual that reproduces by budding for a time. Finally, however, by a peculiar process called strobilation, the hydra-like individual (hydra-tuba) divides transversely into disks that cause it to resemble a pile of saucers. This stage is known as the *strobila* (Fig. 213). Each of the disks develops tentacles and swims away as very small medusae called *ephyra.* These gradually develop into the adult form of *Aurelia.*

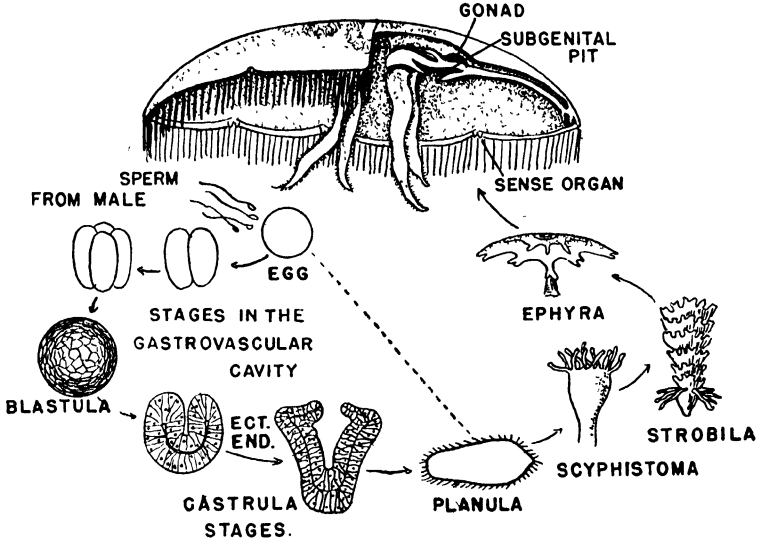

Fig. 213.—Life cycle of Aurelia, a representative of the Class Scyphozoa. (B. Shamos.)

In the *Aurelia* type of alternation of generations, the hydroid stage is reduced (the hydra-tuba), and the medusa is the more prominent generation. Not all the Scyphozoa show alternation of generations.

E. Anthozoa.—Sea anemones are beautiful, flower-like animals found along the coast in tide pools. In body plan they are not unlike *Hydra,* but they are all colors of the rainbow and range in size from very small, delicate creatures to large forms, 2 ft. across, that live on the Great Barrier Reef of Australia. This group also includes corals, sea fans, sea pens, etc.

1. METRIDIUM. *a. General Features.*—Sea anemones may be very fragile and delicate, but the common example usually studied in the laboratories, *Metridium,* has a stout muscular body covered with soft, tough skin. Surrounding the mouth and anterior end are several circlets

of hollow tentacles armed with stinging capsules and cilia. The ectoderm is turned in to form the gullet. At the basal end of the animal is a smooth muscular, slimy basal disk by which the animal is able to hold fast as well as to slide along slowly. On either side of the gullet is a longitudinal groove lined with cilia, the siphonoglyph (Gr. *siphon*, a tube; *glyphein* engrave). The cilia in these grooves create a current that keeps a fresh supply of water in the gastrovascular cavity, thus ensuring the internal parts of the anemone with a continuous supply of food and oxygen.

A distinguishing characteristic of the anemones is that the gastrovascular cavity is divided by a series of vertical partitions, the *mesenteries*.

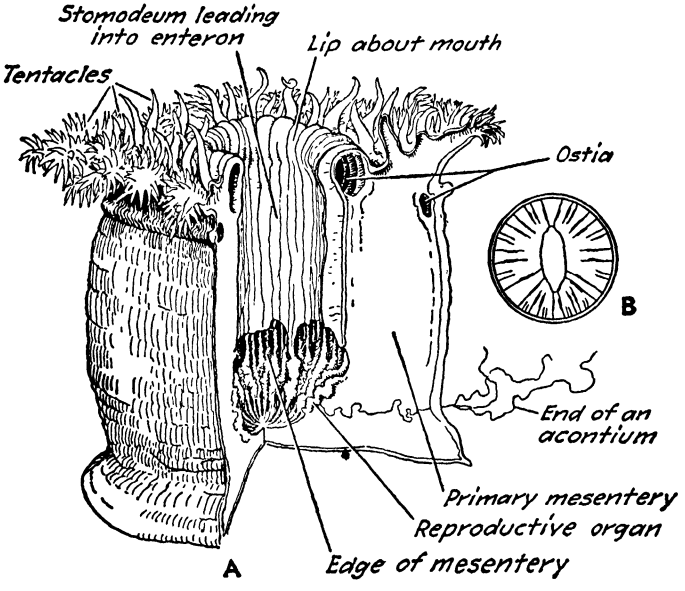

Fig. 214.—Sea anemone, Metridium marginatum. (A) View of polyp with one quadrant removed. (B) Diagram of transverse section showing mesenteries. (From Woodruff, Foundations of Zoology, The Macmillan Company.)

which are double sheets of endoderm supported by a central layer of jelly or mesoglea. They serve greatly to increase the digestive and respiratory surface. In *Metridium*, there are six pairs of these thin double-walled partitions, the *primary septa*, which divide the gastrovascular cavity into six radial chambers (Fig. 214). Projecting from the wall, but not reaching the gullet, are the *secondary mesenteries*, and between the primaries and the secondaries are the *tertiaries*. There is considerable variation in size, number, and position of mesenteries in the anemone group. Below the gullet, the radial chambers are in open communication but above the point at which the mesenteries attach to the gullet, communication between the chambers is by means of pores or ostia.

The edges of the mesenteries below the gullet are expanded into convoluted digestive filaments Glands in these filaments secrete digestive juices The filaments also bear long, delicate threads containing stinging capsules, the *acontia*, which can be thrust out through pores in the body wall and through the mouth They are for offense and defense

The anemones have a well-developed nerve net and several sets of specialized muscles

b Reproduction (1) ASEXUAL —Asexual reproduction occurs by budding and by longitudinal division Small fragments of the anemones will regenerate whole animals

(2) SEXUAL —The animals are *dioecious*, *i e*, the sexes are separate Gonads are developed in the mesenteries near the edges. Ripe sex cells,

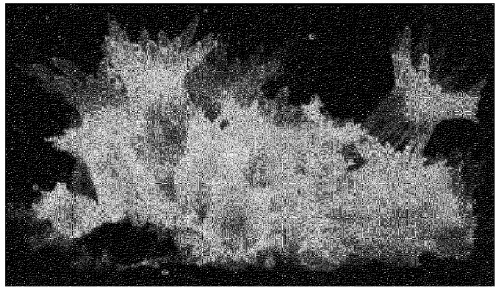

Fig 215 —Coral polyps (Astrangia), greatly enlarged These delicate animals secrete tiny skeletons which bit by bit create large masses of coral, and these in turn may form large islands (Courtesy of The American Museum of Natural History)

the eggs and sperm, are passed into the gastrovascular cavity and out through the mouth Eggs are fertilized in the water, and from them develop the ciliated larvae, the planulae Each of the planulae soon settles down and becomes an anemone There is no alternation of generations among the Anthozoa

2. THE CORALS —The coral polyp looks like a small sea anemone One of the varieties that lives in the waters on our North Atlantic coast is the *Astrangia danae* (Fig 215) A number of these animals live together in colonies Each has a calcareous cup or skeleton, and this is the *coral* In the course of centuries of time, enormous masses of coral are formed, coral islands, reefs, and other formations There are many types of coral polyps, each producing a different type of skeleton Of special interest is the precious *red coral*, much used in the making of jewelry

F. Importance of the Coelenterates.—From a biological viewpoint, the coelenterates are important as illustrating many biological principles,

from an economic standpoint, they are of little value to man. They are, however, a food supply for many animals, especially fish.

Corals are used in making jewelry. The coral Polyps have also built islands and reefs that protect some shores.

G. Biological Principles and Problems Illustrated by the Coelenterates. 1. DIVISION OF LABOR.—It has been seen that there is some division of labor among the Protozoa, for example, the setting aside of certain cells in *Volvox* for reproduction. The Coelenterates show great advance in the division of labor in their two-layered body, each layer having particular functions. In *Hydra*, the *ectoderm* is protective and sensory, and the *endoderm* has a secretory and digestive function. The principle of division of labor is still further illustrated by the differentiation of special cells, as stinging capsules, gland cells, absorbing cells, etc., and in a differentiation of organs such as ovaries, testes, etc. Finally, a further division of labor is shown in *polymorphism*. In forms like *Hydractinia* and *Physalia*, which form colonies, certain individuals take over certain functions. There are, for example, feeding individuals, reproductive individuals, stinging individuals, etc.

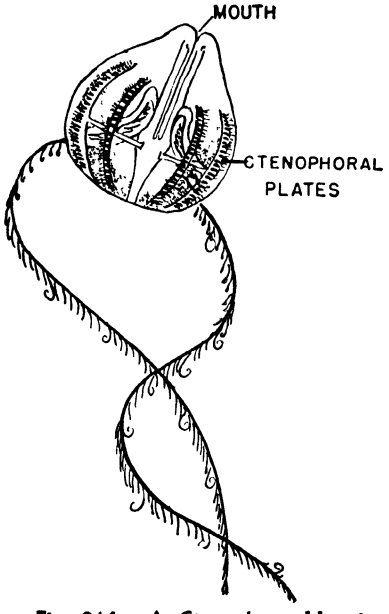

Fig. 216.—A Ctenophore, Hormiphora plumosa. The ctenophoral plates are swimming plates characteristic of Ctenophores. (After Chun, by B. Shamos.)

2. BODY PLAN.—The sac-like plan of the *Hydra* body shows a great advance. It is a fundamental structure in multicellular animals and resembles the gastrula stage that all higher animals go through.

3. ALTERNATION OF GENERATIONS.—Alternation of generations occurs in several groups of plants (page 207), so that it is not a phenomenon limited to animals. However, this alternation of a generation that can reproduce only asexually with a generation that bears the sex organs and so produces sex cells is shown in all gradations in the coelenterates. In *Hydra*, both asexual and sexual reproduction occurs in the polyp stage, there being no alternation of generations; in *Obelia*, both stages are well represented, the asexual generation being the hydroid colony and the sexual generation being the small medusa; in *Gonionemus*, the hydra-like polyp is the small inconspicuous generation, and the medusa is the conspicuous generation; in *Liriope*, there is no asexual generation. Between

the forms mentioned, there is a wide variety of conditions. In the corals and the anemones, there is no alternation of generation.

4. Budding, Fission, Regeneration.—The process of reproduction by budding and by fission is common among members of certain groups of the coelenterates. The groups also show remarkable powers of regeneration of whole animals from fragments.

5. Commensalism and Symbiosis.—The sea anemone on the shell of a crab (Fig. 30) is a good example of commensalism; they live together with mutual benefit, yet each could live separately, so that the association is not so close as the symbiotic relationship of the green Algae in *Hydra viridis*. Many other coelenterates harbor Algae and so illustrate the principle of symbiosis.

III. Ctenophora

The *comb jellies*, or ctenophores, are beautiful fragile creatures, often classed with the coelenterates until it was discovered that their structure and development are very much specialized. Now they have been placed in a special phylum. They are transparent, gelatinous animals that float on the surface of the water, usually near the shore. Ctenophores (Gr. *ktenos*, comb; *phoreo*, to bear) have eight rows of combs. At night they are luminescent, and the light flashes along the rows of combs as they swim in the water (Fig. 216).

Questions

1. How are sponges classified?
2. Why is it said that a sponge is loosely put together?
3. Describe the general structure of a hydra. Why may a hydra be said to resemble a gastrula?
4. Describe the types of reproduction in *Hydra*.
5. Compare binary fission and budding as methods of reproduction.
6. Why is *Hydra viridis* green?
7. Outline the life cycle of *Obelia*.
8. Compare the structure of a hydranth or hydra to that of a medusa.
9. Describe the types of zooids characteristic of *Hydractinia*.
10. Outline the life cycle of *Aurelia*. Compare this life cycle to that of *Obelia*.
11. What are the general characteristics of the sea anemones? The corals? How are coral islands formed?
12. Compare the alternations of generations in *Obelia*, *Gonionemus*, and *Aurelia*.
13. Define: perisarc, coenosarc, hydranth, gonangium, blastostyle, gonotheca, planula, ephyra, strobila, diploblastic, manubrium, mesoglea.
14. Give an account of the biological principles illustrated by the coelenterates.
15. What is the most characteristic feature of the ctenophores? Why are they not classed with the coelenterates?

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Hyman, L. H.: "The Invertebrates; Protozoa through Ctenophora," McGraw-Hill Book Company, Inc., 1940.

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CHAPTER XX

THE FLATWORMS AND ROUNDWORMS; PLATYHELMINTHES AND NEMATHELMINTHES

The smallest worm will turn, being trodden on.
—SHAKESPEARE.

I. Flatworms, Platyhelminthes

Flatworms and roundworms are important because so many of them are parasitic. Biologically, they are interesting because they show advance over the coelenterates in that they have three cellular body layers, as have all the higher animals. These are the ectoderm, outside layer, endoderm, inside layer, and a middle layer, the mesoderm. Also, instead of the radial symmetry possessed by the coelenterates, they are bilaterally symmetrical.

The flatworms may be free living or parasitic. Since they have three layers, they are said to be triploblastic. Platyhelminthes (Gr. *platys*, broad; *helmins*, worm) have flattened bodies. There are about 7,000 species.

A. Classification.—Four classes of Platyhelminthes are recognized:

Class I. TURBELLARIA (L. *turbo*, disturb). Mostly free-living; found in either fresh or salt water; a few in the soil; some parasites; *Planaria* (Fig. 217*C*).

Class II. TREMATODA (Gr. *trema*, a pore; *eidos*, resemblance). Either ecto or endo parasites; *liver fluke* (Fig. 220).

Class III. CESTODA (Gr. *kestos*, a girdle; *eidos*, resemblance). Parasitic; tapeworm (Fig. 221).

Class IV. NEMERTINEA (Gr. *nemertes*, unerring). Often classed in a separate phylum; *Cerebratulus*.

B. Representatives. 1. PLANARIA.—This common flatworm is the form often used as a type for the study of flatworms. It is about 20 mm. in length, is bilaterally symmetrical, and is triploblastic, *i.e.*, has three germ layers, ectoderm, endoderm, and mesoderm.

a. Habitat.—The *Planaria* are found in fresh water clinging to the undersides of logs or stones. They are easily collected by placing a piece of raw liver in the stream for some hours, after which the meat will usually be covered with worms.

b. External Features.—The *Planaria* has a definite head (Fig. 217*C*) differing in this respect from *Hydra*. The upper surface of the body is termed the *dorsal surface* and the undersurface, the *ventral surface*. On

the dorsal surface of the head are two eyespots. The surface of the body is covered with cilia. The mouth is in a peculiar position on the ventral surface posterior to the middle of the animal. A small genital pore is also on the ventral surface, just behind the mouth.

c. The Digestive System and Digestion.—The digestive system consists of a mouth, a tubular muscular organ, the pharynx, and an intestine containing three main trunks, which are much branched (Fig. 217*C*).

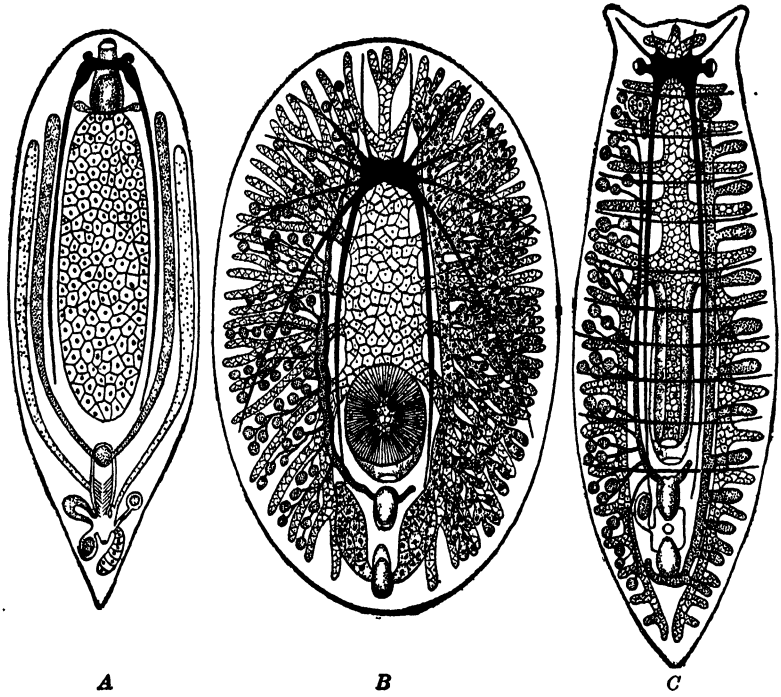
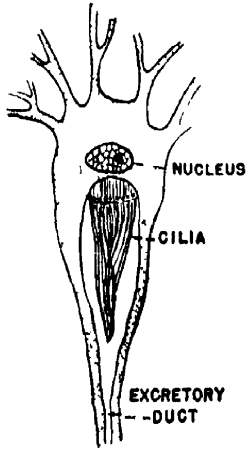


Fig. 217.—General organization in three classes of Turbellaria. (After von Graff.) (A) Rhabdocoel. (B) Polyclad. (C) Triclad (Planaria). The digestive system is represented in cell outlines and nuclei; testes are closely stippled; ovary is at posterior extremity on right. In B and C, the male reproductive system is stippled on the left of the body and the female reproductive organs on the right. (From Van Cleave, Invertebrate Zoology.)

The proboscis may be protruded and used as a seizing organ for food. Sucking movements are possible through the action of a muscular pharynx. These movements tear the food into small bits, and it is then swallowed. Although there is some extracellular digestion in the gastrovascular cavity of *Planaria*, as in *Hydra*, digestion is mainly intracellular. Certain cells lining the intestine are able to form pseudopodia and ingest solid food, thus forming food vacuoles. Digestion takes place in these food vacuoles, and the digested food is then absorbed and passes by

diffusion throughout the tissues of the body. Indigestible remains of the food are eliminated through the mouth

d. The Excretory System and Excretion —In none of the forms studied thus far was there an excretory system *Planaria* has a complex excretory system, which consists of a network of tubes running the length of the body on each side Side branches from these tubes end in flame cells, so named because the beating of the cilia within them suggests the flickering of a flame (Fig 218) Each flame cell has a hollow center that is continuous with the cavity of the tubules of the system The beating of the cilia creates a current that causes the material in solution to move through the tubules to several minute pores that open to the outside



FLAME CELL

Fig 218 —Diagram of a flame cell (Adapted from various sources by B Shamos)

e Muscles and Locomotion —The body of *Planaria* is muscular There is a set of circular muscles just under the ectoderm, also longitudinal and oblique fibers lying in the mesoderm The surface of the animal is covered with cilia In the surface layer, or *ectoderm*, are also gland cells that secrete a sort of slime upon which the animal moves in a slow gliding motion, aided by the cilia

f Nervous System —At the anterior end of *Planaria* is a bilobed mass of nerve tissue, often called a *brain* From these lobes, two nerve cords extend posteriorly one on either side and give off branches to all parts of the body The two strands are connected by many cross branches, which have been likened to the rungs of a ladder (Fig 217) The brain and the branches constitute the central nervous system However, the brain is not necessary for muscular coordination in *Planaria*, since the body will move along after the head containing the brain has been removed In addition to the central nervous system, a nerve net is present

g Sense Organs and Irritability —In addition to the eyes, which have been mentioned, sensory cells are distributed over the surface of the body They may be specialized for different functions, as the reception of stimuli for touch, temperature, and the like Pointed projections, or sensory lobes, on either side of the head are sensitive to touch and water currents They may be sensitive to other stimuli

h Regeneration —The planarians show the same remarkable powers of regeneration as have been shown by the Protozoa and the coelenterates If the animal is cut into two pieces, the anterior piece will regenerate a

tail, and the posterior piece will regenerate a head. A section removed from the body (Fig. 219) will regenerate both head and tail.

Some grafting experiments reveal that the head of the *Planaria* dominates the body; also, that any level controls the region posterior to it; *i.e.*, the animal has *definite polarity*. For example, if a piece of the head region be grafted in a more posterior region, it will grow out into a head and at the same time influence the region around it to cooperate in forming a new pharynx near the grafted head. Experiments also show that the anterior part of the body regenerates faster than the posterior region.

i. Reproduction.—The *Planaria* has a very complicated system for sexual reproduction. The animals are hermaphrodites; *i.e.*, each animal has a complete set of male and female sex organs, but exchange of sperms takes place so that the eggs of one animal are fertilized by sperm from another animal (cross-fertilization). After the breeding season, the reproductive organs degenerate and are renewed at the next breeding time. The reproductive organs of the *Planaria* are too complex to be described here (Fig. 217).

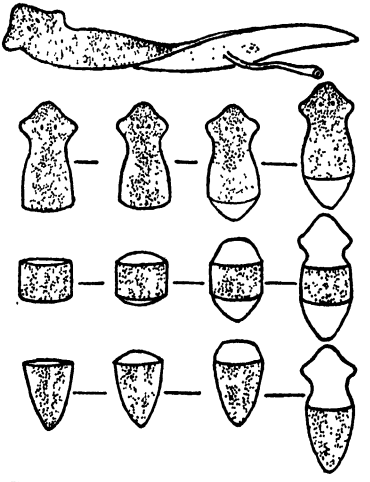


Fig. 219.—Regeneration in Planaria. (B. Shamos.)

ASEXUAL REPRODUCTION.—Not all species of *Planaria* reproduce asexually, but some multiply by transverse fission, the constriction occurring behind the pharynx. After the two parts have separated, each piece regenerates the missing part.

2. THE LIVER FLUKE; FASCIOLA HEPATICA.—This species is a representative of the Trematoda.

a. Habitat.—In the adult stage, the sheep liver fluke lives in the bile ducts of sheep, cows, pigs, and occasionally in man. It causes much damage every year. In spite of this, it has a very interesting and complicated life cycle. Since there are so many stages and the success of the animals in each of the stages depends upon so many factors, it serves as an excellent illustration of how living things may survive in spite of many environmental complications.

b. General Features.—In many respects, the sheep liver fluke resembles the planarians in both body form and structure. A few differences may be pointed out. The mouth is surrounded by a muscular disk, the *anterior sucker*. There is a *ventral sucker*, which is used for attachment only.

Midway between the anterior and posterior suckers is the *genital opening*, and at the posterior end of the body is the *excretory pore*.

c. Internal Features.—The digestive system is somewhat similar to that of *Planaria*, being much branched and ramifying to all parts of the body. The excretory system, instead of having two main tubes, as in *Planaria*, has only one tube and only one opening. In other respects, it resembles that of *Planaria*. The nervous system is of the planarian type. There are also three layers of muscles, a circular layer, a longitudinal layer, and an oblique layer. As in all animals, beginning with the flat-

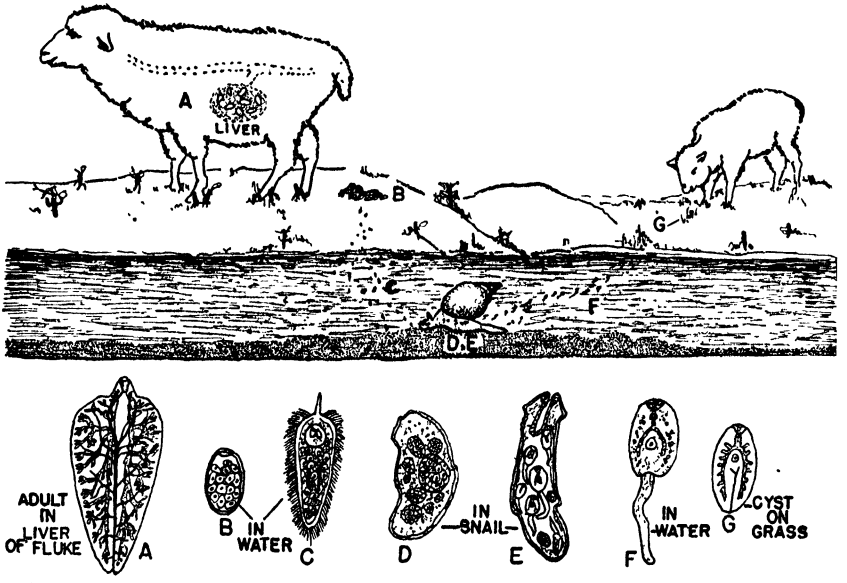


Fig. 220.—The life cycle of the liver fluke, Fasciola hepatica. (A) Adult fluke. (B) Egg. (C) Miracidium. (D) Sporocyst. (E) Rediae. (F) Cercariae. (G) Cyst. (Adapted from various authors by B. F. Edwards.)

worms, three cellular layers are present in the body, the *ectoderm*, *mesoderm*, and *endoderm*. Between the body wall and the alimentary canal lies a loose tissue, the *parenchyma* (Gr. *para*, beside; *enchyma*, infusion) in which the internal organs are embedded.

d. Life Cycle.—The liver flukes are hermaphrodites and have complicated reproductive systems. One fluke may produce as many as 500,000 eggs, and since there may be 200 or more flukes in the liver of a single sheep, over 100 million eggs may be laid in one parasitized sheep.

Before leaving the body of the parent, the eggs begin segmentation. They pass through the bile ducts of the sheep to the alimentary canal and are carried to the outside with the excrement of the sheep. If they chance to reach water, they hatch into free-swimming, ciliated larvae

called *miracidia*. After a time, they die, unless they reach the body of a certain species of fresh-water snail into which they burrow, each forming a sac-like *sporocyst*. Within the sporocyst develops another larval stage, the *redia*. These break through the wall of the sporocyst and go into the tissues, where they may reproduce by an asexual method for one or more generations, thereby increasing their numbers. Finally, however, these rediae produce a third type of larva, the *cercariae*. These leave the snail, swim about for a time, then crawl upon a blade of grass and encyst. There they remain until a sheep eats the grass. In the alimentary canal of the sheep, the cyst wall dissolves, and the young flukes bore through the intestinal wall, the liver and bile ducts. In about 6 weeks they become mature, and the cycle begins all over again.

The complex life cycle of the liver fluke may be summarized as follows:

1. The adult fluke lives in the bile ducts within the liver of sheep, cows, pigs, and occasionally man. When mature, the flukes lay eggs, which pass down the bile ducts into the intestine and then to the outside with the feces.

2. The eggs, upon reaching water, develop into free-swimming, ciliated larvae, *miracidia* (Fig. 220*C*).

3. The miracidia find a certain species of fresh-water snail into which they burrow, forming a sac-like *sporocyst*. Later the sporocysts develop into a second kind of larva, *redia*. These reproduce in an asexual manner for one or more generations (Fig. 220*D*, *E*). Finally the rediae produce a third type of larva, the

4. *Cercariae*, which are free-swimming. After a time, these encyst on the grass, and, (Fig. 220*G*) if eaten by sheep, the cyst will dissolve and the young flukes find their way to the bile ducts in the liver. In about 6 weeks, they become mature flukes, begin to lay eggs, and so begin a new cycle (Fig. 220*A*).

3. The Tapeworm, Taenia.—The tapeworms are members of the third class of flatworms, the Cestoda. They are long, ribbon-like animals and are endoparasites.

a. Habitat.—Many types of tapeworms live in the intestines of almost all groups of vertebrate animals. The members of genus *Taenia* live as adults in the alimentary canal of man. There are two common species, *Taenia solium*, which man gets from eating uncooked pork, and *T. saginata*, which he gets from eating uncooked beef.

b. General Features of Taenia solium.—When fully grown, this tapeworm is usually from 6 to 10 ft. long, though it may reach a length of 25 ft. The head is very small, about the size of a pinhead. It is knob-like and is armed with from 22 to 32 hooks and 4 suckers, by which it anchors itself to the intestine, and is able to hold on in spite of the constant passage of material in the intestine. The body is whitish in color and flat,

resembling a dirty piece of white tape, divided by grooves running across the body into about 600 to 2,500 segments called *proglottids* (Gr. *pro*, before; *glotta*, tongue). These proglottids bud off just behind the head

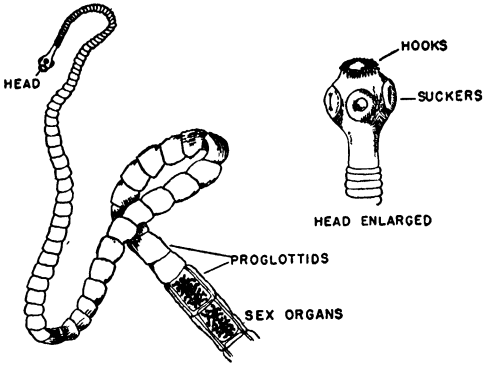


Fig. 221.—The human tapeworm (Taenia).

(Fig. 221). For this reason, the youngest proglottids are behind the head and are small, increasing in size along the length of the animal until the mature size is reached.

Since the tapeworm does not do its own digesting, it has no need of a special digestive system. It absorbs digested food through the body wall.

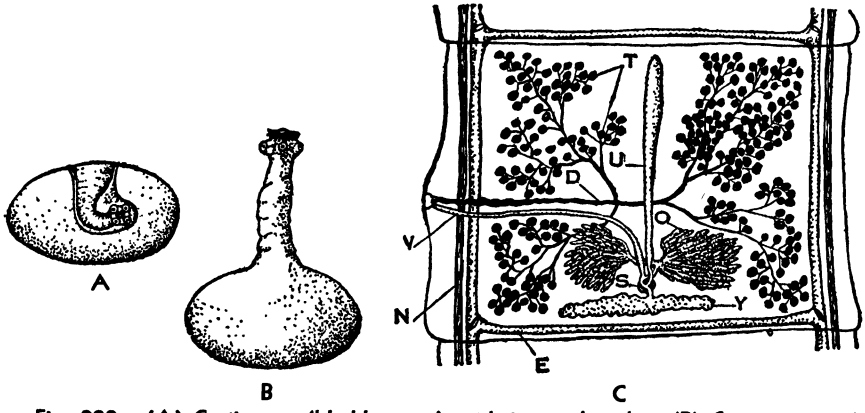


Fig. 222.—(A) Cysticercus (bladderworm), with inverted scolex. (B) Cysticercus with everted scolex. (C) Diagram of a proglottid, showing organs of reproduction. (D) Sperm duct. (E) Excretory duct. (N) Nerve cord. (O) Ovary. (S) Shell gland. (T) Testis. (U) Uterus. (V) Vagina. (Y) Yolk gland. (After Leuckhart. From Wieman, General Zoology.)

The nervous system resembles that of planaria but is less well developed. *Excretory tubes* (Fig. 222) with branches ending in flame cells open at the posterior end and carry wastes from the body.

c. Reproduction and Life Cycle.—When each of the proglottids is mature, it contains a full set of reproductive organs (Fig. 222*C*). A ripe proglottid, ready to be cast off, is filled almost completely with eggs. When the proglottids are cast off, they are carried to the outside with the human feces. If they happen to be swallowed by pigs, the eggs hatch in the alimentary canal, and then the embryos, having six hooks, burrow into the intestinal wall and make their way or are carried in the blood to the muscles, where they produce egg-shaped cysts. These cysts grow into little sacs, which are called *bladder worms* or *cysticerci* (Fig. 221*A* and *B*). From the inside wall of the cyst, an inverted head develops. When uncooked pork is eaten by man, the walls of the "bladder" are digested off, the head everts, and the young embryo attaches itself to the intestinal wall by means of the suckers on its head. Pork that is infested with bladder worms is called "measley" pork. Cysts may develop in man as well as in pigs and sometimes may get into the eyes or brain with disastrous results.

Taenia saginata has a life cycle similar to that of *T. solium*. The cow gets the infection by eating grass polluted with excreta from a person infected with this tapeworm. Man, as has been said, gets this species by eating rare or uncooked beef. No hooks are present on the head as in *T. Solium*.

4. The Nemertinea.—The nemertines (page 312) are often placed in the phylum Platyhelminthes. They are, however, uncertain in their relationships and for this reason may be regarded as a separate phylum. They are mostly marine, living coiled up in burrows in the sand. However, some of them live among the seaweeds.

They have an alimentary canal with mouth and anus, a distinct blood vascular system, and an excretory system with flame cells. There is a long proboscis that may be thrust out of its sheath.

The nemertines exhibit remarkable powers of regeneration. The helmet-shaped larva of the nemertines is known as the *pilidium* (Gr. *pilidium*, dim. of *pilos*, a cup) larva, and this has a superficial resemblance to the trochophore larva of the *annelids* (Fig. 223).

C. Biological Principles Illustrated by the Flatworms.—The flatworms exhibit a number of features that are possessed by all higher animals. For this reason, they may be said to show distinct advances in the biological scale of life.

1. Three Layers of Cells.—Three cellular layers are present; the *ectoderm*, or outside layer; the *mesoderm*, or middle layer, and the *endoderm*, or inside layers. In the flatworms, as well as in higher animals, these three layers give rise to organs and systems of organs.

2. Differentiation of a Head.—The flatworms are the first of the animal groups to have a definite head with sense organs and a brain and central nervous system.

3. Symmetry.—The flatworms are bilaterally symmetrical, *i.e.*, the structures of the body are arranged symmetrically on two sides. Bilateral animals have right and left sides and dorsal and ventral surfaces. All animals classed as bilaterally symmetrical are not perfectly so, since one side may be more developed than the other, and there may be other differences.

4. Parasitism.—The principle of parasitism has been shown to exist even in the protozoan group. When one finds such complex examples of the way in which parasites live as the liver fluke and the tapeworm, the question naturally arises, how did parasitism arise? A study of the tapeworm shows that parasites often lose many of their organs as they become adjusted to a parasitic way of living, as in the case of loss of a

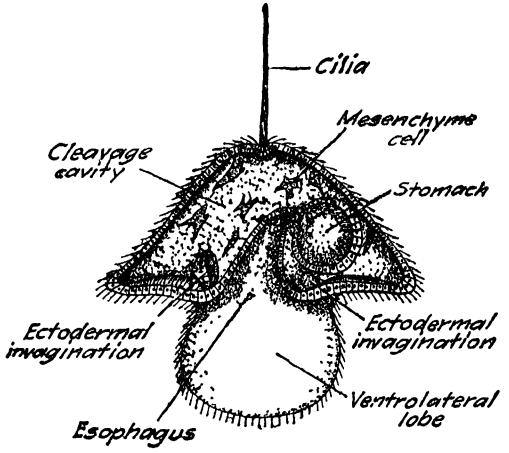


Fig. 223.—The pilidium larva of a Nemertine. This larva bears a superficial resemblance to the trochophore larva of the Annelids and Mollusks. (From Wolcott, Animal Biology.)

specific digestive system. Active, free-living animals need well-developed muscular and nervous systems, but since parasites do not, there is very often a degeneration of these systems, also; however, there is an amazing development of the reproductive system. Large numbers of offspring must be produced if the race is to survive. There are so many hazards in the transfer of individuals from one host to another that there is a very great mortality in parasites during the completion of their life cycles.

A parasitic way of life requires two things: an adaptation on the part of the parasite and also an adaptation on the part of the host. The host may take care of parasites in two ways: (1) it may develop an immunity to the toxic substances given off by the parasite, or (2) it may form a cyst around it, as in the case of the bladder-worm larva of the tapeworm.

It is more than probable that the art of parasitism begins with a harmless commensal association; certain adjustments take place, and

then the parasite begins to feed on the tissues of the host and later begins to be dependent upon the host for food, either the tissues or the digested food of the host. As pointed out in an earlier chapter (page 55), the relationship of commensalism, symbiosis, and parasitism may all be manifestations of the same sort of process.

II. The Roundworms, Nemathelminthes

The roundworm, or threadworm, group is often spoken of as the unsegmented roundworms to distinguish them from the *segmented worms*, the annelids. It is an important group because so many of its members are parasites that are found in most animal groups and even in plants.

A. Habitat and General Features.—The roundworms live in almost every place where other animals can live. Some live in fresh water, some in salt water, in the soil, and in plant and animal tissues. They range in length from about ¼ mm. to 4 ft. In form, they are long and cylindrical, tapering at each end. The animals lack locomotor organs and respiratory and circulatory systems. Movement is effected through muscular contractions of the body.

B. Classification.—The Nematoda are the most important class of the roundworms, because hookworm and *Trichinella* and other parasites of man are included here.

Class I. NEMATODA (Gr. *nematos*, a thread; *eidos*, form). *Ascaris, Trichinella, hookworms.*

Class II. NEMATOMORPHA (Gr. *nematos*, a thread; *morphe*, form), or *Gordiaceae. Hairworms*, which as adults live in water. Classification is uncertain, since they are unlike typical nematodes; *Gordius.*

Worms of uncertain classification but often included with the nematodes: Acanthocephala (Gr. *akanthos*, thorn; *kephale*, head), *Echinorhynchus;* Chaetognatha (Gr. *chaite*, horsehair; *gnathos*, the cheek), the arrowworm, *Sagitta.*

C. Comparison with Flatworms.—Nemathelminthes differ from Platyhelminthes in that the Platyhelminthes are flat, the Nemathelminthes are round; there is an absence of cilia in the roundworms, and the intestine has two openings; there is a dorsal and ventral nerve cord in the roundworms that is unlike the lateral nerve cords in *Planaria.*

Some of the common examples of the roundworms are *Ascaris, Trichinella, Enterobius vermicularis*, pinworm, *Trichuris trichura*, whipworm, *Loa loa*, eyeworm, and *Dracunculus medinensis*, guinea worm (Fig. 224). On account of the complexity of these animals and a lack of agreement as to whether many of their features are degenerate or primitive, a study of their anatomy is usually omitted in first year Biology. Certain of their life histories are, however, important for the student in general biology, and they are always included.

D. Some Important Representatives. 1. ASCARIS LUMRICOIDES is the form usually studied as a representative of the *roundworms.* It is

a parasite living in the intestines of man (for life cycle, see page 819). A form similar in appearance is found in hogs.

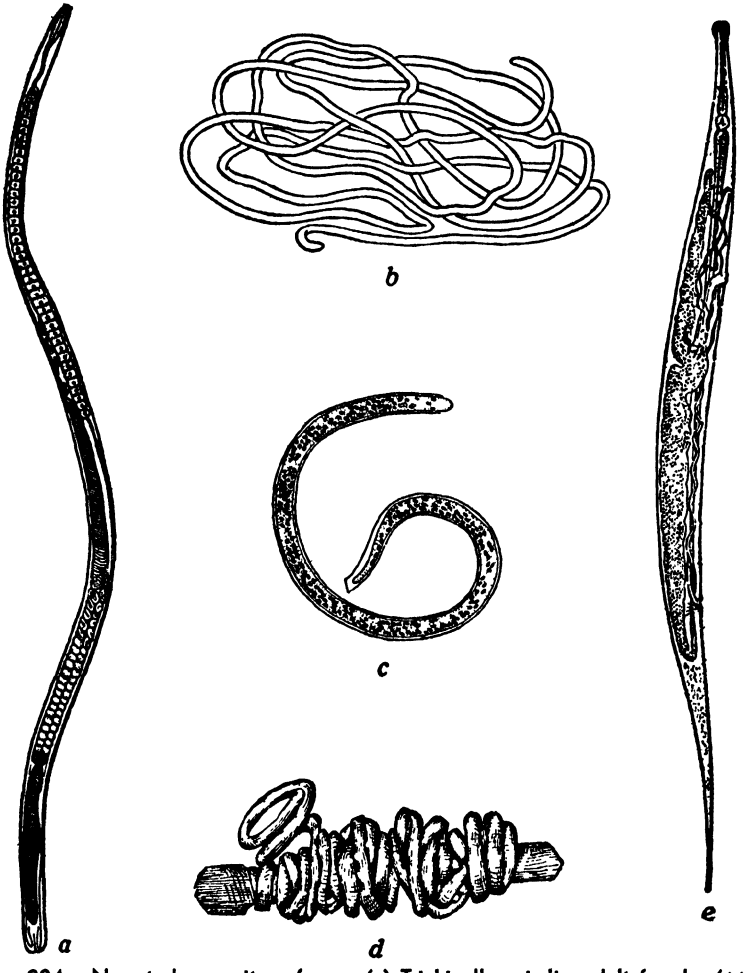


Fig. 224.—Nematode parasites of man. (a) Trichinella spiralis, adult female. (× 37.) (b) Paragordius varius, a "horse-hair snake" pseudoparasitic in the digestive tract. (Length, 10–30 cm.) (c) Wuchereria bancrofti, a microfilaria from the blood. (× 500.) (d) Dracunculus medinensis, the guinea worm, wound up on a stick. (About 2½ feet long.) (e) Enterobius vermicularis, the pinworm, female. (× 10.) (From Hegner, College Zoology, The Macmillan Company, after various authors.)

2. Hookworm.—The two common species of hookworms parasitic in man are *Necator americanus*, the New World species, and *Ancylostoma duodenale*, the Old World species. They cause much suffering and loss of efficiency, especially in the Southern part of the United States. They

are small worms, visible as whitish threads, which bite the lining of the intestine and suck the blood and lymph. If many worms are present, much blood is lost, and the patient becomes anemic and "lazy," both

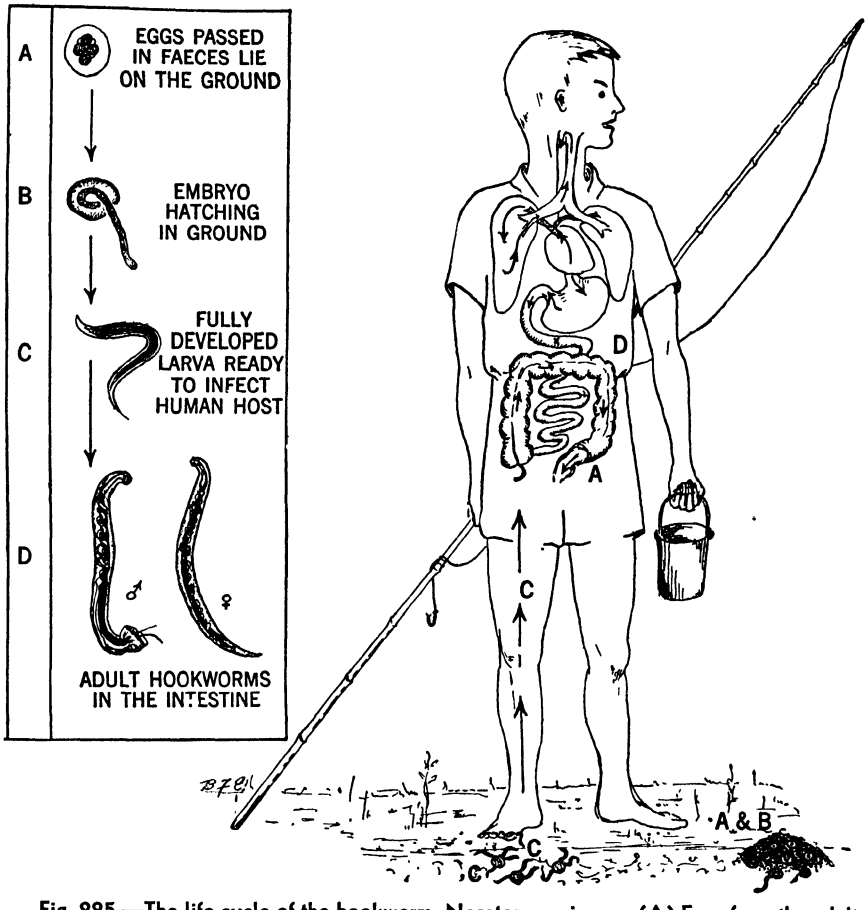


Fig. 225.—The life cycle of the hookworm, Necator americanus. (A) Eggs from the adult worms pass out of the intestine of the host and are deposited on the ground. Eggs hatch and embryos go a short distance in the ground. (C) The fully developed larva attaches itself to a grain of sand or pebble and is ready to infect the human host. Entering the skin of the foot, the larvae are carried in the blood stream to the heart and from there to the lungs. From the lungs they make their way to the windpipe, or trachea, into the esophagus and are swallowed. When they reach the intestine they attach themselves to its walls and begin to feed upon the blood of the host. They obtain the blood by piercing the lining of the intestine. (B. F. Edwards.)

physically and mentally, and on account of injury to the lungs is subject to tuberculosis. Children infected with hookworms are retarded in development. A single worm may produce as many as 10,000 eggs a day. The eggs pass out of the body in the waste material of the host.

Embryos hatch in about 24 hours in moist soil, and in about 5 days the young larvae are about ½ mm. in length. These young larvae usually gain entrance to a new host by boring through the skin of the feet (Fig. 225). They then bore into the blood vessels, are carried to the heart and from there to the lungs. From the lungs they make their way through the windpipe into the throat, are swallowed, and, after passing through the stomach, reach the intestine. Here the mature worms begin to feed by puncturing the intestinal wall and sucking blood and lymph. The worm injects a small amount of poison into the wound which prevents coagulation of the blood. This leads to much loss of blood even after the worm has left the wound. Length of life of the hookworm is about 5 years.

It is estimated that there are 2 million persons in the United States suffering from hookworm disease. Preventive measures are proper disposal of human excrement and wearing of shoes to prevent infection through the feet. Hookworm disease is easily cured with proper medical care.

3. Other Important Roundworms.—For the life cycles of *Filaria*, causative agent of elephantiasis, and *Trichinella*, the organism causing *trichinosis*, see pages 818 and 819.

E. Biological Principles Illustrated by the Roundworms. 1. Body Cavity.—A body cavity is present, and the animal exhibits the "tube-within-a-tube" type of body. This cavity, however, is not the same as the coelom of the higher animals, which is lined with mesodermic epithelium. The wall of the roundworms is composed of ectoderm on the outside and mesoderm on the inside, but the alimentary tube is composed of endoderm only.

2. Body Plan.—The "tube-within-a-tube" plan of the higher animals is shown by the roundworms.

3. Parasitism.—The parasitic forms show degeneration of the sense organs. The simplicity of organization, absence of segmentation structure of muscle cells, etc., in the roundworms are thought by some authorities to be a sign of degeneracy; by others, these features are regarded as primitive.

Questions

1. Why are flatworms said to be triploblastic?
2. What important parasites are in the flatworm group?
3. Compare a hydra with a planarian with regard to external features and digestive, excretory, and nervous systems.
4. Discuss regeneration in *Planaria*.
5. Give a full account of the life cycle of the liver fluke of the sheep. Of what advantage to the liver fluke is it to have so many larval stages?
6. Describe the general features of a tapeworm. How does man become infected with the human tapeworm? At what stage in the life cycle? What stages in the life cycle of

Taenia live in hogs and cattle? Is there any difference between the pork and beef tapeworms? Describe reproduction in the tapeworm.

7. Why does the tapeworm not need complex digestive organs?
8. Define: bladder worm, proglottid, pilidium, miracidium, redia, cercaria, sporocyst.
9. What are some biological advances shown by flatworms?
10. Compare a flatworm and a roundworm.
11. *a.* Give an account of the life cycle of the hookworm.
    b. Why are hookworm victims anemic and subject to tuberculosis?
12. What biological advances are shown by the roundworms?

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CHAPTER XXI

ANIMALS OF UNCERTAIN RELATIONSHIPS; BRYOZOA, BRACHIOPODA, TROCHELMINTHES, ETC.

To him who in the love of Nature holds
Communion with her visible forms, she speaks
A various language.

—BRYANT.

Moss animals, lamp shells, rotifers, Gastrotricha, and arrowworms are obscure in their relationships with other animals. They are mentioned briefly here because some of them are very common in protozoan cultures and because the survey of the animal kingdom would not be complete without some mention of them.

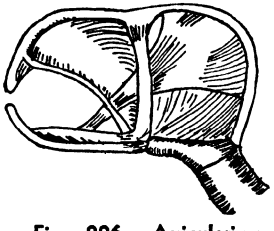

Fig. 226.—Avicularium, or "vulture head" of Bugula. The "head" has a flexible neck and the organelle moves to and fro. Its function is not known. (M. Hamilton.)

I. Bryozoa

(Gr. *Bryon*, moss; *zoon*, animal)

The Moss Animals.—These animals get their name from the fact that they form moss-like coverings on rocks, etc., in the water. They resemble the hydroids in appearance, since they are fixed to some support, are transparent, and are somewhat similar in shape. One form common along the Atlantic coast, *Bugula*,

Fig. 227.—Moss animal, Cristatella. Model of a fresh water colony (much enlarged). (Courtesy of the American Museum of Natural History.)

develops a structure that resembles a bird's head (Fig. 226) and for this reason is sometimes called a *vulture-headed moss animal. Cristatella* (Fig. 227) is an interesting fresh-water species.

II. Brachiopoda

(L. *brachium*, arm, *poda*, foot)

The Lamp Shells.—The lamp shells resemble Mollusca. They get their common name from the fact that in certain species the shape of the shell suggests an antique lamp (Fig. 49*A*, *Magellania*). Lamp shells are of particular interest to zoologists, because they have changed very little in size, shape, and structure since the Silurian period in the world's history some 300 million years ago. In the past ages, many species of lamp shells existed, but only a few species are still alive today.

The moss animals and lamp shells are often classed together as the Molluscoida.

III. Trochelminthes; the Rotifera, Wheel Animalcules

(L. *rota*, a wheel; *ferre*, to carry)

A. Habitat.—These wheel animalcules are often present in fresh-water cultures; however, some of them are marine. A few of the rotifers are parasites. Most of them are free-swimming, but a few are attached to rocks or sticks.

B. General Features.—Rotifers get their name from the fact that in some of them disks of cilia (Fig. 228) are located at the anterior end. When the cilia are in motion, these disks give the appearance of moving wheels. Rotifers are microscopic in size and are often found in Protozoa cultures. One of the peculiarities possessed by rotifers is their ability to withstand "drying out" for long periods of time. In this condition, they are blown about by the wind.

The body is bilaterally symmetrical and is covered externally with a cuticle. The trochal disk is at the anterior end. Various modifications of two bands of cilia surround the mouth. At the posterior end is a tail or foot. In many species, this is forked; in others, there are cement or adhesive glands. The tail or foot is also an organ of locomotion by which the animal pushes itself along.

C. Internal Features.—The body cavity is a false coelom. In it are located the internal organs. The mouth leads into the pharynx, and inside of the pharynx is a mill-like organ, the mastax. This is composed of chitinous jaws that masticate the food. The pharynx leads into a short esophagus, and this, in turn, leads into the stomach. Joined to the stomach is the intestine, which leads to the cloaca, and this leads to the outside through the anus. Cilia line most of the internal surface of the alimentary canal and aid in moving the food material through it. Food is digested in the glandular stomach; the undigested particles pass through the intestine into the cloaca and out through the anus.

The excretory system is well developed. It consists of a number of flame cells, which lead posteriorly by two nephridial ducts into a bladder,

which contracts at intervals and empties into the cloaca, and out through the anus

D. Reproduction.—The reproduction of rotifers has been the subject of much investigation on account of the natural *parthenogenesis* that occurs Parthenogenesis (page 355) is reproduction from eggs that have not been fertilized Males are always smaller than the females and may even live as parasites on the female Sometimes, as a result of a change in environment, particularly in the type of food supply, parthenogenetic females will give rise to eggs that will produce both females and males Whitney has shown that if *Hydatina senta* is fed a colorless flagellate,

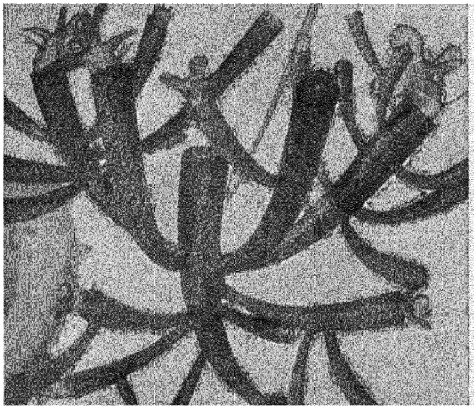

Fig. 228.—A colony of tube building rotifers (Courtesy of The American Museum of Natural History.)

Polytoma, mostly female-producing daughters appear, but when it is fed a green flagellate, *Chlamydomonas*, many male-producing daughters appear

The female has an ovary for egg production, a yolk gland for supplying the yolk, and an oviduct for carrying the eggs from the ovary to the cloaca They are discharged to the outside through the anus The male has a testis for producing sperm and a penis for transferring them to the female Rotifers may lay eggs (oviparous) or bring forth their young alive (ovoviparous)

Two types of eggs are produced. (1) winter eggs which are fertilized, have thick shells, and develop into females, and (2) summer eggs, the latter develop parthenogenetically, are thin-shelled and are of two

sizes. The larger of these produces females; the smaller, males. A summary of the life cycle of a rotifer is as follows:

EGGS OF THE LATE SUMMER

Female		Female
Large egg		Small egg
Female		Male
Egg	+	Sperm
	Winter eggs[1]	
Females		Females
Eggs	— *Summer* —	Eggs
	Parthenogenesis for many generations	
Females		Females
	Then repeat	

[1] Fertilized eggs that pass the winter in a thick shell.

The winter eggs lie dormant in the water for a time, or until conditions are favorable for hatching. The young embryos resemble the *trochophore* larvae of the annelids and mollusks. There is not very much change from this in the adult condition.

E. Biological Principles Illustrated by the Rotifers. 1. PARTHENOGENESIS, or production of animals from eggs that have not been fertilized.

2. SEXUAL DIMORPHISM, a striking difference between the male and female individuals.

3. TROCHOPHORE LARVA.—The larva of the rotifers is a trochophore larva similar to that of the annelids and the mollusks. Certain adult rotifers are so much like the trochophore larva as to suggest that they may represent the survival of a primitive type.

IV. Chaetognatha

Chaetognatha (page 321).—These animals are sometimes classed with the Nemathelminthes. They are small, slender, transparent marine invertebrates with distinct coelom, alimentary canal, nervous system, two eyes, and other sensory structures.

Sagitta, the arrowworm, is the best known example.

V. Phoronidea

(Gr. surname, *Phoronis*)

Sometimes the animals of this small group of about a dozen species are classed with the Molluscoidea, sometimes with other groups. They are small marine animals of sedentary habits. Most of them live in tubes. The larva (actinotrocha) resembles the trochophore larva of the annelids.

Questions

1. Rotifers live in water, yet they may be blown about by the wind. Explain.
2. How do rotifers exhibit a natural parthenogenesis?

3. What is the difference between the summer and winter eggs of rotifers?
4. How does the type of food supply influence the production of different kinds of eggs in rotifers?
5. Describe the life cycle of a typical rotifer.
6. Is there any significance in the fact that the larva of the rotifer is of the trochophore type?
7. Define: trochal disk, mastax, ovoviparous, viviparous, dimorphism.

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CHAPTER XXII

THE ANNELIDA

Man is certainly stark mad; he cannot make a worm, and yet he will be making gods by the dozens.

—MONTAIGNE.

The segmented worms form a large group of animals found widely distributed. They live in the moist ground, in the sea, and in fresh water. In adapting themselves to so many situations, many have become aberrant, so that the general characteristics of the group do not apply to these specialized forms. There are about 4,500 species of annelids.

A. General Features.—The annelids (L. *annellus*, a little ring; *eidos*, resemblance) are so named because their bodies are segmented, internally and externally. These segments do not appear as buds, as was the case with the tapeworm, but are partitions of a single animal. Annelid characteristics may be summarized as follows: (1) bilateral symmetry, (2) presence of a true *coelom*, (3) presence of segments called *metameres*, (4) an excretory system composed of *nephridia*, (5) and a ventral nervous system. Many have segmented, nonjointed appendages.

In addition to sexual reproduction, many annelids reproduce in an asexual manner by transverse fission. This occurs from the posterior end, works forward, and may result in a temporary chain-like colony.

It is the fashion to speak of the "lowly worm" or the "poor worm," yet worms are well organized and, as the following description of the earthworm will show, they are "fearfully and wonderfully made."

B. Classification.

Class I. ARCHIANNELIDA (Gr. *archi*, first or primitive; *annelida*). Primitive marine forms; *Polygordius* (Fig. 229).

Class II. CHAETOPODA (Gr. *chaite*, hair; *pous*, foot). Setae or hair-like appendages present. Coelom present; earthworm, *Lumbricus*, and sandworm; *Nereis* (Fig. 238).

Class III. HIRUDINEA (Gr. *hirudo*, leech). Flattened forms with anterior suckers for blood sucking and posterior suckers for attachment. No setae; leeches (Fig. 239).

Class IV. GEPHYREA. Annelids without segmentation, setae, or parapodia; *Bonellia*.

C. Representatives.—Nearly all classes in biology use the earthworm as a form for study, either as a representative of the annelid group or as a type form that illustrates many biological principles. A close relative, the sandworm, *Nereis*, is also often used either as a type or for comparison purposes.

1. THE EARTHWORM; LUMBRICUS TERRESTRIS.—There are many types of earthworms, but the species *terrestris* is a good form for study on account of its size and availability. It is called *angleworm, night crawler,* and other names.

a. Habitat.—Earthworms live in burrows in moist, rich soil in regions where the climate is not too cold. They cannot live where it is too dry, since the moist skin serves as a means of respiration. The burrows are very little larger than the diameter of the body. Sometimes they burrow as far as 6 ft. down into the ground, but generally they are only about 2 ft. deep.

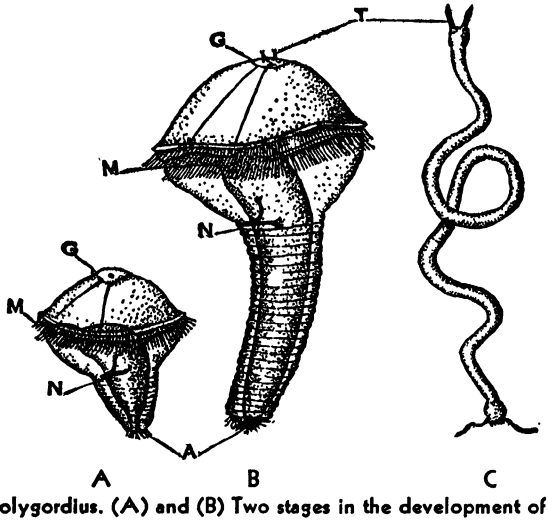

Fig. 229.—Polygordius. (A) and (B) Two stages in the development of the trochophore larva which grows by the addition of segments to the posterior end. (C) Dorsal view of the adult. (A) Anus. (G) Rudimentary supra-oesophageal ganglion. (M) Mouth. (N) Proto-nephridium, provided with flame cells. (T) Tentacles. (After Hatschek and Fraipont. From Wieman, General Zoology.)

b. External Features of Lumbricus (L. *lumbricus,* earthworm) *terrestris.* (1) BODY SHAPE AND SEGMENTATION.—The body is round, flattened on the ventral surface, and both dorsal and ventral surfaces are somewhat flattened at the posterior region. The worm may grow from 8 to 14 in. in length; it is slender and segmented, the number of segments, or metameres, varying up to 150. There are 31 segments from the anterior part of the animal to the bulge forming the clitellum, and this number remains constant, whereas the number behind the clitellum may vary, depending upon the size of the animal. A sort of fleshy lip overhangs the mouth of the earthworm. This is the *prostomium* (L. *pro,* before; *stoma,* mouth) and it is not considered a true segment. Because the mouth opening is on the underside of the first segment, this segment is not complete.

(2) THE CUTICLE.—This is a protective covering secreted by the ectoderm beneath it It is iridescent and contains minute pores through which secretions of the unicellular glands beneath are poured out, there is also an exchange of gases between the blood just beneath the cuticle and the moist soil The surface of the body is somewhat "slimy" and presents a shiny appearance on account of the mucus secreted by the glands in the skin. This mucus helps to keep the animal from drying out

(3) THE CLITELLUM.—Segments 31 or 32 to 37 are somewhat fused to form a saddle-shaped structure known as the *clitellum* (L. *clitellae*, a pack-

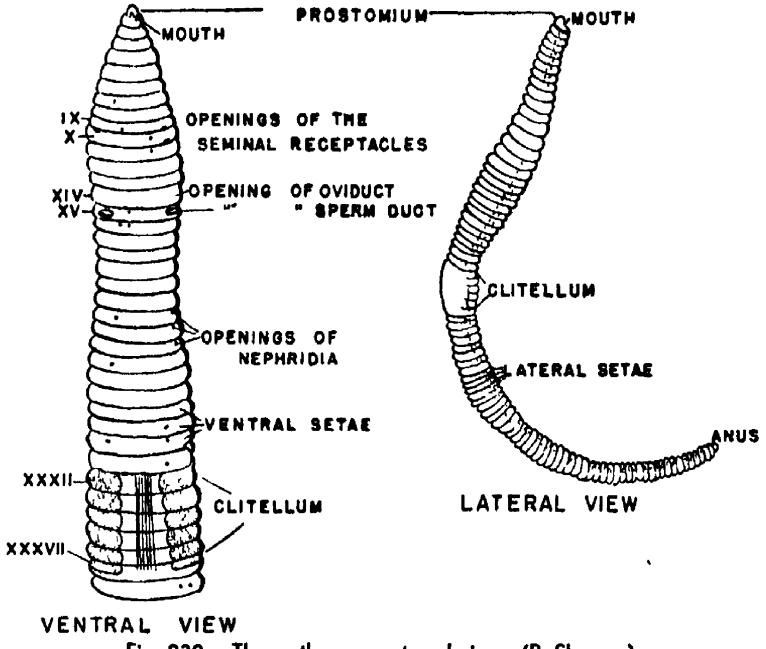

Fig 230.—The earthworm, external views. (B Shamos)

saddle) (Fig 230) The function of this is to secrete a cocoon in which the eggs and sperm are deposited (see below)

(4) THE SETAE.—Each segment except the first three and the last bears four pairs of chitinous bristles, the *setae* (L. *seta*, a bristle) Two pairs are on the ventral surface and one pair on each side They are moved by *retractor muscles* and aid the worm in moving around The setae aid the animal in crawling and are of especial service to it in climbing out of a burrow If an attempt is made to pull a worm from its burrow, it extends its setae and holds on "for dear life" The setae near the anterior end hold the worm in place while the posterior part of the body is being drawn forward.

(5) OPENINGS.—The internal structures are related to certain segments. For this reason, the segments are numbered in all figures of the earthworm. The external openings of various organs locate their position in the body. They are as follows:

1. The *mouth*, ventral half of the first segment.
2. Openings of the *sperm ducts*, or *vasa deferentia*, segment 15.
3. Openings of the *oviducts*, segment 14. Not easily seen.
4. Openings of the sac-like organs (the *seminal receptacles*), which receive and store sperm, between the ninth and tenth and tenth and eleventh segments. Not easily seen.
5. Openings for the ducts of the *nephridia*, the *nephridiopores*. A pair in each segment except the first three and the last. They are immediately anterior to the outer setae of the inner pairs. Not easily seen.
6. *Dorsal pores* through which the body cavity communicates with the outside. These are located in the mid-dorsal line at the anterior edge of each somite from the eighth or ninth to the posterior end of the body. Not easily seen.
7. Opening of the alimentary canal (*the anus*) in the last segment.

c. Internal Features. (1) BODY PLAN.—If a longitudinal cut is made through the body wall of an earthworm on the dorsal surface, a little to one side of the center, and the cut edges are pinned back (Fig. 231), the general plan of the body is seen to be a "tube within a tube," the alimentary canal being the inside tube and the body wall the outside tube. The space between the alimentary canal and the body wall is the *body cavity or coelom.* This body cavity is divided into compartments by many partitions (or *septa*), which correspond to the grooves on the outside, except that the septa are absent between segments 1 and 2, and incomplete between segments 3 and 4 as well as segments 17 and 18. The walls of the coelom are lined with an epithelium, the *peritoneum.*

A colorless fluid fills the coelomic cavity and flows from one compartment to another.

The alimentary canal is continuous and passes through the septa. Above the alimentary canal is the dorsal blood vessel, beneath it is the ventral blood vessel and the nerve cord.

(2) THE DIGESTIVE SYSTEM AND DIGESTION.—The mouth of the earthworm leads into a *mouth cavity* or *buccal pouch.* In segments 4 and 5 is a muscular *pharynx*, which is used for sucking in food particles. Behind the pharynx is the *esophagus*,[1] which extends from segment 6 to 14 and then enlarges to form the thin-walled *crop*, or *proventriculus*, in which food is stored. Just back of this, in segments 17 and 18, is the muscular *gizzard* in which food is ground into fine particles. The *stomach–intestine* follows the gizzard. It is infolded at the middle of the dorsal surface; this fold,

[1] Also spelled *oesophagus.*

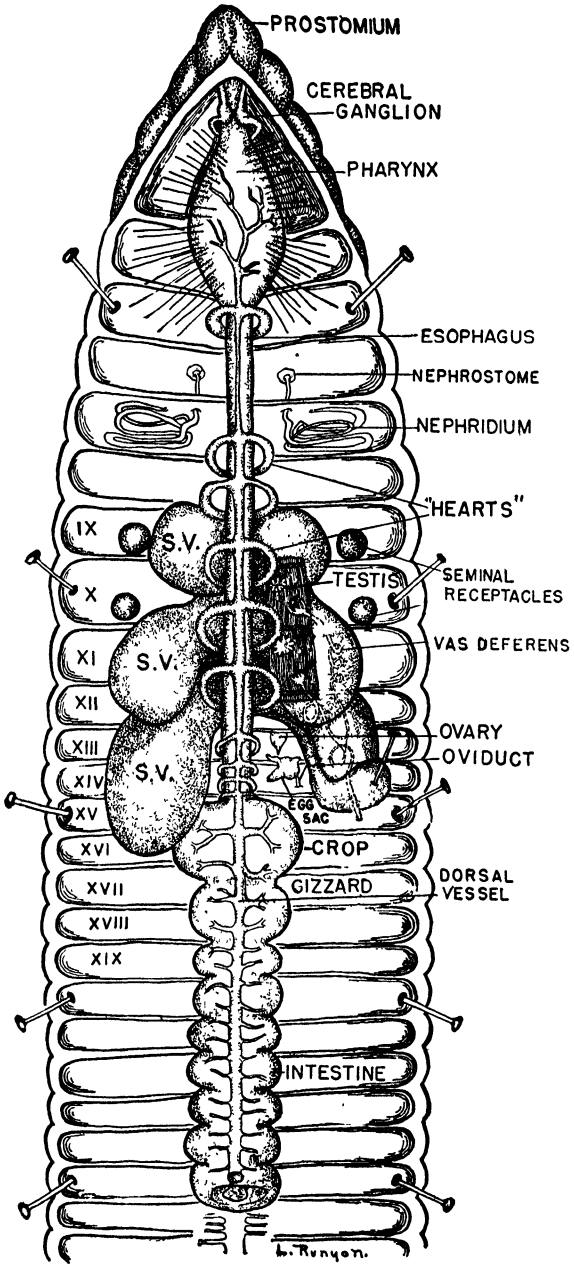

Fig. 231.—Dissection of the earthworm, Lumbricus terrestris, somewhat diagrammic and simplified. The calciferous glands which open into the oesophagus are omitted (see Fig. 232). Only one pair of nephridia are shown though there is a pair of them in every segment except the first three and the last. (L. Runyon.)

which is called the *typhlosole* (Gr. *typhlos*, blind; *solen*, channel) forms a ridge or projection that hangs down into the cavity of the intestine. This is shown in Fig. 233, which represents a cross section of the earthworm in the region of the stomach intestine. The typhlosole increases

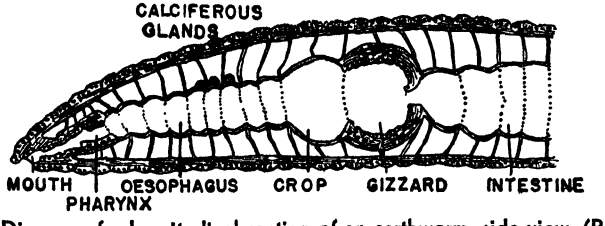

Fig. 232.—Diagram of a longitudinal section of an earthworm, side view. (B. Shamos.)

the absorbing surface of the stomach intestine and may perform other functions that are not well understood.

When the food reaches the esophagus, a secretion from the calciferous glands (Fig. 232) is mixed with it. This secretion is alkaline, but its exact function is not known. It may neutralize any acid that is present in the

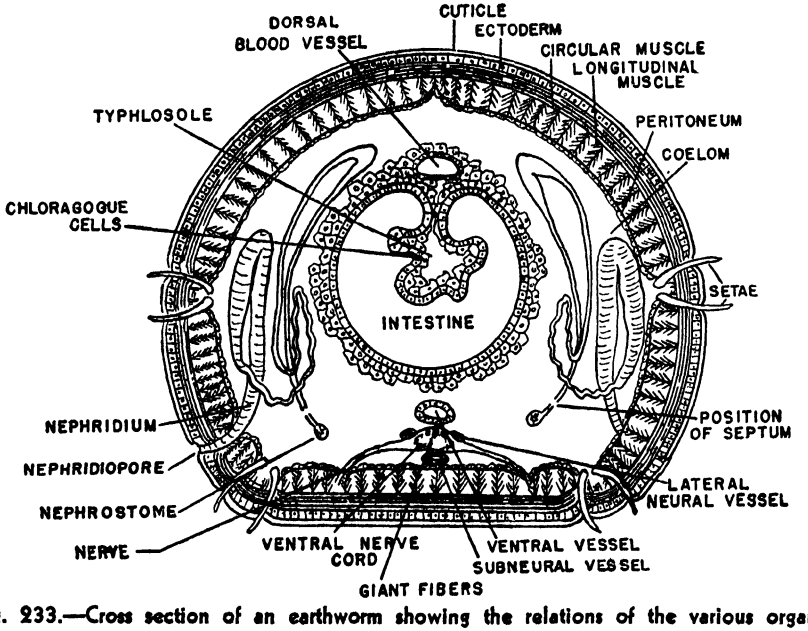

Fig. 233.—Cross section of an earthworm showing the relations of the various organs. (B. Shamos.)

food. From the esophagus the food passes into the crop, which is a place of temporary storage; it then enters the gizzard. Here it is reduced to fine particles and thoroughly mixed. From the gizzard it passes on into the stomach–intestine.

As has been previously pointed out, foods to be digested by living organisms must be in soluble form. The walls of the stomach intestine contain glands that secrete *enzymes*. These possess the power of breaking down three types of food, carbohydrates, proteins, and fats. The food is split up by enzymes into simpler substances, which are then absorbed through the walls of the stomach intestine and transported to all parts of the body by the circulatory system and the fluid of the body cavity.

The food of the earthworm consists of dead animals and plants. This material is sucked into the mouth while the worms are out of their burrows at night. They usually keep the tip of the tail in the burrow. This enables them to "beat a hasty retreat" if disturbed. Earthworms swallow quantities of earth while feeding. After the nutritive material contained in this earth is absorbed, the residue is deposited on the surface of the ground in the form of "castings," which form little piles of earth near the burrows of the worms.

(3) THE CIRCULATORY SYSTEM AND ITS FUNCTIONS.—The circulatory system of the earthworm is a closed system; *i.e.*, there is a complicated system of blood vessels through which the blood makes a complete circuit.

(*a*) The Blood.—The blood consists of a liquid portion, the *plasma*, in which float colorless cells, the *corpuscles*. The red blood corpuscles of the higher animals are red because they carry a chemical substance, *hemoglobin* (Gr. *haimo*, blood; L. *globus*, globe), which has an affinity for oxygen. In the earthworm, this substance is dissolved in the *plasma* instead of being carried by the corpuscles, and therefore the plasma is red.

(*b*) The Blood Vessels.—Just above the alimentary canal lies a large vessel, the *dorsal blood vessel*. This is easily seen in the living worm, since the skin is quite transparent. In the region of the esophagus, branches from the dorsal vessel become enlarged to form five pairs of pulsating loops, the so-called *hearts* (Fig. 234), which surround the esophagus and connect with the *ventral vessel*, which lies just above the nerve cord. A blood vessel lies on each side (*lateral neural*) of the nerve cord and one (*subneural vessel*) underneath it. These five longitudinal trunks, with many branches and capillaries and some minute lymph spaces, make up the circulatory system of the earthworm. This is a closed circulatory system and represents a great advance over the condition that exists in *Hydra* and other lower invertebrates.

(*c*) The Circulation.—Blood is forced forward in the dorsal vessel by wave-like (*peristaltic*) contractions of the vessel. Valves are present in this vessel that prevent the backflow of the blood from the anterior end. From the dorsal vessel, the blood passes into the five pairs of "hearts" or *aortic loops* to the ventral vessel. There are valves in the "hearts," also, that allow the blood to flow in only one direction. From the ventral

vessel, the blood passes to the body wall and the nephridia. Since the earthworm uses its skin as a respiratory organ, carbon dioxide is given up and oxygen taken in by the blood that circulates in the capillaries in the skin. The oxygenated blood returns from the body wall to the lateral neural vessels, *i.e.*, the two long longitudinal trunks on each side of the

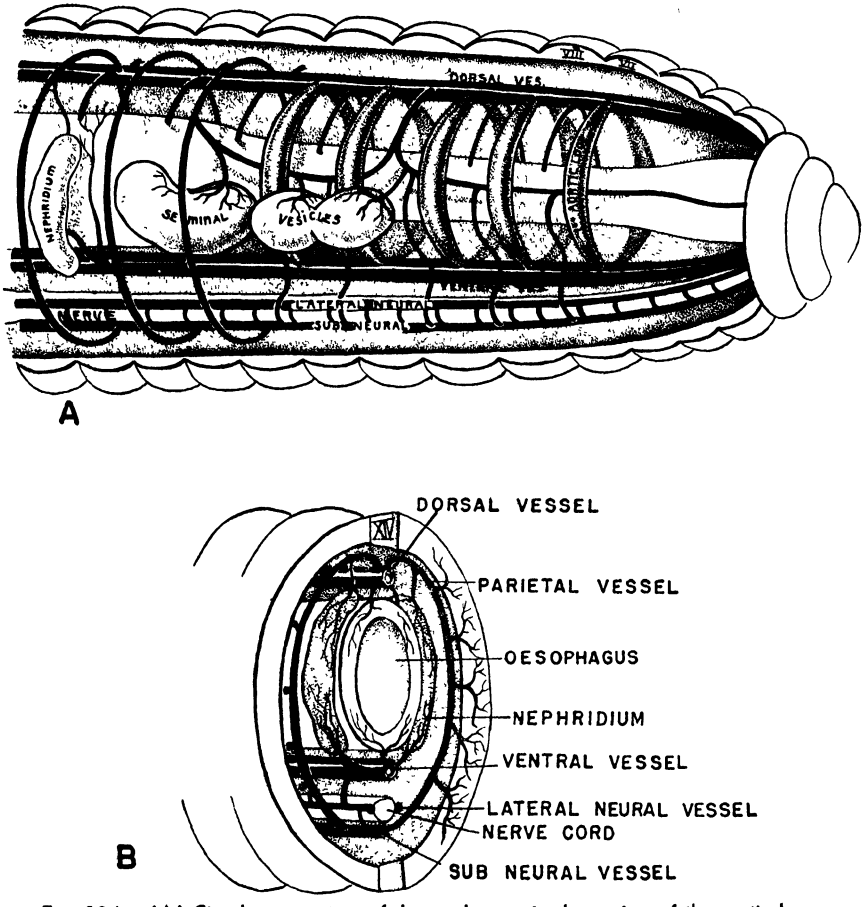

Fig. 234.—(A) Circulatory system of the earthworm in the region of the aortic loops or "hearts" (anterior end). (B) Cross section of the earthworm showing the relations of the blood vessels to each other in segment XIV. (F. A. Baker.)

nerve cord. From here it passes to the subneural vessel beneath the nerve cord. The direction of the flow in the subneural trunk is posterior, and then the blood passes upward to the dorsal vessel through the parietal vessels.

(*d*) Functions of the Blood.—The blood is the transportation highway for oxygen, food, wastes, and other substances. When the blood flows

to the outer skin of the earthworm, the hemoglobin is loosely associated with the carbon dioxide. The carbon dioxide passes out through the skin while oxygen from the air passes through the skin and unites with the hemoglobin, forming *oxyhemoglobin*. The tissues must have oxygen for the purpose of respiration. The blood flows away from the body wall to the capillaries in the tissues. Exchange of materials between the blood and the tissue takes place in very small lymph spaces (see below). Blood also transports other substances, such as secretions from the glands, etc.

(*e*) The Lymph.—Blood plasma and a few corpuscles make up the *lymph*, which passes from the blood stream through the capillaries to the tissues and bathes the tissue cells. The lymph is, therefore, the "middleman" between the blood and the tissues. It takes the oxygen to the

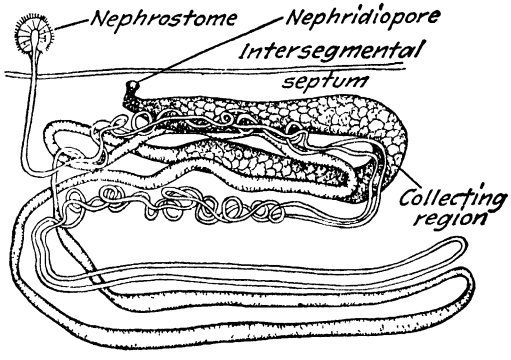

Fig. 235.—Diagrammatic view of the nephridium of an earthworm. In the body this is invested with soft connective tissue and the loops of the tubule are crowded together. Highly magnified. (From Wolcott, Animal Biology.)

tissues from the blood and collects carbon dioxide and the waste products of metabolism and then enters the blood stream through the *capillaries*. The fluid in the body cavity resembles the lymph; it also receives some of the wastes from the tissues.

(4) Respiratory system and its functions.—The process of respiration has been described in connection with the circulatory system. The earthworm uses its moist outer skin to obtain oxygen and to get rid of carbon dioxide. In other words, the skin functions as a respiratory organ. This is possible because of the large number of small blood vessels just underneath the surface.

(5) The excretory system and excretion.—Two coiled organs with ciliated funnels are present in each segment, except the first three and the last; these are the excretory organs, or *nephridia* (Gr. *nephridios*, of the kidneys). In Fig. 231, only two of these nephridia are represented. Some of the wastes also pass directly to the exterior from the fluid in the body cavity through the pores in the body wall. A single nephridium

consists of a ciliated funnel (the *nephrostome*) and a thin, much coiled tube (Fig. 235). The cilia of the nephrostome beat, creating a current that brings the coelomic fluid containing nitrogenous wastes from the coelom into the tubule. It passes out of the tubule by way of the *nephridiopore*, an opening for each tubule on the ventral surface of the animal (Fig. 230). The nephrostome passes through the *septum* that contains the tubule.

(6) THE NERVOUS SYSTEM.—In *Hydra*, the nervous system was simply a net of nerve fibers. In the earthworm, just above the pharynx in the third segment are two masses or collections of nerve cells called *ganglia;* these constitute the "brain" of the earthworm. From the anterior end of these two ganglia, nerves extend to the lip (Fig. 236), and from each ganglion a nerve passes downward, surrounds the pharynx, and joins the ventral nerve cord. These are the *circumpharyngeal connectives* which connect with a pair of subpharyngeal ganglia just beneath the pharynx. These ganglia mark the beginning of the ventral nerve cord, which enlarges into a ganglion in each segment and gives off three pairs of nerves in every segment posterior to 4. Each of these ganglia is really two that are fused together. Near the dorsal surface of the cord are three longitudinal "giant fibers" or neurochords that conduct impulses directly from one end of the body to the other. The brain and ventral nerve cord form the *central nervous system* while the associated nerves, afferent and efferent, constitute a *peripheral nervous system.* Thus the earthworm possesses a well-organized nervous system.

Stimuli are received by sensory cells and passed to the ventral nerve cord by afferent nerves. They are sent out by efferent neurones. Here is a *simple reflex.*

Sense Organs.—The earthworm does not possess eyes, yet it is sensitive to light. This sensitiveness to light is due to certain nerve cells located in the skin.

Experiments have demonstrated that earthworms prefer certain types of food, such as cabbage leaves, carrots, etc., and must, therefore, possess senses of taste and smell.

(7) MUSCLES AND MOTION.—The earthworm has a well-developed muscular system. In the body wall there are (1) an outside circular layer and (2) an inside longitudinal layer (Fig. 233). These contract in such a way as to produce a muscular wave and so aid in locomotion. The wall of the intestine also has a layer of longitudinal muscles, and these contract to produce the peristaltic wave that forces the food along the alimentary canal and expels wastes. There are also muscles in the walls of the blood vessels, in the muscular tube of the nephridia, and in the outer sheath of the nerve cord. Muscles also attach the pharynx to the body wall.

The setae are moved by two sets of muscles. One set, the *protractors*, pull the setae outward; the other set, the *retractors*, contract and draw the setae back in their sacs. Both sets of muscles are attached to the inner ends of the setae. The earthworm moves along by means of the setae and by contractions of the muscles in the body wall.

(8) Regeneration and grafting.—Most invertebrates possess the power of regeneration, and the earthworm is no exception. It is a more highly organized animal than *Hydra*, and regeneration occurs less easily; the extent of regeneration depends upon where the worm is cut. If the front end is cut off anywhere back to the eighteenth segment, a new anterior will appear, but only segments 1 to 5 are regenerated. If it is

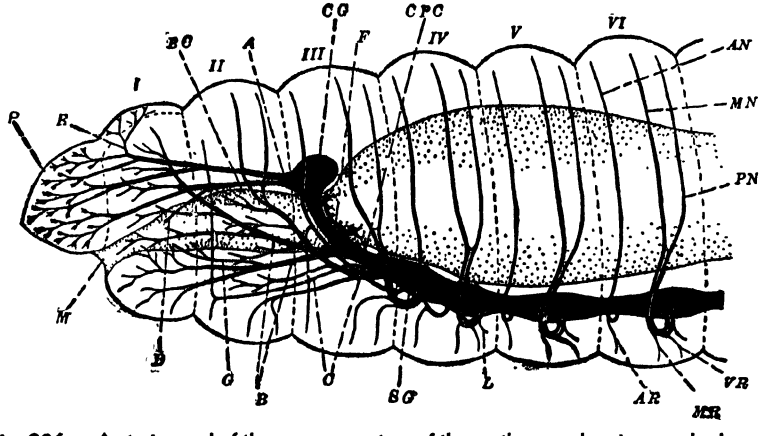

Fig. 236.—Anterior end of the nervous system of the earthworm showing cerebral ganglion and larger nerves. (P) Prostomium. (BC) Buccal cavity. (CG) Cerebral ganglion. (CPC) Circumpharyngeal connective. (AN) (MN) (PN) Segmental nerves. (M) Mouth. (SG) Subpharyngeal ganglion. (After Hess.)

cut off back of the eighteenth segment, not a new anterior end but another tail will grow out! Naturally, such a worm, with a tail at each end but no mouth, will starve to death. If it is cut across the posterior end, a new tail will be regenerated consisting of many segments. The anal segment is restored first, and the new segments grow in between this and the old part of the worm.

It is possible to graft several pieces of earthworm together; thus very long worms may be obtained. Extra tails may be grafted from one worm to another, and other combinations may be made.

(9) Reproductive system and reproduction.—The earthworm is provided with both male and female reproductive organs; it is, therefore, a hermaphrodite. In the *ovaries*, female gametes, or *eggs*, are produced. The ovaries are small and hence difficult to find, even though one knows the segment (13) in which they lie. *Two oviducts* with ciliated funnels are

present; the funnels also lie in segment 13. The oviducts pass through the septum between segments 13 and 14 and enlarge into *egg sacs* in segment 14. These structures cannot be seen easily except in mature worms during the breeding season.

The male organs consist of three pairs of conspicuous *seminal vesicles*, two pairs of *testes*, and two pairs of *sperm ducts* or vasa deferentia. The testes comprise two pairs of glove-shaped organs enclosed in a chamber formed by the walls of the seminal vesicles. Behind each testis is a sperm duct with a ciliated funnel. The two sperm ducts on each side unite and

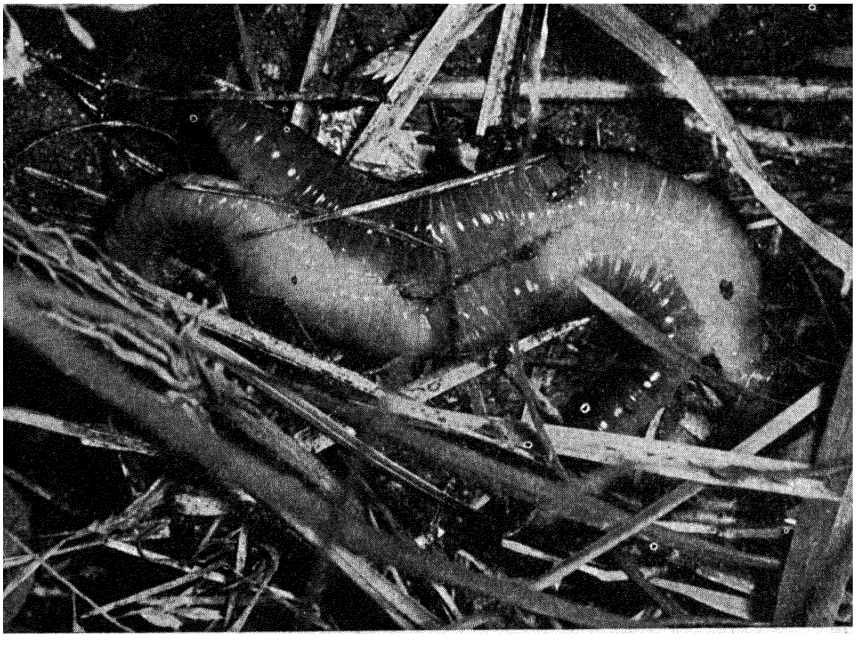

Fig. 237.—Copulating earthworms. (Courtesy of The General Biological Supply House.)

continue back to segment 15, where they open to the outside (Fig. 231). They are easy to see. The sperm pass out of the testes and into the seminal vesicles, where they are stored. Now, although the earthworm possesses both male and female reproductive organs, its eggs are not fertilized by its own sperm. Between segments 9 and 10 and 10 and 11 are two pairs of sacs (seminal receptacles) for receiving sperm from another worm. Two worms come together (Fig. 237), or *copulate*, in such a manner that their anterior ends point in opposite directions, and the ventral surface of the clitellum of one is opposite the ninth and tenth segments of the other. Mucus is secreted and a *slime tube* is formed. Then the spermatozoa are expelled from the seminal vesicles of each worm, and these pass along the seminal *grooves* and into the seminal receptacles of

the other worm. The worms then separate, each carrying portions of the slime tube. Inside the slime tube, the clitellum secretes a substance which forms a sort of cocoon or sac. This slips over segment 14 and receives eggs, then over segments 9–11 and receives sperm; the cocoon then slips over the head of the worm and hardens. Inside this little cocoon, the sperms fertilize the eggs, and here the young worms begin their development.

(10) DEVELOPMENT OF THE EARTHWORM.—The fertilized egg soon divides into two equal parts. It has, then, cleavage of the holoblastic type (page 259); a hollow blastula is formed. Soon after the segmentation cavity is formed, two cells, known as the *mesoblastic cells*, move into the cleavage cavity. These divide, forming two mesoblast bands (Fig. 238), and from these the mesoderm develops. As the mesoderm is developing in the cleavage cavity, gastrulation occurs by invagination to form the endoderm and ectoderm. The gastrula elongates, and the archenteron opens at both ends to form mouth and anus. As the mesoderm fills the space between the entoderm and the ectoderm, segmental cavities develop, which are the cavities of the segments. In about two or three weeks, the embryo escapes from the cocoon as a small worm.

The larva of many annelids is called a *trochophore* (Gr. *trochos*, wheel; *phoros*, to bear) *larva* (Fig. 229). It is of special interest, because some other animal phyla develop a similar larva in the early stages. The larva of a Molluscan, for example, is a trochophore larva in its early stages and is much like that of the annelids but becomes very different as it develops. This seems to show a relationship between the very dissimilar mollusks and the annelids.

d. The Importance of Earthworms.—Earthworms are biologically important as illustrating certain biological principles (see below). They serve as a food supply for many animals—birds, frogs, etc.; in addition, they are of importance to man. It is estimated that an acre of soil may contain as many as 50,000 earthworms. Charles Darwin, the great English biologist, wrote a book called the "Formation of Vegetable Mold through the Action of Worms." He observed the activities of earthworms over a period of more than 40 years, and from the facts he gathered made some calculations that are very interesting. He estimated that more than 18 tons of earthy castings may be carried to the surface of a single acre of ground by earthworms in a single year; in 20 years, these castings would form a layer 3 in. thick. Darwin mentions a stony field that was so changed by earthworms that "after thirty years (1871) a horse could gallop over the compact turf from one end to another and not strike a single stone with its shoes." Thus a stony field may be changed into pasture land in a few years. More important than this, however, is the fact that the constant burrowing of earthworms renders the soil more

porous. This gives the air and moisture so necessary for the roots of plants a chance to penetrate the soil. Also, the castings serve as fertilizer, since they contain the wastes from the alimentary canal of the worms.

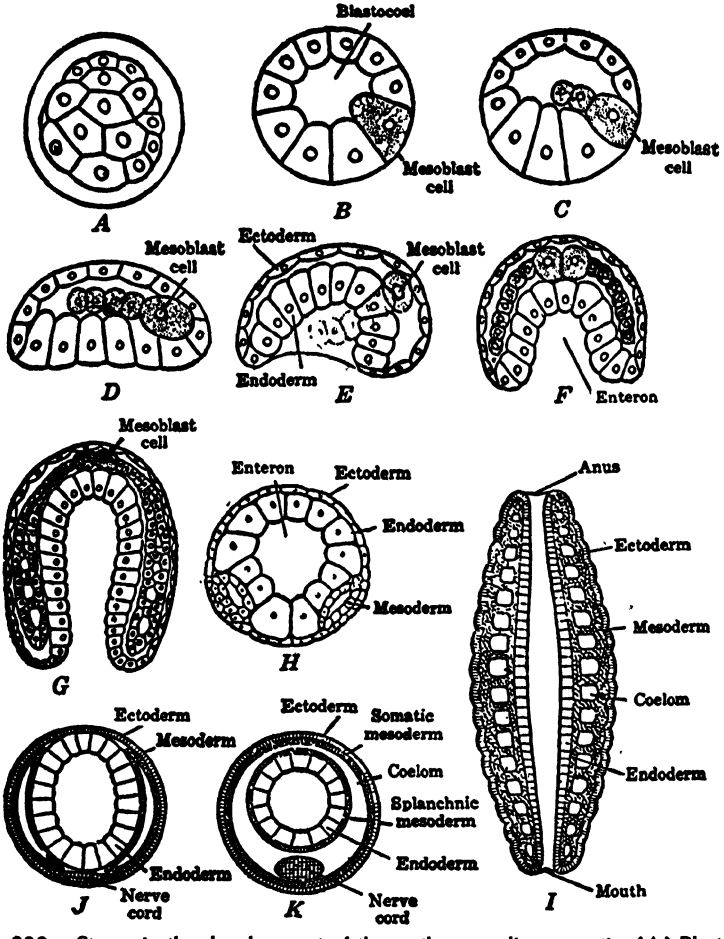

Fig. 238.—Stages in the development of the earthworm, diagrammatic. (A) Blastula. (B) Section of a blastula, showing blastocoel and one of the primary mesoblast cells (of the mesoderm). (C) Later blastula. (D) Early gastrula. (E) Lateral view of gastrula showing invagination. (F) Section of E. (G) Later stage showing cavities in mesoderm bands. (H) Transverse section of G. (I) Diagram of a longitudinal section of a young worm after the formation of an anus and a mouth. (J) Cross section of I. (K) Later stage, transverse section. (After E. B. Wilson.)

2. NEREIS VIRENS.—*Nereis* is often called the *clamworm*, *sandworm*, or *marine earthworm*. In Greek mythology, the Nereids were sea nymphs, the daughters of the ancient sea god Nereus.

a. Habitat.—The *Nereis* burrows in the sand, leaving only the head protruding, or swims in the salt water. It is abundant along the Atlantic coast of the United States. It is less specialized than the earthworm, although it belongs to the same class. Since the earthworm has been fully described, only brief mention will be made of the features of the *Nereis.*

b. External Features.—The *Nereis* is distinguished from the earthworm by its flattened body, distinct head and appendages. Like the earthworm, however, it is segmented externally and internally. The *prostomium* hanging over the mouth bears two kinds of appendages, which are tactile in function: (1) the *dorsal tentacles* and (2) the *ventral palps.* There are also two pairs of eyes on the prostomium. The first segment is called the *peristomium* (Gr. *peri,* around; *stoma,* mouth) and bears two pair of *tentacles, or cirri.* The rest of the segments are alike, except the posterior one, which bears a pair of cirri. The lateral appendages of the *Nereis* are of especial interest. These are called *parapodia* (Gr. *para,* beside; *pous,* foot) and are of especial interest because they are used in respiration and locomotion. Each parapodium has two fleshy lobes, a dorsal *notopodium* and a ventral *neuropodium;* and each of these surrounds a large bristle or seta (*aciculum*), to which the muscles of the parapodium are attached. Both notopodia and neuropodia have large groups of bristles or setae. A *dorsal* and *ventral cirrus* is usually present (Fig. 239*C*).

The body is covered with a *cuticle* secreted by the epidermis.

c. Internal Features. (1) MUSCLES, LOCOMOTION.—Beneath the epidermis is a layer of *circular muscles,* and underneath that is a *longitudinal layer.* These layers make up the body wall. There are other muscles in the intestine and in the parapodia. The *Nereis* swims by undulations of its body and by use of the parapodia.

(2) COELOM.—The *Nereis* has the "tube within a tube" type of body also. A *true coelom,* lined with mesodermal epithelium, is present.

(3) DIGESTIVE SYSTEM.—*Nereis* has a pair of chitinous jaws and a muscular pharynx, which can be everted to form a sort of proboscis. The pharynx narrows to form the esophagus, which has a digestive gland opening into it on each side. The esophagus joins the straight stomach–intestine, which extends the length of the animal and opens to the outside through the anus.

(4) CIRCULATORY SYSTEM.—There is a dorsal vessel that is connected with a ventral vessel in each segment by right and left transverse vessels. There are many branches and capillaries, giving the *Nereis* a well-organized blood system. The hemoglobin, which gives the blood its red color, is dissolved in the plasma and not in the corpuscles, as in the case of the vertebrates.

(5) RESPIRATORY SYSTEM.—There is some exchange of gases through the skin of the *Nereis*. However, this surface is greatly increased by the thin, flattened parapodia. In these appendages is an extensive network

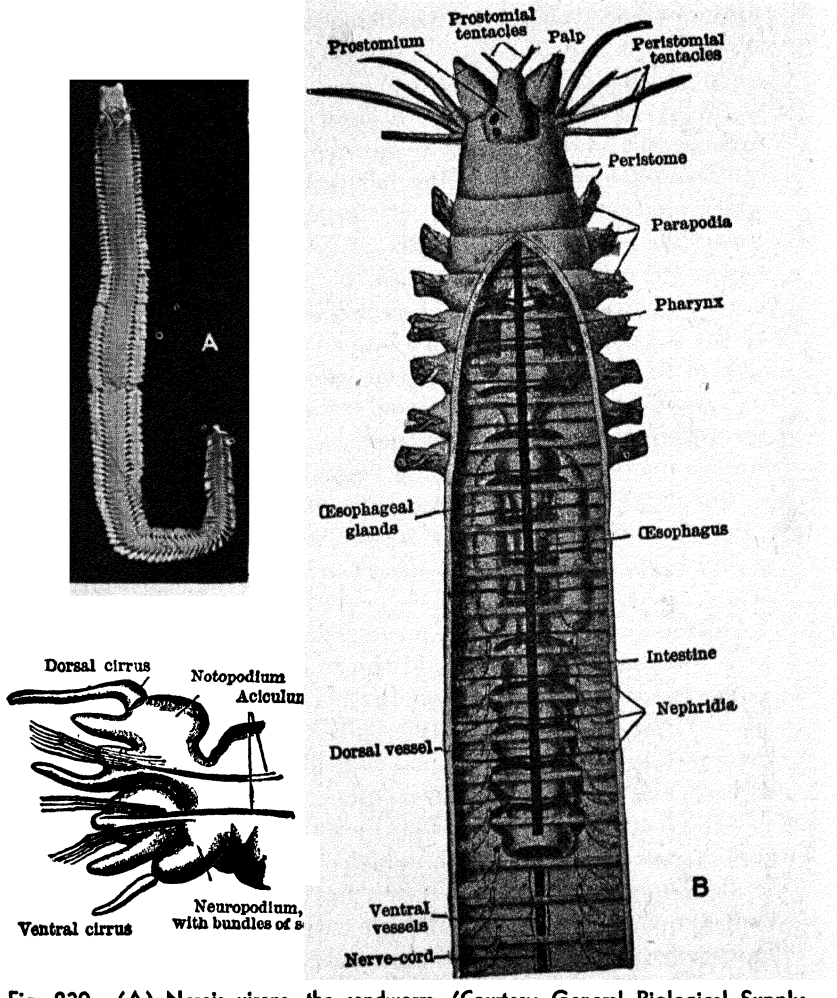

Fig. 239.—(A) Nereis virens, the sandworm. (Courtesy General Biological Supply House.) (B) Anatomy of Nereis. (From Parker and Haswell, A Textbook of Zoology, The Macmillan Company.) (C) Parapodium of Nereis. (From Wieman, General Zoology, after Quatrefages.)

of capillaries. Here, as well as in the blood vessels in the body wall, the blood receives oxygen and gives up carbon dioxide.

(6) EXCRETORY SYSTEM.—Paired nephridia of the earthworm type are present in nearly all the segments.

(7) NERVOUS SYSTEM AND SENSE ORGANS.—In the head, there is a pair of *suprapharyngeal ganglia*, the so-called brain. These are connected by the circumpharyngeal connectives with the subpharyngeal ganglia, which in turn join a ventral nerve cord running the length of the animal and having a pair of ganglia in each segment. From these ganglia, branches are given off to all parts of the body. The two pairs of eyes appear to be able to see moving objects. The tactile organs were mentioned above.

(8) REPRODUCTIVE SYSTEM AND REPRODUCTION. The reproductive system is simple, although the sexes are separate. Gonads are in all segments except those in the anterior end of the body. The sex cells, ova or sperm, as the case may be, arise in the lining of the coelom. These are shed in the water, where fertilization takes place. A typical ciliated swimming *trochophore larva* is developed. This settles to the bottom and develops into a young worm.

3. HIRUDINEA.—These are the *Leeches*. They have dorsoventrally flattened bodies, a prostomium, and a definite number of segments (Fig. 240). The leech does not add segments as it grows older, nor does its external segmentation correspond to the internal segments, since there are fewer internal segments. A number of fine lines traverse each external segment. There are also two suckers, one surrounding the mouth and another at the posterior end for the purpose of attachment. The coelom cavity is almost obliterated by a growth of connective tissue. The animals have no bristles or parapodia. They are hermaphrodites.

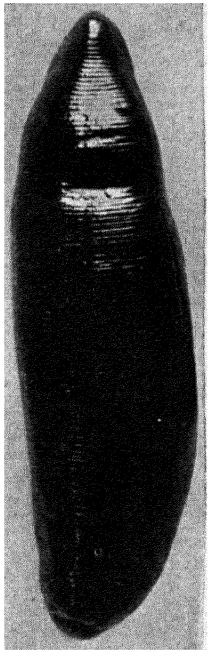

Fig. 240.—A black leech. These animals have suckers at each end; the posterior sucker is to "hold on with" and the anterior one is for drawing blood from other animals. Some leeches can swallow three times their own weight in blood. (Photograph by C. Clarke.)

The medical leech *Hirudo* (Gr. *hirudo*, leech) *medicinalis* is of special interest because of its use by physicians in "blood letting." The blood meal is taken by the leech as follows: The animal attaches itself by the posterior sucker, makes a wound with the mouth, and begins to suck blood. The salivary glands of leeches manufacture a substance called *hirudin*, which keeps the blood from coagulating.

The mouth is provided with three jaws with chitinous teeth for biting. The pharynx is muscular, and this leads into the crop, which has 11 pairs of lateral branches. The blood is sucked in and stored in the pouches

until it is digested in the small globular stomach. After the blood meal, the leech drops off and becomes inactive while digesting the large amount of blood. One of these animals can ingest three times its weight in blood, and it may take 9 months to digest this meal!

4. Other Annelids.—There are some beautiful worms! Some of these are all colors of the rainbow and live in tubes. Others are not beautiful

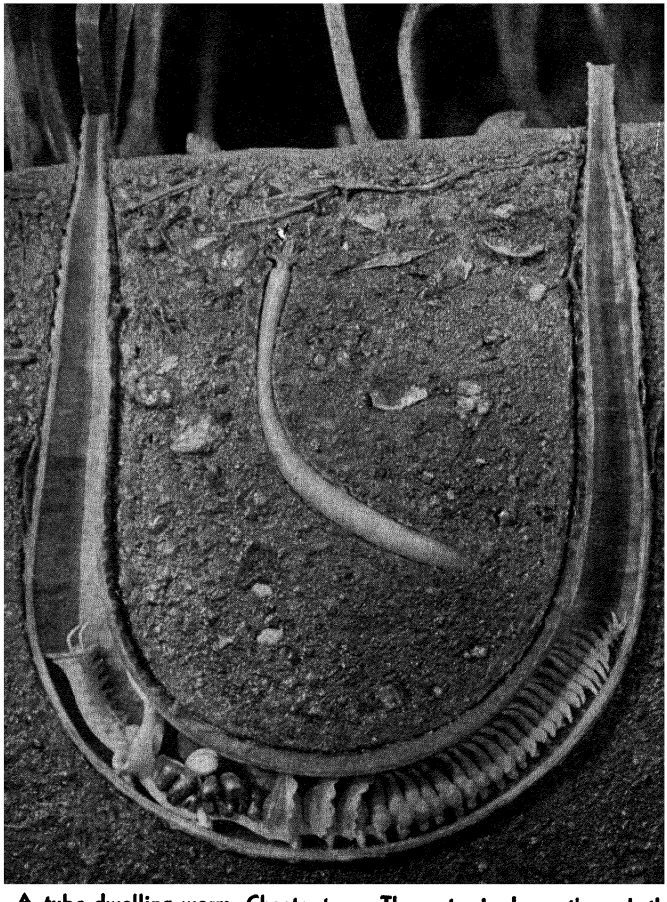

Fig. 241.—A tube-dwelling worm, Chaetopterus. The water is drawn through the tube by "flaps" or wing-like structures near the middle of the body of the worm. These move back and forth creating a current.

but are interesting. For example, the *Chaetopterus* lives in a U-shaped tube (Fig. 241) and is luminescent. Its eggs are often used for embryological studies.

5. Biological Principles and Problems Illustrated by the Annelids.—Many important biological advances over the groups studied to date are shown by the earthworms.

a. Closed System of Blood Vessels.—There is an efficient blood-transportation system, which is characteristic of higher animals.

b. Body Plan and Coelom.—The tube-within-a-tube type of body is characteristic of all higher animals. It is made possible by the appearance of a body cavity lined with mesodermic epithelium, a true coelom.

c. Metamerism.—The division of the earthworm's body into segments is an important advance. The most successful animals that live on the earth today possess bodies built on this plan; these are the annelids, the arthropods, and the vertebrates. The division of the body into segments makes it possible for certain segments to specialize in different functions. It is easy to observe this characteristic in the earthworm and in other annelids, as well as in the arthropods, such as the grasshopper, but it is not so easy to recognize in the vertebrates; yet the backbone, made up of a row of similar bones (the vertebrae), shows that segmentation exists in the vertebrates, also.

d. Trochophore Larva.—The trochophore larva of the annelids is quite similar to that of several widely different phyla. This gives a basis for study of relationships of all the groups that have this type of larva.

e. Distinct Head.—The emphasis of head development, or process of *cephalization*, is carried much further in the arthropod and vertebrate groups than it is among the annelids. For the first time, there is a distinct head (*Nereis*).

f. Nephridia.—There is a new type of excretory system, the *nephridia*.

Questions

1. In addition to the earthworm, what are some other types of annelids?
2. Why is it impossible for earthworms to live in dry places?
3. Why do earthworms come up to the surface at night? Do they ever come up in the daytime? Explain.
4. What type of symmetry is exhibited by earthworms? What is meant by a "tube within a tube" type of body?
5. Why are animals with segmented bodies "successful" in competition with other animals? What are some other groups of animals that are segmented?
6. Describe locomotion in an earthworm. Of what use are the lateral setae?
7. The earthworm usually extends only a portion of its body from its burrow when seeking food. Explain.
8. Give a running account of digestion in the earthworm. Include in this account a discussion of the organs and structures and enzymes concerned with digestion.

CHAPTER XXIII

THE ECHINODERMATA

Let the mere starfish in his vault
Crawl in a wash of weed indeed,
Rose-jacynth to the finger-tips.
—BROWNING.

I. The Echinoderm Group

(Gr. *echinos*, hedgehog; *derma*, skin)

A. General Features.—The echinoderms are called the *spiny-skinned animals*, because they are covered with an *endoskeleton*, which has imbedded in it spines of various sorts. Cuvier classified these animals with some others as the Radiata on account of their radial symmetry. It was found, however, that the radial symmetry of the coelenterates is *primary*, whereas that of the echinoderms is *secondary*, being derived from a bilateral larval condition.

Many types of animals are found in the echinoderm group, especially along the seashore, about 4,000 species.

B. Classification.

Class I. ASTEROIDEA (Gr. *aster*, star; *eidos*, resemblance). Typically free-moving, five-rayed animals with arms not sharply marked off from the disk and the body somewhat flattened. The internal visceral organs extend into the arms. An ambulacral groove is present in each arm; *starfish* (Fig. 242).

Class II. OPHIUROIDEA (Gr. *ophis*, snake; *oura*, tail; *eidos*, resemblance). The brittle stars. These are distinguished from the starfish by having the arms sharply marked off from the disk and by the absence of ambulacral grooves; *brittle stars* (Fig. 249*A*), *basket stars*.

Class III. ECHINOIDEA (Gr. *echinos*, hedgehog; *eidos*, resemblance). These animals are covered with spines and there are no free arms or rays; *sea urchin* (Fig. 249*B*), *sand dollar*.

Class IV. HOLOTHURIOIDEA (Gr. *holos*, whole; *thurios*, rushing). Animals with soft muscular bodies, the body wall having only small calcareous plates. Around the mouth are branching contractile tentacles; *sea cucumber* (Fig. 250).

Class V. CRINOIDEA (Gr. *krinos*, lily; *eidos*, resemblance). The crinoids resemble flowers. Some are fixed, some free-moving; the five arms are branched; *sea lily* (Fig. 251).

C. Representatives. 1. THE STARFISH; ASTERIAS (Gr., *asterias*, starred).—This is the best known member of the echinoderms. They are found along the seacoasts and are often seen clinging to piles or other objects in the salt water (Fig. 28).

a. External Features.—The common starfish (Fig. 242) possesses five arms or *rays*, but there are many species that have more than five.

These arms surround a *central disk*. The aboral surface is covered with *spines* of various types, and between the spines are dermal branchiae, or *papillae*. To keep these papillae free from debris, pincer-like or jaw-like structures, the *pedicellariae*, are arranged around the bases of the spines (Fig. 243*A*). There are large and small pedicellariae, which serve to protect the dermal branchiae as well as to keep the body surface free from foreign objects.

On the central disk, on the aboral side, is the opening for the water vascular system, the *madreporite*, a sieve-like structure. Near this is the *anus*, not easily seen. Two rays and that part of the disk near the madrepore form the *bivium;* the other three arms and their adjacent portions of the disk form the *trivium*.

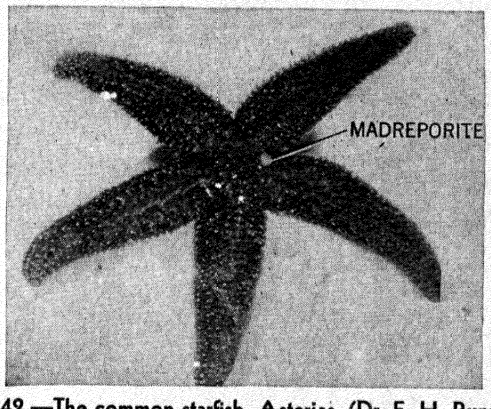

Fig. 242.—The common starfish, Asterias. (Dr. E. H. Runyon.)

b. Internal Features. (1) THE SKELETON.—The starfish has an *endoskeleton;* calcareous plates, or *ossicles*, are bound together by connective tissue and support the body. The body is capable of some movement, however, for the arms may be flexed. The two middle rows of plates are called the *ambulacral plates*, and between these plates are pores, the *ambulacral pores*, through which the tube feet project. Outer rows of plates form the margin of the groove (adambulacral plates), and five flat oral ossicles surround the mouth.

(2) COELOM.—There is a large *coelom*, extending into the arms, filled with coelomic fluid.

(3) DIGESTIVE SYSTEM AND ITS FUNCTIONS.—The mouth leads through a very short esophagus into the stomach, which has two portions. The portion that joins the esophagus, or the cardiac portion, is partially separated from the pyloric portion by a constriction (Fig. 244). In each arm there is a pair of large glandular structures, the *hepatic* or the *pyloric caeca*, each connected with the pyloric portion of the stomach by a duct

and digests its prey *in situ; i.e.*, digestive juices are poured over the mollusk and the animal digested in its own shell. The digested food is then taken into the stomach of the starfish. Retractor muscles pull the stomach back into its place after feeding is completed. The digested food is absorbed through the walls of the digestive canal into the coelom to

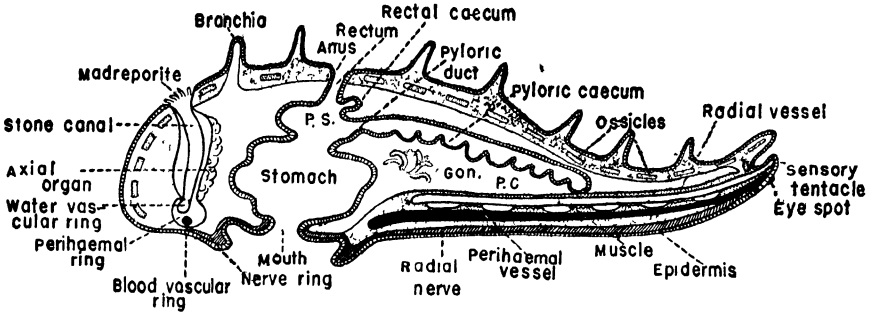

Fig. 244.—Diagram of a longitudinal section through the disk and arm of a starfish. (Gon.) Gonad. (P. C.) Perivisceral cavity. (P. S.) Pyloric sac. (F. A. Baker.)

be distributed by the coelomic fluid. The fluid in the coelom is kept in motion by the cilia. Undigested matter is ejected through the mouth.

(5) WATER VASCULAR SYSTEM.—This is a system peculiar to echinoderms (Fig. 243*B*). It consists of a madreporite, the stone canal, and a complicated system of tubes. The stone canal is connected with a ring

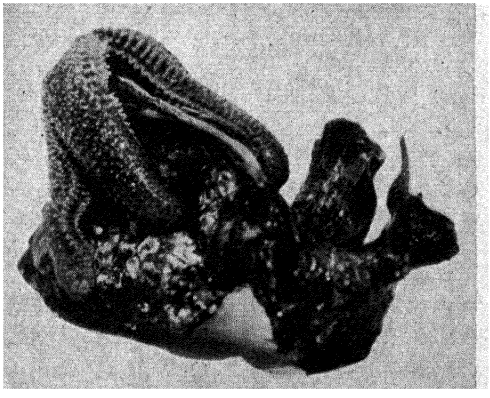

Fig. 245.—Starfish attacking an oyster. Starfish do much damage to oyster beds. They also eat mussels and other shellfish. (Courtesy of the U.S. Bureau of Fisheries.)

around the mouth and runs upward to the madreporite. Inside the *ring canal* are nine small bodies, *Tiedemann's bodies*, the stone canal joining the ring canal where the tenth might be expected. Amoeboid cells are produced in these bodies, which are of gland-like structure. Five radial canals, one in each arm, pass outward above the ambulacral grooves. From the

(Fig. 244). The functions of these glands is the production of digestive enzymes. From the pyloric portion of the stomach, a short *rectum*, or intestine, empties to the outside through the pore-like anus near the madreporite. A pair of branched pouches, the *rectal caeca*, probably have an excretory function.

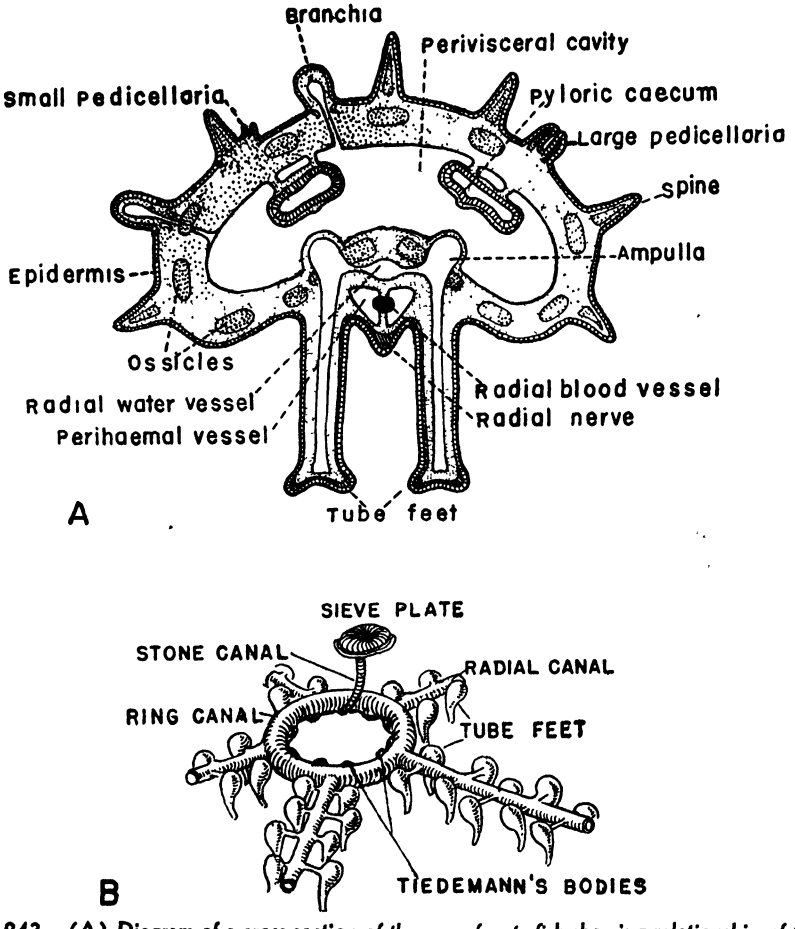

Fig. 243.—(A) Diagram of a cross section of the arm of a starfish showing relationship of the structures. (B) The water vascular system of a starfish. (F. Baker.)

(4) Food.—The starfish is very partial to shellfish. It catches its prey with its arms and then "humps over," as shown in Fig. 245. The ends of the tube feet are sucking disks. These are attached to the shells, and a steady pull is exerted until the mussel, clam, or other bivalve opens its shell. If the animal is too large to be swallowed by the starfish, it everts its stomach through its mouth, spreads it over the soft mollusk,

radial canals side branches are given off, from which arise the tube feet and ampullae. The tube feet serve several functions, which will be referred to later. Primarily, however, they are organs of locomotion.

(6) CIRCULATION.—Running parallel to the water vascular system is a series of vessels that make up the circulatory system. The coelomic fluid also serves as part of this system, since it absorbs the digested food and distributes it. In this fluid are certain cells, the *amoebocytes*,

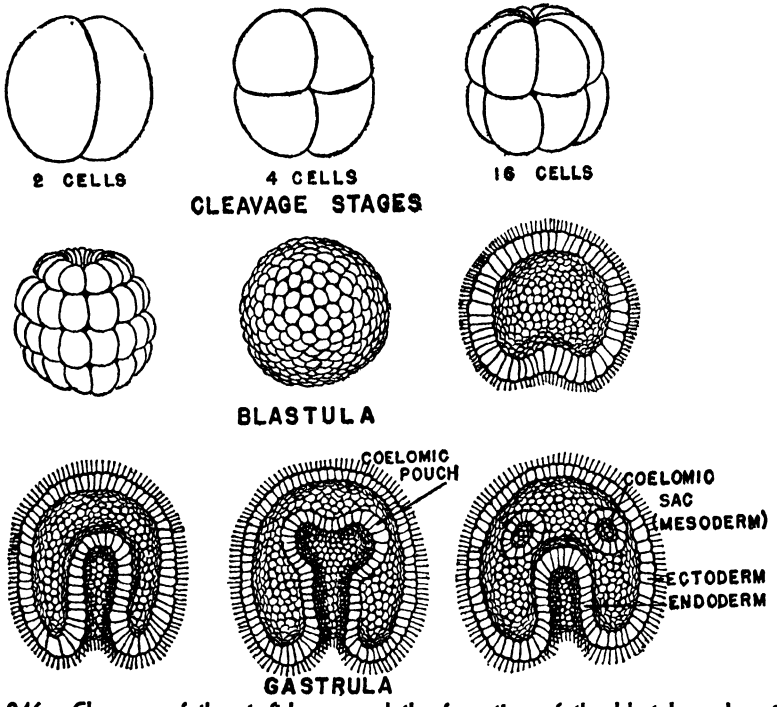

Fig. 246.—Cleavage of the starfish egg and the formation of the blastula and gastrula. (F. A. Baker.)

which have the power of picking up particles of waste material and carrying them to the *dermal branchiae*. From here they pass to the exterior.

(7) RESPIRATION.—The dermal branchiae are extensions of the coelomic wall (Fig. 243*A*). In addition to the work mentioned above, they have a respiratory function.

(8) EXCRETION.—This function is carried out in part by the *amoebocytes*. There is also a certain amount of diffusion of wastes through the walls of the tube feet and the dermal branchiae. The *rectal caeca*, mentioned above, probably have an excretory function.

(9) NERVOUS SYSTEM AND SENSE ORGANS.—Around the mouth is the oral *nerve ring*, and extending from this, a branch goes the length of

each arm, ending in a pink *eyespot.* There is also a small *anal nerve ring* from which branches extend to the nerve cells distributed in the epidermis.

The pedicellaria and tube feet are sensitive to touch, and the eyespot is sensitive to light.

(10) REPRODUCTION AND LIFE CYCLE.—The sexes are separate, there being five pairs of gonads in each animal. These lie in the cavities of the rays, a pair in each ray, beside the pyloric caeca. Pores from each pair of gonads open to the outside between the angles of the rays or arms. Eggs are produced by ovaries in the female, and sperm are produced in

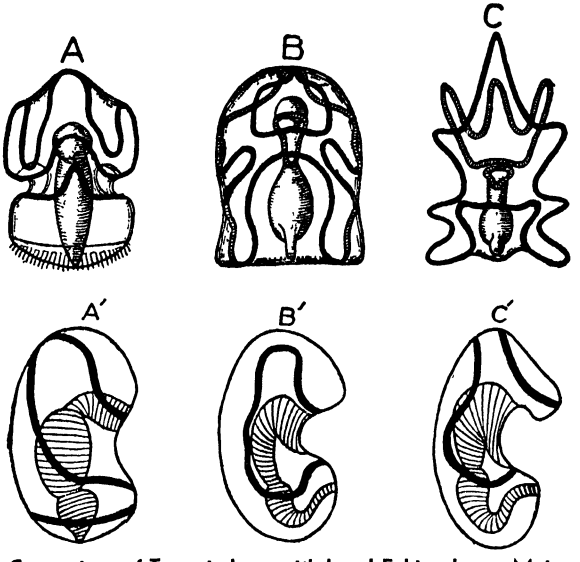

Fig. 247.—Comparison of Tornaria larva with larval Echinoderms. Main ciliated bands in black, lesser systems cross-lined. Ventral aspect: (A) Tornaria; (B) Auricularia (sea cucumber); (C) Bipinnaria (starfish). Lateral view: (A′) Tornaria; (B′) Auricularia; (C′) Bipinnaria. (After Wilder. From Lull, Organic Evolution, The Macmillan Company.)

the *testes* of the male. These are shed into the water, and fertilization of the eggs takes place there.

The starfish egg has been much studied by students in biology, since the development of the early stages is easy to follow. Total or *holoblastic cleavage* occurs, and a hollow-ball *blastula* is formed (Fig. 246). This is ciliated and swims about. After a short time, there is an infolding of the blastula to form the *gastrula,* and this develops into a ciliated swimming *larva* (Fig. 246). It is called the *bipinnaria larva* and somewhat resembles the tornaria larva of *Balanoglossus,* a lower chordate (Fig. 247).

Starfish and other echinoderm eggs are of interest in the study of biology because they may be made to develop *parthenogenetically.* Jacques Loeb, in 1900, was able to raise free-swimming larvae from

unfertilized eggs by subjecting them to various stimuli. Since that time much work has been done along this line by using various concentrations of acids, sea water, centrifuging, pricking, and the like.

Other types of experiments with starfish or other echinoderm eggs include separation of the blastomeres of a dividing (fertilized) egg. Up to about the 20-celled stage, each of these will develop into an entire animal. Not all types of eggs will develop in this manner.

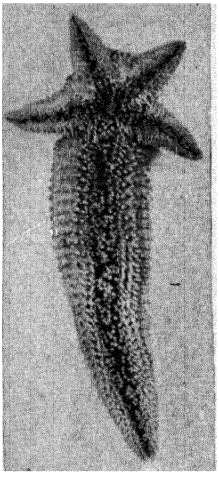

Fig. 248.—Regeneration of four starfish arms. (Dr. E. H. Runyon.)

Experiments have also been performed in crossing one species with another. This is possible in some cases. Also, nuclei of the eggs have been removed and then the eggs fertilized by sperm of another species.

Echinoderm Larvae.—The larvae of the different classes of echinoderms begin development in the same way but become distinct types. Their names are *bipinnaria* (starfish group), *ophiopluteus* (brittle-star group), *echinopluteus* (sea-urchin group), *auricularia* (sea-cucumber group), *crinoid* larva (sea-lily group).

(11) Regeneration and autotomy.—The starfish has the power of regenerating any arm that may be lost (Fig. 248). One arm with a small piece of the disk will regenerate an entire starfish if conditions are favorable. If an arm is mutilated or caught by an enemy, it may be cast off at its base where it joins the disk. This self-mutilation is called *autotomy* (Gr. *autos*, self; *tome*, cutting).

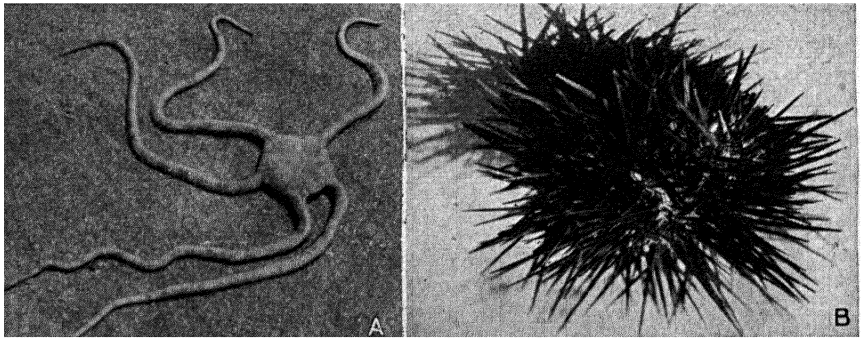

Fig. 249.—(A) "Brittle" or serpent starfish, Ophiura or Ophioderma. (Dr. R. W. Hegner.) (B) Sea urchin, Arbacia. (Courtesy of the American Museum of Natural History.)

c. Importance of Starfish.—Starfish destroy great numbers of oysters, clams, and other marine animals used as human food. Since a single starfish may eat as many as two dozen oysters in a single day, they are

very destructive to oyster beds. Before their powers of regeneration were known, they used to be "swept" up with a frayed rope "mop," then broken up and thrown back into the water, making several starfish where one grew before!

2. The Brittle Stars and Basket Stars.—These are representatives of class 2, Ophiuroidea. Since they possess long, snake-like arms, they are sometimes called "serpent stars" (Fig. 249*A*). In certain species, the long arms are branched. They can move about comparatively rapidly, can climb, and almost "run" along the sea bottom.

The feeding habits of brittle stars are very different from those of starfish. Minute organisms and decaying matter that lie on the mud of the sea bottom are scooped into the mouth by means of special tube feet; rows of spines extend over the mouth opening and serve as strainers,

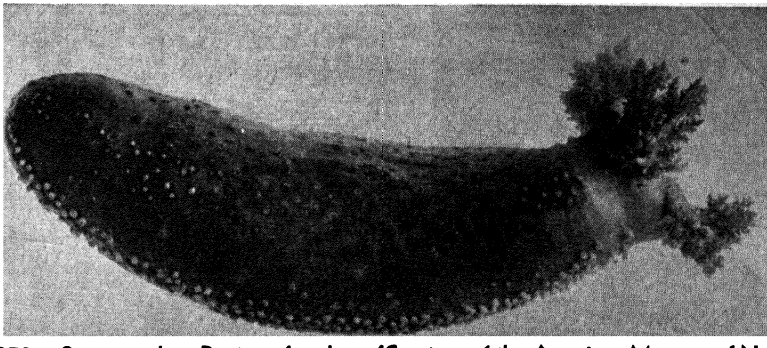

Fig. 250.—Sea cucumber, Pentacta frondosa. (Courtesy of the American Museum of Natural History.)

keeping out particles that are too large. About 2,000 species of brittle stars have been described.

Some species of basket stars are said to branch so often that the tiny end branches reach the enormous number of 80,000! These branches are useful as a means of clinging to seaweed and corals and in capturing small animals.

Arms are easily lost and regenerated; mutilated arms may be cast off (autotomy).

3. The Sea Urchins, Echinoidea.—Arbacia are often called *sea hedgehogs* because they are covered with long, sharp, movable spines (Fig. 249*B*). In certain species, these spines are poisonous. The skeleton of the common sea urchin is made up of plates fitted together so as to form a hollow ball. At mouth end are five teeth connected with a structure called *Aristotle's lantern.* This complicated structure appears to be used for grinding. Other representatives of the sea-urchin group (Echinoidea) are the heart urchin, *Echinocardium,* and the sand dollar, *Echinorachnius.*

4. The Sea Cucumbers, Holothurioidea.—The only thing about the sea cucumber that resembles a cucumber is its shape. The mouth is surrounded by branched tentacles that are contractile (Fig. 250). The body is soft and bears tube feet along its sides. Dried sea cucumbers are sold under the name of *trepang* or *bêche de mer* (worm of the sea). They are used for food in the countries of the South Pacific Ocean and in China.

The sea cucumber has a most remarkable power of regeneration. When irritated, the muscles contract to cause a split in the body wall near the anus. The viscera is then ejected there or forced through the mouth. This is a protective device, because the enemies of the sea cucumber become entangled in the swollen visceral mass. The sea cucumber can then regenerate the viscera.

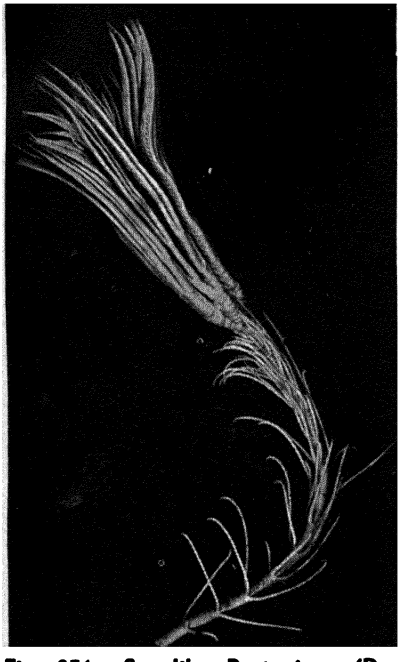

Fig. 251.—Sea lily, Pentacrinus. (Dr. E. H. Runyon.)

5. The Sea Lilies, Crinoidea. The sea lily is often referred to as a feather star (Fig. 251). This seems to be an appropriate name, since its arms (usually five in number) are much branched and featherlike. These animals are usually attached to some solid object in the sea, but sometimes they break away from their stalk and swim about for a time.

In ancient times, the crinoids were the most numerous of all echinoderms. Fossil forms are numerous, especially in Paleozoic deposits, where whole beds of limestone were formed chiefly of their remains.

II. Biological Principles and Problems Represented by the Echinoderms

A. Radial Symmetry.—All the echinoderms have bilateral symmetry as larvae. It is evident, therefore, that the radial symmetry, so characteristic of all the adults, is secondarily acquired.

B. Regeneration.—The regeneration of lost parts is possessed by the echinoderms to a high degree.

C. Artificial Parthenogenesis.—The eggs of echinoderms may be made to develop without fertilization by various methods—by use of chemicals, pricking, centrifuging, etc.

D. The Echinoderm Larva and the Larva of Balanoglossus.—The tornaria larva of *Balanoglossus*, one of the lower chordates, resembles the echinoderm larvae to a remarkable degree both in development and appearance (Fig. 247). Although nothing is really settled as to the origin of the vertebrates, the points of similarity in these larvae suggest some sort of relationship. It is only a suggestion, however, and the relationship, if any, is obscure.

Questions

1. Explain why the echinoderms are of biological rather than practical interest.
2. What are the chief characteristics of each of the five groups of echinoderms?
3. Compare radial symmetry in the coelenterates and the echinoderms.
4. Discuss regeneration in echinoderms.
5. Why is the starfish of indirect economic importance?
6. Show how the starfish egg is of importance biologically.
7. What evolutionary significance is suggested by the resemblance of the larva of the starfish and *Balanoglossus*?
8. Define: artificial parthenogenesis; autotomy; trepang.

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HEGNER, R., and HEGNER, J. Z.: "The Parade of the Animal Kingdom," The Macmillan Company, 1935.

CHAPTER XXIV

THE MOLLUSKS

The frugal Snail, with forecast of repose
Carries his house with him where'er he goes.
—CHARLES LAMB.

The *mollusks* (L. *mollis*, soft) form the second largest group of animals. Included in this very diverse array of forms are such animals as *chitons*, *clams*, *snails*, *oysters*, *whelks*, *devilfishes*, *squids*, and *Nautili*. Comparing a clam with a devilfish brings out the apparent differences of the members of the group. The body plan, however, is similar. There are about 78,000 species of mollusks.

A point of biological interest is that the larvae of some of the mollusks are of the *trochophore type*, suggesting relationship to the annelids and other animals with this type of larva.

I. The Mollusks in General

A. Habitat.—Mollusks are found on land, especially in moist places and in fresh and salt water.

B. General Features.—Many types of mollusk secrete calcareous shells, but their bodies are soft, and there is no trace of a skeleton. Depending upon the species, they have a symmetry that is bilateral (*chitons*) or asymmetrical (*oysters*, *snails*, etc.). The body is three-layered or triploblastic.

The shell is secreted by a fold of the body wall, the mantle, which also lines the shell. The shell may be single, as is the case with the snail, or bivalve, as is the case with the mussels and clams. Between the mantle and the body is a mantle cavity. The body cavity, or coelom, is secondarily obliterated. The ventral part of the body is a muscular *foot*, so called because it is often used as a means of locomotion. It may be modified, as in the snail, for creeping; for plowing in the sand, as in the clam; or, as in the squid, for capturing its prey.

C. Classification.

Class I. AMPHINEURA (Gr. *amphi*, on both sides; *neura*, nerves). Marine types having bilateral symmetry; on the dorsal side is a series of calcareous, overlapping plates (usually eight); probably the most primitive of the mollusks; *Chiton* (Fig. 256).

Class II. GASTROPODA (Gr. *gaster*, belly or stomach; *pous*, foot). Body is more or less spirally coiled; part of the digestive tract is in the muscular foot; in some species, as the

slugs, no shell; when present, it is in one piece and is usually coiled; *snails, slugs, limpets, whelks* (Figs. 257, 258*A*).

Class III. SCAPHOPODA (Gr. *skapho*, boot; *pous*, foot). Elongated marine types possessing a trilobed foot for boring into the sand; head rudimentary; the symmetry bilateral; shell tusk-shaped; tooth shell, *Dentalium* (Fig. 259). About 300 species.

Class IV. PELECYPODA (Gr. *pelekos*, hatchet; *pous*, foot) or *Lamellibranchiata* (Gr. *lamina*, thin sheet; *branchia*, gill). Aquatic, mostly marine, having gills and heads without tentacles or eyes; some spoken of as headless; shells, secreted by the mantle, have paired valves; *mussels, clams, oysters, scallops*, and *shipworms* (Figs. 252, 253).

Class V. CEPHALOPODA (Gr. *kephale*, head; *pous*, foot). All marine; eye is complex and superficially resembles the vertebrate eye; part of the foot has grown around the head and has been modified into tentacles, that are prehensile; one or two pairs of gills are present; carnivorous; used as food by man; *squids, devilfish, Octopi, Nautili* (Figs. 260, 261, 262).

II. The Fresh-water Mussel

The mussel may be used as a type form in studying mollusk characteristics. It is a member of the large and important group of Pelecypoda

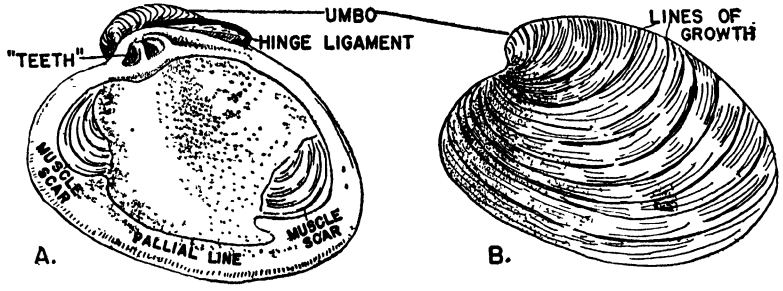


Fig. 252.—Clam shell, Venus mercenaria (salt-water form). (A) Internal view, showing anterior (left) and posterior (right), adductor muscle scars, and the pallial line where mantle was attached. (B) External view, showing lines of growth.

(see above). There are many species of fresh-water mussels, as well as the salt-water clam that it so closely resembles. The different species differ somewhat in structural details and in their life histories. The following account is somewhat generalized.

A. Habitat.—The fresh-water mussels, or clams, sometimes called *bivalves*, are usually found in the mud at the bottoms of fresh-water ponds and streams.

B. External Features.—The bodies of the fresh-water mussel and the salt-water clam are enclosed in shells that consist of two valves of symmetrical halves. They are held together by a tough ligament, the *hinge*. In some species, so-called *teeth* are present. These are irregular tooth-like projections that fit together in an interlocking manner (Fig. 252). The dome-shaped part of the shell is the *umbo*. This is the oldest part of the shell, and lines of growth center around it in concentric circles (Fig. 252*B*).

The shell has three layers, an outer horny layer, *periostracum*, which protects it from carbonic acid in the water, a middle *prismatic* layer, and an inner pearly layer, *nacreous* layer. Inside the empty shell are to be seen the markings where the anterior and posterior adductor muscles were attached. Near these are the scars showing attachment of protractor and retractor muscles while parallel to the free margin is the pallial line to which the mantle was attached.

C. Internal Structures and Their Functions. 1. THE MANTLE.—The mantle lines the two valves and encloses the body. It is a soft tissue and is continuous with the inhalent and exhalent siphons. The water

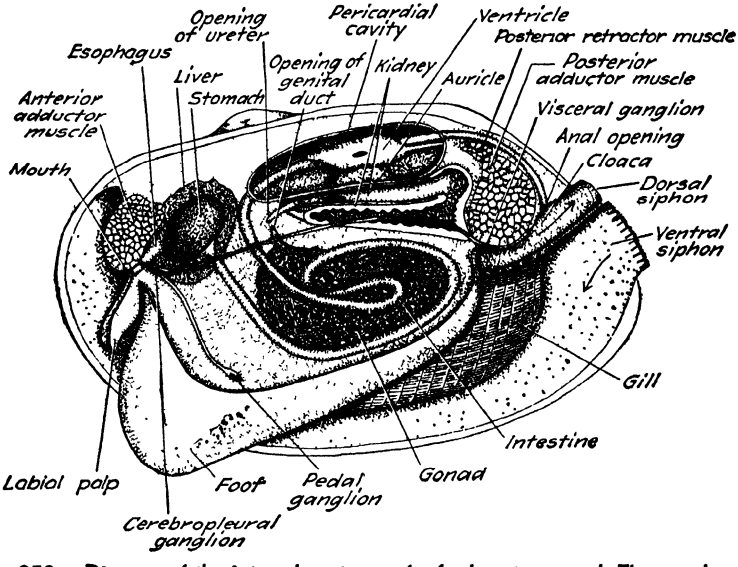


Fig. 253.—Diagram of the internal anatomy of a fresh water mussel. The mantle and the gills on the near side are not shown and the body is indicated as having had a part of the wall cut away. The stomach, liver, gonad, pericardium, and kidney are shown in section. (From Wolcott, Animal Biology.)

enters the body through the inhalent (ventral) siphon and leaves through the exhalent (dorsal) siphon (Fig. 253).

2. DIGESTION.—The food of the mussel consists of microscopic organisms. The mouth opens into the mantle cavity just under the anterior adductor muscle. On each side of it is a pair of palps. These are leaf-like organs covered with cilia, which create a current, thus directing the water containing the food into the mouth. A sense of taste is supposed to be located in the palps.

The mouth leads into a short esophagus, which, in turn, opens into the stomach. Here the food is mixed with digestive enzymes from the digestive gland that surrounds the stomach and opens into it by a duct on each side. From the stomach, the food goes into the long coiled intestine. The

crystalline style, an organ found only in *mollusks*, is in a diverticulum of the intestine. It secretes an enzyme that is concerned with the digestion of carbohydrates. After coiling around, the intestine goes through the reduced coelom, in which the heart lies, and ends in the anus near the exhalent (excurrent) canal. Waste matter passes from the intestine out of the anus and to the outside through the excurrent canal.

3. CIRCULATION.—The circulatory system is of the open type. The *heart*, lying in the pericardial cavity (coelom) is wrapped around the intestine. It has three parts—two auricles and a ventricle—and it pumps blood into the arteries. The arteries lead to blood sinuses, which are irregular canals in the tissues. The sinuses do not have the epithelial lining of the true blood vessels. Most of the returning blood is carried to the kidneys by the *vena caval* vein. After the removal of the nitrogenous wastes, the blood goes to the gills by the *afferent branchial veins*, where it is purified. It returns to the auricles through the *efferent branchial veins*. From the auricles it goes to the ventricle and is pumped out again to the arteries. The colorless blood contains several types of white corpuscles.

4. RESPIRATION.—Hanging in the mantle cavity on each side of the body is a pair of *gills* that are covered with cilia. The surfaces of the gills have many minute pores through which the water enters the complicated system of tubes making up the gills. Food and other debris are left on the surface, being removed by currents of water. The gills have a rich blood supply. Oxygen is absorbed from the water by the blood circulating in the capillaries; at the same time carbon dioxide is passed through the capillary walls into the water. The deoxygenated water leaves the mantle cavity through the exhalent siphon.

5. EXCRETION.—Just below the heart is a pair of excretory organs, one on each side. Each has two parts; the kidney proper, which is the lower part and which has glandular walls, and an upper part, a thin-walled bladder connected with an excretory pore through which wastes are discharged to the outside.

6. COORDINATION.—The nervous system consists of three pairs of ganglia and their branches. The head ganglia, or *cerebropleural* ganglia, are situated one on each side of the esophagus and are connected with each other by a *cerebral commissure*. Each of the head ganglia gives off branches to the anterior part of the animal and, in addition, two nerve cords; one of these extends posteriorly to a *visceral ganglion* situated just under the posterior adductor muscle, and the other extends ventrally to the pedal ganglion, which is situated at the junction of the visceral mass and muscular part of the foot (Fig. 253).

7. SPECIAL SENSES.—The sense organs are also poorly developed. Along the edges of the mantle and the siphons are scattered sensory cells

probably sensitive to light and touch. On each visceral ganglion is a patch of yellow epithelial cells, the *osphradium* (Gr. *osphradium*, strong scent), which is thought to be sensitive to certain chemicals in the water.

8. Reproduction and Life Cycle.—Though a few are hermaphroditic, the sexes are usually separate. The gonads surround the coils of the

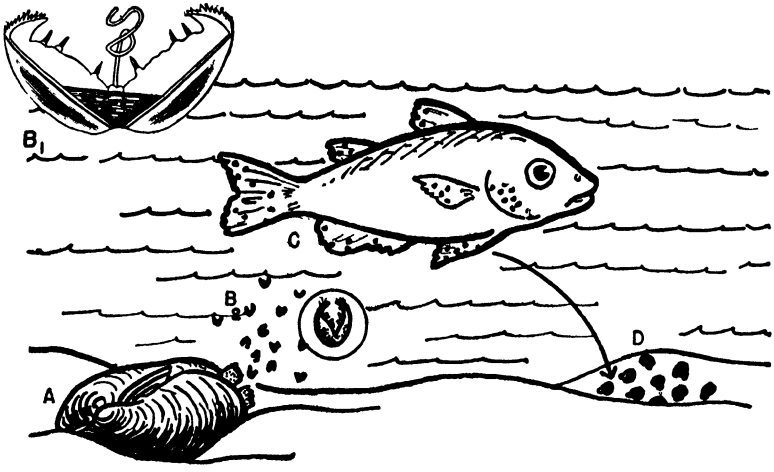


Fig. 254.—The life cycle of the fresh water mussel, Anodonta. (A) Mussel or clam. (B) Larvae of mussel, glochidia. (C) "Blackheads" on fish. (D) Young mussels. (B. Shamos.)

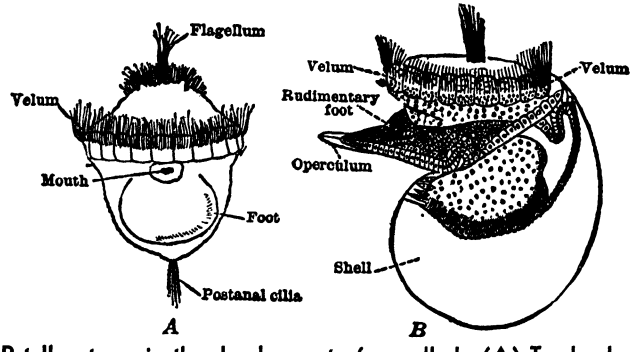


Fig. 255.—Patella, stages in the development of a mollusk. (A) Trochophore stage. (B) Veliger stage, 130 hours old. (After Patten.)

intestine, which lie in the foot. When the sperm cells from the testes of the male are mature, they are shed into the water. The eggs from the ovaries are shed into the mantle cavity and do not pass out into the water but become attached to the gills. In this position, they are constantly bathed with fresh water. The sperm are brought into the mantle cavity of the female through the inhalent siphon, reach the eggs attached to the gills, and fertilization takes place.

In some species, the eggs hatch, and the young remain attached in the mantle cavity of the female over the winter.

The young bivalved larva of the mussel is known as a *glochidium* (Gr. *glochis*, point of an arrow). Enormous numbers of glochidia develop, but the mortality is great because these larvae must find and attach themselves to the fins or gills of a fish if they are to survive (Fig. 254). Many sink to the bottom and die. Those that do become attached to the fish lead a parasitic life for a time. The tissues of the fish grow over them, and they form protuberances known as *blackheads*. The fish to which they are attached move from place to place, and in this way mussels are distributed. Eventually, the young mussel breaks away from the tissues of the fish and begins a free existence, growing gradually into an adult.

9. The Veliger Larva.—A parasitic stage is not always present in the Pelecypoda. In marine forms, fertilization takes place in the water instead of in the mantle cavity. The fertilized egg develops first into a *trochophore* larva and then into a *veliger* (L. *velum*, a veil; *gerere*, to bear). The veliger larva (Fig. 255) corresponds to the glochidium of the fresh-water form.

III. Representatives of the Mollusk Groups

A. Chitons; Amphineura.—Chitons are bilaterally symmetrical mollusks. They are sometimes called *Rock sucks*, because they stick tightly to rocks. They are able to do this because the entire lower part of the animal is a flat, muscular foot. The body is covered with a shell made up of eight overlapping plates (Fig. 256), which are capable of some movement. When detached from rocks, they "roll up" into a ball to protect themselves.

B. Snails, Whelks, Conches; Gastropoda.—The gastropod group is a very large one, including many diverse forms.

1. Snails.—Snails have spiral shells into which they can withdraw completely for protection. Land snails have part of the mantle cavity modified as a lung for breathing air. They also have slime glands near the anterior end of the body. These glands secrete a slimy substance that is deposited on the substratum and provides a smooth surface, over which they glide evenly along. This slime also protects the body from rough surfaces. Snails move slowly; hence the expression "snail's pace." Land snails usually have two pairs of tentacles, or horns, at the anterior portion of the body. At the end of each long tentacle is an eye. These tentacles are quite sensitive to touch; if one is touched, it will be drawn in like a glove. The shorter tentacles are probably organs of smell.

Snails have a peculiar organ for feeding, the *radula*. This is a chitinous band bearing numerous minute teeth on its dorsal surface. It serves to

tear up food and draw it into the mouth. Edible snails eat only tender young vegetation and are reared for the market in some countries, where they are esteemed as an article of food.

In most snails, the spiral shell winds to the right; in others, it winds to the left. The manner of coiling is a character that is definitely inherited.

2. Slugs.—Slugs are relatives of the snails that do not possess an external shell, having only a thin plate embedded in the mantle. In order

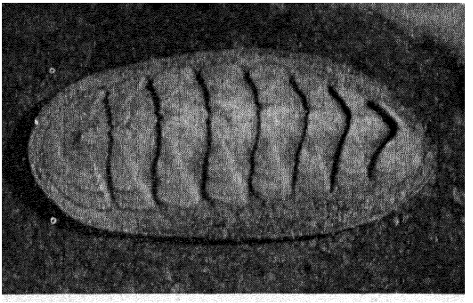


Fig. 256.—The Chiton. One of the mollusks with a shell made up of flexible plates. (Courtesy of The American Museum of Natural History.)

to keep from drying out, therefore, they must live in moist situations. The garden slug (*Limax maximus*, Fig. 257), does considerable damage. It burrows in the ground and remains inactive during the cold weather unless it finds its way to a greenhouse, where it remains all winter. Like the snails, slugs secrete slime.

3. Whelks, *Buccinum*, and Periwinkles, *Busycon*.—These members of the snail tribe live in salt water. Their favorite places are the

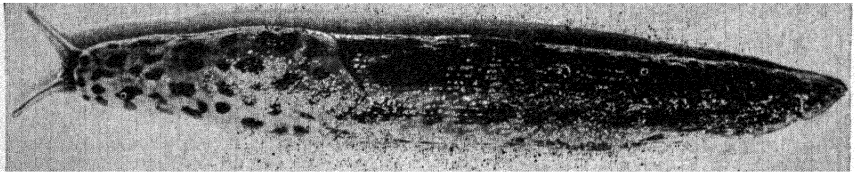


Fig. 257.—The spotted garden slug, Limax maximus. Mucus keeps the skin of this animal moist. The shell is beneath the slight hump just in front of the center of the body. (Courtesy of the U.S. Bureau of Entomology.)

crevices between rocks and just below low-tide mark. In Europe, the whelks are used for food.

4. The Oyster Drill, *Urosalpinx* (Fig. 258).—This looks like any ordinary snail, but it is able to rasp a hole in an oyster shell and suck out the soft living tissue within. It destroys large numbers of oysters.

5. The Queen Conch, *Strombus gigas*.—This animal may be a foot long and weigh 5 lb. It is used for food in some regions, but it is especially

interesting for its beautiful shell. The shell has an expanded lip and is lined with a delicate pink; it is much used for ornamental purposes.

6. The Ear Shell, *Abalone.*—The shell of this animal is one of the most beautiful of the snail group, the inner surface being iridescent, pearly, and lustrous. The row of holes in the outer shell is for the out-

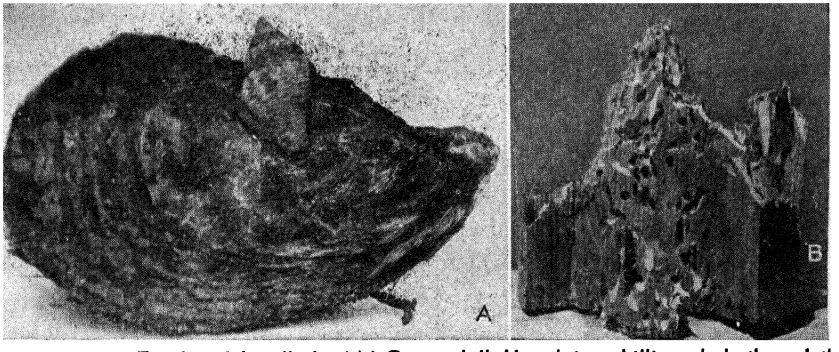


Fig. 258.—Two harmful mollusks. (A) Oyster drill, Urosalpinx, drilling a hole through the shell of a living oyster. In spite of the small size of "the drill" the oyster cannot protect itself against this animal. (Courtesy of The American Museum of Natural History.) (B) Work of the ship worm, Teredo navalis. These mollusks do much damage every year to ships' timbers, wharf pilings, etc. (Dr. R. W. Hegner.)

going current of water. The animals are used for food and the shells for making ornaments, buckles, buttons, etc.

7. The Limpet.—The limpet does not have the spiral shell so often found in *gastropod* animals. The shell is a high-arched disk that covers the animal. The limpet digs a shallow hole the size of the shell and clings

Fig. 259.—Tooth or elephant tusk shells, Dentalium. (Dr. R. W. Hegner.)

to the substratum so tightly that considerable force is required to dislodge it.

C. Tooth Shells, Scaphopoda.—The bodies of the *tooth shells* are enclosed in a tubular shell open at both ends (Fig. 259). On account of the resemblance of these organisms to elephant tusks, they are sometimes called *tusk shells.* Dentalia have digging organs and burrow in the sand.

D. Oysters, Scallops, Etc., Pelecypoda.—This large group is important economically. The features of this class are well shown by the freshwater mussel described above. It remains to mention only a few of the more important types to be found in the groups.

1. THE OYSTER, *Ostrea* (Fig. 258).—Since piles of oyster shells are found in the "kitchen middens" of ancient man, it is to be concluded that the oyster was used as food before the dawn of history. Kitchen middens are refuse heaps marking the site of primitive human habitations.

> The man had sure a palate cover'd o'er
> With brass or steel, that on the rocky shore
> First broke the oozy oyster's pearly coat,
> And risk'd the living morsel down his throat.
> —GAY.

Many species of oysters have been described; they range in size up to 3 ft. in diameter. The largest species lives in Japan. All oysters are attached to some solid object when they are adults. They are free-swimming for a few days, however, after they hatch from the fertilized egg. A single female oyster may lay as many as 60 million eggs in one season, but since there are many enemies, only a few oysters finally become adult. The young oysters are called *spat*. *Pearls* are sometimes found in our clams and oysters, but the best pearls occur in the pearl oysters of tropical seas (see below).

2. THE SCALLOP, *Pecten*.—Scallops are interesting on account of their method of locomotion. They do not plow along the bottom, as the clam does, but "clap" the two sides of the shell together and "swim." The *beaming scallop* has a row of deep blue, tiny eyes around the edge of its mantle and is very beautiful. The large muscle that closes the scallop's shell is used for food. All the rest of the body is thrown away. It is just the opposite with the oyster; the muscle is thrown away, and the rest of the body is eaten.

3. THE SHIPWORM, *Teredo navalis*.—The shipworms have been called *animated augers*, because with their rasping organ they are able to bore their way into wood. Figure 258*B* shows an example of this work. The wood is not used for food but only as a place to "dig in" for protection. These worms do much damage to ships and cause the loss of millions of dollars annually.

E. Squids, Devilfish, Nautili; Cephalopoda.—These are the most highly organized of the mollusks. They are all marine. Representative cephalopods are the devilfish, squids, cuttlefish, etc.

1. THE SQUID, *Loligo* (Fig. 260).—Squids are sometimes called *sea arrows* on account of the way they dart around in the water. They are among the most highly developed of the invertebrates. Eight of their

10 arms are provided with two rows of sucking disks and the other 2, with four rows. The animals are capable of changing color so that they harmonize somewhat with the background. A thin, horny plate, "the pen" (Fig. 260*B*), lies buried under the mantle, constituting the shell of the squid. Within the body is a sac filled with a fluid resembling ink. When the squid is attacked, it discharges the contents of the sac into the water, making it cloudy, and behind this "smoke screen" makes its escape. Squids are used for food by man in many countries. The animals of the sea, especially whales, eat them in great quantities. The largest invertebrate is the *giant squid*, which may attain a length of 50 ft.

2. The Cuttlefish, *Sepia*.—A close relative of the Squid is the Cuttlefish which has a shell of calcareous plate embedded in its fleshy

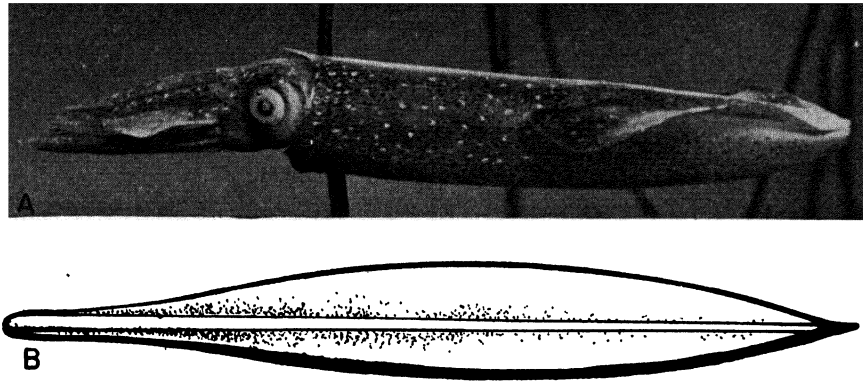


Fig. 260.—(A) The squid or "sea arrow," Loligo pealii. (Courtesy of The American Museum of Natural History.) (B) "Pen" of a squid. (B. Shamos.)

mantle. This is the cuttlebone given to caged birds as a source of lime salts. The contents of its ink sac, a rich brown pigment called sepia, is used by artists.

3. The Devilfish, *Octopus* (Fig. 261).—Devilfish, or *Octopi*, live in warm waters, concealing themselves in dark caves and crevices in coral reefs. There are eight sucker-bearing arms, which attack passing prey, crabs, and other animals. The shells of these food animals are broken open by the horny jaws and the radula of the devilfish. Digestive juices are poured into the wounds. After the tissues are digested, they are then sucked up. The devilfish has a head and well-developed eyes.

Many of the tales of the ferocity of the octopus are probably very much exaggerated. Most of them are too small to do harm to an animal the size of man, but a giant form that lives in the Pacific Ocean reaches a diameter of 28 ft. and is really dangerous. The octopus is esteemed as food in some countries.

4. The Chambered or Pearly Nautilus (Fig. 262).—This animal gets its name from the character of its beautiful shell, which is divided into compartments. The animal occupies the last chamber that it has

Fig. 261.—Devilfish, Octopus. Like the squid, the devilfish has long arms with suckers. (Dr. R. W. Hegner.)

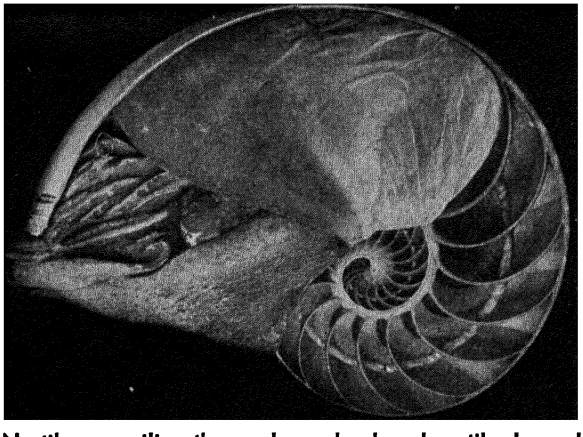


Fig. 262.—Nautilus pompilius, the pearly or chambered nautilus has a shell coiled in a flat spiral and many chambers formed by curved septa. It is found in the Pacific and Indian Oceans and is edible. (Courtesy of The American Museum of Natural History.)

built, protruding its arms to catch its prey—crabs and other animals. When it outgrows its quarters, it builds a new and larger compartment and lines it with mother-of-pearl. Oliver Wendell Holmes has immortalized this animal in a beautiful poem:

Year after year beheld the silent toil
That spread his lustrous coil!
Still, as the spiral grew,
He left the past year's dwelling for the new,
Stole with soft step its shining archway through,
Built up its idle door,
Stretched in his last found home, and knew the
Old no more.

IV. The Importance of Mollusks

A few of the mollusks are injurious; the slugs injure the vegetation in gardens and greenhouses, and the ship worms do great damage to ships, wharf piles, etc. In addition, a certain fresh-water snail is the inter-

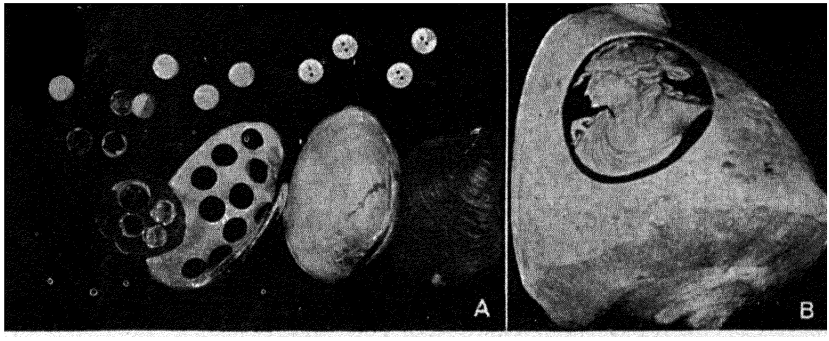


Fig. 263.—Some products from mollusks. (A) Buttons, cut from mussel shells by machinery. (B) Cameos are cut from some varieties of mollusk shells. (Dr. E. H. Runyon.)

mediate host for the destructive liver fluke, *Fasciola hepatica*. The majority of the mollusks, however, are beneficial to man. Many of them are scavengers and help keep the water in which they live pure.

Probably the most important form from the standpoint of use for food is the oyster. In addition to the natural sources, oyster beds are planted in the Chesapeake Bay and other salt waters. The oyster industry is an important one, about 30 million bu. being gathered and sold for food yearly in the United States. Other mollusks much esteemed as food are the mussels, scallops, little-neck and other clams. In some parts of the world, snails are in demand as food, being grown for the market. Also, abalones and squids are used for food on our western coasts and in other countries.

Pearl buttons are made from many types of mollusk shells (Fig. 263*A*), about 50,000,000 tons of the shells being used in the United States each year.

Pearls occur in the common oyster, and also in clams, but the best pearls are found in the pearl oysters of northwestern Australia, Japan,

India, and Ceylon. Pearls are formed as a result of injury. A small irritating particle such as a grain of sand or a larval stage of a parasite gets next to the mantle, and a pearly substance is secreted by the mantle around the particle. Many layers of the substance are laid down by the mantle, and in time a pearl results. When pearls are discolored, an expert can peel off the dull scratched layer.

Pearls may be of many shapes, the most valuable being round. They may also be of many colors, white, pink, blue, yellow, black, etc. The Japanese have learned to cultivate pearls by introducing appropriate particles between the shells of pearl oysters.

Certain types of cameos are carved on the shells of some mollusks (Fig. 263*B*).

V. Biological Principles and Problems Illustrated by the Mollusca

A. The Trochophore Larva.—The molluscan larva resembles the annelid larva, being of the trochophore type. This suggests relationship between the two groups.

B. Parasitism.—The glochidia lead a parasitic life for a time.

C. Right and Left Spiraling.—This feature is definitely inherited and is evident very early in the development of the young larva.

Questions

1. The mollusks form a large group of diverse forms; what characteristics do all of them possess?
2. Describe the shell of a clam. How is it kept closed? How is it formed?
3. Describe the contents of the mantle cavity.
4. Are there any peculiarities with regard to the relationship of the digestive system of the clam and the heart?
5. How are the inhalent and exhalent canals used?
6. Compare the life history of a fresh-water mussel and that of a salt-water clam.
7. What type of larva is characteristic of some mollusks? What other groups have this type of larva?
8. Describe the gills of a clam.
9. What type of excretory organs has the clam?
10. Is the nervous system of the clam as highly organized as that of the earthworm? Explain.
11. Discuss the sense organs of the clam.
12. What mollusks are very important as food?
13. How are pearls formed? Where do we get pearl buttons?
14. How is it possible for the *Teredo* to damage wood?
15. Where is the skeleton of a slug found?
16. What external features of the chambered nautilus resemble those of the devilfish?
17. Define: crystalline style, radula, veliger, glochidium.

Suggested References

Buchsbaum, R.: "Animals without Backbones," Chap. 18, University of Chicago Press, 1938.

Hegner, R. W.: "Invertebrate Zoology," Chap. IX, The Macmillan Company, 1933.

CHAPTER XXV

THE ARTHROPODA

Framed in the prodigality of Nature . . .
—SHAKESPEARE.

I. The Arthropods in General

The largest known group of animals are the arthropods. In this group are found widely different forms, such as crayfish, lobsters, crabs, water fleas, barnacles, millipedes, centipedes, insects, scorpions, king crabs, and spiders. In spite of the great variety of forms, these animals have many features in common. They are *bilaterally symmetrical, segmented* animals with *jointed appendages*, which are usually paired. There is a definite relation of body segments to appendages, as will be shown later. In addition, all the members of this group have a *chitinous* (Gr. *chiton*, covering) covering or *exoskeleton*, which is thin and flexible where joints occur and is usually folded to allow movement. If the animal is to grow, this exoskeleton must be shed periodically by a process of moulting or *ecdysis* (Gr. *ek*, out; *dyein*, to come). In typical arthropods the body is divided into three regions, the *head*, the *thorax*, and the *abdomen*. The nervous system is of the annelid type, and the circulatory system is of the open type, there being sinuses or spaces filled with blood in some parts of the body instead of a continuous circuit of blood vessels, as found in the earthworm (closed type). The coelom is reduced, being represented only by the cavities in the gonads, and the body cavity is a *haemocoele* (Gr. *haima*, blood; *koilos*, hollow) filled with blood. There are about 695,050 arthropods.

II. Classification

With the omission of sections and divisions, the following classes are found in the Arthropoda (Gr. *arthron*, joint; *pous*, foot):

Class I. CRUSTACEA (L. *crusta*, a hard shell). Mostly aquatic; a few parasitic; *lobsters, crabs, crayfish* (Fig. 264). (For subclasses, see p. 386.)

Class II. ONYCHOPHORA (Gr. *onychos*, claw; *phoros*, bearing). One genus; *Peripatus* (Fig. 274).

Class III.[1] CHILOPODA (Gr. *cheilos*, lip; *pous*, foot). Flattened body; segments except head and tail bear one pair of legs; *centipedes* (Fig. 275*A*).

Class IV.[1] DIPLOPODA (Gr. *diploos*, two; *pous*, foot). Segments except head and tail bear two pairs of legs; *millipedes* (Fig. 275*B*).

[1] *Centipedes* and *millipedes* are often classed together in class Myriapoda (Gr. *myrios*, ten thousand; *pous*, foot).

Class V. INSECTA (L. *insectum*, insect) or *Hexapoda* (Gr. *hex* six; *pous*, foot). The *insects* (Figs. 289–291). For orders of insects, see pages 412 to 419.

Class VI. ARACHNOIDEA (Gr. *arachne*, spider). *Spiders*, (Figs. 295, 296) *scorpions* (Figs. 294), *horseshoe crabs*, (Fig. 292) *ticks*, (Fig. 297) *harvestmen* (Fig. 295). For subclasses and orders, see p. 421.

Class VII. TRILOBITA (Gr. *tri*, three; *lobos*, lobes). Extinct Arthropoda that were plentiful during the Cambrian era (Fig. 293).

III. The Crayfish

Either the lobster or the crayfish is an excellent type of crustacean to study in the laboratory. The lobster is large, and its parts are easy to see, but it is somewhat expensive. For this reason, and because it is easy to get, the crayfish or *crawfish* is more commonly used. Other names for the crayfish are *crawdad* and *fresh-water lobster*.

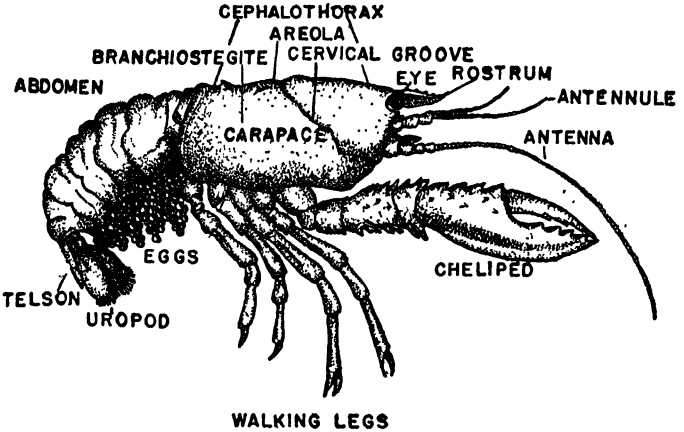


Fig. 264.—Female crayfish, Cambarus virilis, showing external features. (L. Runyon.)

A. Habitat.—The genus *Cambarus* is widely distributed in fresh-water ponds and streams. A larger type, *Astacus*, is found on the Pacific coast and in Europe. Crayfish often build air tunnels down to their horizontal burrows. They may often be found at the mouths of their burrows, with "feelers" or antennae waving on the outside.

B. External Features.—The external features of the crayfish fall naturally into (1) body features and (2) appendages (Fig. 264).

1. BODY FEATURES.—The body of the crayfish is divided into three divisions; the *head*, *thorax*, and *abdomen*. Two of these are fused together into the *cephalothorax* (Gr. *kephale*, head; *thorax*, chest). This includes the first 13 segments of the body. The line where the two have fused is visible and is known as the *cervical groove*. The part of the exoskeleton which covers the head-thorax is the *carapace*. This projects into a sharp point in front, the *rostrum* (L. *rostrum*, a beak); the lateral portions cover the gills and are free at the edges. The areas over the gills are the

branchial areas or *branchiostegites* (Gr. *branchia*, gills; *stegein*, to cover). The entire body is segmented, but the 13 segments are not visible on the dorsal part of the head thorax.

There are 6 ring-like segments in the abdomen, making a total of 19 in the body. Each segment consists of an arched or convex *tergum*, a thin, overhanging plate, the *pleuron*, and a flattened, ventral *sternum*.

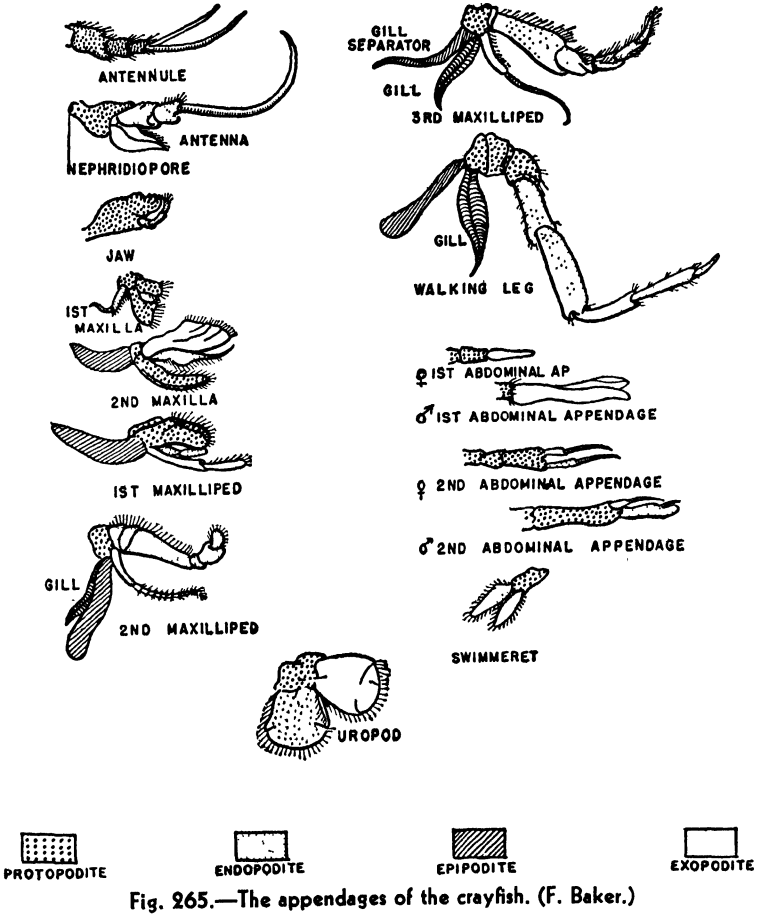


Fig. 265.—The appendages of the crayfish. (F. Baker.)

Between the segments of the abdomen are membranes that allow movement between them.

2. The Appendages.—The crayfish has 19 pairs of appendages, 1 pair for each segment. These are quite different in structure in different regions of the body, yet they are all developed from one plan, the *biramous* (L. *bis*, twice; *ramus*, branch) type. In early development, the appendages are similar, but some become modified for special usage.

The fundamental parts of an appendage are (1) the *protopodite*, composed of a *coxopodite*, which attaches the appendage to the body, and a *basipodite*, a branch of the protopodite, the *epipodite*, often extending into the gill chamber, may be present (page 884), (2) an *exopodite*, the lateral branch, and (3) and *endopodite* or median branch (Fig 265) Some of these parts are absent in various appendages, as the following table will show The most highly modified appendages are on the anterior part of the body, and the simplest are on the abdomen

a The Appendages of the Head —The *antennules* and the *antenna* are sensory organs, they wave continually back and forth in the water Around the mouth, the appendages have become modified as feeding organs These include one pair of *mandibles* and two pairs of *maxillae*

b Appendages of the Thorax —The thoracic appendages are three pairs of maxillipeds (Gr *maxilla*, jaw, L *pes*, foot) and five pairs of walking legs The legs with large claws, or chelipeds (Gr *chele*, claw, L *pes*, foot), are used in offense and defence and for capturing food The walking legs are *uniramous* (L *unus*, one, *ramus*, branch) because of the reduction of the exopodite In the female, the opening for the oviducts is at the base of the third pair of walking legs, and in the male the opening for the sperm ducts is at the base of the fifth pair of walking legs

c Appendages of the Abdomen —Each of the segments of the abdomen bears a pair of appendages called *swimmerets* or *pleopods* In the male, the first two pairs are modified as copulatory organs by which the sperm are transferred to the *seminal* receptacle of the female The opening for this vesicle in the female is between the fifth pair of walking legs The tail consists of paddle-like *uropods* (Gr *oura*, tail) and the *telson*, which serves as a powerful tail fin by means of which animals can swim backward in the water The anus is on the ventral surface of the telson

For easy reference, a summary of the appendages, (Fig 265), and their location and uses are tabulated on pages 377–379

C The Internal Anatomy and Physiology. 1 DIGESTION —The digestive system differs in some respects from that of the earthworm The mouth opens into a short esophagus, which leads to the stomach The stomach is divided into two divisions, an anterior *cardiac* division and a posterior *pyloric* (Gr *pylorus*, a gate) division by a *gastric mill* (Fig 266) This mill contains three ossicles or "teeth," whose function it is to complete the tearing up or grinding up of food that is begun by the appendages of the mouth. Between the two divisions of the stomach are a number of bristles that form a *strainer* On either side of the upper intestine, or midgut, a duct enters from a pair of *digestive glands* (hepato-pancreas) or "liver" These digestive glands secrete digestive enzymes. Sometimes two small bodies, the *gastroliths*, are found above the stomach. These probably serve as storage for lime. The intestine is a small

THE APPENDAGES OF THE CRAYFISH, THEIR STRUCTURE AND USE

I. Appendages of the Head

Appendage	Protopodite	Exopodite	Endopodite	Function of appendage
I. Antennule	3 segments; statocyst for equilibrium in basal segment	Filamentous; many-jointed	Filamentous: many-jointed	Tactile, taste, or smell; equilibrium
II. Antenna	2 segments; excretory pore in basal segment	Broad, thin	Filamentous, long, many jointed	Tactile, taste, or smell
III. Mandible	2 segments; heavy chitinized jaw and basal segment of palp	Absent	2 distal segments	Crushing food
IV. First maxilla	2 thin plates or lamellae extending inwardly	Absent	1 small outer plate	Taste
V. Second maxilla	2 bilobed plates or lamellae extending inwardly; a broad plate, the epipodite	Dorsal plate, the scaphognathite or *bailer*	1 small pointed segment	Taste; creates current of water in gill chamber
II. Appendages of the Thorax				
VI. First maxilliped	2 thin segments extending inwardly; 1 broad plate, the epipodite, extending outwardly	1 long basal segment with many-jointed filament	2 small segments	Taste and tactile senses; hold food

THE APPENDAGES OF THE CRAYFISH, THEIR STRUCTURE AND USE.—(*Continued*)

Appendage	Protopodite	Exopodite	Endopodite	Function of appendage
VII. Second maxilliped	2 segments, basal segment (coxopodite), bearing gill; distal segment (basipodite), bearing expodite and endopodite	Similar to VI	5 segments, the basal one long and fused with the basipodite	Taste and tactile senses; hold food; pass food forward
VIII. Third maxilliped	Similar to VII	Similar to VI	Similar to VII but larger	Similar to VII
IX. Pincer or cheliped; first walking leg	Similar to VII	Absent	5 segments, the terminal two forming a powerful pincer	Defense and offense; hold food; walking; tactile; clean body
X. Second walking leg	Similar to IX	Absent	As in IX but not so large	Walking; attachment of prehension; cleaning body
XI. Third walking leg	Similar to IX; in female, coxopodite contains genital pore	Absent	Similar to X	Similar to X
XII. Fourth walking leg	Similar to IX	Absent	Similar to X but no pincer at end	Walking
XIII. Fifth walking leg	Similar to IX; coxopodite of males bear genital pore	Absent	Similar to XII	Walking; cleaning abdomen and eggs

THE APPENDAGES OF THE CRAYFISH, THEIR STRUCTURE AND USE.—(*Continued*)

III. Appendages of the Abdomen

Appendage	Protopodite	Exopodite	Endopodite	Function of appendage
XIV. First swimmeret of the *male*	Fused with endopodite to transfer sperm to the female	Fused with protopodite	Unsegmented	Transfer of sperm to seminal receptacle of the female
XIV. First swimmeret of the *female*	Reduced	Reduced	Reduced	
XV. Second swimmeret of the *male*	2 segments	1 segment, elongated	Longer and heavier than expodite	Modified to transfer sperm to the seminal receptacle of the female
XV. Second swimmeret of the *female*	2 segments	Many-jointed filament	Many-jointed filament	Attachment of eggs and young
XVI. Third swimmeret (or pleopod)	2 segments	Many-jointed filament	Many-jointed filament	In female, attachment of eggs and young; create currents of water
XVII. Fourth swimmeret (or pleopod)	2 segments	Many-jointed filament	Many-jointed filament	Create water currents; in female, attachment of eggs and young
XVIII. Fifth swimmeret (or pleopod)	2 segments	Many-jointed filament	Many-jointed filament	Create water currents; in female, attachment of eggs and young
XIX. Sixth swimmeret (or uropod)	1 short, broad segment	Flat, oval plate divided by transverse groove into 2 parts	Flat, oval plate	Swimming

tube extending backward from the stomach, near the body wall, to the anus, which opens on the ventral surface of the telson. Except the short mid-gut, the alimentary canal is lined with chitin which is shed with each molt.

The crayfish feeds at night and eats all kinds of small living animals, as well as dead organic material. Sometimes they turn cannibal and eat each other. The mouth appendages, the *maxillae* and the *maxillipeds*, hold the food while it is being crushed by the *mandibles*. It then enters the cardiac portion of the stomach, is ground by the "gastric mill," and strained into the pyloric portion of the stomach. From here it passes into the midgut, and some of the finer particles may enter the digestive glands. Digestion and absorption may take place in the midgut or the digestive glands.

The digested food is distributed by the circulatory system, and the undigested residue leaves the intestine by way of the anus as feces.

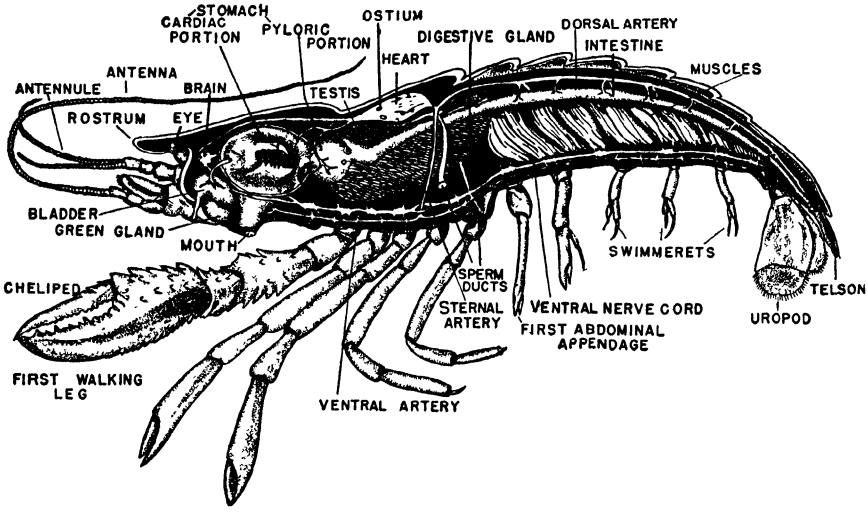


Fig. 266.—The dissection of the male crayfish, lateral view. (L. Runyon.)

2. CIRCULATION. *a. The Blood and Blood Vessels.*—The blood of the crayfish is colorless and has suspended in it colorless cells or corpuscles. After standing, the blood becomes somewhat blue. The *haemocyanin* (Gr. *haima*, blood; *kyanos*, dark blue), which absorbs oxygen, is in the plasma. The heart is a pump and is saddle-shaped. There are three pairs of slit-like openings, or *ostia*, through which the blood is drawn into the heart (Fig. 267). Each of the ostia is guarded on the inside by a valve that prevents the backflow of blood. The blood leaves the heart through the arteries. In various parts of the body are open spaces or sinuses in which the venous blood collects, thus replacing the veins. The main arteries are the single anterior median or *ophthalmic artery*,

supplying the cardiac portion of the stomach, the esophagus, and head; paired *antennary arteries*, which send branches to the cardiac part of the stomach, excretory organs, muscles, and other tissues in the head; and the paired *hepatic arteries*, which lead to the salivary glands. From the posterior tip of the heart arises a large dorsal artery that supplies the intestines and the muscles of the body wall. The *sternal artery* arises from the dorsal artery after it leaves the heart; it passes ventrally through the nerve cord and divides into two arteries, the ventral abdominal artery, which runs beneath the nerve chain and sends branches to the ventral abdominal region and abdominal appendages, and the anterior ventral thoracic artery, which runs forward beneath the nerve chain and sends branches to the ventral thoracic region and to appendages 3 to 13. The relationship of these arteries is shown in Fig. 267. The main sinuses are the *pericardial* sinus, which surrounds the heart and from which the blood passes into the heart; the *sternal sinus*,

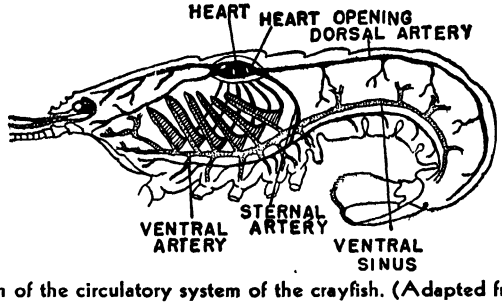


Fig. 267.—Diagram of the circulatory system of the crayfish. (Adapted from Gegenbaur by L. Runyon.)

located beneath the thorax, from which several branches lead to the gills; and the *perivisceral* sinus, which surrounds the alimentary canal in the cephalothorax. On account of the sinuses, the circulatory system of the crayfish is spoken of as an "open type."

b. Path of the Blood.—The rhythmical contractions of the heart force the blood through the arteries to all parts of the body. Valves are present in each artery where it leaves the heart, and these prevent the blood from flowing back. Through the smaller divisions of the arteries, the capillaries, the blood reaches the sinuses. These all communicate with the sternal (ventral) sinus. From the sternal sinus, the blood passes into paired lateral sinuses by way of five pairs of small canals, and from the lateral sinuses it goes into the sinuses of the gills, the afferent branchial vessels, thence to the efferent branchial vessels at the top of the gill filaments. These communicate with six pairs of branchiocardiac canals, which lead dorsally to the pericardial sinus surrounding the heart. In its passage through the gills, the blood has lost its CO_2 and has gained oxygen, so that the blood from the pericardial sinus, which is now drawn

through the slit-like openings, the *ostia* (page 380), of the heart is oxygenated. From the heart, it goes through the arteries to every part of the body.

c. Functions of the Circulatory System.—The primary functions of the circulatory system are the transportation of absorbed food, oxygen, and other materials to the tissues; transfer of carbon dioxide from the tissues to the gills; and wastes from the tissues to the excretory organs.

3. RESPIRATION.—Under the branchial areas referred to above are the paired feathery gills in the branchial chamber or gill cavities. There are three types of gills: (1) those attached to the sides of the thorax, the *pleurobranchiae;*[1] (2) those arising from the epipodites of the thoracic appendages, the *podobranchiae;* and (3) those that arise from the coxopodites of the thoracic appendages, the *arthrobranchiae.* Several of the segments have lost the pleurobranchiae.

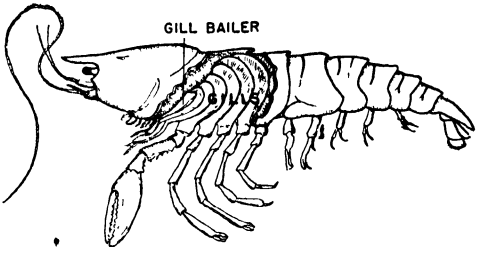


Fig. 268.—Gills of the crayfish. Part of the carapace, or gill cover, has been removed. (B. F. Edwards.)

Movement of the water over the gills is brought about by action of the *scaphognathite* or bailer of the second maxilla (Fig. 268). It moves back and forth in such a manner that the water is drawn in under the free edges of the branchiostegite, passed over the gills, and then passed out the anterior opening or aperture of the gill chamber. As the water passes over the gills, the carbonic acid in solution in the blood is given up, and oxygen dissolved in the water is absorbed.

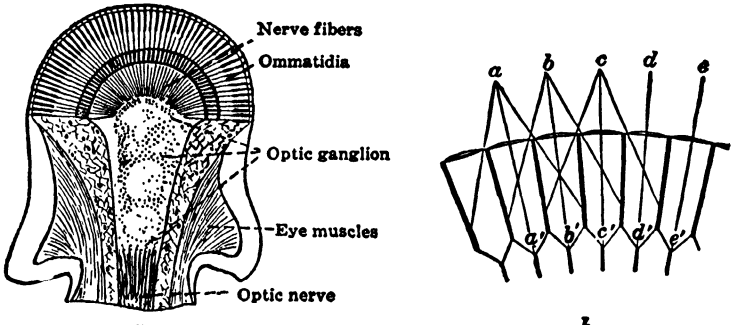
4. EXCRETION.—Interior to the esophagus in the ventral part of the head is a pair of *green glands* somewhat like nephridia. Each of these has a glandular portion which is green and a dilated, thin-walled portion, the bladder (Fig. 266). From each of these glands a duct leads to a pore in the coxopodite of the antennae. The glands are richly supplied with blood and absorb the nitrogenous wastes and excess water from that medium. Wastes are delivered to the outside through the excretory pores.

5. COORDINATION.—The nervous system of the crayfish resembles that of the earthworm but is more complex (Fig. 266). The two longitudinal cords are so intimately fused that it is difficult to see the two

[1] Not present in Cambarus.

strands. The "brain," or *supraesophageal ganglion*, is located in the anterior part of the head. It is made up by the fusion of ganglia in the first three segments and is joined to the *subesophageal ganglion* of the *ventral nerve cord* by two *circumesophageal connectives* or commissures, one passing on each side of the esophagus. The subesophageal ganglion is made up of fused ganglia from segments 3 to 7. From this are given off nerves to the eyes, antennae, and antennules. Each segment posterior to segment 7 contains a ganglionic mass that sends nerves to the surrounding tissues.

6. Special Senses.—The crayfish is said to have a limited power of learning.



a b

Fig. 269.—(a) Eye of crayfish in longitudinal section. (b) Diagram of a part of a compound eye showing how rays of light are absorbed by the pigment surrounding the ommatidia and only those that pass through the center such as (a-a), (b-b), etc., reach the nerve fibers. (a) after Borradaile and Potts; (b) after Lubbock. (From Hegner, College Zoology, The Macmillan Company.)

a. Vision.—The eyes are on movable stalks, one on each side of the head. They are of the compound type, each eye being composed of a large number (about 2,500) of individual units called *ommatidia* (Gr. *omma*, eye). The convex surface of the eye is covered by a transparent cuticle, the cornea, and this is made up of four-sided facets, one facet for each of the visual rods or ommatidia. The ommatidia are side by side but are separated from each other by pigment cells. Their complex structure is shown in Fig. 269.

The eye of the crayfish is supposed to have the "*mosaic*" type of vision. By this is meant that each ommatidium that is stimulated registers an image of that part of the object which is in focus. The sum of the images is transmitted to the brain as a single image. This method of image formation is especially efficient in recording motion, which is important to the crayfish in avoiding danger.

b. Equilibrium.—In the basal segment of each antennule (coxopodite) is a chitinous-lined sac, the *statocyst*. On the floor of this are the sensory

cushion and three sets of hairs (about 200), each connected with a nerve fiber. The crayfish places a number of large grains of sand (the *statoliths*) among these hairs. Any change of position of the crayfish causes movement of the statoliths, which stimulate the hairs and so help the animal orient itself while swimming. It was thought at one time that these statocysts were organs of hearing, but their primary function is that of equilibrium. The statocysts are shed with the exoskeleton at the time of moulting, and new ones develop with the new exoskeleton. If there are no sand grains or other hard objects in the water in which the crayfish is living at the time of moulting, the sense of equilibrium is impaired. Kreidl placed shrimps that had just moulted, and were therefore without statocysts, in water containing iron filings. The animals placed some of these in the statocyst chamber in place of the usual sand grains. By bringing an electromagnet near the shrimps, the position of the iron filing statoliths could be changed, and the shrimps attempted to respond to these stimulations. The animals finally took up a position corresponding to the resultant pulls of two forces, those of the magnet and of gravity.

c. Touch, Smell, Taste.—The body of the crayfish is sensitive to touch by reason of simple nerve ends. Many of these are connected with tactile hairs. Touch organs are especially numerous about the mouth, on the large claws, and on the edges of the tail fan. The antennae and antennules are also sensitive to touch. A sense of taste may be located in the palps of the mandibles. It is also thought that the senses of taste and smell are in the antennae and antennules.

7. Motion and Locomotion.—The muscles of the crayfish are internal and are attached to the inside of the skeleton, which is just the opposite condition from that in man. In man the skeleton is internal, and the muscles are attached to the outside. The most powerful muscles in the crayfish are located in the abdomen (Fig. 266). They are used to bend that part of the animal forward, thus producing a backward motion in swimming. Crayfish can move in any direction, forward, backward, or sideways. In the basal segments of the chelipeds are strong muscles for opening and closing the pincers. Mandibular muscles move the jaws, and all appendages have muscles for their operation. There are internal muscles in the heart and in the stomach and intestine, that enable these organs to carry on vital activities. In variety and range and movement, the crayfish shows a great advance over the earthworm.

8. Reproduction.—Crayfish are either male or female. In the male, the reproductive organ is a pair or *testes*, and from them tubes, and the sperm ducts, or *vasa deferentia*, lead to the base (coxopodite) of the fifth pair of walking legs. Figure 270*B* shows that these ducts are much coiled.

The female reproductive organs, the *ovaries* (Fig. 270*A*), are also located under the heart. The ducts from the ovaries, the *oviducts*, lead to the base (coxopodite) of the third walking leg. The opening for the *seminal receptacle* is between the fifth pair of walking legs on the ventral surface of the body. To this receptacle the sperm are transferred by the male in the fall, and here they remain until the eggs are laid in the spring. When the eggs are laid, they emerge from the opening in the base of the third walking leg and pass down over the opening of the seminal receptacle. The sperm come out of the seminal receptacle and fertilize the eggs. The eggs are covered with a sticky substance by which, when they reach the swimmerets, they become attached to them. From 300 to 600 eggs may be laid by a single female at one time. The eggs remain attached to the mother until they are hatched. The young crayfish do not drop off

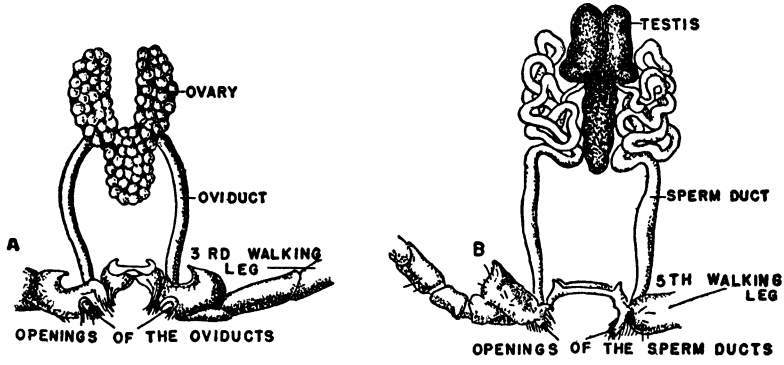


Fig. 270.—(A) The reproductive system of the female crayfish. (B) The reproductive system of the male crayfish. (B. Shamos.)

immediately but remain attached to the swimmerets by a slender thread until they have moulted twice. They then drop off and begin an independent existence.

Typically, the Crustacea pass through one or more larval stages. Some of these stages may occur in the egg, as is the case with the crayfish. One of the important stages is the *nauplius stage* (see below). Nauplii have three segments and three pairs of appendages. This larval stage is usually spoken of as the typical Crustacean larva.

D. Regeneration.—The crayfish can replace an antenna or an eye or any of its appendages just as an earthworm can replace or regenerate parts of its body. But regeneration in the crayfish may be rather peculiar. Sometimes a lost eye will be replaced by an antenna.

AUTOTOMY.—If the leg of a crayfish is injured, the animal will perform a bit of surgery on itself by breaking off the whole leg close to the body. Since the point of attachment of the appendages is quite narrow, the blood will coagulate easily over the narrow wound when the leg is

broken off at that particular point. The self-surgery is called *autotomy* (page 356). The breaking is considered a reflex.

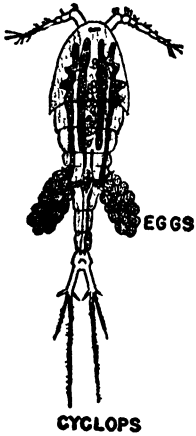
E. Enemies of Crayfish.—Crayfish must protect themselves from many enemies. Toads, frogs, salamanders, water snakes, and turtles esteem them as food. In some countries they are considered delicacies by man.

F. Importance of Crayfish.—It is probable that with the decline of the lobster and shrimp supply, crayfish will become important as an article of food in America.

Sometimes crayfish are pests. They are known to weaken earthen dams and levees along the Mississippi River by burrowing into them. These burrows start leaks that rapidly enlarge. In some sections, particularly in the lowland fields, crayfish destroy young crops of buckwheat, corn, and beans.

IV. Other Crustacea

The large group of *Crustaceans* is subdivided into five subclasses, and each of these contains a number of orders. Only a few of the most interesting forms in each of the subclasses will be mentioned.



CYCLOPS

Fig. 271.—Water flea, Cyclops, a member of the class Crustacea, subclass Copepoda.

A. Branchiopoda (L. *branchia*, gills; *pous*, foot). The fairy shrimp, *Eubranchipus vernalis*, is found in fresh-water ponds and streams, as is also the water flea, *Daphnia pulex*. *Daphnia* is very often seen in protozoan cultures. It is important as food for fresh-water fish.

B. Ostracoda (Gr. *ostrakodes*, having a shell). *Cypris* is a good representative of this group; it develops a shell and looks like a small *mollusk*.

C. Copepoda (Gr. *kope*, oar; *pous*, foot).—The copepods are quite common in small fresh-water ponds and streams (Fig. 271). They may be free-swimming or parasitic. *Cyclops* is also called the *water flea*. It is easily recognized by its median eye and two egg sacs. In some tropical countries, *Cyclops* is an intermediate host for the parasitic guinea worm (page 322). Fish lice or carp lice are copepods of the genus *Argulus*.

D. Cirripedia (L. *cirrus*, curl; *pes*, foot).—There are two types of common barnacles, the goose barnacle, *Lepas fascicularis*, attached by a stalk, and the acorn barnacle, *Balanus balanoides*. Superficially, the barnacles look like mollusks. Their nauplius larvae are free-swimming, but they become attached and grow shells that they can close at low tide and open again at high tide, when they are able to secure their food.

Barnacles often exist in great numbers (Fig. 272). They may so cover the bottoms of ships that the ships must be put into drydock and cleaned.

Sacculina carcini, a relative of the barnacles, is a good example of a form that has become degenerate through a parasitic mode of living. It bears little resemblance to the crustaceans as an adult, but its larval stages indicate where it belongs. It is parasitic on crabs, sending into the body of its host root-like structures, through which it absorbs food. A bag-like portion is fastened to the undersurface of the abdomen of a crab (Fig. 273).

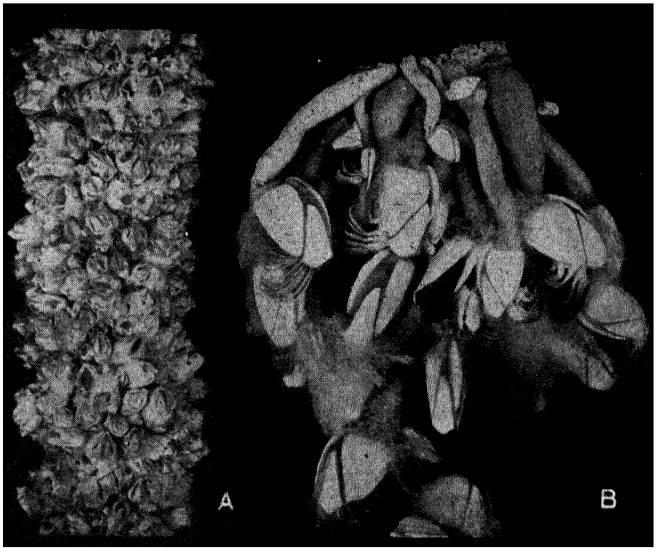


Fig. 272.—(A) Acorn or rock barnacles, Balanus balanoides. (B) Goose barnacles, Lepas fascicularis. The barnacles belong to the class Crustacea, subclass Cirrepedia. (Dr. E. H. Runyon.)

E. **Malacostraca** (Gr. *malakos*, soft; *ostrakon*, hard shell).—The important order Decapoda includes the lobsters, crayfish, shrimps, and crabs. It is a very important group economically, as the above-mentioned species are used for food. Indeed, lobsters faced extinction at the hands of fishermen until laws were passed for their protection. In addition to being used in the fresh state, great quantities of lobsters, shrimps, and crabs are canned.

The lobster, *Homarus americana*, is very similar to the crayfish, but crabs are quite different in shape. The cephalothorax is broader and the abdomen is not well developed, being folded under the thorax (Fig. 44). A soft-shelled crab is one that has just shed its hard skin and has not yet developed the new exoskeleton. The edible blue crab, *Callinectes*, is widely distributed. Other interesting crabs are the rock crab, *Cancer*

irratus, the hermit crab, *Pagurus*, which borrows a gastropod shell for a home (on account of its mode of life, the abdomen has become degenerate), and the fiddler crab, *Uca*. These crabs are found in abundance along the seashore and are peculiar in that one foreleg, usually the right, has a very large pincer and one small pincer, suggesting a fiddle and a bow

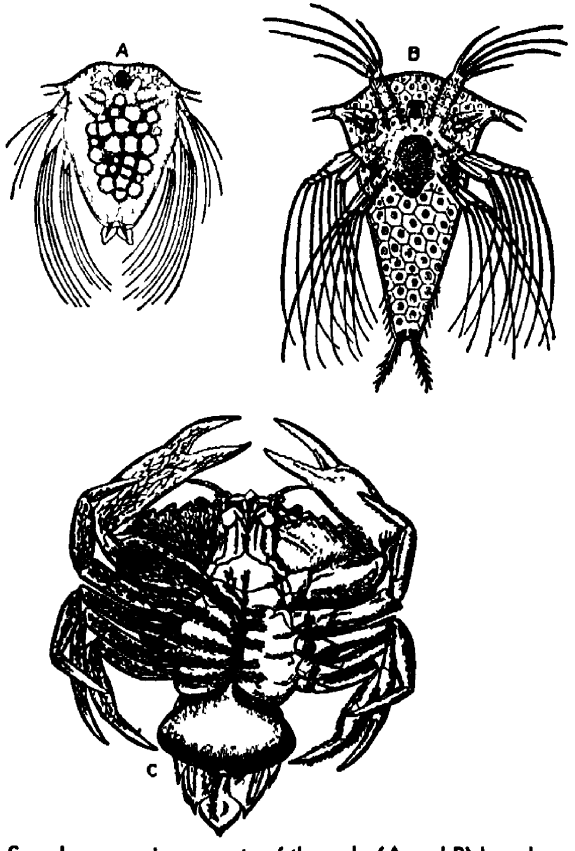


Fig 273.—Sacculina carcini, a parasite of the crab (A and B) Larval or nauplius stages (C) Crab, Carcinus maenas with a mature Sacculina in situ, showing ramifying roots which extract nourishment from the crab (After Delage From Lull, Organic Evolution, The Macmillan Company)

Shrimps and prawns, found in salt water, resemble crayfish But the abdomen is bent sharply downward and the front legs lack the large pincers The edible shrimp, *Crago*, and prawn, *Laemonetes*, are much sought after as food.

F. The Isopoda (Gr *isos*, alike or equal; *pous*, foot) live in both fresh and salt water as well as on land in damp places. The land forms are

known as *sow bugs* and *pill bugs*, sometimes as *wood lice*. They are flattened dorsoventrally.

G. **Amphipoda** (Gr. *amphi*, on both sides; *pous*, foot) are known as *beach fleas*. They are mostly marine, though some live in fresh water. They jump about on beaches; hence the name. They are flattened laterally instead of dorsoventrally like the isopods. *Gammarus locusta* is a good example.

V. Peripatus

Peripatus (class Onycophora) is a tropical form, worm-like and primitive (Fig. 274). It is found under stones, bark of trees, and in other moist, dark places. It feeds upon insects and spiders, capturing them by

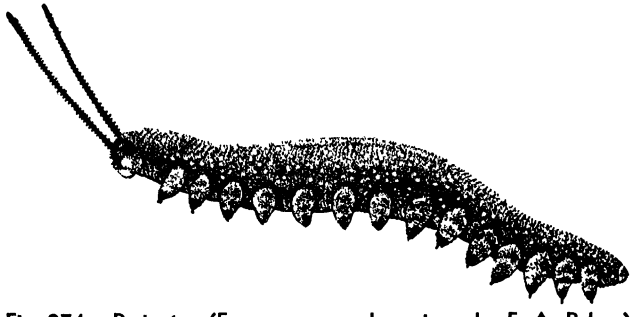


Fig. 274.—Peripatus. (From a preserved specimen by F. A. Baker.)

means of slime, which it can eject forcefully from a pair of glands that open upon the oral papillae. This ejection of slime may also be a weapon of defense. About 15 genera and 73 species are known.

This form is important because it has both annelid and arthropod characteristics as well as some features peculiar to itself. Among the annelid characters are the segmentally paired nephridia, the outer covering or thin cuticle, and the muscle layers; the arthropod characteristics are type of circulation, *i.e.*, the open type, haemocoele instead of a coelom, cilia in the reproductive organs, and a respiratory system that is a system of air tubes. It is unlike either the annelids or arthropods in that it shows no external segmentation, though there is a pair of legs for each internal segment of the body. The legs end in claws; hence classification.

Many species of *Peripatus* are viviparous, and one female may bring forth as many as 30 living young in a season.

VI. Centipedes and Millipedes

Centipedes and millipedes are often classed together as Myriapoda. They have long bodies with many pairs of similar legs and breathe by

means of air tubes or tracheae that open to the outside by pores or spiracles in the body wall, sometimes arranged in pairs

A. Centipedes (L *centum*, hundred, *pedes*, feet), class Chilopoda (page 373), have dorsoventrally flattened bodies consisting of a series of segments, each of which except the first and the last two bears one pair of seven jointed legs (Fig 275*A*) A pair of poison claws is located on the first body segment The poison ejected through the openings on the ends

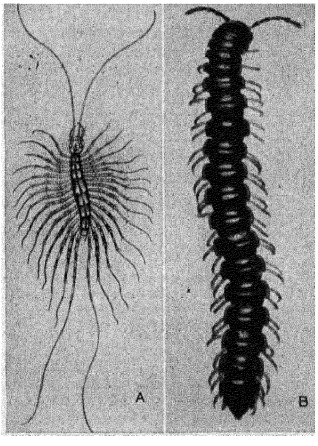


Fig 275 —(A) House centipede, Scutigera forceps (B) Millipede (Julus) (Courtesy of the Bureau of Entomology and Plant Quarantine)

of the claws will kill small animals but will not harm human beings Centipedes have one pair of long antennae and two pairs of maxillae

The largest centipedes live in the tropics, where they may grow to be 1 ft long House centipedes are only about 1 in long, have very long legs, the last two of which are about 2 in long The number of legs a centipede has inspired the following humorous lines

A centipede was happy, quite,
Until a toad in fun

Said "Pray which leg moves after which?"
Which raised her doubts to such a pitch
She fell exhausted in the ditch,
Not knowing how to run!

Centipedes are quite harmless. They hide in daytime under stones, logs, and in other damp places, emerging at night to seek food, insects, spiders, etc.

B. Millipedes.—The millipedes (L. *mille*, thousand; *pedes*, feet), class Diplopoda (page 373), have subcylindrical bodies that are segmented, almost every segment bearing two pairs of legs. This has probably come about through the fusion of segments. The head has one pair of maxillae (Fig. 275*B*).

Millipedes live in dark, moist places and feed on decaying vegetable matter, though they may eat living roots and so become pests. They are slow-moving and when disturbed are likely to roll their hard bodies into a coil.

VII. The Biogenetic Law

Von Baer, working with embryos, first discovered that no matter how the adult vertebrates might differ from each other, their embryos went through somewhat similar stages in development. It was suggested that these stages indicated the character of their ancestors. Later it was observed that this was also true of the invertebrates. This embryonic repetition was called by Haeckel the *biogenetic law*. It is often simply expressed: "*Ontogeny*, or the development of the individual recapitulates the *phylogeny*, or the development of the race." The theory has been discounted by many biologists because generalizations have been carried too far. One reason for mentioning this theory here is that the favorite illustration of the law is the life history of the shrimp, *Penaeus* (Fig. 276). The egg of this shrimp hatches as a *nauplius* larva which has three pairs of appendages and a single median eye. The nauplius stage may represent an ancestral type now extinct. This molts and the next stage is called the *protozoean* stage, the animal now having six pairs of appendages. The *zoeal* stage follows the next molt, and the animal resembles *Cyclops*. Further molts take place and the *Mysis* stage is reached, the animal resembling the adult *Mysis*. It has a distinct cephalothorax and 13 segments. Following the next molt, the juvenile shrimp appears with 19 segments.

A knowledge of developmental stages is often useful in determining to which group animals belong. Barnacles, for example, do not look much like arthropods in the adult state (Fig. 272), nor does *Sacculina* (Fig. 273).

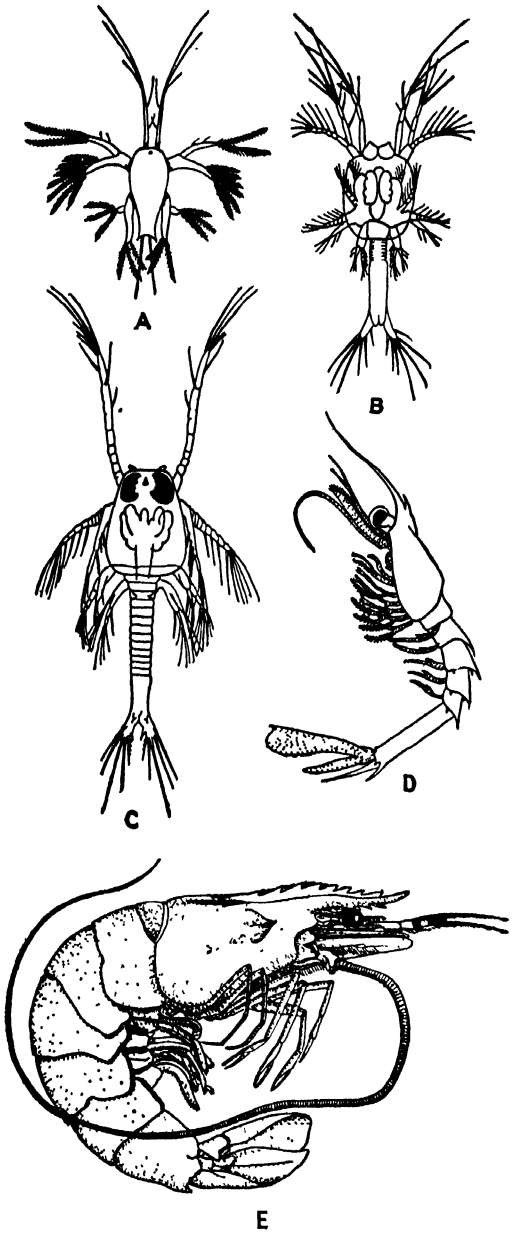


Fig. 276.—The developmental stages in the life history of a shrimp, Penaeus sp. (A) Nauplius stage. (B) Protozoea stage. (C) Zoeal stage. (D) Mysis stage. Highly magnified. (After Fritz Müller.) (E) An adult shrimp, Pennaeus semisulcatus. (From Wolcott, Animal Biology.) (After de Haan.)

Questions

1. Why do you consider the arthropod group well named? How would you account for such widely different animals as crabs and beetles being included in the same phylum?
2. How do arthropods grow? What other groups of animals have endoskeletons? How do they differ from those of the arthropods?
3. Name examples from each of the six classes of arthropods. How do they differ from each other?
4. Do the appendages of the crayfish have a basic plan? Explain.
5. Give an account of digestion in the crayfish. Include in this account a description of the type of digestive organs and the digestive process.
6. Describe respiration in the crayfish. How does it differ from that of the earthworm?
7. Compare the excretory system of the earthworm and that of the crayfish.
8. Would you say that the nervous system of the crayfish is more specialized or more primitive than that of the earthworm? Give reasons for your answer.
9. What are the peculiarities of crayfish blood? Is the circulatory system "open" or "closed"? Explain.
10. Describe the eye of the crayfish. What type of vision does the crayfish probably have? What other sense organs does the crayfish have?
11. What external differences are there in the male and female crayfish?
12. How are the eggs fertilized? What advantage is there in having the eggs fastened to the swimmerets? Why do the young remain attached to the mother for a time?
13. What is a soft-shelled crab?
14. How do we know that barnacles are Crustacea?
15. Name one instance in which it would be impossible to classify the animal if the embryonic stages were not known.
16. Why is *Peripatus* an interesting form?
17. What is the biogenetic law? Upon what is it based?
18. Name the most important crustaceans used for food.
19. What is the nauplius larva? What extinct animal does it resemble somewhat?
20. Define, as related to the Crustacea: ecdysis, moult, haemocoel, sinus, ostia, bailer, statolith, gastril mill.

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CHAPTER XXVI

THE ARTHROPODA (*Continued*)
THE INSECTA

And I will restore to you the years that the locust has eaten, the cankerworm and the caterpillar and the palmerworm, my great army which I sent among you.
—*Joel*, 2: 25.

I. Insects in General

Insects live almost everywhere, in fresh and salt water, in the soil and on the land, in nearly every kind of a situation, from wet places to the desert, in and on plants and animals, including Man. They are the largest known group of animals, about 625,000 having been described.

According to students of paleontology, insects have existed on earth since the Pennsylvanian times of the late Paleozoic era, or more than twice as long as man has been here. During this period of time, they have become highly specialized and well adapted to their environment. Man wages a ceaseless war against insects, and it may well be, as pointed out by one of our foremost students of the insects, Dr. L. O. Howard, that the very existence of man in the future will depend upon how well he succeeds in controlling this mighty host.

When an important crop is threatened with destruction because of insects, the entomologist, who studies life cycles, habits, and reproduction of insects, is called in to find a way to destroy them without damaging the crop; if some disease is transmitted by an insect, it is the medical entomologist who studies the suspected insects to solve these problems.

Not all insects are injurious; many of them are harmless, and many are beneficial to Man. It would be hard to estimate the value of insects in pollinating flowers, especially those of fruit and crop plants. Some insects aid in destroying insect pests; bees give us honey and wax; the lac insect gives us shellac; the cochineal insect furnishes a red dye; there are many other beneficial insects.

II. The Grasshopper

In some sections of the country, the cicada (Fig. 290) is called the *seventeen-year locust*, but the true locusts are the short-horned grasshoppers (Fig. 277). The old name for insects, which is often used now, is Hexapoda (page 374). Grasshoppers are members of the Orthoptera.

A. External Features.—The chitinous exoskeleton of the grasshopper differs from that of the crayfish in that the chitin contains no lime. The

exoskeleton is secreted by the skin just beneath it, the hypodermis. Where the segments join each other, the chitin is membranous, and the joints allow movement of parts The body is divided into three distinct regions (1) the head, (2) the thorax, (3) the abdomen (Fig 278).

1 THE HEAD —The head in an adult grasshopper appears to be unsegmented because six segments are completely fused It bears a pair of "feelers" or antennae, in which are located the organs of smell On each side of the head is a large compound eye, made up of a large number of six-sided facets (Fig 278) that fit together exactly to form a sort of mosaic Arranged in the form of a triangle, one at the base of each antenna and one in the middle of the "face" are three simple eyes or *ocelli* Because the eye is much curved and because each facet is located at the end of a rod-shaped column (*ommatidium*), the animal can see in all directions Such compound eyes are especially fitted to perceive moving objects

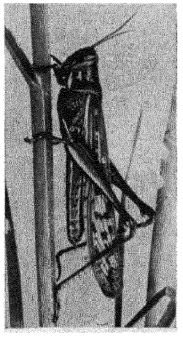

Fig 277 —The short horned grasshopper or locust, Schistocera americana (Courtesy of U S Bureau of Entomology)

The *mouth parts* are especially adapted for eating grass and hard substances (Fig 279) The upper lip, or *labrum*, moves up and down as the insect eats Just under this is a sort of tongue, the *hypopharynx* The jaws, or *mandibles*, are hard and toothed so as to tear and chew food They move from side to side when the animal is eating Behind the mandibles are the *maxillae*, which aid in holding and cutting food Attached to each of these is a "feeler" or *palpus*, which looks like a short antenna Finally, there is the lower lip, or *labium*, which is two-lobed and bears a palpus on each side The labium is used to hold the food between the jaws In certain other insects the mouth parts are modified into tubes, as in the moths and butterflies, or into piercing and sucking organs, as in the mosquitoes.

2 THE THORAX —The thorax consists of three segments, the *prothorax* (Gr *protos*, first) in front, the *mesothorax* (Gr. *meso*, middle) in the middle, and the *metathorax* (Gr *meta*, over) behind The prothorax, a saddle-shaped structure just behind the head, bears the first pair of legs The mesothorax has the first pair of wings attached to it on the upper side and the middle pair of legs on the underside. The metathorax bears the second pair of wings and the hind legs Figure 278 shows the relationship of these parts.

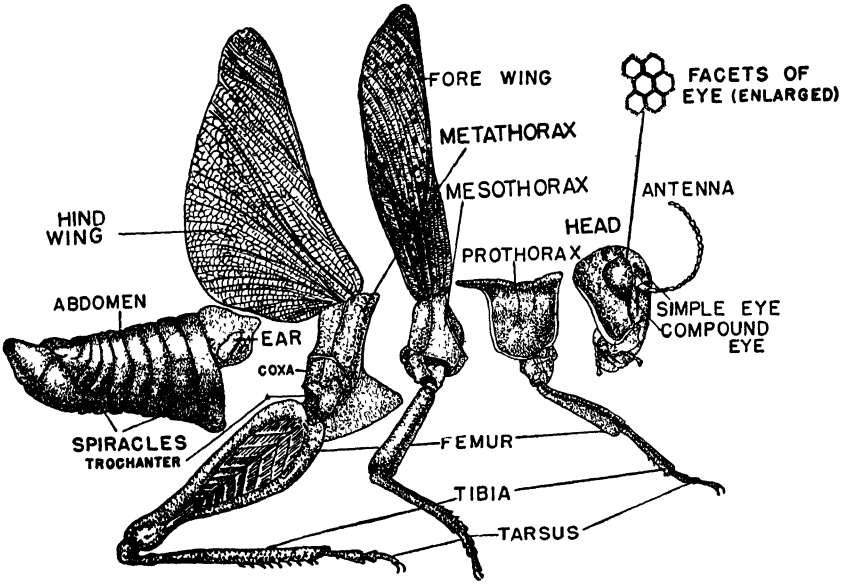

Fig. 278.—The external features of the male grasshopper. (B. Shamos.)

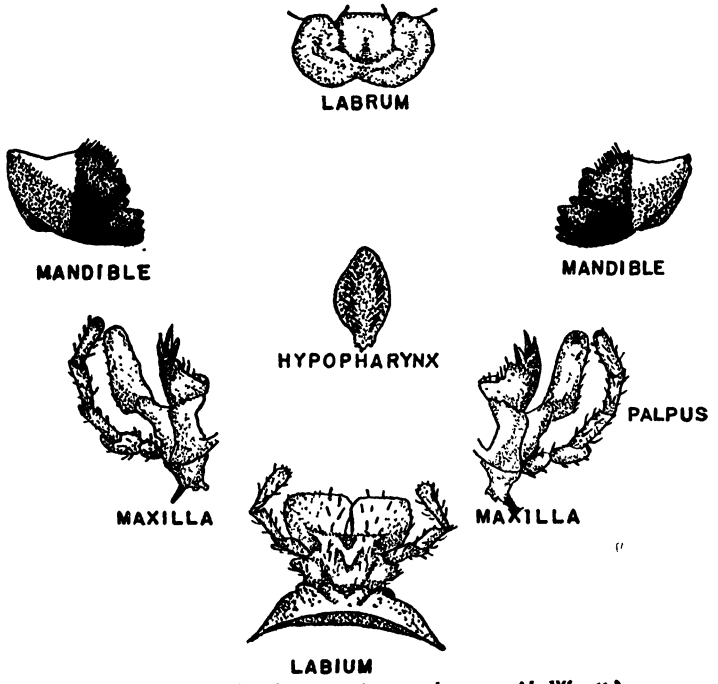

Fig. 279.—Mouth parts of a grasshopper. (J. Wyatt.)

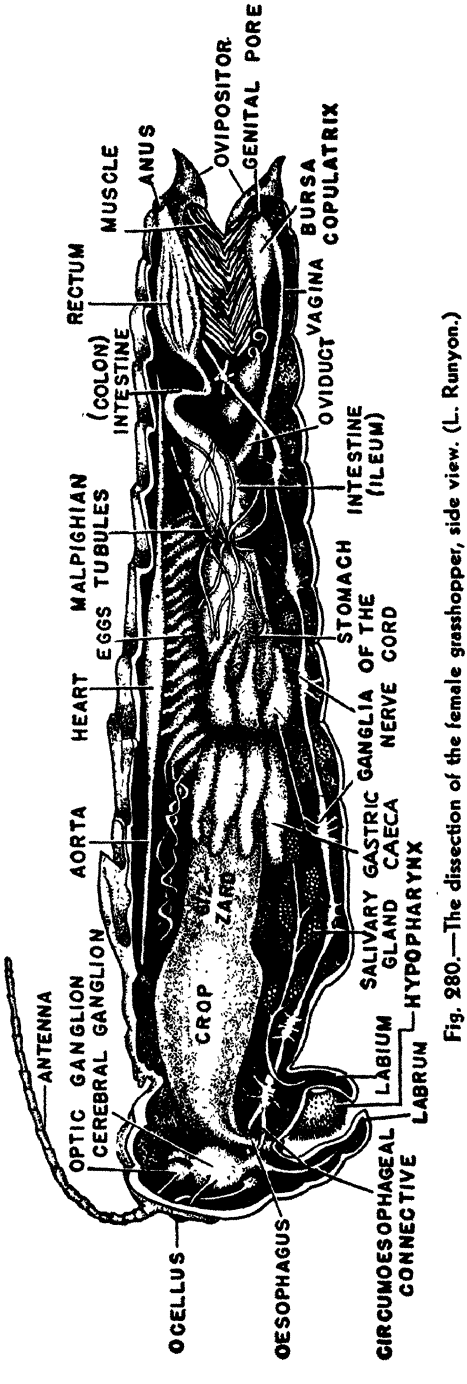

Fig. 280.—The dissection of the female grasshopper, side view. (L. Runyon.)

a. The Wings.—The two pairs of wings are quite different, the anterior pair being somewhat thickened and narrow, whereas the posterior pair are thin and transparent, sometimes brightly colored. They are broad, and when the animal is at rest they fold up and are covered by the anterior pair. Both pairs are supported by the so-called *veins*. Specialists use the number and arrangement of the veins as a means of classification of insects.

b. The Legs.—The legs of the grasshopper are modified so as to fit it for the life that it leads. Since it clings to upright stems (Fig. 277), the feet are modified for clinging. In the leg of the grasshopper and the insects, in general, there are two short segments, the *coxa*, next to the body, and the *trochanter;* two long segments, the *femur* and the *tibia;* and finally the *tarsus*, consisting of three segments and ending in two claws having a fleshy pad between them, the *pulvillus*. A grasshopper can leap fifty times its own length. This is possible because of the length of the third pair of legs, the leaping legs, and of the muscles attached to them.

3. The Abdomen.—The abdomen of the adult consists of 10 easily recognized segments and 1 at the posterior end that is incomplete. On the first segment is a tightly stretched membrane that is the eardrum, or *tympanum*. Along the sides of eight of the abdominal segments are spiracles through which the air enters the breathing tubes, or *tracheae*. At the extreme end of the female is located a pair of pointed appendages that constitute the *ovipositor*, or egg placer (Fig. 280). The posterior end of the male is rounded.

Some insects, especially weevils, have such highly developed ovipositors that they are able to pierce pecan shells and other hard surfaces to make a place for their eggs. The sting of a bee is a good example of an ovipositor modified for defense.

B. Internal Anatomy and Physiology. 1. Digestion.—A comparison of the grasshopper with the crayfish shows similarities in features but differences in details. The grasshopper possesses a *gizzard* instead of a gastric mill. Its digestive system is divided into three main divisions: the fore-gut, the mid-gut, and the hind-gut. The mouth opens into the *pharynx*, which is in the head (Fig. 280). On either side of the pharynx, opening into it, is a salivary gland. The pharynx leads into the esophagus, which, in turn, enlarges to form the crop. In this organ are rows of spine-like teeth on the chitinous wall. Behind the crop is the gizzard, which is not sharply separated from the crop. The gizzard is lined with plates through which the food is strained into the thin-walled *ventriculus* or stomach. Opening into the anterior end of the stomach are eight spindle-shaped double pouches, the gastric caeca, which secrete a digestive fluid. From the stomach leads the intestine,[1] the posterior part of which is

[1] The regions of the intestine are three: (1) the *ileum*, extending from the point where the malpighian tubules enter the gut and ending in the dorsal bend; (2) the *colon*, about ¼ in. long which turns abruptly from the ileum; (3) the enlarged rectum, into which the colon leads.

expanded into the rectum. This opens to the outside through the anus. The food is digested in the stomach, and some absorption takes place there into the fluid in the haemocoele. Absorption is completed in the intestine.

2. CIRCULATION.—The circulatory system of the grasshopper and of other insects is simpler than that of the crayfish. The heart, lying in a haemocoele, is made up of chambers, one for each segment it passes through. It is filled with and surrounded by blood. Blood enters the heart, as in the crayfish, through *ostia* that have valves to prevent the blood

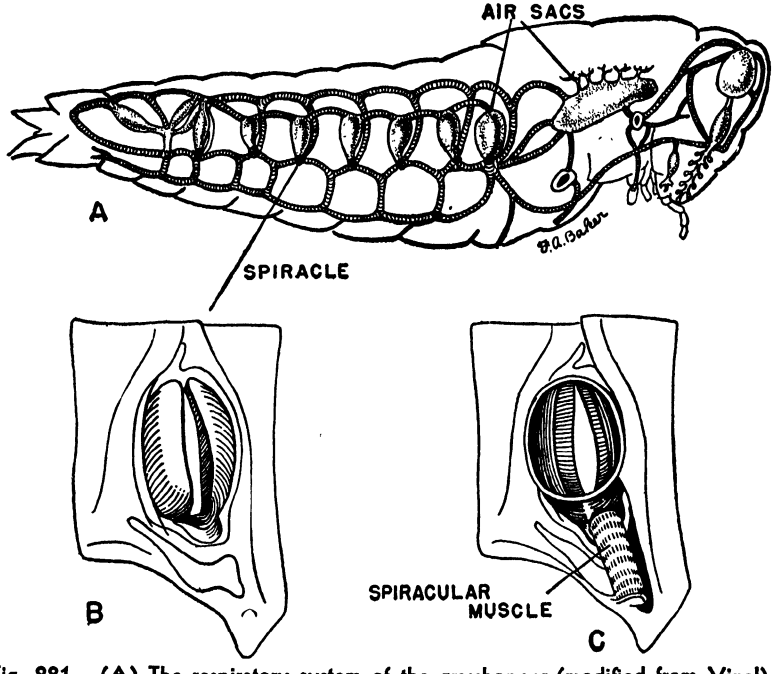

Fig. 281.—(A) The respiratory system of the grasshopper (modified from Vinal). (B) Left spiracle of mesothoracic segment, outer view. (C) Right spiracle of mesothoracic segment, inner view. (B and C after Snodgrass.)

from flowing in any direction except through the vessel toward the head. The heart contracts rhythmically, and the blood flows forward toward the anterior part of the body and into the haemocoele. It circulates slowly through the sinuses, carrying food to all the tissues. The system of sinuses is so constructed as to direct the flow, and it finally finds its way again to the posterior of the tube-like heart. In the crayfish, the blood serves the usual functions of transporting foods and the oxygen and carbon dioxide that are concerned with respiration. In insects, however, respiration is taken care of by a system of tubes or *tracheae* (Gr. *tracheia*, windpipe), and the blood functions only in the distribution of food and waste products.

3. RESPIRATION.—The tracheae (Fig. 281*A*) constitute a complex network of minute tubules connected with the spiracles (Fig. 281*B*) along the sides of the thorax and abdomen. No such system is present in the crayfish. In a living grasshopper, it will be noted that the abdomen enlarges and contracts with a sort of pumping motion. This causes the air to be drawn into and expelled from the spiracles. Each *spiracle* (L. *spiraculum*, a breathing hole) is lip-like and is protected from dust by minute hairs. Each is guarded by valves that can be opened and closed to regulate the flow of air and are connected with a system of tubes or tracheae that extend to every part of the insect's body. There are 10 pairs of spiracles, 2 on the thorax and 8 on the abdomen. Those on the abdomen are easy to see on the anterior margin of each segment near the union of the sternum with the tergum. The tracheae are kept open by rings of chitin and are expanded in some places to form large air sacs (Fig. 281*A*). They are divided and subdivided into smaller divisions, the *tracheoles*, which are delicate and through the walls of which there is an exchange of gases by diffusion, the oxygen from the air going to the tissues and the carbon dioxide being collected from the tissues. In most animals, this is done by the blood. A "tracheal system" is characteristic of insects and is present in a few species of spiders; no other animals possess this type of respiratory system. Certain aquatic insects possess gills.

4. EXCRETION.—The grasshopper is provided with special excretory organs, the *Malpighian tubules* (named for their discoverer, Malpighi), which open in the anterior part of the hind-gut. They are coiled in the haemocoele and so are bathed in blood. From it they extract the nitrogenous wastes and pour them into the intestine. These wastes leave the body as dry wastes through the anus.

5. COORDINATION.—The nervous system of the grasshopper is on the same general plan as that of the crayfish, though specialization has gone further. In the embryo, there are ganglia in every segment, including six in the head. In the adult, three of these have fused to form the brain and three to form the first ganglion of the ventral nerve cord, the subesophageal ganglion. The brain is in the dorsal part of the head and is connected with the subesophageal ganglion by a pair of circumesophageal commissures or connectives. There are three ganglia in the thorax and five in the abdomen. Branches from these and from the brain supply all parts of the body (Fig. 280). The ventral cord is a double-ganglionated structure. With the brain removed, the animal can still walk, jump, and fly. It does not, therefore, have a coordinating function. It does serve to relay stimuli from the sense organs on the head and acts as an inhibiting center. If it is removed, the animal moves continually and will respond to even slight stimuli. The segmental ganglia are connected and coordinated by nerves that run in the ventral nerve cord.

The reactions of insects are more numerous and specialized than those of the crayfish.

Motion and Locomotion.—The number of muscles in an insect's body is very large, and, for their size, they are very powerful. They are of the striated type. It is interesting to note that the skeleton of the grasshopper is on the outside, whereas the muscles and their attachments, which are responsible for all movement, are on the inside, just the opposite condition from that which exists in the vertebrates. The grasshopper can fly as well as walk and jump. Jumping is accomplished by use of the powerful hind legs.

6. Special Senses. *a. Vision.*—The eyes, simple and compound, have already been mentioned. It is probable that the ocelli are only light-perceiving. The compound eyes, though six- instead of four-sided (Fig. 278), are constructed on the order of those of the crayfish (Fig. 279). Each facet is connected with an *ommatidium*, and there may be thousands of these in a single eye, separated from each other by a thin layer of pigment. This "mosaic" type of eye is especially useful in detecting movement.

b. Auditory Sense.—On the first abdominal segment is a tympanic membrane stretched across a small pit (Fig. 278). A small liquid-filled vesicle, closely connected with the auditory ganglion, is beneath the tympanic membrane. An auditory nerve connects the auditory ganglion with the ventral nerve cord. Members of the Orthoptera make characteristic sounds in various ways: locusts, by rubbing portions of the wings together; katydids, by rubbing a broad segment of the hind leg over the outer surface of the front wing; crickets with special *stridulating* organs on the wings, the "file and scraper."

c. Smell and Taste.—Experiments appear to indicate that certain pits in the antennae are organs of smell. In some insects, there may be thousands of these smell organs. *Taste cups* are on the inner surface of the labrum or upper lip.

d. Touch.—Tactile hairs are scattered over the body and are on the antennae or "feelers." Each of these hairs has a nerve cell at its base that is connected with the central nervous system by a nerve branch.

7. Reproduction and Metamorphosis.—The sexes are separate. The difference between the posterior portions of the bodies of the male and female has already been referred to. In the male, the reproductive organs, the *testes*, lie dorsal to the intestine. The two join to form a single mass, and from either side of this a much-convoluted tube, the sperm duct or *vas deferens*, arises. They fuse to form a single tube just before reaching the copulatory organ. Accessory glands and *seminal vesicles* for storing sperm are present. In the female, a pair of *ovaries* lie in a position corresponding to that occupied by the testes in the male. The ovaries consist of a number of ovarian tubes in which the eggs are formed

An *oviduct* leads from each ovary. These unite to form the *vagina*, which opens into the genital opening between the plates of the *ovipositor*. As in the *crayfish*, the female receives and stores sperm in a *spermatheca*. A duct from this opens dorsal to the vaginal pore, so that the eggs pass down the oviducts to the vagina and are fertilized as they are laid. The shell is already on the egg when it reaches the genital opening, but there is a small hole, the *micropyle*, through which the sperm enters. One sperm unites with the nucleus of the egg. The female is able to make a hole in the ground with the ovipositor, and so the eggs are laid side by side in

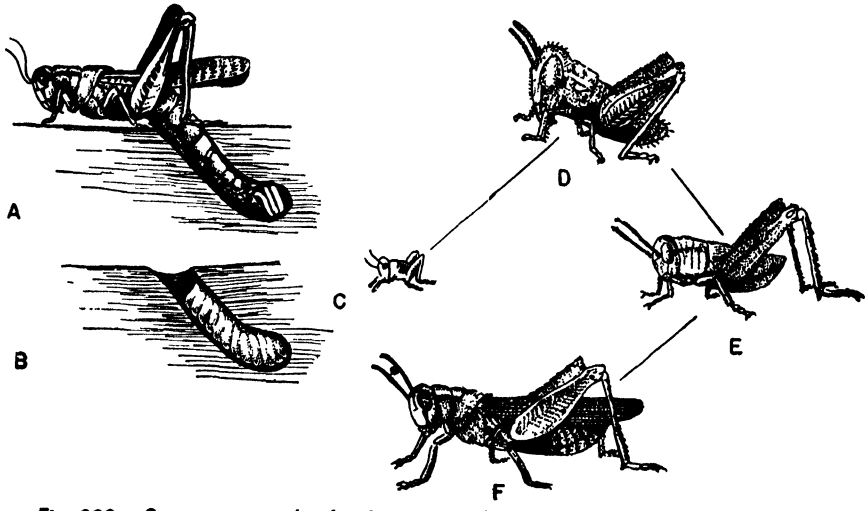

Fig. 282.—Some stages in the development of the grasshopper. (A) Female grasshopper laying eggs in the ground. (B) Egg mass in hole. (C) Young grasshopper, just hatched. (D) Young grasshopper, greatly enlarged, showing large head, lack of wings, etc. (E) (F) Later stages of development. (F. A. Baker.)

rows at a depth of about 1 in. and cemented together by a frothy substance. They are arranged obliquely so that all slant upward (Fig. 282*B*). This facilitates the escape of the young from the lower layers.

On account of the large amount of yolk, the egg in division does not cut in two, then four, etc., to form a hollow ball (blastula) as does the egg of *Amphioxus* (page 684), but the zygote nucleus divides many times; then the nuclei move to the periphery, and cell walls soon surround each nucleus, forming cells (Fig. 283). Later the cells pass inward, and the usual three germ layers, *ectoderm*, *mesoderm*, and *entoderm*, are formed. It was mentioned above that parts of the alimentary canal were lined with *chitin*, a substance secreted only by the ectoderm. This is explained when it is known that the fore-gut and the hind-gut, which are lined with chitin, are formed by the infolding of the ectoderm. The mid-gut develops from the endoderm.

Metamorphosis.—The young grasshopper, or nymph, resembles its parents, but its head is large in comparison with the rest of its body and lacks wings. To grow and develop, it must shed its exoskeleton periodically in the same way as the crayfish does. The grasshopper type of development or metamorphosis is called *gradual metamorphosis* (Fig. 282).

Some authors list four types of development of insects: (1) development without metamorphosis (*ametabolous*), Thysanura, Mallophaga, etc.; (2) gradual metamorphosis (*paurometabolous*), grasshoppers and bugs; (3) incomplete metamorphosis (*hemimetabolous*), dragonflies, May flies, etc.; and (4) complete metamorphosis (*holometabolous*), butterflies, moths, etc. In the first type of metamorphosis, the animals go through a series of developmental stages but have practically the same form as the adult all the time. In gradual development or metamorphosis, the nymphs look something like the adults, and the rudimentary structures develop slowly. In incomplete metamorphosis, as in the dragonflies, the eggs hatch into the *naiads*, which live in the water and are active. These forms go through greater changes in development than do the nymphs in gradual metamorphosis. In complete metamorphosis, the larvae develop into *pupae*, usually enclosed in cocoons, and remain quiescent for a time. Later they are completely transformed. The pupal state is sometimes called a *chrysalis*, especially in butterflies, and the final or mature state, usually winged, the *imago* (page 888). There is a far cry from the caterpillar to the butterfly! Each type of metamorphosis in this series involves greater changes than the preceding type. Insects do not grow larger after they reach the adult stage.

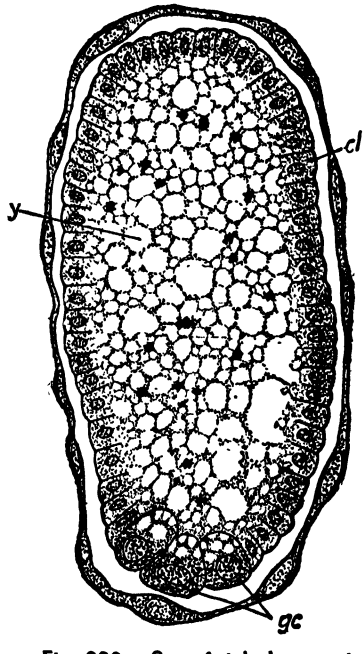

Fig. 283.—Superficial cleavage in an insect egg (Fly, Miastor) (cl) Cleavage cells. (gc) Germ cells. (y) Yolk. (After Hegner.)

III. The Honeybee

The honeybee is a more specialized type of insect than the grasshopper. It is not a native of the United States, and the Indians called it *the white man's fly*. Bees are in no sense tamed but carry on their work as they have for thousands of years.

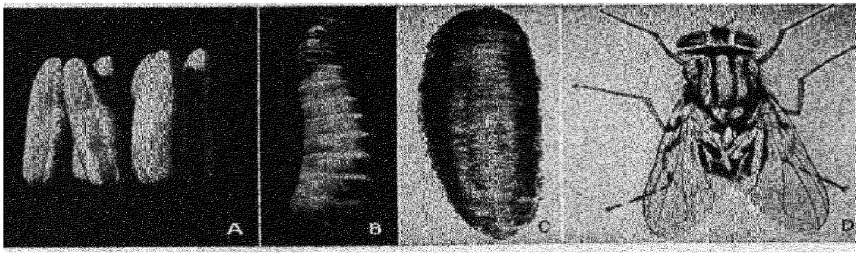

Fig 284 —Diptera The life history of the house fly, Musca domestica (A) Eggs (B) Larva (C) Pupa (D) House fly (Courtesy of the U S Bureau of Entomology)

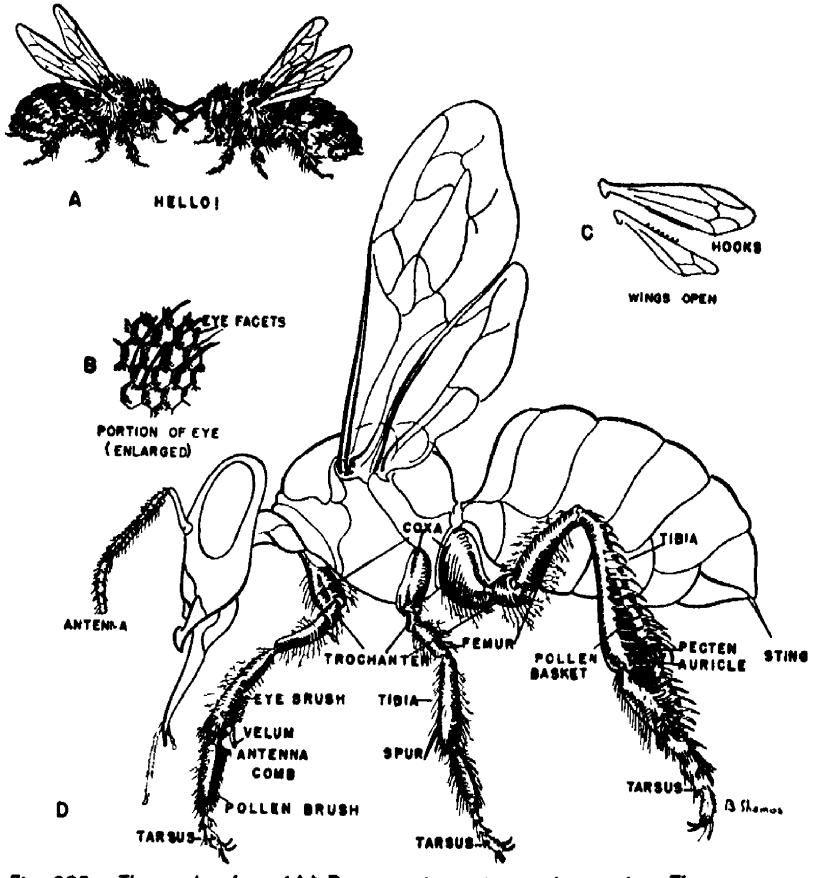

Fig 285 —The worker bee (A) Bees crossing antennae in greeting The antennae are sensitive (B) Enlarged portion of the eye showing facets and hairs (C) Wings (D) Legs of the worker and general structure of the body. (B. Shamos)

A. External Features.—The external features of the worker honeybee are well shown in Fig. 285. There are three types of bees in a hive (Fig. 286): the *queen*, the *drone*, and the *worker*. Each of these differs markedly

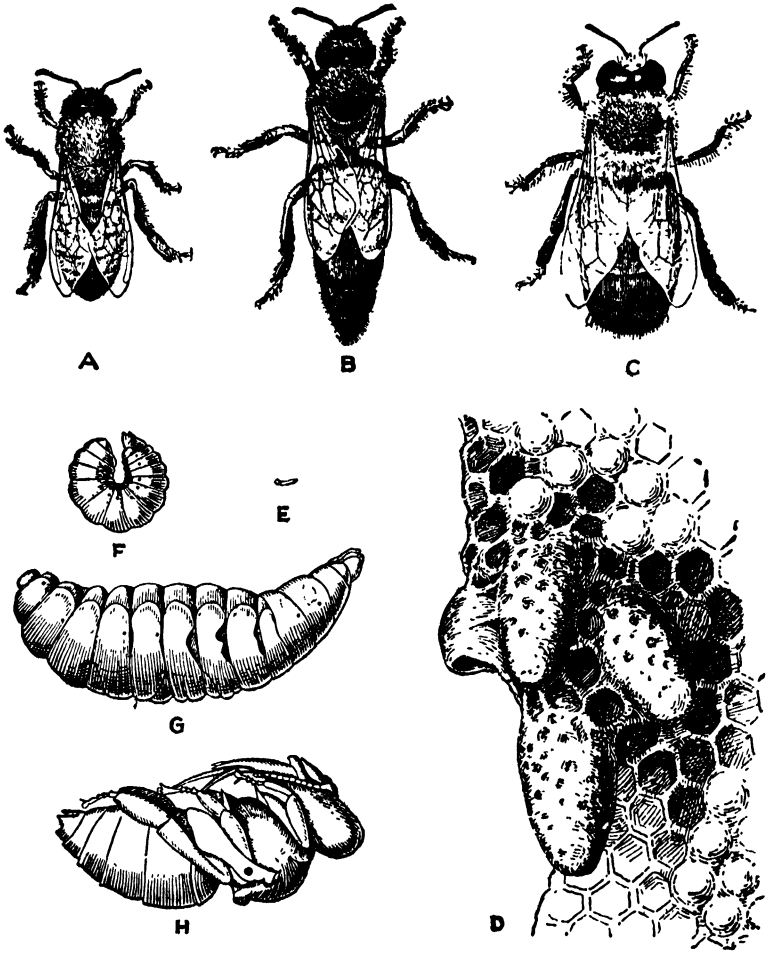

Fig. 286.—The honey bee, Apis mellifica. (A) Worker. (B) Queen. (C) Drone. (D) Queen cells. (E) Egg. (F) Larva. (G) Pupa, early stage. (H) Pupa, late stage. (Courtesy of U.S. Bureau of Entomology.)

in structure. Unless otherwise noted, the following description applies to workers.

1. General Features.—The body is covered with a chitinous exoskeleton except at the joints, where it is membranous to allow motion. Covering this is a coat of hair, which gives the bee its fuzzy appearance.

In older bees, this may be partly worn off. Like the grasshopper, the body of the honeybee is divided into head, thorax, and abdomen. The head bears a pair of compound eyes, one on either side, and three small *ocelli*. In addition, there are a pair of feelers or antennae and complicated mouth parts. The prothorax bears the front legs; the mesothorax, the middle legs and the anterior pair of wings; and the metathorax, the hind legs and the posterior pair of wings. The abdomen is composed of six external segments having a dorsal tergum and a ventral sternum. At the end of the abdomen is the *sting*.

2. Mouth Parts.—The mouth parts of the honeybee are adapted both for chewing and for sucking up nectar. The *clypeus* is the region below the antennae, and attached to it is the upper lip, or *labrum*. Just below this is the *epipharynx*, probably an organ of taste. Partly hidden by the labrum are the jaws or *mandibles*. These are used mainly for

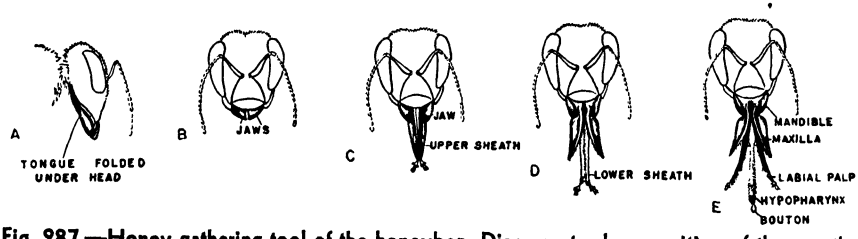

Fig. 287.—Honey-gathering tool of the honeybee. Diagrams to show position of the mouth parts when in use and when not in use. (F. Baker.)

manipulating wax. The *maxillae* are elongated and provided with stiff hairs along their edges; *maxillary palps* are present but vestigial. The *labium* is modified for sucking nectar; the *ligula* is a tongue-like structure covered with hairs, having at its tip a spoon-like structure, the *bouton*, used in collecting nectar. Flattened *labial palps* are attached to the ligula at its base. The labial palps and the maxillae can be pressed together to form a tube when the bee is collecting honey. Within this tube the ligula, with honey on the hairs, is drawn back and forth. Lowering of the *epipharynx* allows the honey to enter the *pharynx*, and from here it goes to the *honeysac*. The relationship of the mouth parts of the honeybee is shown in Fig. 287.

3. The Legs.—The legs of the honeybee, like those of the grasshopper, have two short segments, the coxa and the trochanter, two long segments, femur and tibia, and a five-jointed tarsus provided at the tip with a pair of strong claws. Between the claws is an adhesive organ that enables the animal to hold fast to slippery surfaces. The leg of the honeybee, however, has structures that the grasshopper does not have. These are adapted to the activities of pollen gathering and the making of wax.

a. Forelegs.—The anterior pair of legs has along the anterior margin of the tibia short, stiff hairs used as an *eye brush.* In gathering pollen, some of it sticks to the hairs of the eyes (Fig. 285*B*). There is also a *pollen brush* on the first joint of the tarsus, used to collect pollen grains on the hairs of the body. The *antenna cleaner* is at the base of the first notch of the tarsus. In this notch is a semicircular area lined with stiff hairs. When placed over the antennae at their bases, the notches are closed, and the antennae are drawn through and effectively cleaned.

b. Middle Legs.—These have a *spur* or *spine* near the outer end of the tibia used for removing the flakes of wax from the underside of the abdomen.

c. Hind Legs.—These are longer and broader than the other two pairs. A depression in the surface of the tibia, with long hairs that curve

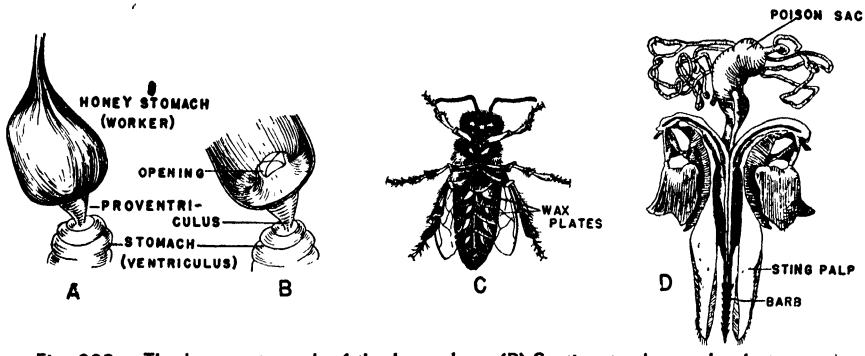

Fig. 288.—The honey stomach of the honeybee. (B) Section to show valve between the honey stomach and the true stomach. (C) Wax plates on the underside of the abdomen. (D) Sting of bee greatly enlarged. (A and B after Snodgrass.)

outward, is the *pollen basket.* Rows of pollen combs are on the inner surface of the first tarsal joint. These are used to scrape the pollen from the second legs and posterior part of the abdomen. The *pecten,* a row of stiff hairs on the lower edge of the tibia, is used to remove the pollen from the combs of the opposite leg, and it falls on the flattened plate, the *auricle* (Fig. 287). The pollen is then pushed into the pollen basket when the auricle is pressed against the end surface of the tibia. When the pollen basket is filled (Fig. 110), the bee returns home and deposits the load in special cells. Mixed with honey and saliva, it is the "bee bread" used as food for both larvae and adults.

4. The Sting.—Only the workers and the queens have stings. The sting is a complex organ, attached to muscles and the poison sac (Fig. 288*D*). Externally, there are two palps, or feelers, which locate the place to be stung. The sting is a hollow organ with barbs on the end. When this

sting is thrust into the skin, the poison sac contracts, and the poison is injected through the sting. More often than not, the bee dies when it stings another animal, for when the sting is left in the wound, parts of the viscera are likely to be attached to it and to be torn away with it so that the bee is fatally wounded. The sting of the queen is modified as an *ovipositor*.

5. THE WINGS.—The wings are membranous, and there are two pairs. The smaller hind wings are hooked on to the forewings by hooks (*hamuli*) when the bee is in flight (Fig. 285*C*).

B. Internal Anatomy and Physiology. 1. DIGESTION.—Two pairs of *salivary glands* open into the mouth. It is suggested that the secretion of the head glands may be used to soften the wax as it is being kneaded. The mouth leads into a short *pharynx*, which is connected to the long, thin esophagus extending through the thorax. In the abdomen the esophagus leads into a thin-walled crop or *honey stomach*. Between the honey stomach and the *true stomach* is the *proventriculus*, in which is a valve-like arrangement controlling the passage of honey and pollen into the true stomach, or ventriculus (Fig. 288*A*). Following the stomach is the *intestine*, expanded at its posterior end into the *rectum*, which opens to the outside through the *anus*. The food of the adult is pollen and honey, the pollen furnishing the necessary proteins. The larvae are also fed pollen and honey. For the first 3 days, all are fed "royal bee jelly," a secretion from glands in the heads of the workers. The queen larvae receive this food during the entire larval period.

Honey Making.—The nectar of flowers is sucked up by the workers and swallowed into the honey sac. Here the more complex sugars are transformed into simple sugars. Other changes take place that are not well understood. The composition and taste of honey vary in various localities and depend somewhat upon the character of the flowers from which the honey is gathered. When the worker returns to the hive, the honey is placed in the cells. Since it still has too much water, the honey cell is left uncapped until it has evaporated somewhat. The hive is "air-conditioned" by the workers, who keep the air in circulation by the vibration of their wings. Just before the cell is capped, the worker adds a drop of material from her poison sac, which acts as a preservative.

2. RESPIRATION.—The system is, in general, somewhat like that described for the grasshopper, though the spiracles are small and not easily seen. The spiracles lead to an elaborate system of air passages, the *tracheae*, expanded in certain portions into *air sacs*. Air is forced out of the spiracles by the telescoping of the abdominal segments and the contraction of the sides. It is drawn in by the reverse of this process. The smaller branches ramify to all parts of the body, and through them oxygen from the air is brought to the tissues and carbon dioxide taken

away. In animals other than insects, this function is performed by the circulatory system.

3. THE EXCRETORY, CIRCULATORY, AND NERVOUS SYSTEMS of the honeybee are much like those of the grasshopper, though more specialized.

4. SPECIAL SENSES. *a. Vision.*—The compound eyes and ocelli have been mentioned. The eye of the honeybee is like that of the grasshopper in structure, each facet being connected with an ommatidium, or seeing unit. There may be as many as 5,000 of these separated from each other by a thin layer of pigment. Between the six-sided facets are hairs which have a protective function (Fig. 285*B*). Although they cannot distinguish red from other dark colors, experiments seem to indicate that bees are able to distinguish colors in flowers.

b. Smell.—The olfactory pits on the antennae are concerned with the sense of smell. The drone has the greatest number of these, about 37,800. It is thought that this is connected with the finding of the queen in the nuptial flight. The queen has about 2,400 of these pits and the workers about 1,600.

c. Hearing.—Bees may be deaf, though there are some pits on the antennae that may be auditory organs. Since bees produce sound, it would seem that they must have some mechanism for hearing.

d. Taste.—Taste setae, as well as other structures about the mouth, have been described as taste organs. They seem able to distinguish sweet, sour, bitter, and salty.

e. Touch.—Tactile hairs of two kinds occur on the antennae of bees, and there are hair-like end organs of touch on various parts of the body (Fig. 285).

5. REPRODUCTION.—The workers are infertile females that take no part in producing young.

a. The Role of the Drone.—The reproductive system of the drone consists of two *testes* in the abdomen of the male, each connected with a *sperm duct*, or slender tube, the *vas deferens*. Each of these expands to form a sac, the *seminal vesicle*, for the storage of the sperm that are formed in the testes. The two seminal vesicles empty into the *ejaculatory duct*, which is a single median tube, and this, in turn, is connected with the copulatory apparatus. There are also two large glands secreting nourishment for the sperm that empty into the ejaculatory duct. The drone takes no part in the work of the hive; his important function is to transfer sperm to the queen. During the nuptial flight, enough sperm are transferred to the queen to last her lifetime of 5 or more years. The drone usually dies after the nuptial flight, since some vital organs may be torn out with the sperm pocket.

b. The Role of the Queen.—The queen is the mother of the hive and lays all the eggs. She has two large *ovaries*, each consisting of a large

number of parallel tubes, within which the eggs are formed. The ovaries are connected with an *oviduct,* and the two oviducts fuse to form the *vagina,* which leads to the exterior. A reservoir for storing sperm, the *spermatheca,* opens into the vagina on the dorsal side. The queen mates but once, and the sperm may live for years in the spermatheca. She may live 5 or more years and, during the season, may lay 900 to 2000 eggs a day.

The eggs pass down the oviducts to the vagina and may or may not be fertilized. The eggs placed in drone cells are not fertilized, whereas those placed in queen and worker cells are. How the queen determines whether or not the eggs are to be fertilized is not known.

c. The Larvae.—The eggs hatch in 4 days into grub-like larvae. As has been pointed out, the queen larvae receive different food from that given to the drones and workers. The larvae molt several times, then spin a cocoon and *pupate* (Fig. 286). At the end of the larval period the workers place a food supply in the cell and then cap it over. The three types of bees vary as to the time of emerging from the pupal state.

	Hatching of the egg, days	Larval period, days	Pupal period, days	Time of development, days
Worker	3	6	12	21
Drone	3	6½	14½	24
Queen	3	5½	7½	16

Apparently the difference between the queen and the workers is due to the way in which they are fed.

C. The Activities of the Hive. 1. WORK DONE BY THE WORKERS.—When bees settle in a hive, the workers go out and gather a resin-like substance from buds of trees. It is called *propolis* and is used to stop all chinks. They then gorge themselves with honey and attach themselves together, the front feet of one being hooked on to the hind feet of the one in front. In this way, they form a sort of "wax curtain" and remain motionless for a time, or until the *wax* is secreted. The wax is secreted by wax glands and passes through pores to the underside of the abdomen (Fig. 288*C*), hardening as it reaches the air. The plates of wax are removed by the hind legs, passed forward and kneaded by the jaws, and so begins the building of the comb. The comb is made up of six-sided cells arranged horizontally (Fig. 285*D*). The cells are used for the young and for storing honey. The cells for the drones are about one-third larger than the worker cells; those for the queen are larger than either, appearing something like a peanut (Fig. 286*D*).

The workers keep the hive clean, bring in water and pollen, and finally wear themselves out bringing in the nectar from which honey is made. At the height of the season, a worker will live only about 6 weeks.

2. Swarming.—When the hive becomes crowded, the old queen collects some thousands of her subjects, and all fly away to a new home. This may happen twice or three times during a season. When the new queens emerge from their cells, they "fight it out" until only one remains. Workers do not aid in the elimination of the extra queens. Only one remains and becomes head of the hive after her nuptial flight.

3. Bees in Winter.—The males die at the approach of winter, being pushed out of the hive by the workers, probably to conserve the food supply. The workers, born in late summer, and queen are left. But the activity of the hive does not cease entirely, and so a good supply of food must be on hand if the bees are to survive. By forming a ball and exercising, the workers are able to keep the temperature of the hive 20 to 30°F. above that on the outside of the hive. The bees on the outside of the ball exercise the most, and so positions are often exchanged; the bees on the outside move to the center, those in the center moving to the outside.

D. Importance of Bees.—Biologically, the bees are important as an example of extreme specialization for the type of life they lead in a social community. They are important to man as pollinating agents, for many important crops depend upon them entirely. For example, red clover is pollinated only by the bumblebees. In addition, many thousands of pounds of honey and beeswax are sold in the markets every year.

IV. Social Life among the Insects

In the insect world, there are all gradations of social life, from solitary forms to the complex communities of wasps, bees, ants, and termites.

Most insects live individual lives, and, beyond the fact that eggs are laid in a favorable situation, often upon a suitable food supply, there is no parental care of the young whatever. Some take an active part in providing for the next generation at the time of egg laying but take no part in providing for the developing young. For example, a number of wasps make nests, provide them with flies, caterpillars, or spiders that they have paralyzed by stinging, then lay a single egg in each nest, and seal it up. The young larva hatches, finds plenty of food, feeds, grows, pupates, and finally emerges without ever having known its parents.

There are various theories as to how social life among the insects has come about. One is the dependence of the young upon the parents, resulting in the close association of the parents and the young.

Annual communities may be formed, as by bumblebees. In the late summer, young females find a protected place to pass the winter, under bark or in some other suitable place. All the others die; only the queens

live through winter. In the spring, each queen finds a small hole, perhaps the abandoned nest of a field mouse. Here she makes a nest of grass and moss and then brings in a mass of pollen and moistens it with nectar. This is protected by a wax wall, and the eggs are laid in the pollen mass, which is then capped over with a wax covering. She makes an open cell and fills it with honey and places it between the nest and the entrance. This furnishes her with food. When the eggs hatch, she gnaws a hole in the wax and drops food, regurgitated honey and pollen, inside for the young larva. The young larvae eat this and soon eat out a hole in the pollen mass. In about 10 days the larvae are fully grown and spin a tough cocoon. The wax cap of the nest is then removed. In this way, the separate cells are made by the larvae themselves. In about two weeks, the adults emerge and take over the work.

For habits of ants, see page 776; for adaptations, "mimicry," protective coloration, and the like shown by insects, see page 769; for further discussion of injurious and beneficial insects, see Chap. XLVIII.

V. The Orders of Insects

An extended description of the innumerable types of insects would be out of place here. Authorities do not agree upon a single classification. Some classifications are made upon the basis of the structure of wings and mouthparts, some upon type of development; some use other features as a basis of classification. No subclasses and few suborders are included in the following brief description of the more important orders of the Insecta, which is placed here for reference. For a more extended classification of this group, the student is referred to special books on the subject of entomology.

Order 1. *Thysanura* (Gr. *thysanos*, tassel; *oura*, tail) or *Aptera* (*Gr. apteras*, wingless). The *bristletails* or *silverfish*. Primitive, wingless Insecta; mouth parts, chewing; no metamorphosis; household pests that do much damage to bookbindings and clothing. About 300 species.

Order 2. *Collembolla* (Gr. *kolla*, glue; *embolon*, peg). The *springtails*. Primitive; wingless; mouth parts chewing; no metamorphosis; often microscopic; found in crevices of bark, under wood, etc.; feed on decaying matter; the snow flea, *Achorutes nivicola*, sometimes a pest in sugar-maple camps, and the garden flea, *Bourletiella hortensis*, damaging to young vegetables. About 1,200 species.

Order 3. *Orthoptera* (Gr. *orthos*, straight; *pteron*, wing). *Grasshoppers, crickets, katydids, praying mantis*, etc. Four wings; sometimes reduced or wanting, the front pair narrow, somewhat thickened, the hind pair membranous, broad, and folded when at rest; metamorphosis gradual (Fig. 289).

Six distinct families; the first three are the singing, jumping Orthoptera, or Saltatoria (L. *saltare*, to leap).

The grasshopper group, family Locustidae or Acrididae, includes the *short-horned grasshoppers*, sometimes colored green; *katydids* and *camel crickets* are included in the family Tettingoniidea.

Ordinary *crickets*, *tree crickets*, and *mole crickets* belong to the family Gryllidae.

Members of this group have wings and produce sounds; the "ear" (Fig. 418) is on the front leg (tibia).

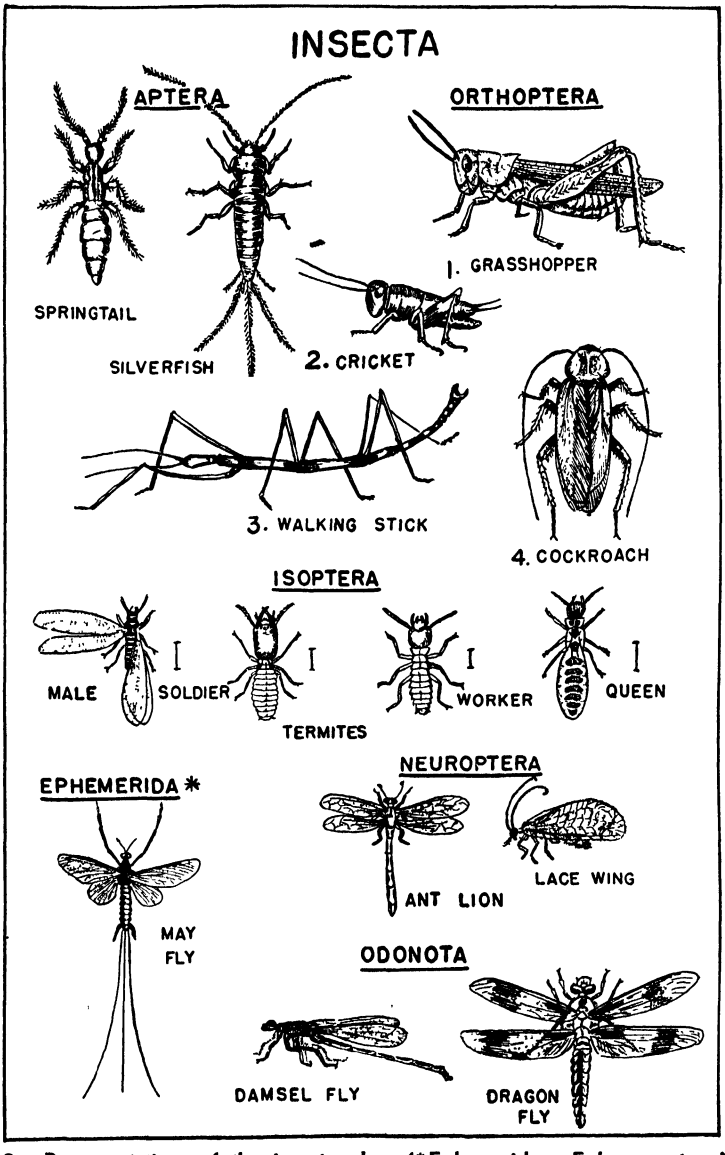

Fig. 289.—Representatives of the insect orders. (*Ephemerida = Ephemeroptera.) (B. F. Edwards. The figures are not drawn to scale.)

Walking sticks, walking leaves, devil's-darning-needle, family Phasmidae; resemble twigs and furnish an excellent example of protective resemblance.

To the family Blattidae belong the familiar cockroaches; the body is flattened; they have been called *the running* Orthoptera; have a bad odor and are considered dirty.

The Mantidae include the *praying Mantis;* they are only orthopterans that are exclusively carnivorous; get their name from the curious position in which they hold their front legs, as in an attitude of prayer. Some tropical members of this family have their wings so modified as to resemble leaves. The Orthoptera include about 18,000 species.

Order 4. *Isoptera* (Gr. *isos,* equal; *pteron,* wing). *White ants or termites.* Colonial insects, living in great nests or colonies and having, like ants, several castes; mouth parts chewing; metamorphosis gradual; feed mostly on wood and do great damage to buildings (page 824). About 2,000 species (Fig. 289).

Order 5. *Neuroptera* (Gr. *neuron,* nerve; *pteron,* wing). *Ant lions, aphis lions, Dobson flies, lacewings,* etc. Two pairs of membranous, net-veined wings; mouth parts chewing; metamorphosis incomplete; larvae may be aquatic or terrestrial.

The lacewing, *Chrysopa oculata,* or *golden eyes,* is a beneficial insect, since its larva, aphis lion, feeds upon plant pests such as apids, thrips, scale insects, etc. About 2,000 species.

Order 6. *Ephemeroptera* (Gr. *ephemeros,* for a day; *pteron,* wing). *May flies.* Four net-veined, gauzy wings, folding vertically over the back when the fly is at rest, the hind pair much smaller, rarely wanting; mouth parts chewing but degenerate or wanting in adults; antennae very short; two or three long, slender, many-jointed "tails" (Fig. 289). Nymphs often live 1, 2, or 3 years in the water, but when they emerge as adults they live but a few hours or days in the air; nymphs breathe by means of tracheal gills; important as food for fish. About 800 species (Fig. 289).

Order 7. *Odonata* (Gr. *odons,* a tooth). *Dragonflies, damsel flies.* Four membranous, slender, finely net-veined wings of about equal size; larvae are aquatic; metamorphosis incomplete (Fig. 289).

Two suborders, the dragonflies, Anisoptera, and the damsel flies, Zygoptera. The dragonflies usually hold their wings in a horizontal position when at rest, whereas the damsel flies hold theirs parallel with the body when at rest (Fig. 289). The Odonata are useful to man because both the larvae and the adults feed upon other insects, the adults upon flies and mosquitoes and the larvae upon mosquitoes and other larvae; larvae also serve as food for fish. About 5,000 species.

Order 8. *Plecoptera* (Gr. *plecos,* folded; *pteron,* wing). *Stone flies.* Four net-veined wings; front pair narrow, hind pair very broad, folded like a fan when at rest; mouth parts chewing but often reduced; metamorphosis incomplete; larvae aquatic and require running water that is well acrated. About 2,000 species.

Order 9. *Corrodentia* (L. *corrodens,* gnawing) or *Psocoptera. Book lice, dust lice, bark lice, deathwatches.* Wingless or with four membranous wings with few veins, the first pair larger and when at rest held roof-like over the abdomen; mouth parts chewing, with a curious rod in the maxilla; metamorphosis simple. Book lice are wingless and do much damage to little-used books (Fig. 290).

Order 10. *Mallophaga* (Gr. *mallos,* wool). *Bird lice.* Small, wingless, flattened insects; mouth parts chewing, not blood-sucking; metamorphosis gradual or wanting; mostly parasitic on birds, a few on mammals; feed on hair, feathers, and dermal scales. Those living on mammals possess one claw for grasping hair; those living on birds have two claws to aid them in moving among feathers; common chicken louse, *Menopon pallidum.* About 2,100 species (Fig. 290).

Order 11. *Thysanoptera* (Gr. *thysanos,* fringe; *pteron,* wing). The *Thrips.* Wingless, or with two pairs of slender, nearly veinless wings, fringed with long hairs and laid longitudinally over the back when not in use; mouth parts rasping, with two pairs of palps but only one mandible; metamorphosis gradual, but the larger nymphal stages quiescent; some

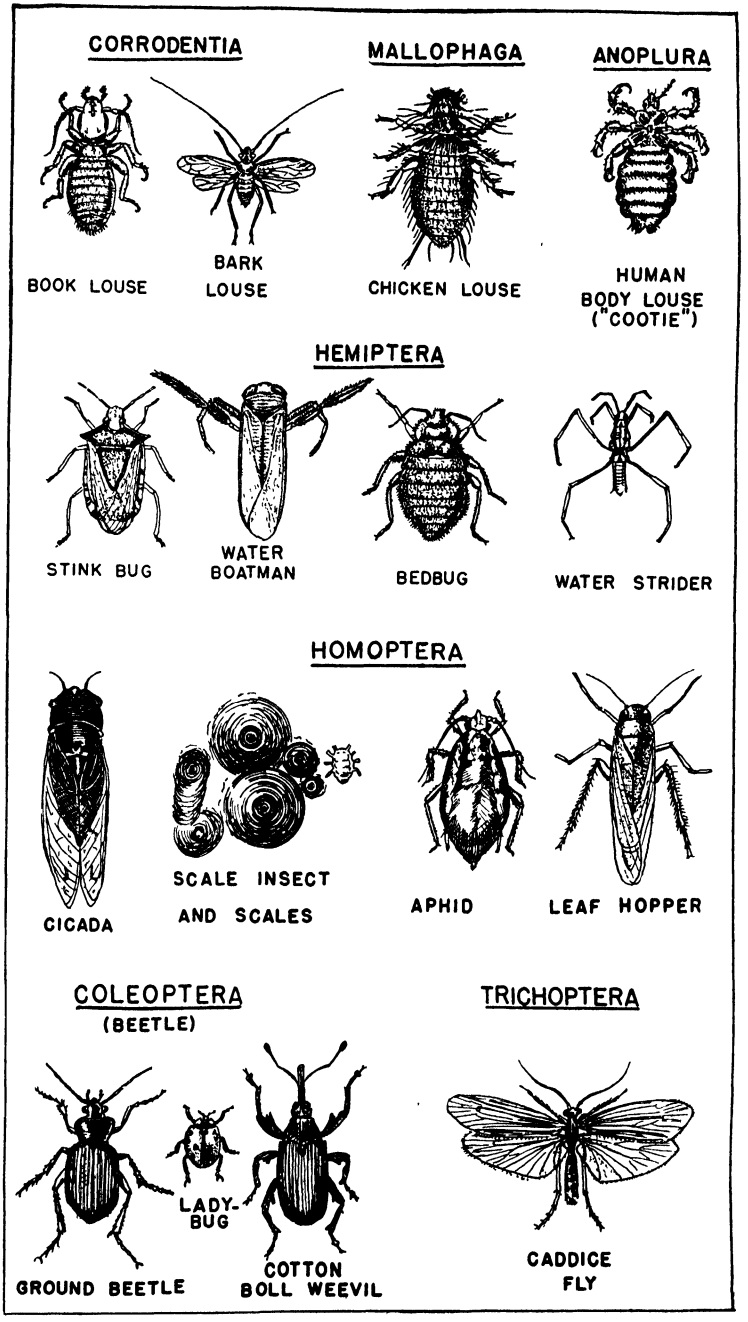

Fig. 290.—Representatives of the insect orders, continued. (B. F. Edwards. The figures are not drawn to scale.)

species injurious to plants, as the *onion thrips, greenhouse thrips*, etc.; others carnivorous and feed on aphids, red spiders, etc. About 600 species.

Order 12. *Anoplura* (Gr. *anoplos*, unarmed; *oura*, tail). *Blood-sucking lice.* Small, wingless, flattened, external parasites of mammals; mouth parts retractile, piercing, sucking; eyes wanting or degenerate; metamorphosis gradual; the eggs (nits) fastened on the hair of mammals. The species that occur on man are the head louse, *Pediculus capitis*, the crab louse, *Phthirius pubis*, and the body louse, *Pediculus corporis.* Typhus and relapsing and trench fevers are transmitted from man to man by the body louse. The *dog louse, hog louse*, and *ox louse* of domestic animals belong to this group (Fig. 290). About 150 species.

Order 13. *The Hemiptera* (Gr. *hemi*, half; *pteron*, wing). *True bugs.* Two pairs of wings, the hind wings shorter and wider than the front pair; distinguished from the Homoptera in having the front pair thickened and stiffened at the basal half, the distal half thinner, usually membranous; many wingless forms; mouth parts piercing and sucking; some with scent glands that give off offensive odors; may be aquatic or terrestrial; the bedbugs that live on warm-blooded animals, human species, *Cimex lectularius; Triatoma megista*, the kissing bug, transmits Chagas' disease (page 815); chinch bugs, destructive to grain; also the squash bugs and stink bugs. About 30,000 species (Fig. 290).

Order 14. *Homoptera* (Gr. *homos*, similar; *pteron*, wing). *Cicadas, leaf hoppers, aphids*, and *scale insects.* Usually two pairs of wings of uniform thickness held over the back like the sides of a roof. Many economically important insects belong to this group. The cicada is sometimes called the *seventeen-year locust, Magicicada*, because the nymphal stage lives in the ground in some sections for 17 years before it emerges; males make loud, shrill calls, but the females have no sound-making organs (Fig. 290).

Among the examples are the *spittle insects* and the *tree hoppers; plant lice*, or *aphids*, mostly small green insects, with or without wings, suck the juices of plants and secrete from the anus a sweet substance, known as *honeydew*, which is attractive to ants, bees, and wasps; the *scale insects* and *mealy bugs*, wingless, legless, degenerate creatures, living beneath a shell of material that they secrete. Among the destructive species are the San Jose scale, *Aspidiotus perniciosus*, the cottony cushion scale, *Icerya purchasi*, the mealy bugs, *Pseudococcus citri* and *Pseudococcus longispinus.*

Several species are useful to man. To this group belong the lac insect, *Tachardia lacca*, from which shellac is made; the cochineal insect, the source of cochineal dye; and the China wax insect, *Ericerus pe-la.* About 25,000 species.

Order 15. *Dermaptera* (Gr. skin wing) or *Euplexoptera* (Gr. *plaited* wing). The *earwigs.* Front wings beetle-like but shorter than the abdomen, hind wings membranous; often wingless; mouth parts chewing; a conspicuous pair of hooks or forceps at the end of the abdomen; metamorphosis gradual; nocturnal; feed principally on vegetation; may become pests. *Labia minor* is a small native species, whereas the European earwig, *Forficula auricularia*, has been introduced into this country. About 900 species.

Order 16. *Coleoptera* (Gr. *koleo*, sheath; *pteron*, wing). *Beetles.* Two pairs of wings, the anterior pair being hard and sheath-like (*elytra*), the hind wings being folded under the hard, leathery forewings; mouth parts, both larva and adult, chewing; metamorphosis is complete (Fig. 290).

The beetles contain the largest number of species of any group of the animal kingdom. They are world-wide in distribution and fitted to live in almost any situation. In a later chapter, some of the harmful beetles, the weevils, are discussed. Some of the beetles do enormous damage (page 825), and some are beneficial. Among the families in which destructive species may be found are leaf beetles, Chrysomelidae; wood-boring beetles, Cerambycidae; click beetles, Elateridae; June beetles, Scarabaeidae and Buprestidae; and the weevils, Curculionidae (page 826). The cotton boll weevil, *Anthonomus grandis* (page 825) and the alfalfa weevil, *Phytonomus posticus*, do millions of dollars' worth of

damage every year. Among the beneficial beetles are the ladybird beetles, *Rodolia cardinalis*, which feed on the San Jose scale that attacks the orange groves; the tiger beetles, of the family Cicindelidae, eat other insects; the predacious diving beetles, the Dytiscidae, also eat other insects in filth. Many more might be mentioned. There are very many useful and interesting forms of beetles.

The fireflies, of the Family Lampyridae, are beetles. They have the power of producing light in their bodies, and they do this without producing heat. The flashing is supposed to be a mating signal, and great numbers often flash in unison. The larvae are predacious, and some of them produce light.

About 250,000 species of Coleoptera.

Order 17. *Strepsiptera* (Gr. *strepsis*, a turning wing). *Stylops*, or *twisted-wing parasites*. Minute internal parasites of insects; four wings, anterior pair reduced to clubs, posterior pair triangular, folding and without cross veins; mouth parts vestigial; worm-like; metamorphosis complete. The stylopids are endoparasites and destroy wild bees, wasps, and some leaf hoppers. About 150 species.

Order 18. *Mecoptera* (Gr. *mecos*, long; *pteron*, wing). *Scorpion flies*. Four long, rather narrow wings with numerous cross veins; head prolonged into a snout, at the end of which are the chewing mouth parts; antennae long and slender; no economic importance.

They get their names from the fact that in some species the males have the tip of the abdomen swollen and carry it curved upward, suggesting the sting of a scorpion.

About 150 species.

Order 19. *Tricoptera* (Gr. *trichos*, hair; *pteron*, wing). *Caddis flies* and *caddis worms*. Four similar, membranous wings, clothed with long, silky hairs, the hind pair shorter and broader; mouth parts reduced from chewing; mandibles absent but palps present; larvae aquatic and build cases of vegetable matter or sand grains fastened together with a silk that is a secretion of modified salivary glands. About 2,000 species (Fig. 290).

Order 20. *Lepidoptera* (Gr. *lepis*, a scale; *pteron*, wing). *Butterflies, skippers, moths*. Four wings, membranous and covered with overlapping scales; mouth parts sucking; metamorphosis complete; second largest group of the insects; range in size from minute to large; many destructive (Fig. 291).

The two large groups are the moths (Heterocera) and butterflies (Rophalocera). One family of butterflies, the skippers, is often set apart (Hesperiidae). They have a skipping mode of flight. Usually the two groups are easily distinguished; the moths are nocturnal, their antennae are thread-like or feather-like, and their wings are held horizontally, whereas the butterflies fly by day and have antennae with knobs on the end, and their wings are held vertically over the back when at rest.

The group is of economic importance; the flowers of the yucca depend upon the yucca moth for pollination (page 165); the common clothes moth, *Tinea pellionella* (page 823), does thousands of dollars' worth of damage each year; some other destructive forms are the codling moth, *Carpocapsa pomonella* (page 826), the gypsy moth, *Porthetria dispar* (page 824), the cabbage butterfly *Pieris rapae* (page 826).

About 120,000 species.

Order 21. *Diptera* (Gr. *dipteros*, two-winged). *Flies, mosquitoes, gnats, midges*. One pair of wings, the second pair being reduced to knobs or halters (balancers); many are wingless; mouth parts are sponging or piercing; young are called *maggots* (Fig. 284); three types of reproduction: by the usual method, eggs laid, *oviparous;* the young brought forth alive, *ovovivparous*, as among the tsetse flies; the young produced by the larvae or pupae, as among certain of the gall midges, *paedogenesis* (Gr. *pais*, child; *genesis*, origin), a type of sexual reproduction by the larval or embryonic stage rather than by the adult (Fig. 291).

Many flies are animal pests, bot flies, screwworm flies, horseflies. Among the crop pests are the Hessian fly, the cabbage and onion maggots. Many members of this

group transmit diseases. Mosquitoes, *Anopheles quadrimaculatus* (page 276); and other species, transmit malaria; *Aedes aegypti*, yellow fever (page 826); the tsetse fly, *Glossina palpalis*, transmits sleeping sickness. Other flies cause the formation of galls on plants.

About 75,000 species.

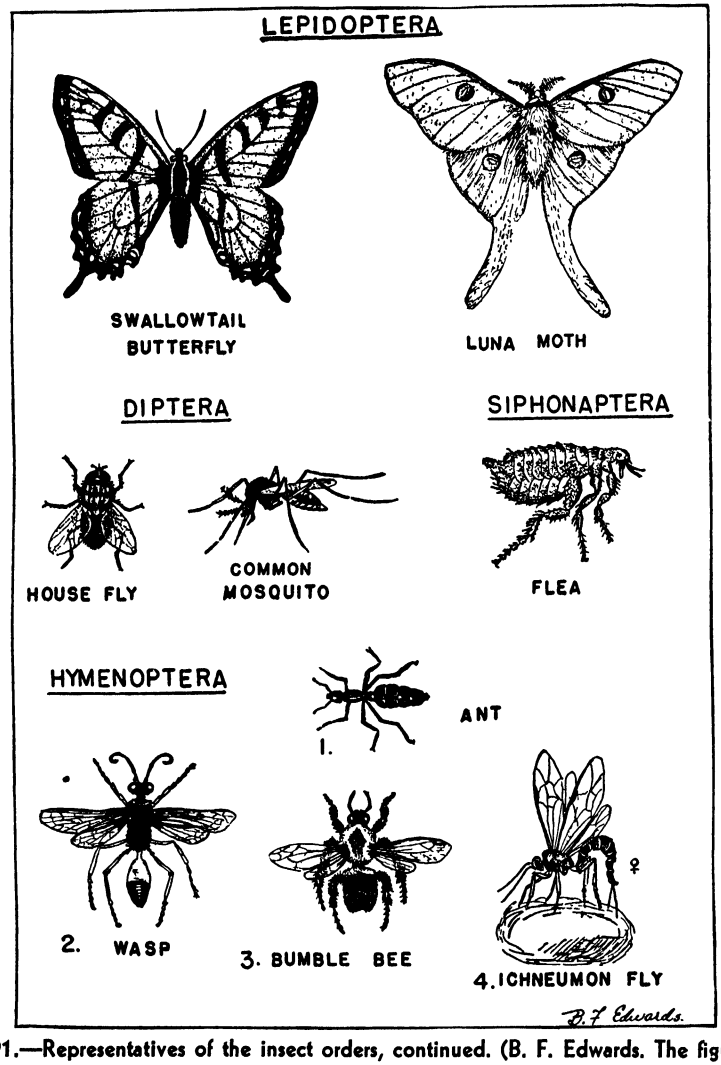

Fig. 291.—Representatives of the insect orders, continued. (B. F. Edwards. The figures are not drawn to scale.)

Order 22. *Siphonaptera* (Gr. *siphon*, tube; *apteros*, wingless). The *fleas*. Wingless; mouth parts piercing, sucking; head small, legs adapted for leaping; metamorphosis complete; larvae slender, cylindrical, without legs or eyes; pupae without wings, enclosed in a cocoon; adult stage, ectoparasitic on warm-blooded animals.

The rat flea, *Xenopsylla cheopis*, transmits bubonic plague; the common cat flea, *Ctenocephalus felis*, also attacks dogs and man; the dog flea, *Ctenocephalus canis*, attacks cats and man; the human flea is *Pulex irritans*.

About 400 species.

Order 23. *Hymenoptera* (Gr. *hymen*, membrane; *pteron*, wing). *Bees, wasps, ants.* Typically, four wings, hind wings smaller, often hooked to the front pair; mouth parts chewing or sucking and lapping; female provided with an ovipositor modified as a sting.

Some species have a system of poison glands, from which the venom is injected into a wound by the sting; sometimes the venom kills other insects and small animals receiving it; in others it has a paralyzing effect, stupefying flies, spiders, caterpillars, or beetles upon which eggs are laid; paralyzed victims are sealed in and furnish food for the young when they hatch.

Hymenopterans may be solitary, as some wasps; or there may be a complex social life, as among the bees, wasps, and ants (Fig. 291).

Some members of this order are pests; the rose slug, *Cladius isomerus*, a saw fly, the gall fly, *Amphibolips*, responsible for oak galls, etc. An interesting form is the fig wasp, *Blastophaga psenes*, which carries on the fertilization of the Smyrna fig.

For the interesting habits of the Hymenoptera, the student is referred to special books on the subject listed at the end of this chapter. About 86,000 species.

NOTE: For special methods of collecting and mounting insects, see *Service Leaflet of General Biological Supply House* 1.

Questions

1. Why would the grasshopper be spoken of as an unspecialized and the honeybee as a specialized type of insect?
2. What is a locust?
3. Compare the crayfish and the grasshopper with regard to appendages and the following systems: digestive, circulatory, respiratory, excretory, nervous.
4. Describe the sense organs of the grasshopper. How is the mosaic type of vision especially useful?
5. What type of metamorphosis is shown by the grasshopper? What other types are to be found among insects?
6. What are some of the usual functions of the blood that are taken over by the tracheae in insects?
7. Why is an insect egg said to have superficial cleavage?
8. What are some interesting facts about the muscles of insects?
9. How are sounds made by crickets? Katydids? Cicadas or locusts?
10. Explain how the legs of the honeybee are wonderfully fitted for their work. Describe the sting, mouth parts, and wings of the bee.
11. How would you distinguish the drone, the queen, and the worker?
12. To what is the difference in development of the worker and the queen due?
13. Why may a drone be said to have a grandfather and grandsons but no father and no sons?
14. What peculiarities are there in the fertilization of eggs by the queen?
15. Describe several types of social life among insects.
16. What special types of adaptations are found among insects?
17. How would you tell a moth from a butterfly? A bug from a beetle?
18. What insects are especially useful in pollinating flowers?
19. Where are the "smell hollows" of a moth?

20. Many flies imitate bees in appearance. How could you be certain that a bee fly is a fly and not a bee?
21. Define, as related to insects: trachea, spiracle, nymph, larva, naiad, ligula, pecten, auricle, proventriculus, entomologist, chitin, Malpighian tubule, ocellus, spermatheca, pupa, chrysalis, imago.

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CHAPTER XXVII

THE ARTHROPODA (*Continued*)
THE ARACHNOIDEA

Much like a subtle spider which doth sit
In the middle of her web, which spreadeth wide;
If aught do touch the utmost thread of it
She feels it instantly on every side.
—Sir John Davies.

I. Arachnoidea in General

The *Arachnoidea* (Gr. *arachne*, spider; *eidos*, form) group includes widely different forms: spiders, harvestmen, ticks, mites, scorpions, and king crabs. They are usually inconspicuous and are not easily seen. A few members of the group are aquatic, but most of them live on land or are parasitic on other animals.

II. Classification

In the following classification, three subclasses and three orders are omitted.

Subclass I. Merostomata (Gr. *meros*, part; *stoma*, mouth).
  Order 1. *Xiphosura*, King crab, *Limulus*.
Subclass II. Arachnida (Gr. *arachne*, spider).
  Order 1. *Scorpionida* (Gr. *skorpio*, a scorpion), scorpions.
  Order 2. *Pedipalpi* (Gr. *podos*, foot; NL. *palpus*, a feeler), *Tarantula*.
  Order 3. *Araneida* (L. *aranea*, spider), spiders.
  Order 4. *Phalangida* (Gr. *phalangion*, a spider), harvestmen.
  Order 5. *Acarina* (Gr. *akari*, a mite), mites and ticks.

III. The King Crab

The king crab, or horseshoe crab (order Xiphosura), is *Limulus polyphemus* (Fig. 292). It is a marine animal with book gills that are similar to book lungs. They are leaf-like and are on the underside of the abdomen, exposed to the water. The *Limulus* has no Malpighian tubules. The food, chiefly worms and mollusks, is held by the chelicerae and chewed by the bases of the walking legs. The *Limulus* comes to the shore to lay its eggs in the spring. These are buried in the sand along the shore.

Limulus is interesting because in some respects it resembles the extinct trilobites (Fig. 293).

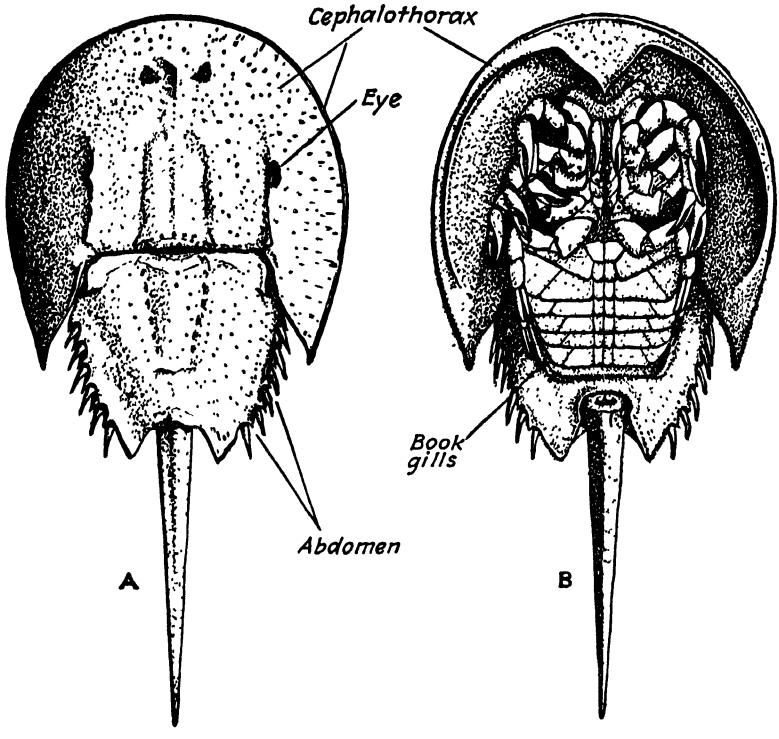

Fig. 292.—King or horseshoe crab, Limulus. (A) Dorsal view. (B) Ventral view. (From Wolcott, Animal Biology.)

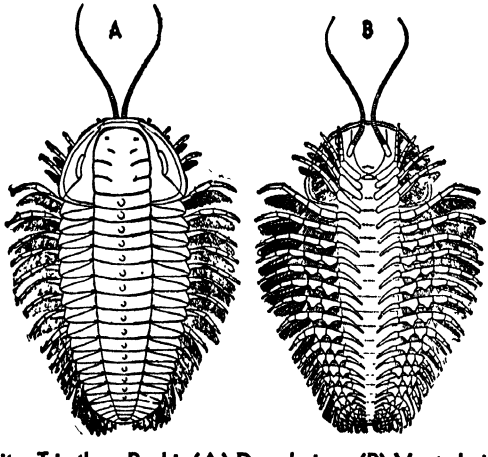

Fig. 293.—A trilobite, Triarthrus Becki. (A) Dorsal view. (B) Ventral view. (After Beecher, from Zittel.)

IV. Scorpions

Scorpions (order Scorpionida) resemble the crayfish in that their pedipalpi resemble the chelicerae of that animal. The body is more clearly segmented than that of most arachnids (Fig. 294). The flattened body is elongated and has a long, slender tail ending in a special stinging organ.

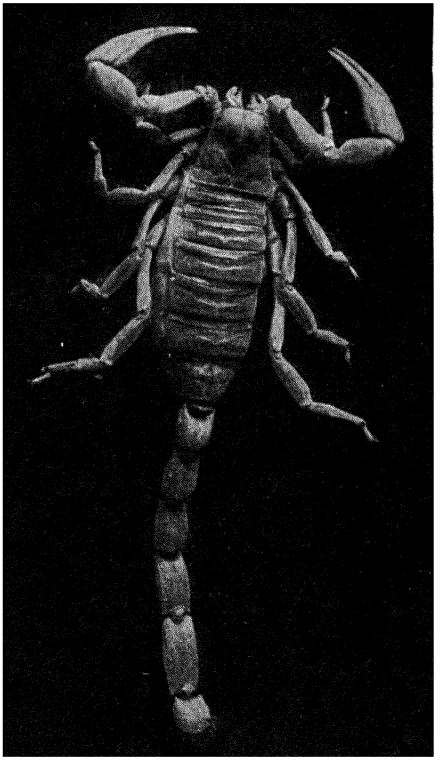

Fig. 294.—A scorpion, Hadrarus hirsutus. (Courtesy of U.S. Bureau of Entomology and Plant Quarantine.)

This it carries bent over its back. Scorpions capture insects and spiders, and larger animals are said to be paralyzed by the poison from the sting.

The young of the scorpions are born alive and are carried around on the back of the female for about a week; they then shift for themselves.

V. The Spiders

A. External Features.—The spiders (order, Araneida) are the best known arachnids. They are easily distinguished from the insects by the fact that the body is divided into two parts instead of three and that they have four pairs of legs instead of three. In spiders, the cephalothorax is

joined to the unsegmented abdomen by a slender waist. The legs are seven-jointed, the joints being the coxa, trochanter, femur, patella, tibia, metatarsus, and tarsus. There are claws at the ends of the tarsi, and between these is sometimes a pad of hair that enables the spiders to run on ceilings and walls. Sometimes the legs are modified to act as jaws.

The mouth parts consist of a pair of *chelicerae* and a pair of *pedipalpi*. The chelicerae are made up of two joints, the basal joint being the *mandible*, and the terminal claw, which is fang-like. In the mandibles are glands that secrete poison. This is injected into the prey of the spider through the openings near the tips of the fang-like chelicerae. The pedipalpi are mostly sensory. Their bases are called "*maxillae*," have six joints, and are used in handling food. While the spider is feeding, the bases of the pedipalpi can be brought together to squeeze the prey while the spider is sucking its juices. In the male, these pedipalpi are modified as *copulatory organs*. The mouth is between the bases of the pedipalpi.

The eyes are simple, usually eight in number, and are situated in the front of the head.

B. Internal Anatomy and Physiology. 1. DIGESTION.—The spider does not eat solid food but sucks the juices of insects and other animals. This is accomplished by a sucking stomach controlled by muscles attached to the cephalothorax and to the stomach. The sucking stomach leads to a true stomach, which gives off five blind caeca at the anterior end. These are for absorption and digestion. The intestine passes from the stomach over the small waist and into the abdomen, where it is enlarged in two places. Into the first enlargement empty the hepatic ducts from the digestive glands or "liver," which secrete a substance resembling the pancreatic fluid of the higher animals. Toward the posterior end is a second enlargement, the "stercoral pocket" (relating to excrement). The *Malpighian tubules* empty into the intestine near the end.

2. CIRCULATION.—The circulatory system consists of a *heart* (lying in a pericardial sinus and located above the intestine), *arteries*, *veins*, and *sinuses*. The blood enters the heart through the ostia. These have valves that direct the flow toward the anterior end and into the cephalothorax. It circulates then in the sinuses, through the tissues, and finally again reaches the pericardial sinus and from there enters the heart.

3. RESPIRATION.—In the arachnids are special respiratory organs, two sacs or *book lungs*. These consist of 15 or 20 leaf-like folds supplied with capillaries through which the blood circulates on its way back to the heart. There are also branching tubes, or *tracheae*, in the posterior part of the abdomen, but they do not play a large part in respiratory activities.

4. EXCRETION.—In addition to the *Malpighian tubules*, which are the main excretory organs, spiders may have rudimental *coxal glands* that are homologous with the green glands of the crayfish.

When the substance reaches the air it hardens, forming the fine silk threads In the making of webs, two types of thread are used a dry, inelastic type, which, in some cases, as in the orb type of web, is used for the framework, and a second type, which is viscid and elastic and which is used to make the spiral threads Spiders let themselves slowly down from high places by spinning out a thread They make various types of traps for insects and many kinds of webs

D Some Interesting Spiders—There are many interesting types of spiders The jumping and running spiders do not build webs but conceal themselves and prey upon insects They do make cocoons to protect their eggs Crab spiders hide in flowers in wait for insects

The trap-door spider makes a hole in the ground, lines it with silk, and closes it with a hinged lid, which it covers with material like its surroundings The burrow is a safe retreat for the little animal

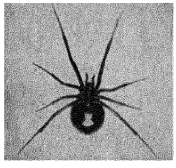

Fig 296—The black widow spider, Latrodectus mactans (Dr E H Runyon)

The native spider that is most harmful is the black widow, *Latrodectus* The female is about ½ in long and is coal black, except for a bright red hour-glass patch on the under side of the abdomen (Fig 296)

Figure 295*B* shows the famous tarantula, a very hairy arachnid that lives in warm climates Sometimes it is classed with the spiders, sometimes placed in the order Pedipalpi It is often carried around in bunches of bananas and has a bad reputation for having a poisonous bite It can kill birds and small mammals with its bite, but it apparently does not kill man

E Importance of Spiders—Few spiders are harmful, and most of them are beneficial because they devour unnumbered destructive insects every year Because they are inconspicuous, their interesting habits are usually overlooked by the layman

VI. Harvestmen

Harvestmen (order Phalangidae), or daddy longlegs, are familiar forms in the woods They get their name from the fact that they are in evidence at harvest time They may be distinguished from spiders by their long legs, segmented abdomen, and the absence of a waist If one tries to catch a harvestman, the legs seem to be shed very easily, probably an adaptation for getting away.

VII. Mites and Ticks

Mites and ticks (order Acarina) are mostly small creatures with the head, thorax, and abdomen fused together. They are mainly parasitic forms.

Mites may be pests that feed upon flowering plants as well as fruit and forest trees, as the brown mites and red spiders; others may feed upon decaying animal and vegetable matter. Other mites cause the formation of galls and diseases of leaves. Still others live in the sebaceous glands and hair follicles of domestic animals and man. The human itch mite, *Sarcoptes scabiei*, can be very annoying. Red bugs, or chiggers, *Trombicula irritans*, also attack man.

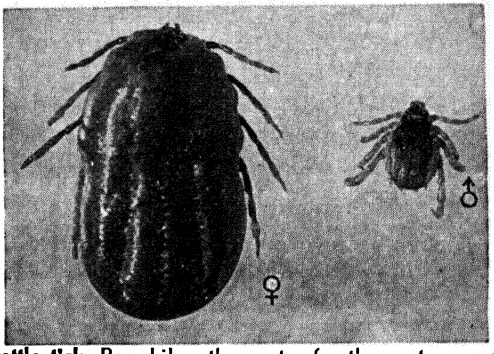

Fig. 297.—Texas cattle tick, Boophilus, the vector for the protozoan **parasite, Piroplasma bigeminum, which causes Texas cattle fever. (Herms.)**

Ticks are important because they transmit several diseases. In the family Argasidae, a tick (*Argas persicus*) transmits fowl spirochaetosis, and another (*Ornithodorus moubata*) transmits African relapsing fever, or tick fever in man. In the family Ixodidae is found a tick [*Margaropus* (*Boophilus*) *annulatus*] (Fig. 297) that is the carrier of Texas cattle fever and another (*Dermacentor andersoni*) that transmits Rocky Mountain spotted fever in man.

VIII. Other Arachnoidea

In the arachnoid group are often included the water bears, or Tardigrada, curious animals with segmented bodies and short, thick legs. Also, sea spiders, or Pycnogonida, which live among the Algae and hydroids of the sea.

IX. Importance of Arachnoidea

Although it is true that the spiders destroy many beneficial insects, they are benefactors in destroying many harmful ones. As has been

pointed out, plants are attacked by mites, and mites and ticks transmit several important diseases to domestic animals and man.

X. Biological Advances Shown by the Arthropods

1. Tendency toward cephalization. Although the nervous system is of the annelid type, there is a pronounced tendency toward fusion of ganglia and localization of control in the head region.
2. Higher development of the sense organs.
3. Paired and jointed appendages. Variety of appendages makes for variety of action.
4. Well-developed exoskeleton.
5. Greater specialization of segments.
6. Gill and tracheal respiration.
7. Green glands.
8. Specialization in the alimentary canal, which is divided and modified.
9. High development of social life and instincts; primitive intelligence in the higher insects and spiders; limited power of learning in the crayfish.
10. Development of protective-coloration, "mimicry," etc. (page 769).
11. All gradations of metamorphosis.

Questions

1. How can you tell a spider from an insect?
2. Are the eyes of spiders like those of insects?
3. How is "spinning" done by spiders? Do all spiders spin webs?
4. Are many spiders poisonous? Describe two that are poisonous. How can you easily identify a black widow spider?
5. Why must the young spider molt to grow? Is there a metamorphosis among spiders?
6. What are some interesting breeding habits among spiders?
7. What human disease is transmitted by the itch mite?
8. What diseases are transmitted by ticks?
9. What are "chiggers"?
10. Why is the *Limulus* an interesting form? What extinct form does it resemble?
11. Define: stercoral pocket, book lung, cephalization.
12. What are the main biological advances shown by the arthropod group?

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CHAPTER XXVIII

THE CHORDATA

The Chordates (Gr. *chorde*, cord) (page 86) include the best known animals, as well as some obscure forms known only to zoologists. Some of these obscure animals are very small, burrowing colonial forms, but the group includes the largest as well as the most complex animals that exist. Fish, amphibians, reptiles, birds, and mammals all belong here.

I. Characteristics of the Groups

Three distinct characteristics set the chordates apart from all other animals and also group the very widely different forms together. These are: (1) The *notochord*, a supporting rod dorsal to the alimentary tract but ventral to the nerve cord. In the lower forms it is a stiff axial rod that is present throughout life; in the higher forms, it is present in the embryo but is replaced by other structures in the adult. (2) A series of paired slits in the pharynx (also in the body of some), known as the *pharyngeal clefts* or *gill slits*. This is an efficient method of providing for respiration, for the gills are placed in direct contact with water. In the higher forms, they appear in the embryo only and are not functional, being replaced by other structures. (3) The *dorsally placed tubular nerve cord*, formed from the ectoderm. At first it is a flat plate of cells. This sinks somewhat, and the outer edges roll up and fuse to form a tube. The cavity is the neurocoele. In the higher vertebrates, the anterior end of the cord is expanded to form the brain. The formation of this tube makes possible a greater centralization or association of the ganglionic masses and permits an increase in the number of nerve cells.

In addition to these three characteristics, the Chordata, especially the vertebrates, have an *endoskeleton* that allows greater freedom of movement, although it does not give so great a leverage to muscles as the exoskeleton of the arthropods. Another advantage of the endoskeleton is that it can be added to as the animal grows. With the arthropods there has to be a periodic molt of the exoskeleton. The development of the endoskeleton made possible the size developed by some vertebrates.

Metamerism is present in the chordates, though it tends to be obscured to some extent.

There are about 70,000 species of chordates.

II. Classification

Subphylum I. **Hemichordata**[1] (Gr. *hemi*, half; *chorde*, a cord) or *Adelochorda* (Gr. *adelos*, concealed; *chorde*, cord). Marine worm-like animals whose relationship to the chordates is questionable.

There is a tubular, hollow, notochord; *Balanoglossus, Cephalodiscus, Rhabdopleura.*

Subphyllum II. **Urochordata**[1] (Gr. *oura*, a tail; *chorde*, cord), also called *Tunicata* (L. *tunica* a tunic) and *ascidians* (Gr. *askos*, bag). Salt water forms with scale-like coverings (tunics).

The larva resembles a tadpole. A notochord is present in the tail of the larva; *tunicates, Salpa.*

Subphylum III. **Cephalochordata**[1] (Gr. *kephale*, head; *chorde*, cord). Fish-like animal chordates.

Body is segmented, and notochord extends from the anterior tip to the tail; *Amphioxus.*

Subphylum IV. **Vertebrata** (L. *vertebra*, a joint) or *Craniata* (Gr. *kranion*, a cranium or head). All vertebrates have a notochord at some stage of development, though it is replaced by an axial skeleton in the higher forms. The skeleton is internal. There is a hollow central nervous system expanded at the anterior end to form the brain and a true body cavity or coelom. *Fish, amphibians, reptiles, birds* and *mammals.*

A. The Protochordates or lower Chordates.—Until recently, the hemichordates were considered to be worms and were classed with the annelids, whereas the tunicates were placed in a group by themselves and classed with the invertebrates. The *Amphioxus* of the Cephalochordata, however, has been long recognized as having vertebrate characteristics.

1. Balanoglossus.—This worm-like animal may be taken as an example of the Hemichordata. It burrows in the mud and feeds somewhat like the earthworm by passing earth through its body and taking out organic matter for food. It varies in length from 6 to 10 in. The body is divided into three parts, a proboscis or anterior portion, a collar, which is ring-like, and a metameric trunk. The mouth opens just in front of the collar. There are a dorsal nerve cord and a large number of pharyngeal slits. The inclusion of this annelid-like form in the chordates rests upon the fact that there is a flexible cellular rod extending into the proboscis from the dorsal wall of the alimentary canal. This stiffens the proboscis and aids the animal in its burrowing. It is considered to be a notochord, though some authorities doubt that it is a true notochord. Figure 298*A* of *Dolichoglossus* is much like *Balanoglossus*. The larva of *Balanoglossus*, the tornaria larva, resembles the echinoderm larva in some respects (Fig. 247).

2. Tunicates, representatives of the Urochordata, may be either free-swimming or fixed forms, though most of them are fixed in the adult stage (Fig. 298*B*). They are salt-water forms and have a sac-like covering or tunic that contains cellulose, unusual in the animal kingdom. One of the common names for the tunicates or ascidians is "sea squirt," so named because when it is stimulated it throws water some distance.

[1] Also spelled *Hemichorda, Urochorda, Cephalochorda.*

The development of the tunicates reveals its chordate characteristics (Kowalevsky, 1866). The larva, resembling the tadpole of a frog, has a *notochord*, a *neural tube* in the tail, and a *pharynx* that opens to the exterior by *gill slits*. The larva is free-swimming but settles down, secretes a sticky fluid by which it becomes attached to some object, and undergoes metamorphosis to form the adult characters. Some of the tunicates are brightly colored.

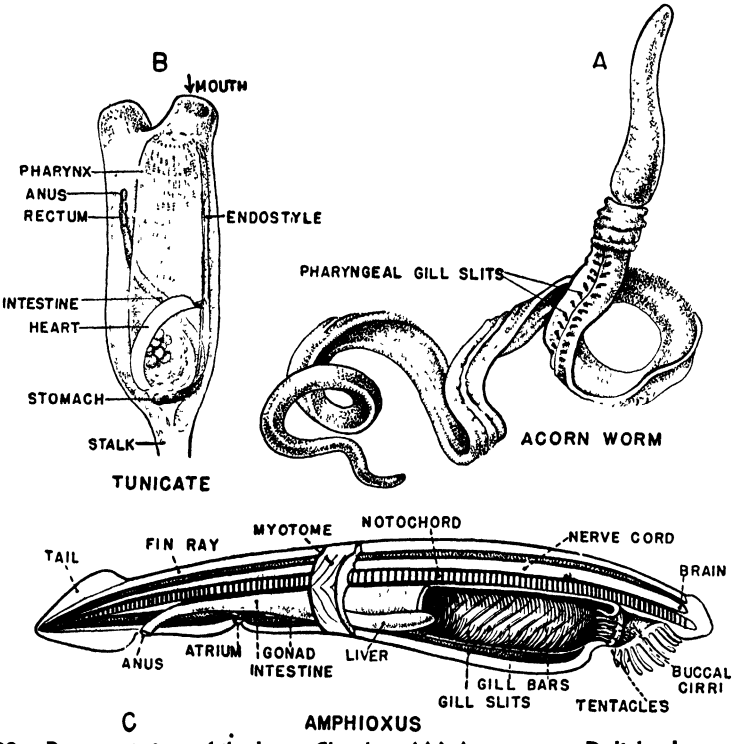


Fig. 298.—Representatives of the lower Chordata. (A) Acorn worm, Dolichoglossus. (After Bateson.) (B) A tunicate, Ciona. (C) Diagram of Amphioxus. (F. A. Baker.)

A typical tunicate is attached and is surrounded by a *tunic*. It has two openings at the anterior end, a mouth opening, also called the *incurrent siphon*, into which the current of water passes, and an *atrial* opening or *excurrent* siphon through which the water escapes to the outside. The current of water brings in food, oxygen for respiration, and takes away wastes. The food consists of microscopic plants and animals. Near the mouth is a sensory sieve, or *velum*, through which the food must pass. In the pharynx is a groove, the *endostyle*, which secretes mucus and in which the food is entangled. The alimentary canal is

U-shaped and opens into the atrial cavity. The nervous system consists of a single ganglion, the brain, which lies between the branchial and atrial tubes.

The animals are hermaphrodites and possess both male and female reproductive organs, though cross-fertilization is the rule. Fertilization takes place in the water, and the animals develop into the tadpole larvae. Reproduction may also take place by budding, and in some forms colonies may be formed having a common tunic. Few chordates form colonies. There may be also another retrogressive feature, alternation of generations, one generation reproducing sexually by the formation of sperm and eggs and the next asexually by budding.

3. Amphioxus.—The best known example of the Cephalochordata is *Amphioxus, Branchiostoma lanceolatus* (Fig. 298*C*), sometimes called the *lancet.* It exhibits the characteristics of the chordates in a simple way and is probably similar to the ancestors of the vertebrates.

a. Habitat.—*Amphioxus* is found along the sandy shores in warm climates. It burrows in the sand headfirst, but when at rest it leaves the anterior end exposed. Sometimes it leaves its burrow at night or in the breeding season and swims about by lateral movements of its body.

b. External Features.—*Amphioxus* has no distinct head and no lateral fins. Along the entire length of the body is a *dorsal fin.* This widens at the posterior end to form the *caudal fin,* which extends forward on the ventral surface about one-third the length of the body and forms the *ventral fin.* These fins are strengthened by *fin rays,* which are rods of connective tissue. In front of the ventral fin, the ventral surface of the body has two metapleural folds, sometimes called the *forerunners* of lateral fins. The anterior end of the body is expanded into an *oral hood,* fringed with sensory tentacles, and on the inner surface are ciliated bands that form the *wheel organ,* which creates a current of water leading to the mouth. The mouth opens on the ventral surface of the oral hood and the anus beside the ventral margin of the caudal fin. Just posterior to the metapleural folds is the *atrial opening,* through which water used in respiration passes to the outside.

c. Internal Anatomy and Physiology. (1) Digestion.—The food of *Amphioxus,* consisting of minute organisms, is brought to the mouth in a water current created by the wheel organ. The mouth opening is in a membrane, the *velum.* It may be closed by the muscles in the velum. The velum has 12 *tentacles* that may fold across the mouth and act as a strainer. The mouth leads into the large *pharynx,* which has clefts in its walls. The number of these clefts varies from 50 to 90 pairs with the species of *Amphioxus.* Surrounding the pharynx and other visceral organs is the atrial cavity. The ciliated hypobranchial groove is in the roof of the pharynx, and on the floor is the the *endostyle,* which functions

as in the tunicates by secreting mucus in which food organisms are entangled. The cilia drive this mucus containing food particles forward by way of two *peripharyngeal* grooves to the hypobranchial groove, whose cilia move the mass back to the intestine. A finger-like diverticulum of the liver, the hepatic caecum, secretes a juice containing digestive enzymes and empties it into the intestine. The intestine is a relatively straight tube in which the food is digested. Digested food is also absorbed from the intestine. The intestine leads to the anus.

(2) CIRCULATION.—There is no heart in *Amphioxus*, the blood being moved by contraction of the blood vessels. By contractions of the ventral aorta, the blood is moved to the afferent branchial arteries in the gill bars, where it is aerated. It then passes back through the efferent branchial arteries to the paired dorsal aortae and then to the median dorsal aorta and then by way of intestinal capillaries to the subintestinal vein. The subintestinal vein collects blood loaded with absorbed food from the intestine and continues to the liver as the hepatic portal vein. It collects blood from the liver and continues forward as the ventral aorta. The direction of blood flow, backward in the dorsal aorta and forward in the ventral vessel, is just the opposite from that of the earthworm and the crayfish (page 361), but like that of the vertebrates.

(3) RESPIRATION.—Water taken in at the mouth passes through the gill slits in the pharynx to the atrial cavity and out of the atriopore. The atrial cavity is not a part of the body cavity, as is shown by the fact that it is lined by ectoderm. The gill slits, which are ciliated, are supported by chitinous rods and are separated by gill bars. These gill bars contain the blood vessels, and the gills on the faces of the bars are ciliated. When the water passes through the gill slits it delivers oxygen to the blood in the capillaries, and absorbs carbon dioxide from it. The oxygen is distributed to all the tissues of the body by the blood.

(4) EXCRETION.—Ciliated nephridia, similar to those of the earthworm, are near the dorsal region of the pharynx. These connect the dorsal coelom with the atrial cavity.

(5) COORDINATION AND SPECIAL SENSES.—*Amphioxus* has a dorsal nerve cord above the notochord. There is a minute canal in this cord, and it is expanded at the anterior end into a cerebral vesicle or rudimentary brain. In young specimens, there is an olfactory pit opening into this vesicle. Near the anterior end is a pigmented mass of cells forming an eyespot. There are also smaller pigmented bodies along the nerve cord. Two pairs of sensory nerves from the cerebral vesicle supply the anterior region of the body, and the nerve cord gives off branches on opposite sides that alternate with each other. These are (1) dorsal nerves that pass to the skin and that have a *sensory function* and (2) ventral nerves that go to the myotomes and that have a *motor function*. In addition to the

organs of special sense mentioned above, there are sensory cells in the ectoderm, on the cirri, and on the velar tentacles.

(6) SUPPORT AND MOTION.—The notochord furnishes a well developed axial support. It is near the dorsal surface and extends the length of the body. The fin rods and the supporting structures of the oral hood are other skeletal elements.

(7) REPRODUCTION.—The sexes are separate, and there are 26 pairs of gonads (*B. lanceolatus*) projecting into the atrial cavity at the base of the metapleural folds. Early summer is the breeding season. When the germ cells are mature, they break out of the gonads into the atrium and are carried out through the atriopore. Fertilization takes place in the water. The eggs of *Amphioxus* are regular in their development (page 684). Following the cleavage divisions is the formation of the blastula or hollow-ball stage, the infolding to form the gastrula, which develops into a free-swimming larva. This develops without metamorphosis.

B. The Vertebrate Groups.—The characteristics of the vertebrates have been mentioned (page 430), and the frog has been described fully as a vertebrate type (Chap. XVII). It is sometimes convenient to study this animal as an introduction to the study of animal biology in general; sometimes it is used at the end of the course. An abridged classification of these groups will be found in Chap. VII, and more detailed descriptions in Chaps. XXIX to XXXII, which are devoted to a study of these important animals.

Questions

1. What are the distinguishing characteristics of the Chordata?
2. Is there any advantage of an endoskeleton over an exoskeleton?
3. What are the four subphyla of the Chordata?
4. Describe briefly a representative of each of the three lower subphyla.
5. Why is the *Amphioxus* often used in the study of a primitive Chordata?
6. Name the vertebrate groups.

Suggested Reference

WALTER, H. E.: "Biology of the Vertebrates," Chap. II, The Macmillan Company, 1939.

CHAPTER XXIX

CYCLOSTOMATA AND PISCES

THIRD FISHERMAN. Master, I marvel how fishes live in the sea.
FIRST FISHERMAN. Why, as men do aland; the great ones eat up the little ones.
—SHAKESPEARE.

I. Hagfish and Lampreys

A. General Features.—The hagfish and lampreys are primitive vertebrates. The most prominent characteristics of these animals are a sucking mouth and the lack of jaws and teeth. They have no scales, are leathery in appearance, and have no paired appendages. The main body support is the notochord, though there is some cartilage in the skeleton. There are seven or more gill slits and a single olfactory pit (Fig. 299*A*).

Hagfish, or myxinoids, secrete slime and if confined in a small space may secrete a quantity. They feed upon either living or dead fish, completely destroying all except the skin and skeleton.

Lampreys live in both fresh and salt water and are predaceous. They have the unpleasant habit of attaching themselves to a living fish, lacerating it with the sharp end of the chitinous tongue, and sucking the blood and other body fluids. They are able to hold on by the sucker-like mouth and chitinous teeth. If the fish is not killed, it has an open sore that is easily infected and so may die. The larva is called *ammocoetes*. It has some features resembling *Amphioxus*, an *oral hood* and an *endostyle*. In the adult, the endostyle becomes the thyroid gland.

B. Classification.

Class I. CYCLOSTOMATA (Gr. *kyklos*, circle; *stoma*, mouth). Slender, eel-like vertebrates but with a sucker-like mouth.
Subclass 1. MYXINOIDEA (Gr. *myxinos*, slime fish; *eidos*, form). The *hagfish*.
Subclass 2. PETROMYZONTIA (Gr. *petra*, a stone; *myzontos*, sucked in). The *lampreys*.

The lampreys are often called the lamprey eels, though true eels belong to the bony-fish group, the Pisces.

C. Importance of the Cyclostomes. 1. BIOLOGICAL.—Biologically, the cyclostomes are important as primitive vertebrates. The amphioxus-like characters of the lamprey larva mentioned above are interesting as showing possible common ancestry of the Cephalochordata and the Cyclostomata. The cyclostomes are more primitive than other vertebrates, as shown by the condition of the brain, the large number of gill slits, and the functional pronephros (primitive kidney) in the adult.

2. Economic Importance.—Hagfish are a serious menace to food fish and are, therefore, considered pests. They are not usually used as food by man.

II. Pisces

A. Classification.

Class II. Pisces (L. *piscis*, fish).
Subclass 1. Elasmobranchii[1] (Gr. *elasmos*, metal plate; L. *branchia*, gill). *Sharks, skates, rays.*
Subclass 2. Osteichthyes (Gr. *osteon*, bone; *icthys*, fish).
Order 1. *Dipnoi* (Gr. *di*, two; *pneo*, breathe). *Lungfish.*
Order 2. *Teleostei* (Gr. *teleos*, complete; *osteon*, bone). Familiar fish, *perch, trout, salmon, goldfish.*

B. Elasmobranchs. 1. General Features.—Elasmobranchs resemble bony fish in that they have paired fins and fish-like gills and arches. The skeleton is of cartilage; scales are of the placoid type; there is a spiral valve in the intestine. The dogfish shark is the type usually selected for study in biology laboratories (Fig. 299*B*). In a general course of biology, however, there is rarely time for intensive study of this form. The dogfish shark is a somewhat generalized vertebrate and is easily dissected. On account of the cartilaginous skeleton, the brain and spinal cord are easily exposed for study. Elasmobranchs are often placed in a separate class instead of in a subclass.

2. The Dogfish Shark. *a. Habitat.*—Dogfish sharks are mostly marine, though there are some fresh-water forms. Two types are common, the spiny dogfish, *Squalus acanthias*, so named on account of the spines in front of the dorsal fins, and the smooth dogfish, *Mustelus canis*. There are slight differences between the two.

b. External Features. (1) Body form and exoskeleton.—The body of the dogfish is fusiform, or spindle-shaped (Fig. 299*B*). The head, trunk, and tail are not sharply separated from each other. The trunk and tail are provided with fins for locomotion. There is an exoskeleton made up of tiny placoid scales, each with a small spine. Along each side of the body is a lateral line that has the function of detecting vibrations in the water.

(2) The head.—The pointed extremity of the head is the *rostrum*. Jaws are present on the mouth, which is ventrally placed. Teeth are on both jaws, arranged in diagonal rows. The nostrils open on the ventral side of the rostrum. On each side of the head are the oval eyes, and there is an ear behind each eye. Six gill slits are present, the first being modified as a spiracle. These communicate with the pharynx. Water enters the

[1] Often placed in a separate class.

mouth and escapes through the gill slits. Mucous canals, embedded in the skin, open on the rostrum and adjacent parts of the skin.

(3) FINS AND TAIL.—Two types of fins, unpaired median fins and paired lateral fins, are present. There are two dorsal unpaired fins, an anterior and a posterior dorsal fin, a ventral fin (present in the smooth dogfish only), and a tail fin. The caudal fin in the elasmobranchs is asymmetrical

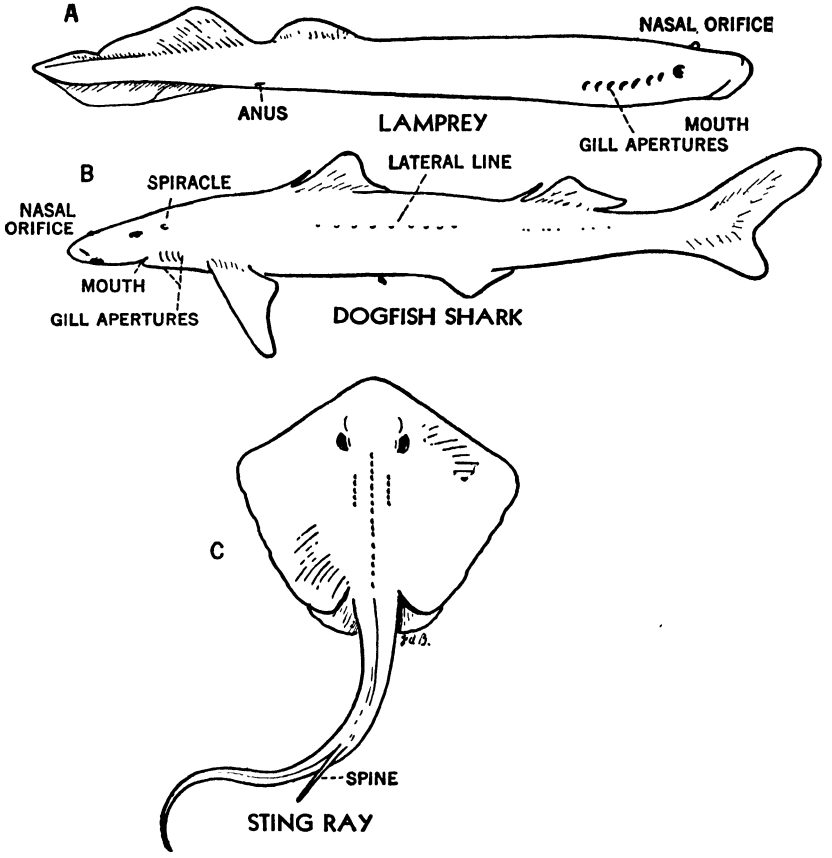


Fig. 299.—(A) Lamprey, Petromyzon marinus. (B) Spiny dogfish shark, Squalus acanthias. (C) Sting ray, Dasyatis hastata. (F. Baker.)

the tail bending up into the narrow dorsal lobe (Fig. 299*B*). This is known as a *heterocercal tail.* The two pairs of paired fins correspond to the limbs of the land vertebrates, the anterior pair, or pectoral fins, just behind the gill slits and the posterior pair, or pelvic fins, at the junction of the trunk and tail. In the male, the pelvic fins may be modified to form *claspers*, or copulatory organs. The anus or cloacal aperture is between the pelvic fins.

c. Internal Anatomy and Physiology. (1) DIGESTION.—The mouth opens into the pharynx, having in its walls paired gill slits and a pair of spiracles. The *pharynx* leads into a *short esophagus*, which opens into the U- or J-shaped *stomach*. At the posterior end, the stomach joins the *intestine*, which has the following regions: the *duodenum* and *ileum*, followed by the *colon* and *rectum*, which opens into the *cloaca*, a sort of general vestibule, since the *gonads* and *kidneys* also open into it. The *cloaca* opens to the outside through the *anus*. Between the stomach and the duodenum is a *pyloric valve*, and in the ileum is a *spiral valve* (Fig. 300), which prevents the food from passing through too quickly and increases the secreting and absorbing surface. A three-lobed *liver* is present, and its secretion, the *bile*, is stored in a *gall bladder* until it is emptied into the duodenum through the bile duct. A *pancreas* lies in the bend of the stomach, and its duct also enters the duodenum, not far from the bile duct. The *rectal gland* empties into the large intestine.

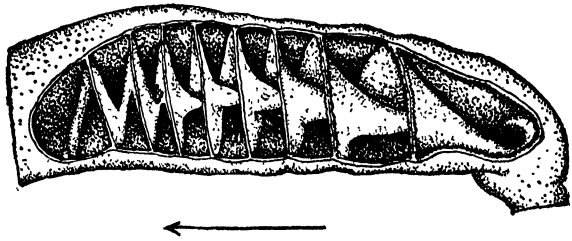


Fig. 300.—Spiral valve of a ray. The arrow shows the direction in which the food passes. (From Wieman, General Zoology.)

(2) CIRCULATION.—Reference to Fig. 301 shows the principal blood vessels. The heart is a *single tube*, bent upon itself in the form of the letter S, lying in the pericardium beneath the pharynx. It has four well-established regions: the *dorsal auricle*, the *ventral ventricle*, with the *conus arteriosus* leading from it, and the *sinus venosus*. The sinus venosus is the collecting organ for the venous blood; into it empty four large vessels, the right and left ducts of Cuvier, and a pair of hepatic veins, which lead into it directly from the liver. The blood enters the heart by way of the sinus venosus, passes to the auricle and then into the muscular ventricle, which contracts and sends it into the conus arteriosus. From here it goes into the ventral aorta, which gives off paired branches to the gills, the afferent branchial arches. These break up into the capillaries of the gills, which are collected into the efferent branchial arches, and here the blood is oxygenated. It is collected through capillaries into the efferent branchial arteries, which pass to the dorsal aorta that they form. An extension of the dorsal aorta going to the brain is the internal carotid artery. The *dorsal aorta* gives off branches that go to all the various parts

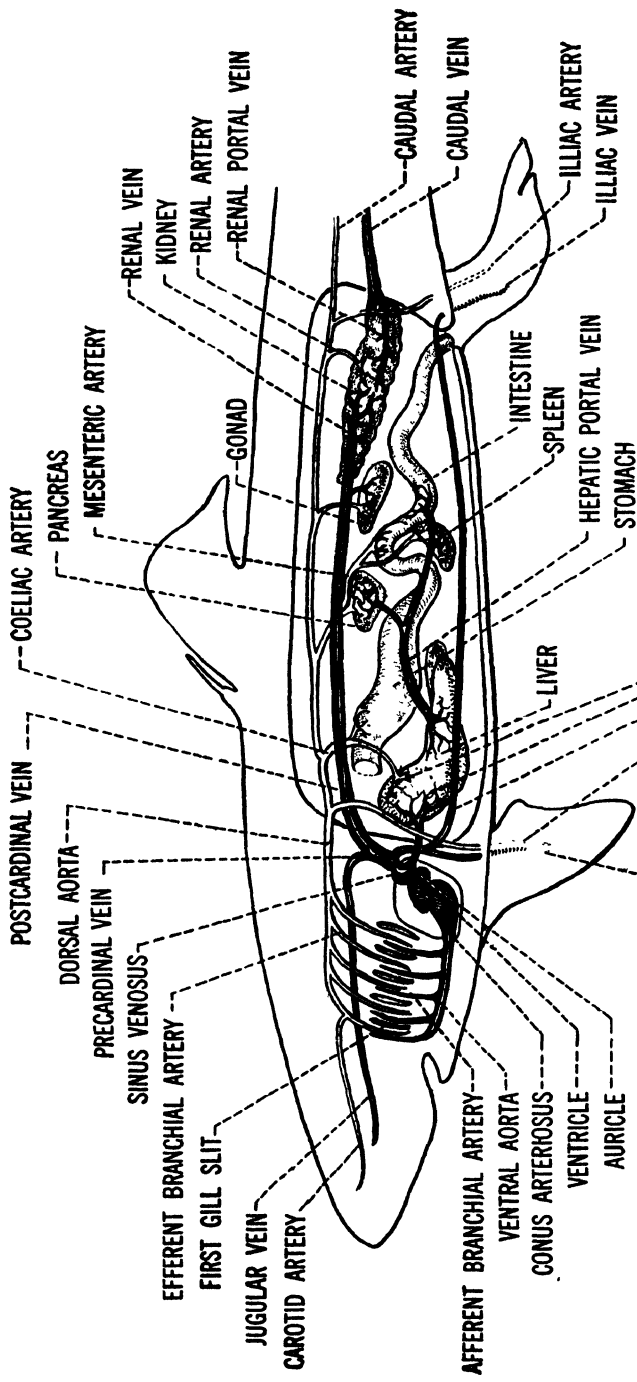


Fig. 301.—Diagram showing the main arteries and veins of the dogfish shark. The arteries, except the ventral aorta, and the afferent branchial arteries, are in outline; the veins in solid black. (F. A. Baker.)

of the body. Thus it will be seen that the oxygenated blood does not return to the heart, as in the higher animals, and that only venous blood goes through the heart. Some of the arteries given off by the posterior extension of the dorsal aorta are the subclavian arteries to the pectoral fins, a large coeliac artery that branches to form the gastric and hepatic arteries, the superior mesenteric artery to the intestine, the inferior mesenteric to the gonads, the renal artery to the kidneys, the iliac to the pelvic fins, and the caudal artery to the tail.

The *venous system* is complex and carries the blood from the capillaries to the great sinus venosus. Paired anterior cardinal sinuses or veins bring the blood from the head; paired posterior sinuses bring the blood from the posterior; these cardinal veins join to form the common cardinal veins, or ducts of Cuvier, which enter the sinus venosus. Other veins from the anterior are paired internal jugulars, from the pectoral fins, paired subclavians; from the posterior, paired lateral abdominal, smaller paired cutaneous, and the paired hepatic. There are two portal systems. (A portal system is a capillary system interposed in the course of a vein.) From the alimentary tract, a large subintestinal vein, loaded with food, goes to the liver. This is the hepatic portal system. In the liver glycogen, a reserve food, or animal starch, is deposited. The capillaries collect the blood and take it to the hepatic veins, which empty into the sinus venosus. The renal portal system consists of a large caudal vein, which branches to send a vein on the outermost side of each kidney. The blood circulates through the kidney and wastes are removed. This blood is then collected by capillaries, which form the renal veins, and these in turn empty into the posterior cardinal veins, which carry the blood forward as described above.

(3) Respiration.—Gills are the main respiratory organs. They are folds of mucous membrane well supplied with capillaries. Water entering the mouth passes between the branchial arches and out through the gill slits. The gills are elaborately branched. As the water bathes them, the blood in the capillaries takes up the oxygen dissolved in the water and gives up the carbon dioxide with which it is loaded. The oxygenated blood is collected by the capillaries of the efferent branchial arteries, passes to the dorsal aorta, and is distributed to all parts of the body.

(4) Coordination. (*a*) Nervous Coordination.—The brain is better developed than in the cyclostomes. Two very large olfactory lobes are conspicuous features. There is a small *cerebrum* of two hemispheres, a pair of *optic lobes*, and a *cerebellum*, which projects backward over the medulla oblongata. Ten pairs of *cranial nerves* are present, as well as a spinal cord. The spinal cord is protected by the *vertebral column*, and paired spinal nerves arise from its sides.

(*b*) Chemical Coordination.—The *endocrine glands* as chemical regulators are characteristic of the higher vertebrates, and it is more

convenient to study them in forms in which their function is known. It is interesting to note, however, that endocrine glands are present in the dogfish. The *interrenal bodies* and the *suprarenal glands*, which unite to form the adrenal gland in the higher *vertebrates*, are separate in the dogfish. The other glands present are the *thyroid*, *thymus*, *pineal*, *pituitary*, *pancreas*, and the *spleen*, which is sometimes considered as having functions of an endocrine nature. Little is known of the functions of these glands in the dogfish. The olfactory organs are a pair of nasal sacs, which open beneath the snout.

(5) SPECIAL SENSES.—The *eyes* are well developed and may be rotated in any position by six muscles. The structure of the eye corresponds, in general, with that of the vertebrate eye.

A system called the *lateral-line system* runs along the body from the head to the tail. It opens at intervals by pores, and at intervals there are special lateral line sensory organs. The lateral-line system is supposed to be able to detect low-frequency vibrations in water.

Tiny sense organs, *pit organs*, or *ampullae of Lorenzini*, are scattered over the body. They are probably a part of the same system as the lateral line organs and the ear.

The *ears* are described by some authorities as specialized lateral-line organs. They lie in the *auditory capsules* and consist of a membranous labyrinth and three semicircular canals. Each communicates with the exterior by a long tube and a small pore, the *endolymphatic duct*. The canals have swellings at the bases, the ampullae in which the organs of balance lie. The ears, in addition to being organs of equilibrium, may be able to detect high frequency vibrations.

(6) SUPPORT AND MOTION.—The *endoskeleton* of the Dogfish and other sharks is of *cartilage*. The skull and vertebral column form the *axial skeleton;* the jaws and gill arches the *visceral skeleton;* and the fins and the pectoral girdles that support them, the *appendicular skeleton*. The vertebrae are said to be *amphicoelous* (Gr. *amphi*, both; *koilos*, hollow). They are hour-glass shaped and are deeply concave at each end. Between the vertebrae are permanent remnants of the notochord. The fins and the tail are the organs of locomotion. The segmented *myotomes* are W-shaped and are separated into dorsal and ventral portions. The muscles are modified in the regions of the paired fins, mouth and gills.

(7) REPRODUCTION AND EXCRETION.—In the cyclostomes, the kidneys and the reproductive organs are quite separate; in the dogfish, they are closely associated and combined into the urinogenital system, the gonads having appropriated some of the tubules of the kidneys. Paired kidneys are dorsally situated in both sexes.

(*a*) Male Urinogenital System.—In the male, there is a pair of *testes*, dorsally situated, each with a mesentery, the mesorchium. In the

smooth Dogfish, they are long slender bodies, more or less fused, supported by a single mesorchium. From the testes, a number of small tubules, the *vasa efferentia*, lead to the anterior mesonephric tubules and into the *Wolffian ducts*, which are the vasa deferentia or sperm ducts. These convey the sperm to an enlarged portion at the posterior end of the ducts, the *seminal vesicles*, which open into the cloaca through the genital papilla. The lower part of the mesonephros is concerned with excretion only. *Ureters* lead from the kidneys or mesonephroi to the Wolffian ducts, also, so that these ducts, for a short space, carry both urine and sperm. The other mesonephric ducts, the Mullerian ducts, are much reduced in the male.

(*b*) Female Urinogenital System.—The female spiny dogfish has a pair of *ovaries*, each suspended by a mesentery, the mesovarium. In the smooth species, the ovaries are long and slender, more or less fused, and extend the whole length of the coelom. There is a single mesovarium in this species for the two ovaries.

In the female, the Mullerian ducts are enlarged to form the *oviducts*, which may be enlarged in the region of the shell gland and at the posterior end as a *uterus*. The Wolffian ducts are purely excretory and lead from the kidneys to an enlarged portion, the urinary sinus, which empties through a urinary papilla into the cloaca.

The *oviducts* are joined beneath the esophagus at their anterior ends and have a single opening, the *ostium*, which is ciliated. Some sharks lay eggs that receive a protective horny covering secreted by the shell gland before they are laid. The dogfish shark is *ovoviviparous; i.e.*, the eggs hatch in the body of the mother, but the young are not attached to a *placenta* (page 694). The sperm are transferred to the oviducts of the female by the male during copulation with the aid of the modified pelvic fins, the claspers.

The eggs rupture from the ovaries into the body cavity and find their way into the oviducts through the ciliated ostium. They are fertilized in the anterior part of the oviduct. The fertilized eggs develop in the *uterus*, which is the expanded lower portion of the oviduct, the young being nourished by the large amount of yolk in the eggs. The little dogfish are called "*pups*" and shift for themselves after they leave the body of the parent.

(8) Coelom.—The *coelom* of the abdominal region is almost completely cut off from the cavity of the pericardium by the transverse septum, the two coeloms communicating by small canals.

3. Sharks in General; Skates and Rays. *a. Sharks.*—There is a great variety of sharks, the whale shark being the largest fish known, reaching a length of 50 ft. or more. Some of the sharks lay eggs instead of being ovoviviparous like the dogfish.

b. Skates and Rays.—The advantage that a very flat body appears to give to fish that live on the bottom has been developed by the skates and rays to the fullest possible extent (Fig. 299*C*). The fins on either side have become enormously expanded and the tail correspondingly reduced, serving simply as a rudder, while undulations of the side fins propel the body forward. As a rule, the underside of the body of skates and rays is light-colored, but the upper surface is darker and may be spotted, so that it blends well with the bottom of the sea when viewed from above. The mouth is on the undersurface and is rather small; hence a ray "cannot at once seize its prey and resorts to stealth to secure its dinner—quietly approaching its victim, which may be a crustacean, or small fish, it darts suddenly over it and smothers it with its body."

Among the better known skates and rays are the torpedo, sawfish, sting ray, and devilfish. The torpedo, or electric ray, possesses electric organs near the head that are capable of giving a powerful shock. It reaches a weight of about 100 lb. and may be found off the Atlantic coast of the United States.

Sawfish are not so broad as are the more typical rays. Their most striking peculiarity is the saw, which is a bony extension at the front end, about 5 ft. in length in a 15-ft. specimen, that has teeth about 1½ in. long extending out from the sides. Sweeping side strokes with such a weapon render the sawfish a formidable opponent.

The sting ray, or stingaree, is a rather obnoxious fish, since it lies half buried in the sand, where it is not noticed until someone steps on its tail with a bare foot and is severely injured by one of its spines (Fig. 299*C*). Near the base of the tail are one or several spines that may reach a length of a foot or more and are barbed along the sides. Wounds due to these spines are ragged and ugly and often subject the victim to the danger of infection. In certain localities, the "wings" of the sting ray are used in preparing a delicacy called *raie au beurre noir*.

4. Importance of Elasmobranchs.—Sharks destroy large quantities of fish, crustaceans, squid, and other animals. They also do great damage to fishing gear. It is estimated that the injury they do to fishing gear along the coast of Massachusetts each year amounts to over $400,000. A "man-eating" shark, *Carcharodon carcharias*, is a tropical species and may occasionally attack man.

Recently the skins of sharks have been used to manufacture sharkskin leather. Oil is also extracted from the livers of sharks. This is used in medicine and industry. The "fish scrap" left after extracting the oil is sold for fertilizer. Although recently shark meat has been canned and sold as crayfish, it is little used as a food. The fins of the rays, as stated above, are considered a delicacy in some places.

C. Bony Fish, Osteichthyes. 1. COMPARISON WITH ELASMOBRANCHS. This group includes a wide variety of forms, ranging in size from ⅓ in. to 30 ft. or more. They are cold-blooded and have an exoskeleton and an endoskeleton. The name *bony fish* is applied to the group because their skeletons are more or less bony in contrast to the cartilaginous skeletons of the cyclostomes and the elasmobranchs. Some of the other more evident points of difference may be summarized as follows:

Elasmobranchii	*Pisces*
Scales placoid or tooth-like	Scales cycloid or ctenoid
Tail fin asymmetrical	Tail fin symmetrical in appearance
Gill slits exposed on the surface	Gill slits covered with a flap or operculum
No air bladder	Air bladder usually present

2. EXTERNAL FEATURES. *a. Body Form.*—Fish are spindle-shaped, in general, though there are various modifications of this in correlation

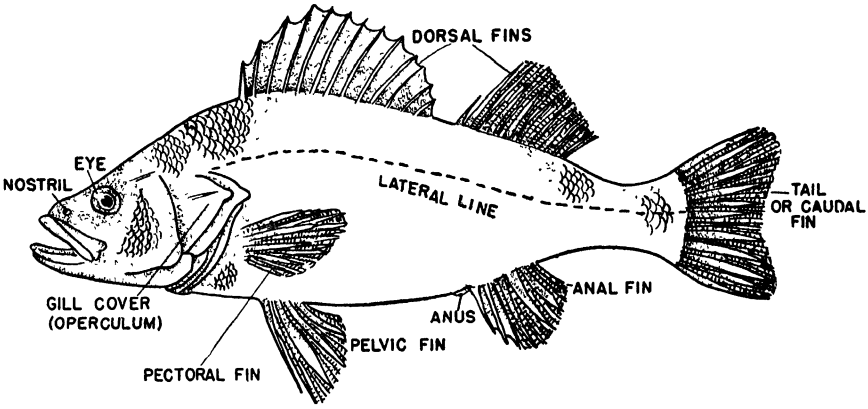


Fig. 302.—Side view of a fish to show external features. Some of the scales are omitted. The function of the lateral line is not certain though it is supposed to be connected with "pressure sense." (B. Shamos)

with the habits of living (Fig. 302). Fish that live in swift currents or that are built for speed are spindle-shaped. Those which live on the bottom are flattened dorsoventrally, as the flounder (Fig. 303), whereas those that live in quiet waters are likely to be somewhat flattened from side to side, as the perch. Eels have long, slender bodies that enable them to enter crevices and holes (Fig. 307*A*). These are only some general forms. There are many bizarre forms of fish of every size imaginable.

The position of the mouth is correlated to the feeding habits of the fish. It may be ventral, terminal, as in most fish, or dorsal, as the Tarpon.

b. Scales.—There are no placoid scales, such as are found on the elasmobranchs, but there are three other types, *cycloid*, *ctenoid*, and *ganoid* (Fig. 304). Cycloid scales, found on the carp and other fish, are

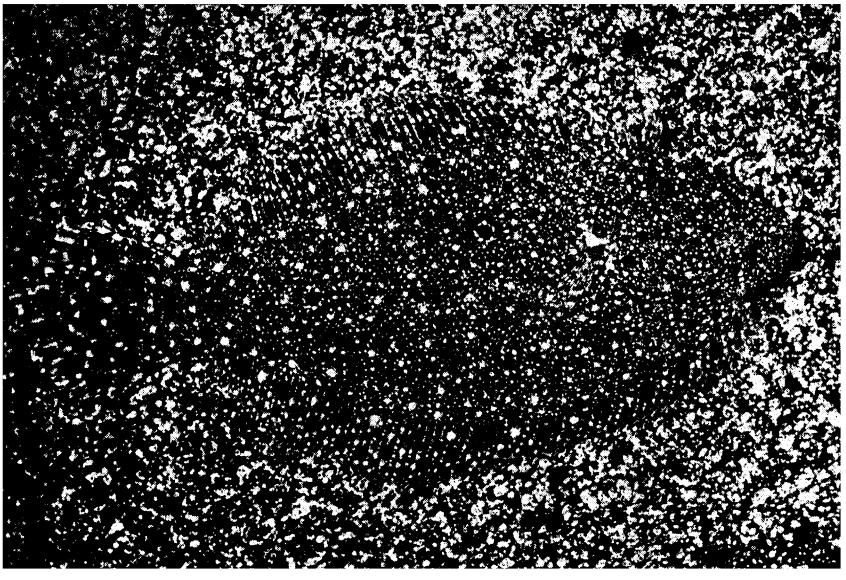


Fig. 303.—The flounder, Pseudopleuronectes americanus. The color pattern of this species changes so as to resemble the background. (Courtesy of U.S. Bureau of Fisheries.)

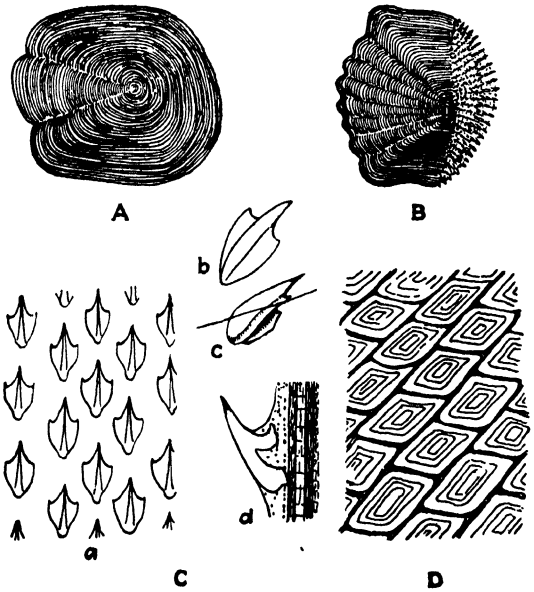


Fig. 304.—Scales of fish. (A) Cycloid. (B) Ctenoid. (C) Placoid. (D) Ganoid. (After Hertwig. From Krecker, General Zoology, Henry Holt and Company, Inc.)

nearly circular with concentric rings; ctenoid scales, characteristic of the perch and the sunfish, are somewhat similar but bear short spines; ganoid scales are usually rhombic in shape and have a hard external covering, ganoin, produced by the dermis. Fish with this type of scale are usually called *ganoid fishes*. Examples are gar pike and bowfins.

c. Fins and Tails.—Though the precise position may vary, there are always two kinds of fins: (1) *unpaired median fins*, which include the dorsal, caudal, and anal fins, and (2) *paired fins*, which include the pectoral, pelvic, or ventral fins. Fins may be variously modified as structures for walking, as in the sea robin, as planes for flying, or as sucking

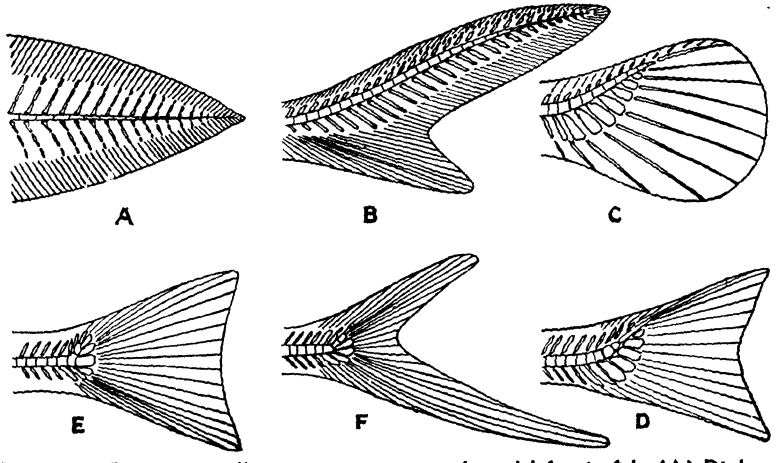


Fig. 305.—Diagrams to illustrate various types of caudal fins in fish. (A) Diphycercal (dipnoan, Protopterus). (B) Heterocercal (cartilaginous ganoid, sturgeon). (C) Homocercal (bony ganoid, Lepisosteus). (D) Homocercal (teleost, salmon). (E) Homocercal (higher teleosts). These figures show a progressive series. (F) Homocercal type representing a secondary modification for a particular purpose (teleost flying fish, Cypselurus). (From Wolcott, Animal Biology.)

disks. The pelvic fins may be lacking, rarely the caudal. The ventral fins may vary greatly in position.

The fact that the shape of the caudal fin varies greatly in the groups of fish is a help in classification (Fig. 305). The symmetrical tail, *diphycercal* or *protocercal*, is shown only in the larval stages of fishes. A *heterocercal* tail is not symmetrical in that the vertebral column extends into the dorsal lobe. A stroke of this asymmetrical tail will send the anterior part of the body forward and is an advantage of fish that feed on the bottom. A sturgeon has this type of tail. The third type is externally symmetrical but internally unsymmetrical. It is called the *homocercal tail*, and a stroke of this tail forces the fish straight forward. Most bony fish with terminal mouths have this kind of tail.

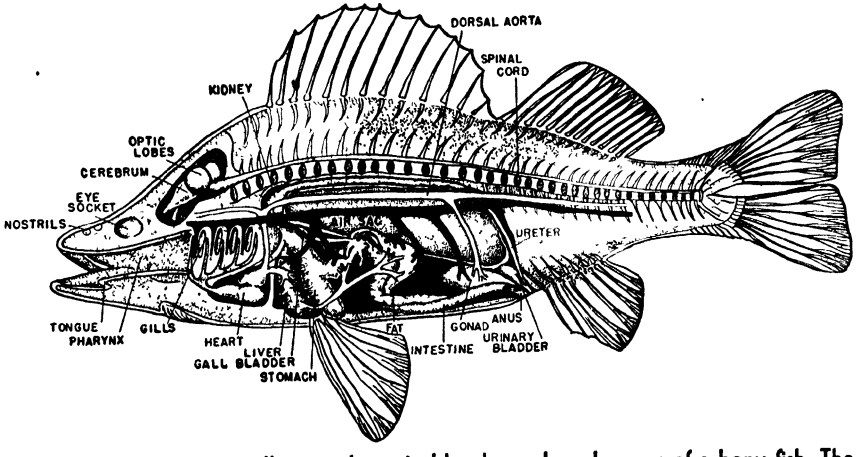


Fig. 306.—Diagram to illustrate the main blood vessels and organs of a bony fish. The air bladder or sac has been pulled down a little to show the position of the kidneys. (L. Runyon.)

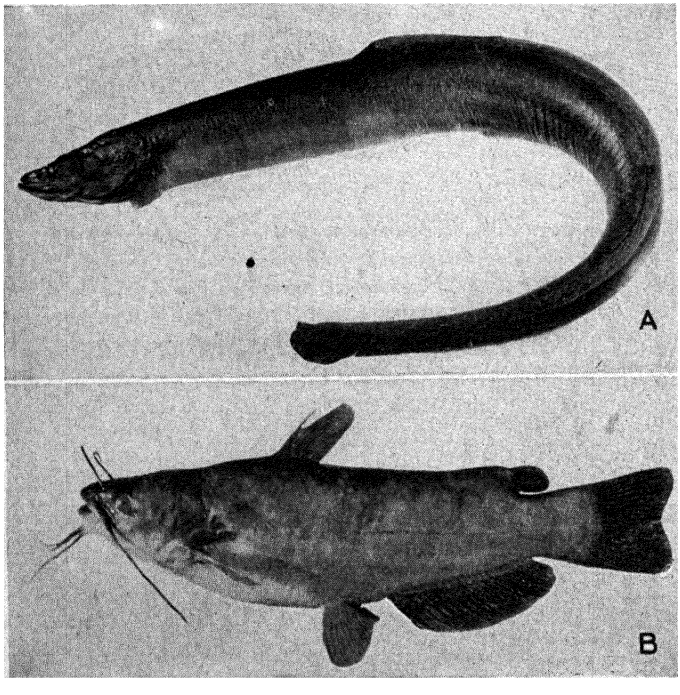


Fig. 307.—(A) American fresh water eel, Anguilla bostoniensis. (B) Common brown bullhead, Ameiurus nebulous. Note sensitive barbules around the mouth of the catfish. (Dr. C. L. Baker at Reelfoot Lake, Tenn.)

d. Coloration.—Many fish are brightly and beautifully colored red, orange, black, or some combination of these colors. The colors may be so arranged as to form definite patterns, and they may be due either to pigment or to special structure of the scales, which contain crystals of guanin (iridocytes). Many fish are protectively colored; *i.e.*, they blend with the background; and some can change their colors through contraction and expansion of chromatophores. This is probably due to light stimulation acting through the eyes and nervous system in the skin. The flounder (Fig. 303) is a good example of this kind of fish.

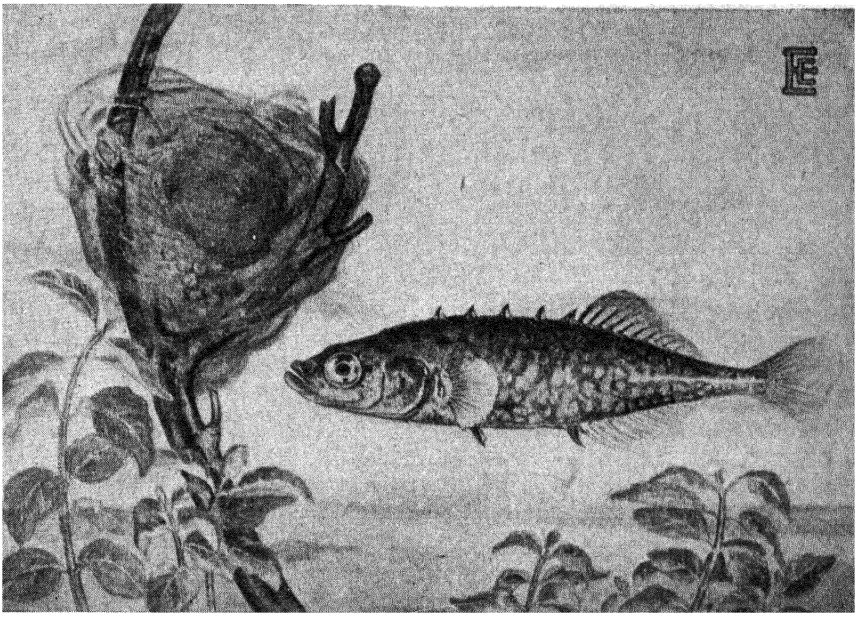


Fig. 308.—Brook stickleback, Eucalia inconstans, and its nest. In this case, it is the male that guards the nest. (Courtesy The New York Conservation Department.)

3. Breeding Habits.—The eggs may be laid singly or in masses attached to some object. In most cases, the eggs are fertilized after they are laid by the male, which deposits spermatozoa, or milt, over them. Thousands of eggs are laid, but few survive, for many animals use them for food. In *ovoviviparous* (L. *ovum*, egg; *vivus*, alive; *parere*, to bear) forms such as the guppy, the eggs are fertilized in the anterior part of the oviducts, pass down the ducts, receiving additional food material and a shell, to the uterus, a modified portion of the oviduct. Here the eggs are developed and hatched, and so the young are born alive.

Development proceeds as shown in Fig. 454. Further details of embryonic development will be found in Chap. XLII. The yolk is used

by the developing embryo as food. By the time it has been used up, the young fish is sufficiently developed to secure its own food.

In some cases, there may be a temporary mating among fish. They may cooperate in making nests, which may be simply a depression scooped out on the bottom or may be elaborately constructed (Fig. 308). In some cases, both the male and the female guard the nest; in other cases, only the male does this work. The male sea horse, a marine fish, has a brood pouch for carrying eggs until they develop.

4. SECONDARY SEXUAL CHARACTERS.—Among fish there may be differences in coloration between males and females as well as differences in size. The male stickleback is more brilliantly colored than the female and has a small protuberance on his head. The male guppy is easily

Fig. 309.—The African lung- or mudfish, Protopterus. When the water dries up in the river, or in the marshes, this fish buries itself in the mud and hibernates until the water again covers its place of living. (Courtesy of The American Museum of Natural History.)

distinguished from the female by his coloring. Other secondary sexual characters are modification of the pelvic fins in the male as claspers and the brood pouch in the male sea horse for carrying the eggs.

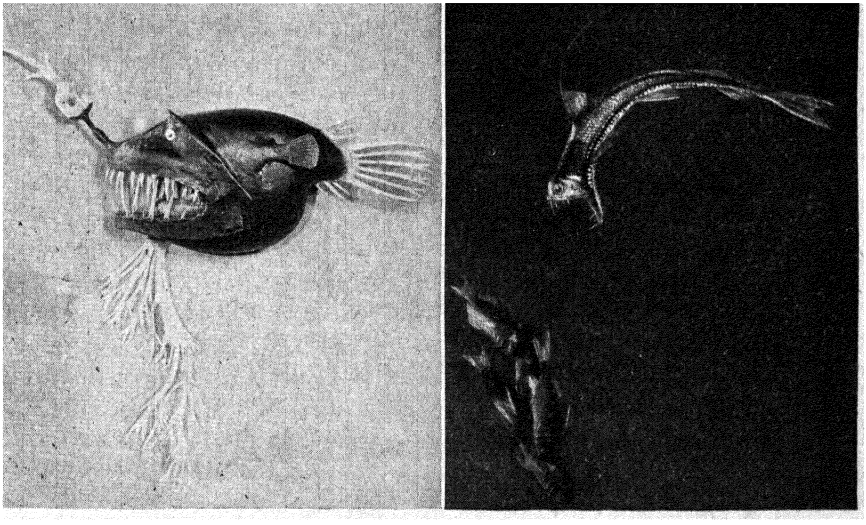
For a description of the internal anatomy and physiology of bony fish, the student is referred to T. J. Parker and W. A. Haswell, "Textbook of Zoology," Part II.

5. SOME INTERESTING FISH. *a. The lungfish*, or Dipnoi, are interesting because they have a modified air bladder, which opens into the pharynx and functions as a lung. Figure 309 shows the African mudfish, *Protopterus*. Ordinarily, they live in marshes, feeding upon crustaceans, worms, insects, etc. During the dry summer, they burrow in the mud, secrete a cocoon of slime with an open tube leading to the outside, and breathe with their lungs. They do not feed but live upon fat in the kidneys and gonads until the rainy season comes again.

b. Deep-sea Fish.—No fish are more interesting than the deep-sea fish, which have become much modified on account of their mode of life. Many families have representatives that have become adapted to

the conditions of the deep sea, which are total darkness, very cold water only a few degrees above freezing, and a pressure of about 1 ton or more to the square inch. The pressure at the surface is only about 15 lb. to the square inch. Since there is no vegetation, all deep sea fish are either carnivorous or eat organisms that sink from upper waters. All the conditions require that fish shall be very much modified from the usual forms if they are to survive.

Among these adaptations are luminescent organs of a great variety. They may be distributed over any part of the body (Fig. 310). Some of these fish have very large numbers of teeth and enormous stomachs. Some are blind and depend upon tactile organs for eyes; the eyes of



are luminescent. (Courtesy of the American Museum of Natural History.)

others are very large to catch all possible light, which at great depths must come from the phosphorescent fish themselves.

c. Fossil Fish.—The Devonian age was called the *Age of Fish* because fish were the dominant form of life at that time. Fish first appeared in Silurian times, about 300 millions of years ago. Their ancestors were soft-bodied forms, probably resembling the *Amphioxus* in some respects. There were many families that are completely extinct.

d. Sea Horse, Sailfish, Swordfish.—The sea horse is a fish with a peculiar body and interesting habits. The brood pouch on the male for carrying the eggs until they hatch was referred to previously.

The sailfish has the dorsal fin modified to resemble a sail. The swordfish has the upper jaw extended to about one-third the length of the body into a flat, sharp-edged, pointed "sword." Just back of the head is a shark-like dorsal fin. The adults are toothless and have no scales.

Specimens 16 ft. long and 300 lb. in weight have been recorded, but they are usually about one-half this size.

Swordfish may attack boats, and many cases are on record in which the sword has been driven through the bottom and fishermen injured or the boat sunk. The sword is supposed to be used for obtaining food as well as for protection. Large fish may be speared, and smaller fish, especially when in schools, are said to be stunned or killed by side strokes of the sword.

6. The Importance of Fish.—It is a familiar fact that fish are important as food for man. Hundreds of millions of dollars' worth of fish are sold in the markets each year by commercial fisheries. Salmon, codfish, halibut, herring, shad, mullet, red snapper, trout, perch, and many others are valuable food fish. Fish eggs are also used as fish roe or the eggs of a Russian species of sturgeon and paddlefish as *caviar*.

Fishing as a sport furnishes recreation for thousands. This may be simply fishing in ponds and streams with a hook and line or may be the complicated sport of deep-sea fishing. Many of the large game fish are good for food, but some, for example the tarpon, are rarely used for food.

Fish are also useful in furnishing certain oil used for various purposes, especially cod-liver oil and "haliver" oil, used in medicine to provide vitamins A and D. Fish scrap left after the extraction of oil is used as a fertilizer.

The mosquito fish, *Gambusia*, is useful in destroying large numbers of mosquito larvae and so aids in preventing the spread of diseases carried by mosquitoes, as yellow fever and malaria.

Ornamental fish are cultivated for home aquariums, the Japanese having developed many odd varieties of the goldfish, which is a native of China. More recently, the cultivation of small tropical fish has been taken up as a hobby by many persons interested in fish as pets.

7. Biological Principles Illustrated by the Fish Group.—For an account of the migrations of fish and other special adaptations not mentioned above, look ahead to Chap. XLVI. By way of summary, the more important biological principles illustrated by the fish are secondary sexual characters, protective coloration, special breeding habits, ranging from no care of young to special nests guarded especially by the male, modifications of tails and fins, and special adaptations for various environments, as flattened bodies for those that live on the bottoms, special adaptations of deep-sea fish, and the like.

Questions

1. What are the general features of a hagfish? Why are hagfish important?
2. Compare the hagfish and the dogfish shark as to external features.

3. What kind of skeleton has the dogfish?
4. What is the function of the spiral valve in the intestine of the dogfish?
5. Compare in a general way the following systems of the frog and the dogfish: digestive, circulatory, respiratory, excretory, nervous.
6. Compare the male and female urinogenital systems of the dogfish.
7. In what ways are the sharks economically important.
8. Give examples of protective coloration and secondary sexual characters of fish.
9. Discuss some breeding habits of fish from an evolutionary point of view.
10. Discuss primitive and modified fins and tails.

Suggested References

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NEWMAN, H. H.: "The Phylum Chordata," The Macmillan Company, 1939.

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CHAPTER XXX

AMPHIBIA

Sweet are the uses of adversity
Which like the Toad, ugly and venomous,
Wears yet a precious jewel in his head;
And this our life, exempt from public haunt,
Finds tongues in trees, books in running brooks,
Sermons in stones, and good in everything.
—SHAKESPEARE.

A. Amphibia in General.—The Amphibia (Gr. *amphi*, both; *bios*, life), as the name implies, are fitted at some time in their lives to live in two different environments, water and air. Frogs and toads are the best known amphibians. The frog has been fully described (Chap. XVII) as an introduction to vertebrate anatomy and physiology. Such an animal indicates very well the transition from life in the water to life on land. The tadpole can live only in water, since it must breathe by means of gills. The first gills are external. These disappear, and four pairs of internal gills are then formed. Water enters the mouth, passes through the gill slits and then out through the spiracles (page 261). When the tadpole transforms into an adult frog (metamorphosis), the lungs become fully developed, and the frog breathes air all the rest of its life. In spite of this, however, it can stay under water for long periods, since the skin is able to carry on a limited amount of respiration. In general, the Amphibia have moist skins, which secrete mucus; the majority prefer damp places. They are cold-blooded, and the heart is three-chambered, having two auricles and a ventricle. Salamanders are often confused with lizards, but all the reptiles have scales, whereas scales are rarely found in Amphibia.

Amphibians show advances over the fish in many ways. The paired fins of the fish have been converted into limbs for moving about on land; in the fish, the nostrils were for the sense of smell only, but in the Amphibia they also take in air for breathing purposes and communicate with the mouth.

The group includes the *salamanders*, *newts*, *frogs*, and *toads*. About 134 of the 2,000 species live in North America.

B. Classification.—There are three orders and many suborders:

Order 1. GYMNOPHIONA (Gr. *gymnos*, naked; *ophioneus*, serpent-like), or *Apoda* (Gr. *a*, without; *pous*, foot). Worm-like, legless amphibians; tail short or absent; the *caecilians* (Fig. 311*A*).

Order 2. CAUDATA (L. *cauda*, a tail) or *Urodela* (Gr. *oura*, a tail; *delos*, visible). Amphibians with tails; gills permanent in some, lost in others; a few breathe through the skin and walls of the pharynx; *salamanders* (Fig. 311*B*) and *newts*.

Order 3. SALIENTIA (L. *salio*, leap). Adults tailless and without gills and gill slits; *frogs* and *toads* (Fig. 312).

C. The Caecilians.—These animals may be looked upon as degenerate. They burrow in the earth and are not unlike earthworms in general appearance, having neither limb nor girdles but having concealed dermal scales. The eyes are rudimentary, the animal finding its way around by a sense of touch. A tentacle-like organ of touch lies in a groove between the eyes. The caecilians live in tropical and semitropical countries.

The blindworm, *Ichthyophthis glutinosa*, is an example of this group. It has the curious habit of laying eggs in a shallow hole near the water

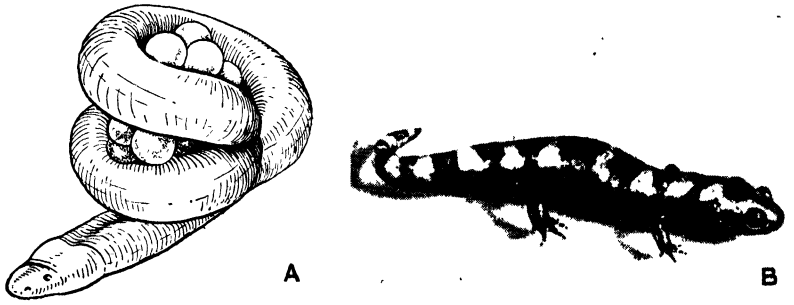


Fig. 311.—(A) A Caecilian, Ichthyophis glutinosa. (After P. and F. Sarasin. From Parker and Haswell, A Textbook of Zoology, Macmillan Company.) (B) Marbled salamander, Ambystoma opacum. (Dr. C. L. Baker, Reelfoot Lake, Tenn.)

and then coiling itself around them (Fig. 311*A*), probably to protect them from other animals. The larval period of this form is passed in the egg, the larva having external gills, which are lost before hatching. After hatching, the animal swims about for a time, but soon the adaptations for aquatic life disappear; the gill clefts close, the tail and fin are lost, and the animal becomes terrestrial. The adults will drown if forced to remain in water!

D. Salamanders and Newts. 1. CHARACTERISTICS.—The tailed amphibians, or Caudata, include primitive and specialized forms. The young are hatched as tadpoles or aquatic larvae. Their metamorphosis into adults may vary considerably, but in general it is inconspicuous. Some salamanders retain their external gills throughout life, even though functional lungs may be developed; others retain only gill slits; still others lose both gills and lungs and use their moist skins as respiratory organs. The main difference between salamanders and newts is one of size.

2. REPRESENTATIVES.—The hellbender, *Cryptobranchus*, is found in the Eastern United States and may reach a length of 18 to 20 in. The giant salamander of Japan may reach a length of over 5 ft.

Ambystoma tigrinum, the tiger salamander, is a form much used for experiments in biology laboratories. It is an interesting fact that its larval form, the axolotl (page 459), was once thought to be a different species. Its gills persist in the adult, but if forced to breathe air it sheds them and becomes the air-breathing *Ambystoma*.

Other salamanders are the *Amphiuma* or Congo eel, the crimson-spotted newt, the *Necturus*, the *marbled salamander*, *Ambystoma opacum* (Fig. 311*B*).

E. Frogs and Toads. 1. COMPARISON OF FROGS AND TOADS.—Frogs and toads, of which there are many species, are representatives of

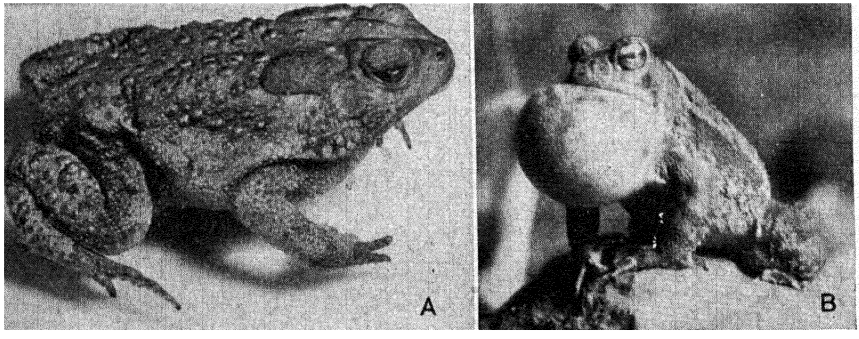


Fig. 312. Toads. (A) American toad, Bufo americanus. (Dr. C. L. Baker, Reelfoot Lake, Tenn.) (B) Toad singing. (Courtesy of Maryland Natural History Society.)

the order Salientia of the Amphibia. The toad differs markedly from the frog in many ways, as can be seen by comparison of Figs. 157 and 312. It is covered with a warty skin, which is not moist, like that of the frog. It wanders some distance from water but always returns to the water to breed. Toad eggs can always be distinguished from frog eggs, because they are laid in the form of strings (Fig. 313), whereas those of frogs are laid in masses.

Toads croak and possess vocal sacs, as do the frogs (Fig. 312*B*). Each frog and toad has its own distinctive call. During the breeding season, there is a chorus to be heard, especially in the evenings. The primary purpose of the call is for mating, though frogs can make sounds to express fear and pain. Bullfrogs may call under water. A few frogs in the Northwestern United States have no voice, and salamanders are mostly silent.

Toads are almost the color of the earth and thus are difficult to see. They often appear just at dusk, hopping along the roadside. Like the

frogs, they *hibernate* (L. *hiberna*, winter quarters) during cold weather. Hibernation is a state resembling deep sleep. Activities are not resumed until conditions are favorable again. It is possible to freeze frogs for a time, and they seem able to resume normal life thereafter. Many animals have the habit of hibernation (page 459).

The toad has a habit of "puffing up" or increasing the size of his body when attacked or irritated. In this condition, it is very difficult for his

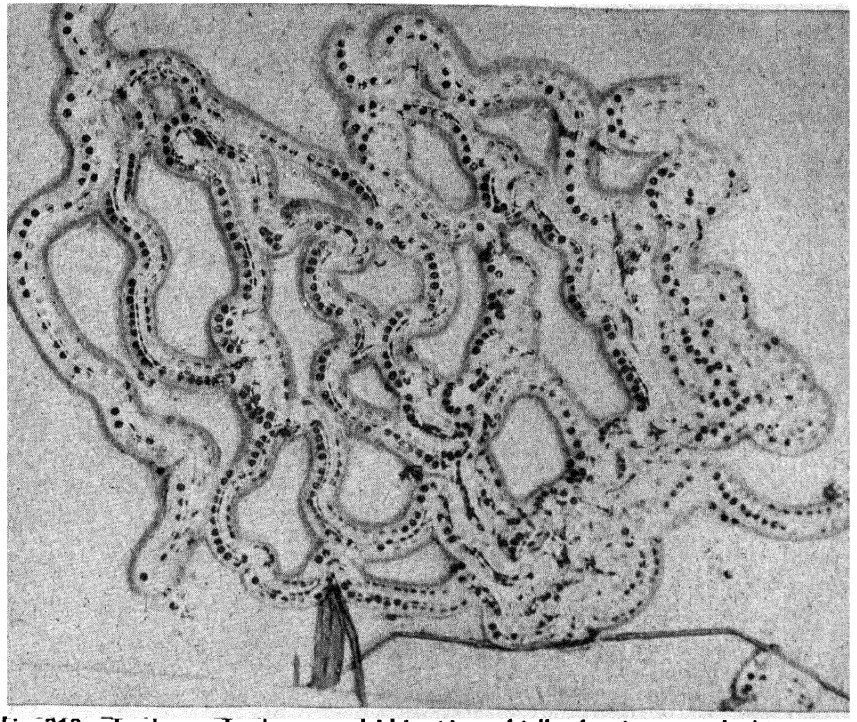


Fig. 313.—Toad eggs. Toad eggs are laid in strings of jelly; frogs' eggs are laid in masses. There may be as many as 4,000 to 12,000 in a single row of toad eggs.

enemies to swallow him. This curious habit has evolved for his protection, although it does not always work.

Another offensive weapon of toads is an irritating, acrid secretion from the glands in the skin.

Toads, like frogs, have four fingers on each hand and five toes on each foot.

2. Representatives.—There is a large group of *tree frogs*. These have adhesive disks on their feet, which enable them to climb, and they usually have large vocal sacs, which give them loud voices. *Hyla versicolor* is a common species. It has the power of changing its color from stone-gray to brown and from white to green. In this way it blends with its

background and escapes notice (Fig. 314). Tree-frog adults range in size from 7/16 in. in the little chorus frog, *Pseudacris ocularis*, to 5½ in. in the Key West tree frog, *Hyla septentrionalis* (Wright).

The genus *Rana* includes the true frogs; examples are the leopard frog, *Rana pipiens*, the green frog, *R. clamitans*, and the bullfrog, *R. catesbiana*. The bullfrog may reach a length of 8 in. It gets its name from its deep voice.

Fig. 314.—Tree frogs, Hyla versicolor. These frogs can change their color through various shades of brown, green, and gray and so are less conspicuous in their natural homes. Soft, adhesive pads on the toe tips enable the animals to climb. (Dr. C. L. Baker.)

The common toad, *Bufo americanus*, is widely distributed. The spadefoot toads have hind feet with spurs adapted for digging.

F. Poisonous Amphibia.—The poison glands of the frogs and toads have been mentioned (page 457), the poison being an effective means of defense. Some salamanders and newts also have poison glands. For example, *Salamandra salamandra* is a poisonous species.

G. Biological Principles Illustrated by the Amphibia. 1. REGENERATION.—Amphibians have a greater power of regeneration than any other

vertebrates. Tadpoles will regenerate lost limbs of tails, but adult frogs seem unable to regenerate lost appendages.

2. PAEDOGENESIS.—It was mentioned above that the larvae of the *Ambystoma* were considered a different species from *Ambystoma* and given the name *axolotl*. They retain their gills under certain circumstances. Larval characters retained after sexual maturity are characterized as *neoteny* (Gr. *neos*, young; *teinein*, to stretch), and the reproduction of young by immature animals is known as *paedogenesis* (page 417). The axolotl is a type that illustrates *neoteny* and *paedogenesis*.

3. HIBERNATION OR ESTIVATION.—When conditions become unfavorable, as cold of winter, amphibians will bury themselves in the mud and hibernate (winter sleep) until spring; also they will estivate (summer sleep) in times of extreme heat or dryness. During this time, the physiological activity of the animals is reduced to a low ebb, and their tempera-

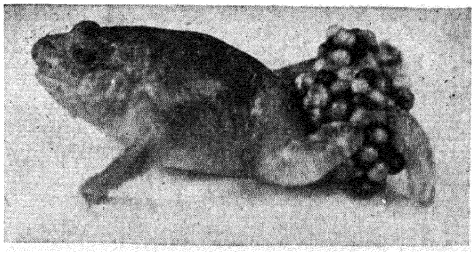


Fig. 315.—The "midwife toad" Alytes obstetricans. The male wears the egg string around his hind legs. (Photograph of a preserved specimen.)

ture is a little above that of the surrounding atmosphere. The slight amount of food needed is supplied from food stored in the tissues.

4. SECONDARY SEXUAL CHARACTERS.—These are shown in the Amphibia by secondary sexual coloration and by the thickened thumb of the male *frog* in the breeding season. In some *salamanders*, there may be masses at the base of the tail, or the teeth may elongate, or there may be other differences. In the bullfrog, the male is distinguished by a larger tympanum than is found in the female.

5. ADAPTATIONS IN BREEDING HABITS.—Most amphibians are oviparous, the eggs being laid in the water and fertilized by the male as they are laid. In a few cases, salamanders and caecilians, the eggs are fertilized internally. Also, a few salamanders bring forth their young alive.

Although the majority of amphibians lay their eggs in water, there are many exceptions to this rule. In many cases, the tadpole stage is inside the egg, the eggs hatching as little frogs. Many salamanders lay their eggs on land.

Among amphibia there are many curious breeding habits. The male obstetrical toad, *Alytes obstetricans* (Fig. 315), carries eggs wrapped

around his hind legs until they are ready to be hatched. He then enters the water, and the young tadpoles are born there. One of the most interesting adaptations is shown by the Surinam toad, *Pipa americana*, of South America, which carries eggs and tadpoles in individual dermal chambers on the back of the female (Fig. 316). A Chilean frog, *Rhinoderma*, uses his vocal pouch to carry the eggs. The young hatch as fully formed young.

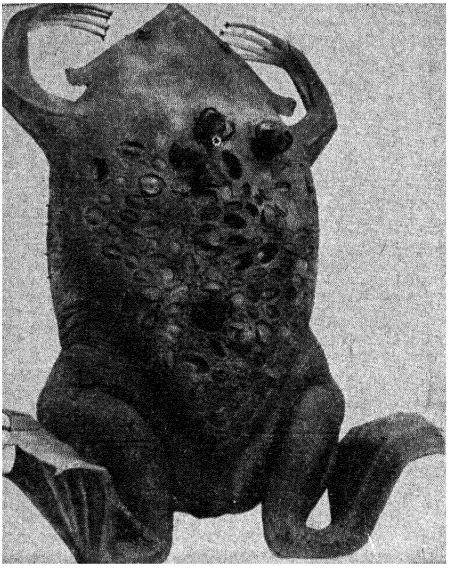


Fig. 316.—The Surinam toad, Pipa americana. This native of South America is a peculiar animal in every way. The body is flat and the feet quite unlike those of other toads. The young develop in cavities on the back of the mother. (Courtesy of The American Museum Natural History.)

As to nests, a South American group, *Leptodactylus*, deposits eggs in foam nests it has made. Certain frogs in Jamaica lay their eggs in the water between leaves of special kinds of plants.

H. Importance of Amphibia.—Frogs, toads, and salamanders, eggs, larvae and adults, are widely used in biology laboratories, and many students get their first ideas of *vertebrate* anatomy and embryology from a study of these forms.

Since frogs destroy many insects, they are beneficial. Frog legs are widely used as food.

I. Amphibia as First Terrestrial Vertebrates. 1. ANCESTORS OF THE AMPHIBIA.—Certain fish sometimes leave the water for short periods, and the lungfish are able to secrete cocoons and breathe in air at times when their native habitats become somewhat dry. But fish are not adapted to live on land. Little is known certainly of the amphibian ancestors, though

it is thought that they probably came from the crossopterygian fish or some as yet undiscovered related group. The first record of amphibian life is a three-toed footprint of *Thinopus antiquus* found in the Devonian sandstone (Middle Paleozoic era). They increased to such an extent that the Late Paleozoic era or Carboniferous period is called the *Age of Amphibians* (page 788).

Many amphibians have become extinct. Among the interesting fossil amphibians are the *stegocephalians* (Gr. *stegos*, roof; *kephale*, head). They reduced the armor of their ancestral armored fish but retained it over the head to the breast girdle. There were also oblique rows of small scales, chiefly on the underside of the trunk and tail. Some of the fossil Amphibia measure from 15 to 20 ft. (*Mastodonsaurus*).

Geologists agree that it is more than probable that at the time of the emergence of the amphibians there were alternating seasons of warmth and rainfall. In the dry seasons the animals had to adapt themselves to life on land in order to survive.

2. Adaptations for Life on Land.—Many changes were necessary in the transition from aquatic to terrestrial life.

a. Limbs.—Paired fins were transformed into limbs that would bear the weight of the animals in the mud and that would serve as locomotor organs. To support these, pectoral and pelvic girdles were developed. Unpaired fins were lost though some have arisen as new structures in frog larvae and in salamanders.

b. Organs of Respiration.—In fish the nostrils were for the sense of smell only, but in the Amphibia they also take in air for breathing purposes and communicate with the mouth.

The development of *lungs* for air breathing, even though they are not highly functional, brought about far-reaching changes, especially in the circulation.

The skin in certain Amphibia may serve for a limited amount of respiration, as in the frogs, but most of the adults have lungs, even though the larvae may still have gills. Fish have glands in their soft epidermis that produce a secretion to protect them from the water, and so amphibian skins were developed to protect them from drying out, a function performed by the mucous glands of the skin.

Internal gills of the fish were lost by the Amphibia. Some gills appear among the salamanders, but they develop before the gill clefts open, are restricted to the outer side of the branchial arches, and are always covered with ectoderm, so that they are not homologous with the gills of fish, though they have the same function of respiration. The development of lungs enabled the amphibians to take oxygen directly from the air.

c. Circulatory System.—In *fish* the blood is aerated in the branchial circulation and is carried from the gills by the efferent gill arteries to the

dorsal aorta and from there distributed throughout the body. In the lung forms the blood is aerated in the lungs and is carried by the pulmonary veins to the right auricle of the heart and goes from there through the aorta to all parts of the body. The four pairs of aortic arches of the fish are transformed, so that only one pair remains in the Amphibia (page 239). In the Amphibia, a cutaneous branch of the fourth arch goes to the skin, which in some forms is an accessory respiratory organ.

The heart is changed from a two- to a three-chambered organ, two auricles and one ventricle. The venous blood goes into the left auricle, and the arterial blood goes into the right auricle. Both auricles empty into the single ventricle, but there is not much mixing of the arterial and venous blood on account of the folds in the ventricle walls (page 242).

d. Sense Organs.—Changes in sense organs involve especially changes in the eyes and ears. Eyelids are developed to protect the eye and keep it moist, the moisture being supplied by lacrymal glands. The *lens* becomes more flattened for distant vision.

The ears are adapted to catch air sound waves. A *tympanic membrane* is stretched over a middle ear in many amphibians. In this middle ear is a *columella*, which transmits the sound waves to another small bone, the *stapes*, set in an opening of the wall of the sacculus. The middle ear is connected with the pharynx by a Eustachian tube.

There are many other adaptations that show the transition of the amphibians from a water to a land environment, but the foregoing are a few of the more important.

Questions

1. Distinguish between the three orders of amphibians.
2. Why is the axolotl an especially interesting animal?
3. Compare a frog and a toad with regard to external features and habits.
4. Are there any poisonous Amphibia?
5. What are some advantages of hibernation?
6. Do any Amphibia exhibit secondary sexual characters?
7. What are some interesting breeding habits among the Amphibia?
8. Do all the Amphibia lay their eggs in the water? What exceptions can you name?
9. What fish were the probable ancestors of the Amphibia?
10. List the adaptations shown by the Amphibia for life on land. What are the probable reasons for these adaptations?
11. Define: neotony; paedogenesis; estivation.

Suggested Reference

NOBLE, G. K.: "The Biology of the Amphibia," McGraw-Hill Book Company, Inc., 1931. See also references at the end of Chap. XVII.

CHAPTER XXXI

REPTILIA

The tortoise like other reptiles has an arbitrary stomach as well as lungs; and can refrain from eating as well as breathing for a great part of the year.

—GILBERT WHITE, 1772.

Living reptiles include turtles, the sphenodon, chameleons, lizards, and snakes. Reptiles are not the slimy creatures often pictured, their horny scaly coverings being anything but slimy; they are often very beautiful.

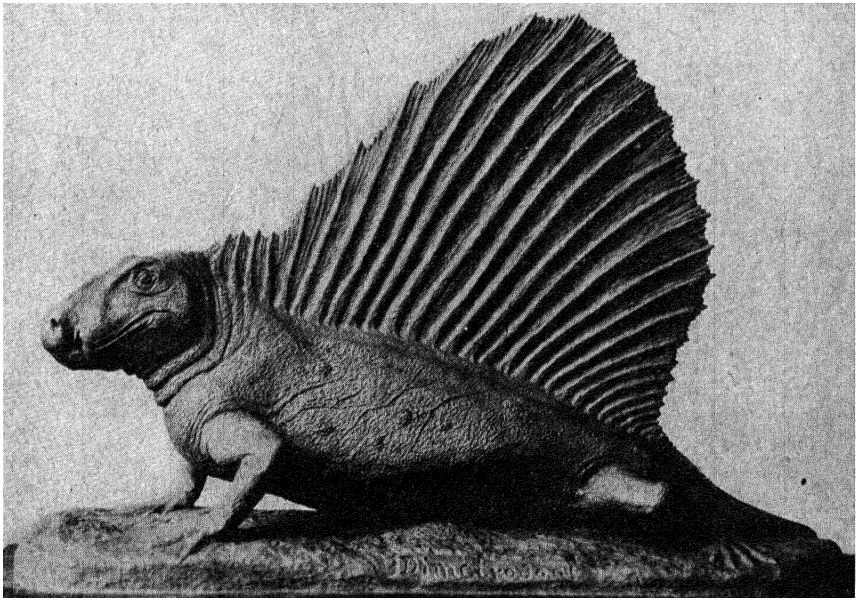


Fig. 317.—Restoration of an extinct reptile, Dimetrodon. Some of the spines in the back are three feet long. (Courtesy of The Smithsonian Institution.)

A. Ancient Reptiles.—The reptiles probably arose from stegocephalian stock (page 788) in Carboniferous times, over 100 million years ago. During the Mesozoic era they dominated the earth on land, in water and in the air. To live in so many types of habitats, they became highly specialized (Fig. 317). Some returned to the sea; others lived in fresh water, in swamps, and on land. Many of the ancient reptiles were

small and resembled the lizards of today; but others, the *dinosaurs*,[1] are the largest animals that ever lived. Indeed, their restorations remind one of giant mammals rather than of reptiles. The "thunder lizard," the *Brontosaurus* (Fig. 519), was about 80 ft. long and weighed about 40 tons! It was herbivorous in its choice of food, living in the shallow waters of ponds and bays. But some of the dinosaurs were carnivorous. *Tyrannosaurus*, the king lizard, was smaller than *Brontosaurus*, being about 47 ft. long, but it must have been a terrible animal, greatly feared.

The flying reptiles, the *pterosaurs*, varied in size from a few feet to about 25 ft., and the fish lizards, *ichthyosaurs*, were perfectly adapted to the water.

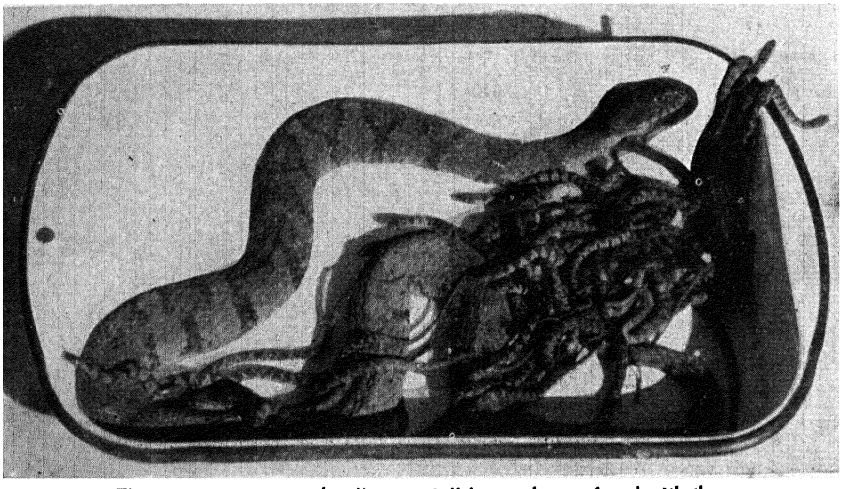


Fig. 318.—The common water snake, "moccasin" (not to be confused with the venomous water moccasin, *Agkistrodon* page 475) Natrix sipedon, with young which are born alive. There were 35 youngsters in this batch. (Dr. C. L. Baker.)

Authorities differ as to the length of time these extinct reptiles lived on earth, but a conservative estimate is that they dominated the earth for more than a million years.

B. Modern Reptiles.—Modern reptiles, as were their ancient forebears, are cold-blooded vertebrates with bodies covered with horny scales or plates. Except for the snakes, there are four well-developed legs provided with claws. All of them breathe air. The skull is well developed and articulates with the skeleton by a single *condyle* (Gr. *kondylos*, a knuckle) or rounded head fitting in a socket in the first vertebra of the spinal column. Most *Reptiles* are *oviparous* (Fig. 319), the eggs being large, with a horny covering, usually laid on or in the ground. There are ovovi*viparous* forms, however, the eggs being held in the body of the mother

[1] For further information about extinct reptiles, see p. 791.

until development is complete, and the young are born alive (Fig. 318). Two membranes make their appearance, an *amnion*, surrounding the embryo and enclosing it in a sac of fluid, and an *allantois*, an embryonic organ acting as an organ of *respiration* or an organ of *excretion* or both. These membranes are characteristic of reptiles, birds, and mammals, and it is proposed to call these three groups the *Amniota*. The young animals, when born, resemble their parents, and there is, therefore, no metamorphosis.

There are about 5,000 reptile species known at the present time, about 300 of them known to the United States. Most of them live in the warmer climates of the earth, there being few in the colder parts of the Temperate Zones and none in the Arctic regions.

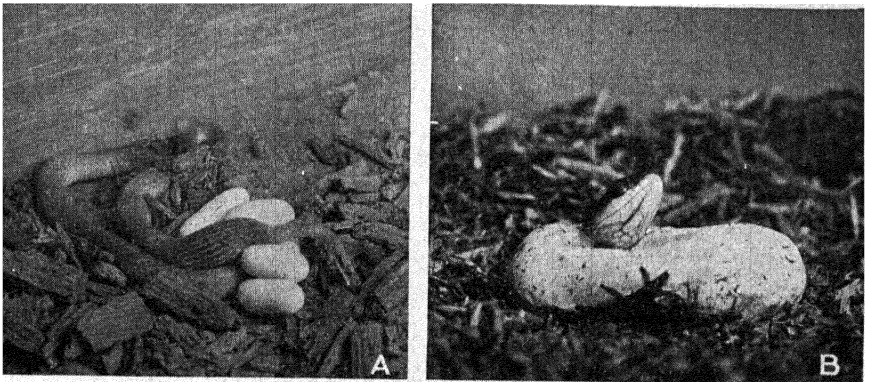


Fig. 319.—(A) Green snake laying eggs. (B) Green snake emerging from an egg. (Dr. F. N. Blanchard.)

C. Advances Shown by the Reptiles over the Amphibia.—The advances shown by the reptiles over the Amphibia have to do mainly with adaptations to terrestrial life. In the discussion of the advances shown by the reptiles over the Amphibia, certain differences between the two groups that may not represent advances are mentioned. The Amphibia had developed adaptations for living on land, but they had not completely given up the water as a place of living. The modern reptiles are adapted for a terrestrial life, even though some members of each group do return to aquatic life. It is an interesting fact that those forms that do become adapted to live in water do not regain the primitive characters shown by their ancestors. There are definite structural changes correlated with the terrestrial mode of life that are more pronounced than in the Amphibia.

1. THE SKIN AND EXOSKELETON, which was moist in the amphibians, requiring them to live in damp places, is replaced in the reptiles by a horny, scale-like exoskeleton that keeps the animal from drying out and furnishes protection. The scaly skins of the reptiles are never slimy but

form a hard external case, which, in the lizards and snakes, must be shed periodically.

2. Digestive System.—In the lower reptiles, there is not much change, but in the higher ones the digestive system becomes more complex, some forms developing a gizzard.

3. The Circulatory System.—The adaptations in the circulatory system that came about as a result of air breathing have gone farther in the reptiles than in the amphibians. There are two auricles and a double ventricle imperfectly divided except in the Crocodilia. The postcaval vein, a new vein in the Amphibia, becomes the main passageway for the blood that formerly went through the postcardinals. The renal portal system is reduced, and the hepatic portal system is developed. The arterial system is not much changed from that of amphibians (page 238).

4. Respiratory System.—The number of alveoli in the lungs is greatly increased, thereby increasing the surface through which respiration is carried on.

5. Urinogenital System.—Below the reptiles the type of kidney is a *mesonephros* (page 247). Beginning with the reptiles, the mesonephros is replaced by a *metanephros*, which is also characteristic of the birds and mammals. Nephrostomes have been lost, and there is no opening into the coelom. The ureter conducts the urine from the kidneys; the old mesonephric or *Wolffian duct* is now the sperm duct in males and is vestigial in females.

Fertilization is usually internal. The eggs are larger than amphibian eggs and have a horny covering or shell. They may be laid in the ground, *oviparous* (L. *ovum*, egg; *parere*, to bear) forms, or retained in the body of the mother until after hatching and the young brought forth alive, *ovoviviparous* (page 443) forms.

6. Embryonic Membranes.—The *amnion* (Gr., fetal membrane) and *allantois* (Gr. *allos*, a sausage), make their appearance (Fig. 337) for the first time. Since these are characteristic of the birds and mammals, also, the three groups are sometimes called the *Amniota*. The amnion is formed by the embryo (Fig. 455). The *allantois*, also developed by the embryo, is an organ of respiration in the reptiles and birds. There is no metamorphosis.

7. Skeleton.—There are an elimination of bones and a strengthening of others, joints are improved, and the girdles are more serviceable. The head articulates with one condyle instead of two, which is characteristic of amphibians and mammals.

8. Nervous System.—Since land life adds to the problem of existence, a better nervous system is developed by the reptiles. The brain parts are larger, as well as the spinal cord, and there are more nerve-fiber connections. A cerebral cortex is developed, *i.e.*, the outer part of the

cerebrum is divided into an outer gray portion and an inner white portion. The "second brain" or enlargement of the spinal column to take care of the great development of shoulder and hip regions was characteristic of the dinosaurs (page 790). The higher reptiles, however, did not develop this plan but acquired larger and more specialized brains.

9. MUSCLES.—There is more individual use of certain muscles and more specialization than in amphibians.

D. Classification of Living Reptiles.—The living reptiles may be classified in four orders:

Order 1. CHELONIA (Gr. *chelone*, tortoise) or *Testudinata* (L. *testudinatus*, like a tortoise). Land and fresh- and salt-water types. The turtles (Fig. 320).

Order 2. RHYNCHOCEPHALIA (Gr. *rhynchos*, snout; *kephale*, head). One living species, *Sphenodon* or *Hatteria*, a lizard-like reptile found only in New Zealand (Fig. 321).

Order 3. CROCODILIA (Gr. *krokodeilos*, crocodile). *Crocodiles* and *alligators* (Fig. 322).

Order 4. SQUAMATA (L. *squamatus*, scaly). *Chameleons*, *lizards*, and *snakes* (Figs. 323, 326).

E. Turtles.—*Turtles* are variously called *turtles*, *tortoises*, and *terrapins*. Ditmars proposes to give the name *tortoise* to the strictly terrestrial species and the name *turtle* to the semiaquatic and marine species and the name *terrapin* to those hard-shelled, fresh-water species that are edible and have a recognized market value.

1. SOME GENERAL FEATURES AND HABITS.—The feature that separates turtles from all other animals is that it is a *reptile* in a box. It can draw its head, legs and all, inside this box-like exoskeleton.

There are turtles that live exclusively on land but the majority are more or less aquatic. The sea turtles come to land only to lay their eggs, and the males of some species are said not to come to land at all.

Turtles are air breathing, but most of them can remain submerged for a long time. A few have a pair of thin-walled sacs, one on either side of the cloaca. These are accessory respiratory organs. The walls of these sacs have a rich supply of blood vessels. The sacs are alternately filled with water and emptied through the anus.

Land turtles eat vegetable food as well as grubs, worms, and other small animals. The water forms devour animal food under water.

All turtles are oviparous, even the aquatic forms coming ashore to lay their eggs. Nests are scooped out in the sand, the eggs are laid in the cavity, and then the sand is packed down over them. Here the eggs hatch without any effort on the part of the mother. The large marine turtles sometimes lay as many as 500 eggs. No care is taken of the nests, and the young turtles must take care of themselves as soon as they emerge from the egg.

Turtles are noted for their length of life. The giant tortoises of the Galapagos Islands are estimated by various authors to live from one to several

hundred years. In size, turtles vary from a few ounces to the large marine turtles, which may weigh 1,000 lb.

2. External Features.—The skin on the heads of turtles may be smooth or be provided with scales, but on exposed parts it is scaly and wrinkled. The body is wide and short and enclosed in a box-like exoskeleton, the dorsal part of which is the convex carapace and the flat ventral part the plastron. This is made up, in most cases, of horny plates covering internal bony plates.

The head is compact in structure. The jaws are usually covered with a horny sheath that forms a cutting edge. The eyes, one on each side of the head, are provided with upper and lower eyelids and a nictitating membrane. The four legs are typically *pentadactyl* (Gr. *pente*, five; *daktylos*, finger). In aquatic forms, these are more or less webbed, and in the marine turtles they are modified into flippers. The tail is usually short and thick.

3. The Skeleton.—The dorsal part of the shell of a turtle is convex and is called the *carapace;* the flat ventral portion is the *plastron* (L. *emplastron*, a thin plate of metal). In most species, these two parts of the shell are fastened together by lateral bridges. On the outside of the exoskeleton are a number of epidermal plates or scutes. These differ in number and arrangement in the different species. They may have color on or under them.

The *endoskeleton* may be divided into the *axial* skeleton and *appendicular* skeleton. The skull is firmly put together. A beak is formed by the horn-covered premaxillae, maxillae, and dentary bones. No teeth are present, and the jaws are strong enough to tear food.

The vertebral column has comparatively few vertebrae. Those of the neck region are freely movable, the joints being of the cup and ball variety. The thoracic vertebrae, united to the carapace, bear ribs that are also closely united with the carapace (Fig. 320).

The pectoral and pelvic girdles are peculiarly situated. They are on the inside instead of on the outside of the ribs.

4. Representatives. *a. Diamondback Terrapin.*—These are greatly prized as food and are expensive, about $75 a dozen. The name comes from the diamond-shaped plates on the back of the shell. This animal hibernates in the winter in the mud, where it is found and dug up. There are successful attempts to raise them on so-called *turtle* farms.

b. Giant Tortoise.—In ancient times, there were enormous numbers of giant tortoises on the Galapagos Islands in the Pacific and Indian oceans in tropical latitudes, but they are almost exterminated now. They live on land, feed on berries, may weigh 500 lb. or more, and reach an age of more than 100 years. The head is comparatively small and the neck long and slender.

c. Snapping Turtles.—The common snapping turtle, *Chelydra serpentina*, can bring its sharp jaws together with such force as to snap off a human finger; the larger alligator snapper, *Macrochelys lacertina*, is able to snap off a foot. It may reach a length of 28 in. and weigh 140 lb.

d. The Painted Terrapin, Chrysemys picta, is a common land turtle.

e. The Leathery Turtle, Dermochelys coriacea, is the largest living species. It lives in the sea and has its limbs modified as flippers. As its

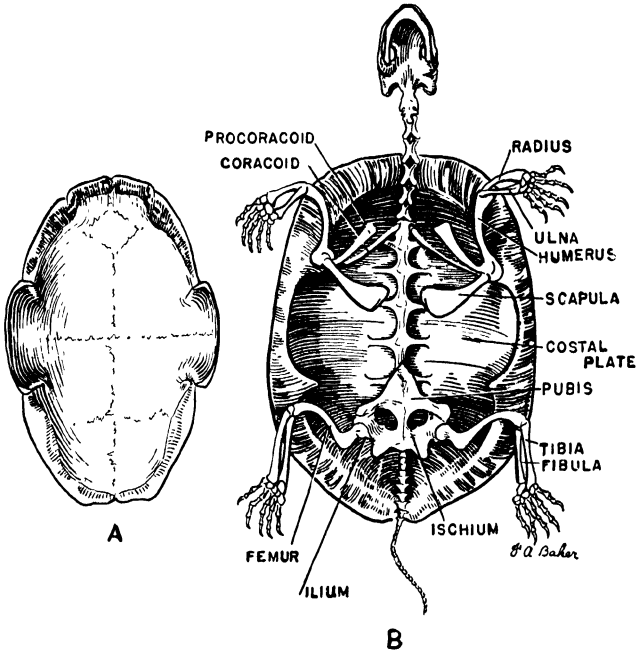


Fig. 320.—Skeleton of the painted turtle, Chrysemys marginata. (F. Baker.)

name signifies, there is a leathery rather than a horny covering over the shell.

F. The Sphenodon.—There is only one representative of the Rhynchocephalia alive today, the tuatera, *Sphenodon*, which lives in New Zealand. Gadow refers to it as "the last living witness of by-gone ages, this primitive, almost ideally generalized type of reptile, this 'living fossil.'" It is much like animals in the ancient Jurassic times. In external appearance, it resembles lizards, but it differs from them in several anatomical features (Fig. 321). Its most interesting feature is the connection of the pineal body with a vestigal third eye.

G. Crocodilia. 1. GENERAL FEATURES AND HABITS.—These are the giants among present-day reptiles, some of them attaining a length of between 20 and 30 ft. Their bodies are covered with scales and bony plates. They have powerful tails, laterally compressed toward the end, and two pairs of legs. These are of little use in swimming. The anterior pair of legs has five digits, slightly webbed, and the hind pair has four pairs of digits, more webbed than the anterior pair. The three inner digits of each foot have claws.

The scales are arranged transversely, the dorsal ones having high keels, giving the skin its characteristic appearance. These scales are supported by plates of dermal bone beneath.

The nostrils are close together near the anterior part of the snout. Each has a valve and can be closed. The tympanum of the ears is pro-

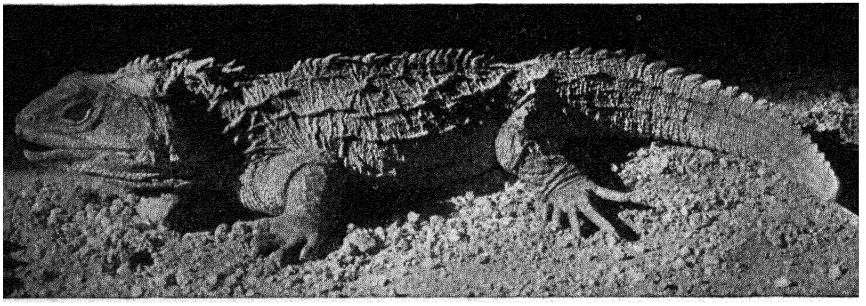


Fig. 321.—The Tuatera or Sphenodon, of New Zealand. This animal has been called a "living fossil" because it is a representative of a group of reptiles that died out after "The Age of Reptiles." (Courtesy of The American Museum of Natural History.)

tected by a movable flap of skin. The eyes are provided with an upper and a lower eyelid and a nictitating membrane.

The teeth of alligators and crocodiles are long and pointed and are set in sockets. From time to time, they are replaced by others that grow out from beneath.

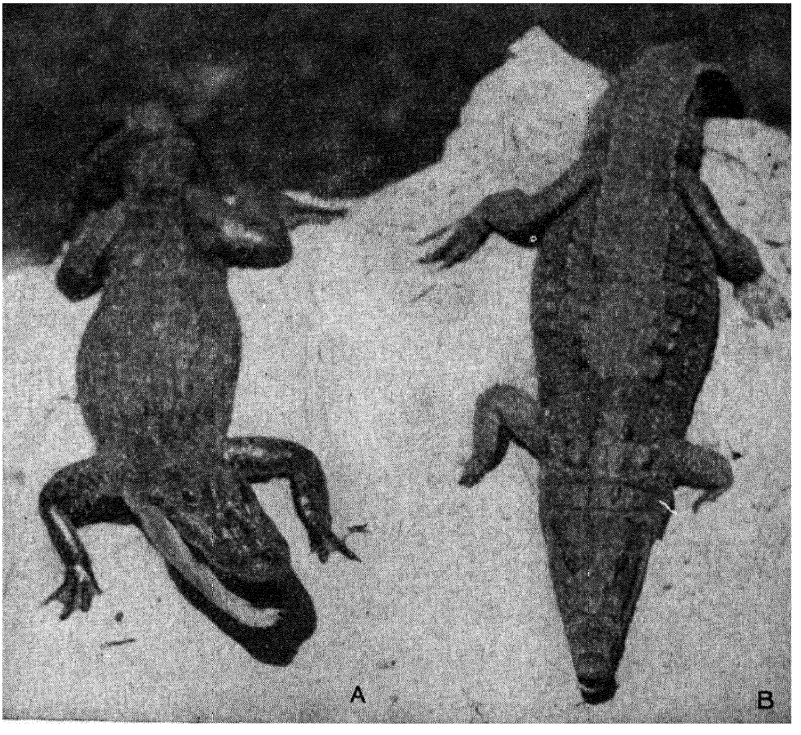
The American crocodile and the East Indian crocodile may enter salt water; the great majority, however, live in fresh-water streams and marshes in the warmer climates of the earth. For two or three months of the year, they hibernate in the mud.

The eyes and nostrils are so elevated that they are in the air, and the flat portion of the head is even with the surface of the water. The alligator often lies parallel to the surface of the water in such a manner that at a little distance it looks like a log.

2. REPRESENTATIVES.—The Crocodilia are a very ancient group, and the present-day representatives differ very little from those of ancient Jurassic times.

a. Gavials.—Apparently the largest form existing today is the species in northern India, the Indian gavial, *Gavialis gangeticus*, which may grow to a length of 30 ft. The *Gavialis* snouts are long and slender.

b. Crocodiles and Alligators.—Figure 322 shows a superficial difference between the alligator and the crocodile, the shape of the snout. One characteristic difference between the two is in the teeth. In the Crocodiles, the fourth tooth fits into a notch in the upper jaw when the mouth



Reptile Institute.)

is closed and is visible, whereas the fourth tooth in the alligators fits into a cavity of the upper jaw and is hidden. There are many other differences of a technical nature.

(1) The American alligator, *Alligator mississippiensis*, is less active and less vicious than its relatives. It is one of the two species known to exist at the present time, the other species being the Chinese alligator, which lives in the Yangtze River in China. The American species grows to a length of about 20 ft. and has a dark-brown hide, much prized for making leather. The snout is very broad. It is found in the waters of southern Florida and in the Okefenokee Swamp. This alligator is one of the few crocodiles with a voice. The sounds it makes are

like a bellow or roar not unlike the mooing of a cow. During the mating season, the male often bellows loudly.

The eggs of the alligator, which are covered with a horny shell, are placed in a nest built of decaying vegetation and mud. Fermentation of the decaying vegetation raises the temperature above that of the air surrounding the nest, thus hastening the hatching of the eggs. No care is taken of the nest after it is made, and the little alligators "shift for themselves" as soon as they hatch from the eggs.

In general, the crocodiles are more active and more vicious than the alligators.

(2) THE AMERICAN CROCODILE, *Crocodilia acuta*, is usually found in salt or brackish water. The Florida species probably swam across the Gulf of Mexico from Mexico. It is distributed along the South American, Central American, and Mexican coasts.

(3) THE AFRICAN CROCODILE, *Crocodilia niloticus*, often called the *Nile crocodile*, has a bad name. It grows to about 20 ft. and causes the loss of many human lives each year, especially in India. It was held sacred by ancient Egyptians. Human sacrifices of young children were often offered to some deity by throwing children into the Ganges River to be devoured by crocodiles. The practice has been discontinued. The crocodile has a tough hide, used by natives as armor. It can be pierced by a bullet, however.

H. The Squamata; Snakes and Lizards. 1. GENERAL FEATURES.—The animals in this group, *chameleons*, *lizards*, and *snakes*, are the dominant group of reptiles living today. Some lizards are without limbs, but the majority of them have legs, whereas the majority of snakes are limbless, though some have rudimentary hind legs. The skin is shed periodically; in the snakes, the skin is shed whole. Before this happens, a new skin is formed under the old, and the old skin becomes dead-looking. When the snake is about to shed its skin, the transparent scales, including the skin over the eyes, become opaque. At the time of shedding, the snake is partially blind. The old skin loosens at the corners of the jaws and is shed headfirst. As the animal crawls out of the old skin, it becomes turned inside out. Lizards shed their skins piecemeal.

2. REPRESENTATIVES. *a. Lizards.* (1) THE CHAMELEON (Gr. *chamoi*, on the ground; *leon*, lion) is able to change its color, but so can many other lizards. For example, in the Southern states, there is a very common lizard, *Anolis*, which can change its color from varying shades of green to brown. This allows it to be protectively colored. One of the common lizards is the *five-lined lizard* (Fig. 323).

(2) THE HORNED TOAD, *Phrynosoma* (Fig. 324), is really a lizard. Its body is covered with spiny scales and the projections on the back of the head resemble horns. The body is somewhat toad-shaped.

(3) THE GILA MONSTER, *Heloderma suspectum*, is the only poisonous lizard in the United States. It has poison fangs in the lower jaw, is conspicuously colored red and black, and does not try to hide. It lives in the southwestern United States.

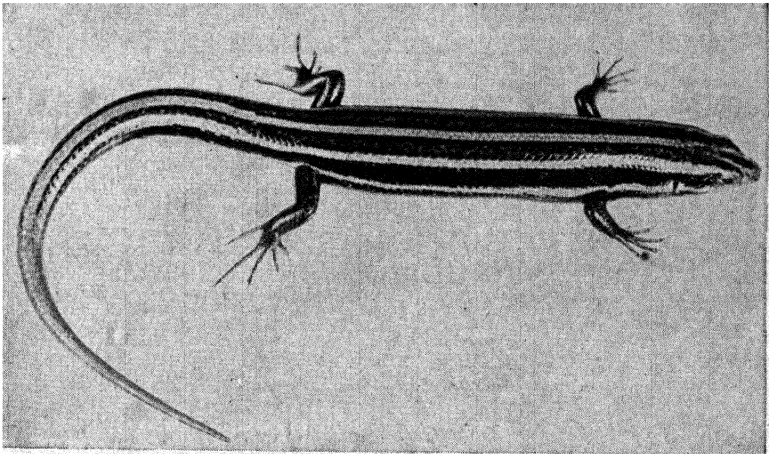


Fig. 323.—Five-lined lizard, Eumeces fasciatus.

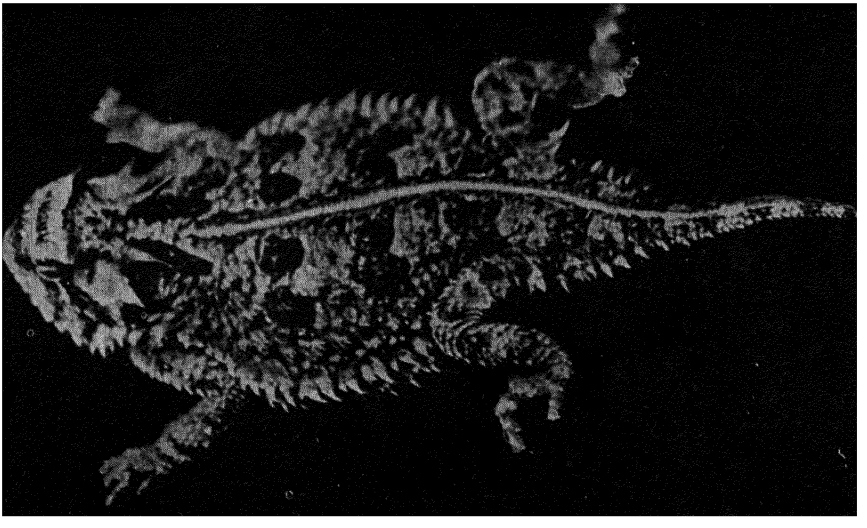


Fig. 324.—"Horned toad," Phrynosoma, a lizard that lives in dry places.

(4) THE FLYING DRAGON is an oriental lizard. Although a slender creature about 5 in. long, it has folded up against each side a large wing-like membrane that may be spread out and used as a parachute, enabling

the lizard to glide from one tree to another. The wings are brilliant orange in color, with black markings.

(5) THE GLASS SNAKE gets its name from the fact that it has a very brittle tail, which breaks off when grasped. It is a legless lizard.

b. Snakes. (1) GENERAL FEATURES AND HABITS.—Snakes are usually without limbs. The exceptions are the tropical pythons and boa constrictors, which have rudimentary hind limbs. Movable eyelids and external ears are not present in snakes. The eyes are lidless, but the eye is protected by a transparent membrane. Except when molting, when the transparent skin over the eyes becomes opaque, snakes see well, but the

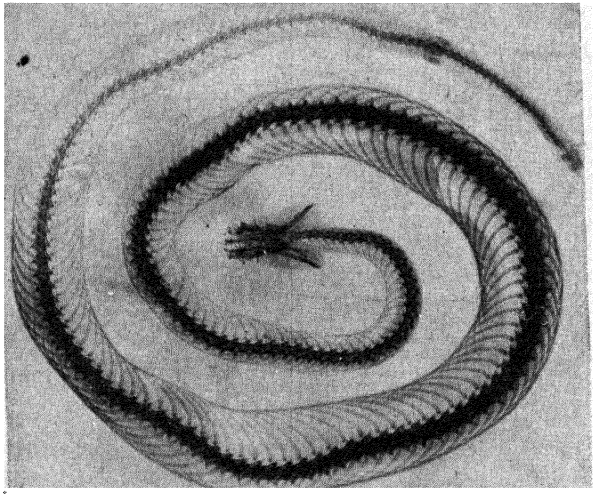


Fig. 325.—An X-ray photograph of a rattlesnake, Crotalus. Note the large number of ribs. (Courtesy of The Army Medical Museum.)

sense of hearing is not well developed. The tongue is an organ of touch. It is soft and forked at the end and can be thrust out even when the jaws are closed. This is possible because there is an opening present between the jaws at the anterior end of the mouth. The sense of taste is of little value, since snakes swallow their food whole and sometimes alive.

There are some peculiarities of structure correlated with the method of feeding. The lower jaw is not fixed directly to the skull but is attached to the quadrate bone, which is attached to the skull. The peculiar way it is attached allows the jaw to move up and down as well as backward and forward. The ligaments connecting the jawbones are elastic and the two halves of each jawbone are connected with an elastic ligament, allowing each half to move sidewise. On account of these peculiarities, snakes are able to swallow fairly large prey, four or five times the diameter of

the neck. The teeth are interesting, for they are replaced when lost. There are many teeth present for the purpose of holding the prey.

When snakes are swallowing their food, they need a special arrangement for breathing. This is accomplished by means of *tracheae* that extend along the floor of the mouth to the teeth. There is also a large *air chamber* behind the lung for air storage. Finally, snakes have active digestive fluids to take care of the large amounts of food that are swallowed at one time. They do not need to eat very often.

The method of *movement* is also correlated to the special structures. For example, the skeleton has a large number of ribs (Fig. 325), and on the underside of a snake are broad plates, the abdominal scutes, to which

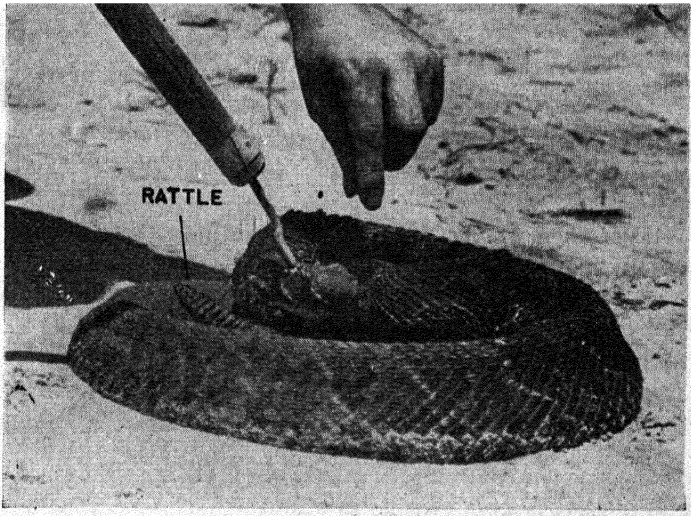


Fig. 326.—Rattlesnake, a poisonous snake. Before striking the snake usually vibrates its tail, causing the "rattles" to make a characteristic noise. (Courtesy of The Florida Reptile Institute.)

the ends of the ribs are attached. The ribs and the muscles move the plates on the belly, and this enables them to move very rapidly. Some snakes can climb trees and swim. Methods of reproduction are mentioned on page 464.

(2) REPRESENTATIVES.—Most species of snakes are harmless, even beneficial. The king snake, *Lampropeltis*, eats other snakes; the common garter snake, *Thamnophis sirtalis*, and the black snake *Coluber constrictor* are harmless. The puff adder *Heterodon contortrix* hisses and puffs out its neck, but this is a defense reaction. There are poisonous snakes to be avoided and dreaded. The pit vipers are poisonous. To this group belong the venomous water moccasin, *Agkistrodon piscivorus*, the rattlesnake, *Crotalus* (Fig. 326), and the copperhead, *Agkistrodon mokasen*. They

get their names from the fact that they have a *pit* located between the eye and the nostril. Another distinguishing feature is the *vertically elongated pupil* of the eye. The other snakes have round pupils. The long poison fangs are for securing food and for defense. A snake "strikes," making a wound and forcing poison into it through the hollow fangs (Fig. 327). If the fangs are lost, they are replaced. The water moccasin, commonly known as the *cotton mouth*, is found especially in the South and the rattlesnakes, in the Southwest. The rattlesnake has a series of shell-like structures on the end of its tail, the *rattles* (Fig. 326), from which it gets its name. Another poisonous snake is the beautifully colored coral snake, *Micrurus*, found in the South. The brilliant red, black, and yellow coloring of this snake is responsible for its several

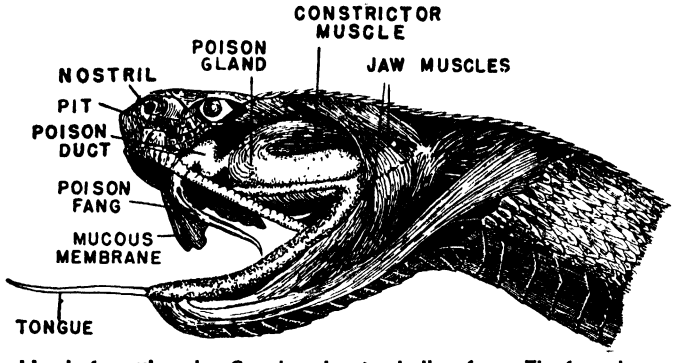


Fig. 327.—Head of a rattlesnake, Crotalus, showing hollow fangs. The fangs have an opening near the end through which the poison is squeezed into the object bitten.

names, harlequin snake and bead snake. Human beings are said to die as a result of its bite. It does not strike as other poisonous snakes do but will bite when stepped upon or handled. The poison acts on the nerve centers rather than on the blood, as does the poison of other poisonous snakes.

The regal python, *Python reticulatus*, is the longest living snake, reaching a length of 33 ft. Like the boa constrictor, it is a constrictor and crushes its prey to death in its coils. It lives in Burma, Indo-China, the Malay Peninsula, and the Philippines. It is an excellent swimmer and tree climber, a favorite perch being a limb of a tree near water. Birds and small mammals are caught for food. When captured, pythons are quite savage and often go on a hunger strike, which can be conquered only by forcible feeding. The body of a rabbit or other animal is forced down the snake's throat while it is held out straight by a group of men.

(3) SNAKE VENOMS.—Snake venoms are not all alike, some having more of certain types of substances than others. One type of substance is cell dissolvers; they seriously injure nerve cells and blood cells and cause the rupture of the walls of capillaries. Another type of harmful substance

is one containing several elements; it begins to digest flesh as soon as it is injected into it. Another substance keeps the blood from clotting. Venoms also reduce the ability of the blood to combat serious infections.

First-aid treatment in snakebite is to tie a tourniquet around the limb or body between the bite and the heart, then to make an incision about $\frac{3}{8}$ to $\frac{1}{2}$ in. deep and suck out all the poison possible. It is possible to take serums for snake poisons, but the antivenins are specific, and the kind for the particular poison received is necessary.

I. Importance of Reptiles.—As has been pointed out, turtles are prized as food by man, some species, as the diamondback terrapin, being especially sought after. Tortoise shell is made from the horny covering of the hawksbill turtle. A synthetic product is replacing this article.

Alligators and crocodiles have been so much hunted for their skins as to be largely depleted in numbers. Alligator leather is in demand for shoes and traveling bags of all kinds. In Africa, the natives use crocodile skins for armor.

Snakes are beneficial in general, eating many harmful rodents, field mice, gophers, and pests of this kind. The insectivorous varieties, such as the ring-necked and green snakes, eat many insects; the king snake will eat other snakes, both poisonous and valuable types, and rodents. Unfortunately, a large number of them will eat birds as well as their eggs and so partly nullify the good they do in destroying animal pests.

There is only one poisonous lizard in the United States, the Gila monster, and a relatively small number (22) of poisonous snakes. Students of snakes, herpetologists (Gr. *herpeton*, reptile; *logos*, discourse) agree that, although poisonous snakes are to be feared and avoided, snakes do more good than harm.

Questions

1. What types of animals are found among the reptiles?
2. Why do you think that the Age of Reptiles must have been an interesting time in which to live?
3. Where did the ancient reptiles live?
4. What are the general features of modern reptiles with regard to type of blood, skin, skull, breeding habits, respiratory system?
5. What are some general features and habits of turtles?
6. Describe peculiarities of the turtle skeleton.
7. Name some representatives of the turtles, and state why they are interesting.
8. Are turtles long- or short-lived?
9. What feature makes the *Sphenodon* such an interesting animal?
10. How could you tell a crocodile from an alligator? In what country are crocodiles sacred?
11. Name at least three representatives of the lizards, and state why they are interesting.
12. What features of the horned toad show that it is a reptile and not a toad?
13. Why is a snake able to swallow animals much larger than the normal size of its mouth? Does the snake possess few or many ribs?

14. Why does the snake need a reserve air supply?
15. Do snakes eat often? Explain.
16. What poisonous snakes are found in your locality? In what ways may snakes be beneficial?
17. Are snakes cold-blooded or warm-blooded? Is it correct to speak of a slimy reptile? Explain.
18. Why is the number of rattles not a sure sign of the age of a rattler?
19. Why are snakes practically helpless when shedding their skins?
20. How does the snake use its tongue? Its poison fang?
21. What are some effects of certain types of snake venoms on human blood?
22. Describe an alligator nest. A turtle nest. Are the young of these two animals ever born alive? Is this true of snakes?
23. Do reptiles pass through a larval period? Compare with the Amphibia in this respect.
24. What is the significance of the appearance of embryonic membranes?
25. Define: amniota; plastron; pentadactyl; herpetologist; venom; pineal body; dinosaur

Suggested References

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———: "The Reptile Book," Doubleday, Doran & Company, Inc., 1907.

CHAPTER XXXII

AVES

Robins and mockingbirds that all day long
Athwart straight sunshine weave cross threads of song.
—SIDNEY LANIER.

I. General Characteristics of Birds

The Aves (L. *avis*, bird), or birds, are easily distinguished from all other animals, for they alone possess feathers. Many other avian characters are shared by the reptiles. For example, the birds are bipedal; so were some of the dinosaurs; the birds have hollow bones, some of the ancient flying reptiles also had these. Air sacs are attached to the lungs. They have no teeth but possess horny beaks; the turtles have these same features. There are many other comparisons that might be cited, but in spite of all of these, the birds are a distinctive group especially adapted to the life that they lead. They form a more homogenous unit than any other group of vertebrates.

II. Ancestry of Birds

The birds have so many reptilian characters that it is easy to think of them as having kinship with that group. Just how they arose, however, is by no means certain. An approach to the study of the possible origin of birds is the study of the origin of flight. Ancient, as well as modern, birds had flight feathers both fore and aft and were capable of gliding from tree to tree. It is not known surely that the dinosaurs were cold-blooded as were the other reptiles. The bipedal dinosaurs had structures more nearly resembling the birds than any other reptiles, and they are looked upon by some authorities as the possible ancestors of the birds. There are various theories as to the possible ancestry of birds but to date none of these has been proved.

One fossil bird gives some idea of what the primitive birds were like, the *Archaeopteryx* (Gr. *archaios*, ancient; *pteryx*, wing) (Fig. 328). It was about the size of a crow, had teeth in sockets, three free fingers for climbing, flight feathers on its legs, and a tail like a lizard's. The 21 vertebrae in this tail were separate, and there were flight feathers on both sides for its full length, quite different from the tail of a modern

bird. This bird could not have had the power of active flight, for the sternum was small and keel-less. It could not, therefore, have supported the large pectoral muscles of the modern bird. It was probably a glider. There were many other reptilian characters, but enough have been given to show that the *Archaeopteryx* was a true connecting link between the reptiles and the birds.

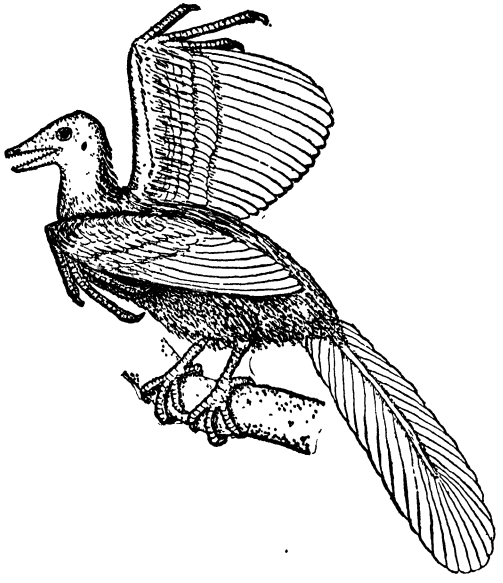


Fig. 328.—Restoration of the Archaeopteryx, a primitive Jurassic bird showing many reptilian features. (After Romanes, Darwin and after Darwin, The Open Court Publishing Company.)

Fossils of birds are rare, but the fact that extinct forms had teeth and other reptilian characteristics establishes their ancestry with fair certainty, though the exact line of descent is not known.

III. Classification

At the end of the chapter will be found a list of important orders of birds. There is much difference of opinion as to the classification of birds among specialists who study them, ornithologists (Gr. *ornis*, bird; *logos*, discourse).

Subclass or Grade I. ARCHAEORNITHES (page 479). Extinct birds, which include the *Archaeopteryx* and *Archaeornis*.

Subclass or Grade II. NEORNITHES (page 495). All other birds.

Subdivision 1. *Ratitae* (page 495). Running birds without a keel.

Subdivision 2. *Carinatae* (pages 495–496). Birds having a sternum with a keel; most birds.

IV. Structures of Birds

A. External Features. 1. Divisions of the Body.—The body of a bird may be divided into a head, a neck, and trunk portions (Fig. 329).

a. The Head.—The head is prolonged in front into a beak. This is very varied in size and shape. It is one of the characteristics by which birds are identified (Fig. 330). The bird uses it for food getting, as a

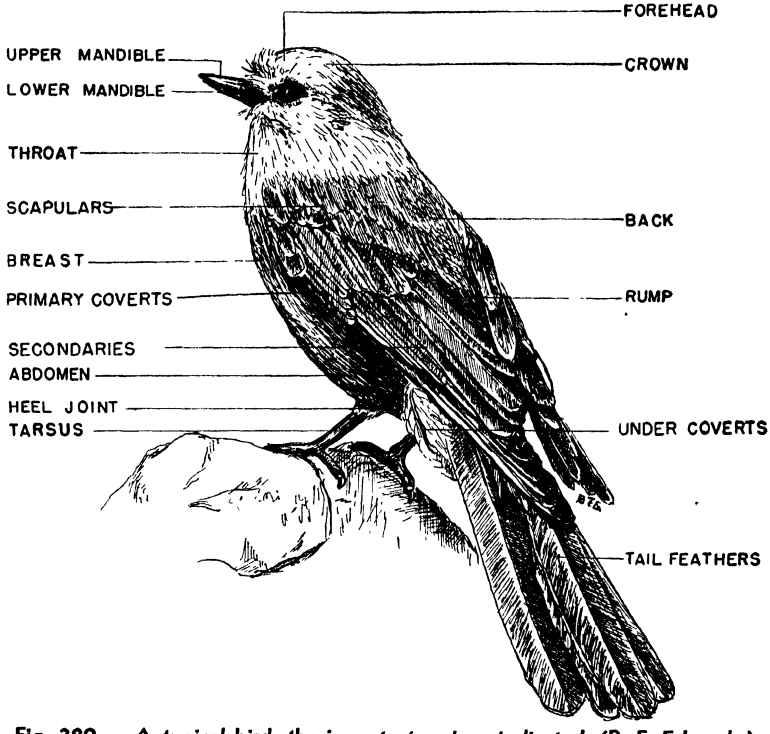
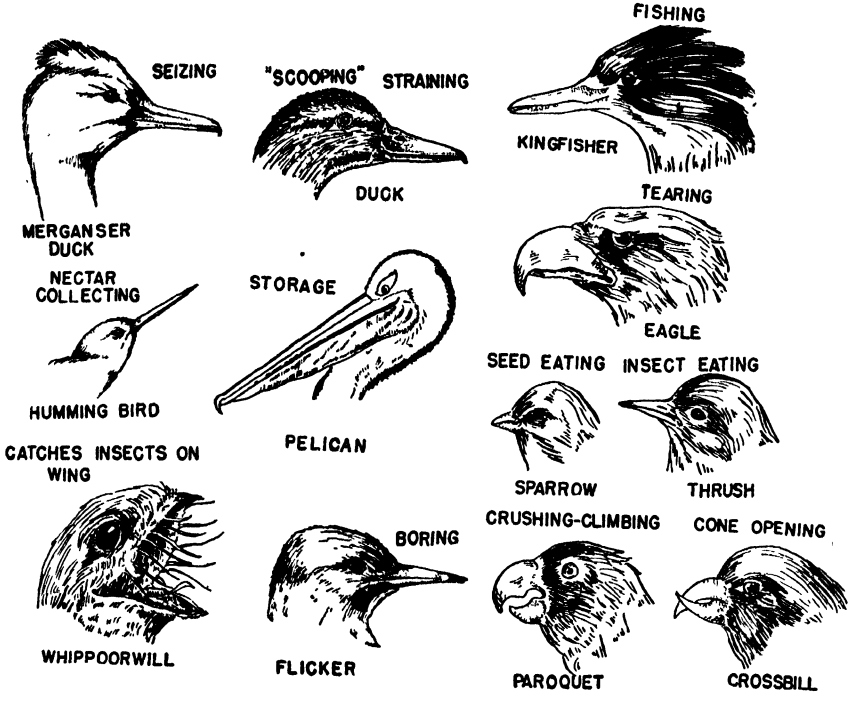


Fig. 329.— A typical bird, the important regions indicated. (B. F. Edwards.)

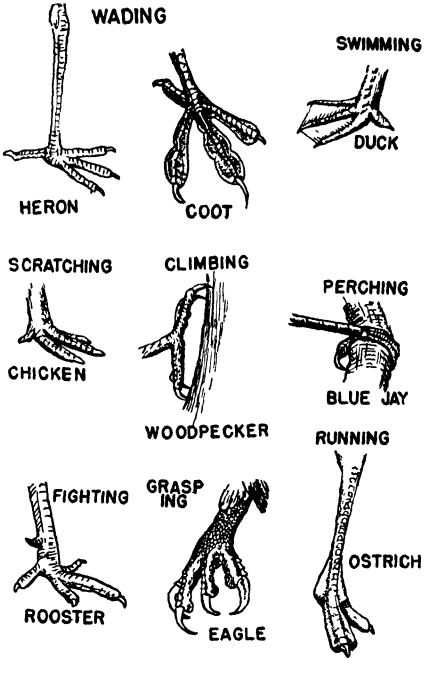
tool for the construction of nest, and as a toilet instrument for preening feathers. In some birds at the base of the beak is a bare region, the *cere* (L. *cera*, wax). The two slits usually near the posterior part of the bill are the nostrils; these communicate with the throat and are used in breathing. On either side of the head are the eyes. These have three eyelids upper and lower, and a third one, the *nictitating membrane* (L. *nicto*, wink). The nictitating membrane can be drawn across the eyeball from the inner to the outer side, thus covering the entire eye. The ears are behind and below the eyes. They are protected by a ring of feathers.



Specialized use	Special structures	Examples
Seizing	Narrow saw-edged bill for seizing fish under water	Merganser
Scooping, straining	Broad for scooping, comb-like edges for straining out particles of food from water	Duck
Fishing	Narrow, spear-like. The bird dives for fish	Kingfisher
Nectar collecting	Long slender bill for collecting nectar and small insects from long flower tubes	Hummingbird
Storage	Bag-like structure on lower bill for collecting and catching fish	Pelican
Tearing	Curved, hooked beak for tearing flesh of animals	Eagle
Seed crushing	Short, stout bill with broad base	Sparrow
Insect eating	Long, slender bill	Thrush
Catching insects on wing	Wide, weak bill with bristles which aid in capturing insects on the wing	Whippoorwill
Boring	Chisel-like for drilling holes in bark in search of insects	Flicker
Crushing, climbing	Curved, hooked	Paroquet
Cone opening	Upper and lower parts of bill crossed. Useful in prying up scales of cones, seeds are then collected with the tongue	Crossbill

Fig. 330.—Special adaptations of bird's bills reveal food habits.

b. Neck.—The neck is long and flexible. In some birds, like the *owl*, it is so flexible that the head can be turned around so that it faces backward instead of forward. When the bird flies, the neck aids in keeping the proper balance.



Special Purpose	Special Structures	Examples
Wading	Long legs, toes on same level	Coot, Heron
Swimming	Web between the toes	Duck
Scratching	Strong blunt claws on end of toes; 3 toes in front, 1 toe at back	Chicken
Climbing	Sharp claws, 2 toes front, 2 at back	Woodpecker
Perching	Foot locks or clasps perch, 3 toes front, 1 at back	Blue Jay
Fighting	Spurs	Rooster
Grasping	Curved, sharp claws for grasping	Eagle
Running	Strong muscular legs	Ostrich

Fig. 331.—Special adaptations of birds' feet.

c. Trunk and Limbs.—The trunk is spindle-shaped and the modified forelimbs, the wings, are folded on either side of the body when the bird is at rest. The hind limbs, the legs, are covered with horny scales, and the feet usually have four toes, each of which is provided with a claw.

Claws are sometimes called *talons* (L. *talus*, the ankle, heel) and are useful to different birds in different ways (Fig. 331).

The wings, as already noted, are modified forelimbs and are adapted for flying. The shoulder is braced by three bones instead of two, as in man. They are the wishbone, the shoulder blade, and the coracoid. This arrangement gives strength to the wing. The muscular forelimb is covered with feathers, the long flight feathers being attached along the posterior margin.

d. The Tail.—At the posterior end of the body is the tail, the fleshy part being concealed by the feathers. The bird can spread out its tail feathers fanwise. The tail is used in balancing but is perhaps more useful as a sort of rudder in flying. It serves the same purpose as the rudder of a boat or an airplane; *i.e.*, it is used for steering. In some birds, as in *woodpeckers*, it may be modified as a supporting organ (Fig. 342).

At the base of the tail, on the dorsal surface, is an oil gland. The bird presses out a drop of oil from this gland with its bill and spreads it over the feathers. This keeps them in good condition.

2. FEATHERS. *a. Structure and Types.*—Feathers are remarkable structures arising from the epidermis. Note the parts of a feather in Fig. 332. The stiff portion is the *shaft;* the expanded portion, the *vane;* the *quill* is embedded in the skin. In Fig. 332, a portion of the vane has been enlarged to show its structure. Tiny barbules hook over one another and hold the parts of the vane together. The interesting thing is that if a strain is put on the vane, it will "split," but the bird can run its bill over it, and it is then as good as new again. The shaft of the feather is hollow, thus making it lighter. Feathers are so constructed as to secure a maximum of lightness, yet they are relatively strong.

Feathers are of use to the bird in many ways. The contour feathers form a smooth outside covering over the spindle-shaped body; the down feathers next to the body help retain the body heat; the wing feathers form an air-resistant expanse essential for flight; the tail feathers may aid in balancing, may act like a rudder, or, in some cases, as a prop (woodpeckers).

b. Tracts.—Feathers grow on the body in definite tracts, and these tracts differ in different birds (Fig. 333). Most birds have areas under the feathers that are quite bare.

c. Molting.—Birds shed their old worn-out feathers, usually in the fall, and get a complete new set. Some molt regularly twice a year; others shed only partially in the spring. The change in color plumage in the spring may be due to a chemical change in the feathers themselves, the tips of the feathers may be broken off, or there may be a partial molting. The change in color, when it occurs, is especially noticeable in the male.

d. Coloration.—The color in feathers may be due to (1) *chemical pigment* that is produced by the bird itself or (2) to *physical structures*. The

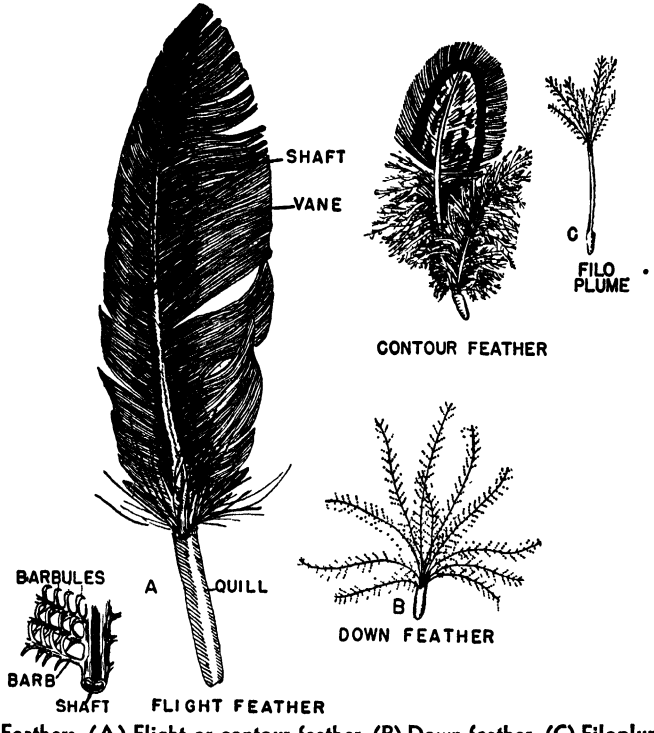


Fig. 332.—Feathers. (A) Flight or contour feather. (B) Down feather. (C) Filoplume, or hair feather. (D) Part of a contour feather magnified to show barbs and barbules. (M. Price.)

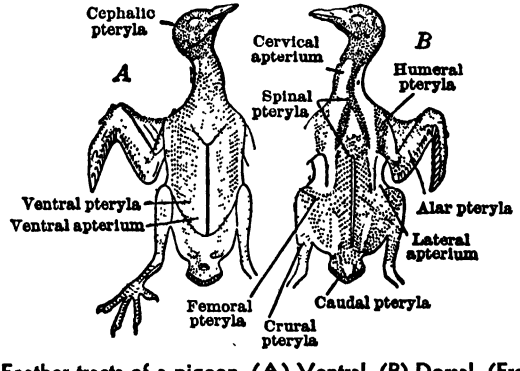


Fig. 333.—Feather tracts of a pigeon. (A) Ventral. (B) Dorsal. (From Nitzsch.)

feathers may be covered with a transparent outer layer that interferes with the rays of light, breaking them up after the manner of a prism. Reds, yellows, and browns may be of this type or due to pigment. Or the

feathers may be covered with fine striations or ridges that will do the same thing. The metallic colors and blues, as in the blue jay, are of this type. Sometimes the two types are combined with striking effect.

(1) PROTECTIVE COLORATION.—Although many birds are brilliantly colored, many of them are protectively colored, especially the females. Many types of females can scarcely be seen as they sit on their nests.

(2) MALE PLUMAGE AND SECONDARY SEXUAL CHARACTERS.—The brilliant plumage of some male birds is familiar to everyone. In addition,

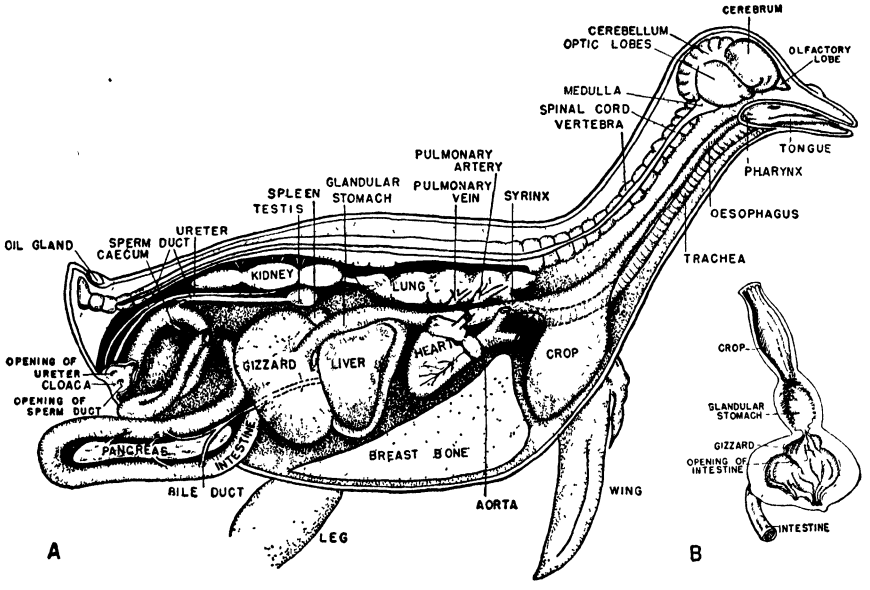


Fig. 334.—(A) Diagram showing the internal organs of a male bird. The air sacs connected with the lungs have been omitted. (B) Part of the digestive system of a chicken showing relations of the crop, glandular stomach, and intestine. (L. Runyon.)

combs, wattles, extra-long spurs, and the crow of domestic chickens are well known.

B. Internal Anatomy and Physiology. 1. DIGESTION.—The food of birds is varied. They may not eat much at one time, but they are almost constant feeders. Some are vegetarians and eat seeds mostly; some are carnivorous; *i.e.*, they eat worms, insects, and other animals; still others thrive on a mixed diet; finally, birds of prey eat many types of animals, carrion, etc. Since birds depend largely upon flight for safety, their meals are very often interrupted. The digestive system allows them to feed quickly and to store food. The mouth cavity opens into the esophagus, which is expanded into a crop. Here the food is stored and softened. The stomach consists of two parts, a glandular stomach, the proventriculus, in the walls of which the gastric juice is secreted, and a muscular gizzard

(Fig. 334*A* and *B*). The gizzard contains sand and bits of gravel, which aid in grinding the food. The intestine, made up of the *duodenum*, the *ileum*, and the *large intestine* and *rectum*, follows the *gizzard*. Its posterior end expands into the rectum, which leads into the *cloaca*. No *gall bladder* is present, but the *bile ducts* empty into the upper part of the intestine (duodenum). The *pancreas* also pours its secretion into the upper part of the intestine. Two blind caeca are at the junction of the large and small intestine.

When drinking water, many birds lean over, take a beak full, then tip up the head, and allow it to run down the throat.

2. Circulation.—The vascular system is much like that of crocodiles in some respects; in others, it resembles that of mammals. There is only one aortic arch in the adult, the right, instead of two, as in the reptiles. Mammals have only one aortic arch, but it is a left and not a right aortic arch, as in birds. The heart is four-chambered, the right and left halves being entirely separated. Where the blood vessels enter or leave, it is guarded by valves, and there are valves also between the auricles and ventricles. The venous blood enters the heart directly through the right and left precava and the single postcava and not through a sinus venosus. From the right auricle the blood goes to the right ventricle and is pumped out through the pulmonary artery, which divides and sends branches to the right and left lungs. The oxygenated blood is returned to the left auricle by the two pulmonary veins, and from there it goes into the left ventricle, out through the aortic arch, and, finally, through the dorsal aorta to all parts of the body. The precavae bring the blood back from the head region, and the postcava brings it back from the posterior regions. These veins empty the venous blood into the right auricle, and so the circuit in the closed system is complete. The blood vessels that enter and leave the heart are located near the median line of the thoracic cavity, held in place and surrounded by a double-walled membranous sac, the pericardium. The lymphatic system is of the open variety.

3. Respiration and Voice.—Birds use up so much energy in flying that they must have a ready oxygen supply. The unique respiratory system provides for efficient distribution of food and oxygen to the tissues and the collection of wastes to be eliminated. The air enters the mouth through the nostrils and goes into the trachea through the *slit-like glottis* in the anterior wall of the pharynx. The trachea, or windpipe, is kept open by rings of cartilage. It bifurcates, sending a branch to each lung. Here the branches divide and subdivide. Small branches of the tubules, *bronchioles*, carry the air into the alveoli or air spaces. Through the walls of the alveoli, the respiratory exchange of gases takes place with the blood in the capillaries. The lungs are not unduly large, but their capacity is greatly increased by a connection with the bronchi of *nine air sacs*.

These lie along the sides and dorsal surfaces of the body cavity, and small branches penetrate the bones. This greatly increases the surface for exchange of blood through the blood capillaries. Another feature of bird lungs is that there is a system of *excurrent bronchi* through which air is carried out without interfering with the air coming in the *incurrent bronchi*. Air is forced into the lungs and sacs as the bird moves rapidly in the air and is forced out by compression of the pectoral muscles that lower the wings. It is possible thus for the bird to breathe easily when in flight.

Birds require tremendous energy for flying, which they obtain by rapid oxidation, thus using up large amounts of oxygen. The temperature of the bird's body ranges from 102 to 110°F. (degrees Fahrenheit = 38+ to 43+°C.). Rapid oxidation naturally results in the production of the large amount of waste materials. Since the circulation of the blood is rapid, respiration in the lungs is very efficient.

The Voice.—Where the trachea divides into the two bronchi, there is an enlargement to form the vocal organ, the *syrinx* (Gr. *syrinx*, a pipe), a structure possessed only by birds (Fig. 334). It contains a valve and muscles that alter the tension of the valve. Altering the tension changes the pitch; the narrower the slit the higher the pitch. This flexible valve is vibrated when air is forced through it from the lungs. Many birds have beautiful songs, especially in the mating season. In addition, most calls are distinctive and are easily learned.

4. Excretion.—The kidneys are metanephric and trilobed. Ureters from the kidneys empty into the cloaca. There is no urinary bladder.

5. Coordination and Special Senses.—The cerebrum is larger than that of the reptiles, but compared with the brains of mammals, the cerebrum is small, and the optic lobes are large (Fig. 334). That the vision of birds is keen is indicated by the way in which some of them obtain their food. Birds of prey are "eagle-eyed" and can see long distances. Water birds that fly high over water may suddenly "plummet down" and seize a fish that they have sighted from far away. Birds possess "near-sight," also, or they could not build their nests so precisely. The eyes have the usual structure of the vertebrate eye. Suspended in the *vitreous humor* is a fan-shaped, highly vascular pigmented body, the *pecten*, the function of which is not known. Suggestions have been made that it may have something to do with the nutrition of the eyeball or that it may assist in the process of accommodation, so remarkably developed in birds. The eyelids have been mentioned, an upper and lower movable lid and a nictitating membrane that can be drawn from the inside inner angle of the eye outward to cover the eye.

The flight of a bird among the branches of a tree without striking one demonstrates its splendid coordination. A naturally good eye, correlated

with a reflex center that is highly efficient, is responsible for this. The very large and much convoluted *cerebellum* (Fig. 334) is correlated with the delicate sense of equilibrium and the great power of muscular coordination belonging to birds.

The cochlea of the ear is more complex than that of reptiles. Birds must hear well, since they are singing animals. The Eustachian tubes open by a single aperture in the roof of the pharynx.

The olfactory lobes of the brain are small, indicating the development of a poor sense of smell. The sense of taste is present but not well developed.

6. Motion and Locomotion.—The voluntary or skeletal muscles of birds are striated. Those of the back are much reduced, but those of the neck, breast, and the limbs are highly developed. The muscles of the breast of the bird are highly developed, since they are used in flying (Fig. 334). These muscles constitute the familiar "white meat" of the chicken or turkey. The breastbone is modified in the shape of a keel in most birds. This permits the attachment of the heavy breast muscles. The mass of muscle is divided into two parts: a tough outside portion, which takes care of the downstroke of the wing, and an inside portion, which is used for lifting the wing on the upstroke. Naturally, this second portion does not have as much work to do and so does not have to be so strong. It is the "tender" part of the "white meat" of the bird.

The muscles of the leg are well developed for bipedal locomotion and for perching. A bird is able to perch, even when asleep, because of the arrangement of certain muscles and tendons. If the hind limb is bent, as from the weight of the body, a pull is exerted on the tendons that flexes all the toes and causes them to grasp the perch automatically.

7. Support.—The skeleton of the bird represents many modifications that are the result of the adaptation of flying. The *skull* bones are thin but are so fused that the sutures between them are lost. There are no teeth in modern birds. The neck is flexible, the cervical vertebrae, the articulations of the centra being saddle-shaped or *heterocoelus* (Gr. *heteros*, other; *koilos*, hollow). This allows use of bill for nest building, preening of feathers, feeding, and other purposes. The trunk skeleton is rigid, the vertebrae being almost completely fused together, and there is an additional bracing of the sides by short projections extending backward from some ribs and overlapping the succeeding rib. These are the *uncinate processes*. For the attachment of flight muscles, there is a pronounced *keel* on the sternum. There are six movable vertebrae in the tail and a *pygostyle* formed by the fusion of the last four caudal vertebrae. The pygostyle supports the large tail feathers. Because of the ability of the bird to move the tail, the pygostyle can be used as a balancer when the bird is standing or perching and as a rudder when the bird is flying

a. Pectoral Girdle and the Wing.—The sternum with a *keel* or *carina* has been mentioned. In addition to this, the pectoral girdle consists of the *scapulae*, or shoulder blades, and the fused clavicles, these being united in the middle to form the wishbone, or *furcula*. The *coracoids* connect the sternum with the anterior ends of the scapulae at the shoulders. The wing bones are the *humerus*, the *radius*, and the *ulna*, the *carpus*, *carpometacarpus*, and the three digits. For the formation of the carpus and the carpometacarpus, there has been fusion of bones. The digits are a *preaxial digit* with one small bone, which supports a small tuft of feathers, known as the *bastard wing;* a middle digit with two bones; and a *postaxial digit* with one small bone.

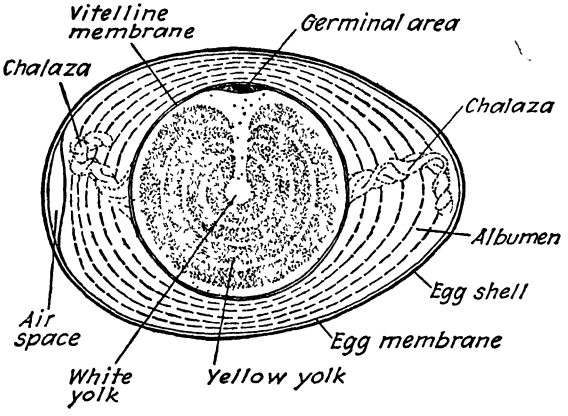


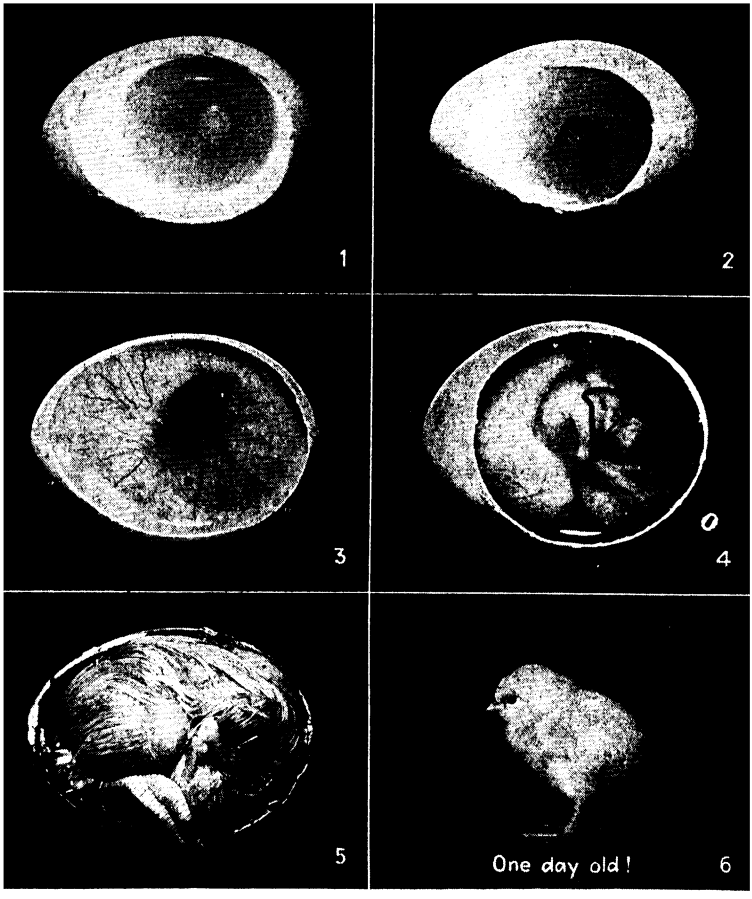
Fig. 335.—Diagram of the egg of a bird. (From Wolcott, Animal Biology.)

b. Pelvic Girdle and the Legs.—The pelvic girdle is strongly fused to the backbone by the *ilia* to form a strong support for the legs. The ilia are also fused to the *ischium* and *pubis* in the adult. The leg bones are a short thick *femur;* a knee cap, the *patella;* a *tibiotarsus*, made up of a large *tibia*, a small *fibula* and some of the proximal *tarsal* bones being fused with it; the *tarsometatarsus*, formed by the fusion of distal tarsals and proximal metatarsals, and four digits ending in curved claws. One of the digits extends backward in many birds and is used for grasping a perch. There are two movable joints in the leg, the *knee joint* and the *metatarsal joint*, the latter being peculiar to birds and dinosaurs. Birds walk on their toes.

8. Reproduction.—The paired *testes* in the male empty into the cloaca through the sperm ducts or *vasa deferentia*. The posterior end of the sperm duct is expanded into a *seminal vesicle* for the storage of sperm.

In the female of most birds, only the *left ovary* and *oviduct* are developed, the right ovary and oviduct being vestigial. In a few birds, as in some hawks, both ovaries and oviducts are developed.

Although some birds, such as ducks and geese, have copulatory organs, in most cases the sperm are transferred by the male directly to the cloaca of the female. The sperm find their way through the oviduct to the anterior end.



when placed in the incubator. (2) (3) At the end of three days, the circulation is well established. (4) (5) (6) Successive stages of development. The eggs of chickens usually hatch in 21 days. (Courtesy of Ralston Purina Company.)

Eggs are produced in the ovary. When mature, they drop into the body cavity; here they are fertilized while still near the ovary. They then find their way into the oviduct. As they pass down the oviduct, the "white" of the egg is added to the yolk. This "white" substance, the albumen, is secreted by glands in the walls of the oviduct. Then the shell membrane, a double structure, encloses the egg (Fig. 335). Finally a shell, secreted by a shell gland in the lower part of the oviduct, is added.

At the time the egg is laid, the future chick has developed very little (Fig. 336). But no further development takes place unless the eggs are kept warm under the bird or in an incubator. The eggs of chickens hatch in 21 days. The eggs of birds do not require the same amount of time for hatching; for example, the eggs of the cowbird hatch in 10 days, whereas those of the ostrich hatch in from 50 to 60 days. Embryonic membranes, the amnion and chorion, develop as in the reptiles (Fig. 337). Young

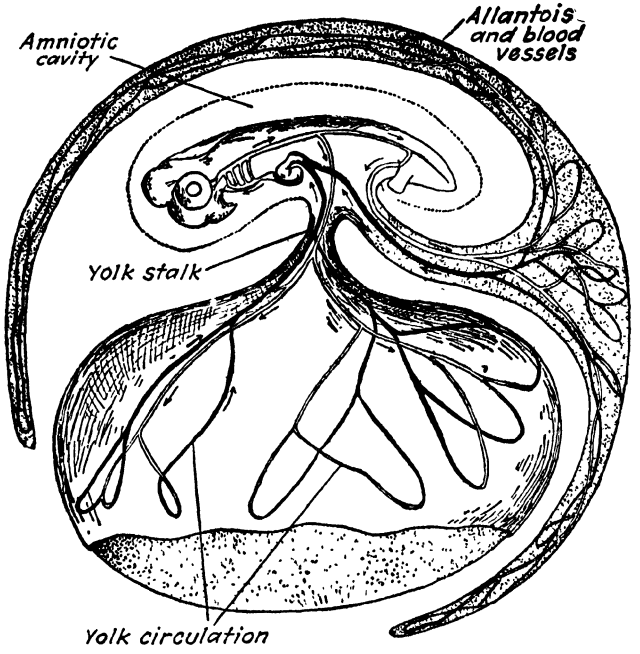


Fig. 337.—Early development of a bird showing functional yolk sac. The allantois has respiratory and excretory functions. (From Wilder, History of the Human Body, Henry Holt and Company, Inc.)

birds are of two general classes, those born naked and helpless, *altricial* (L. *altrix*, nurse), and those able to run around as chickens do shortly after hatching, *precocial* (L. *prae*, before; *coquere*, to ripen). Altricial young remain in the nest for a few days; precocial young are covered with down and are able to follow the mother about soon after hatching. Young quail are good examples of a precocial type of bird.

V. Special Adaptations and Activities of Birds

A. Beaks and Feet.—The beaks and feet of birds show remarkable fitness for the use to which they are put. Birds of prey have strong,

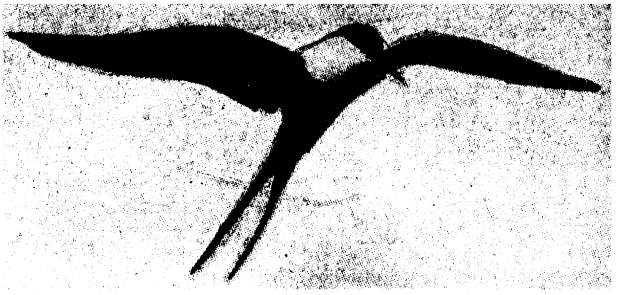
hooked beaks, and birds that eat insects have bills more slender than those of the seed eaters. The crossbill has a bill especially adapted for prying up the scale of a cone. It then secures the seed with a specially adapted tongue. It is so specialized that it cannot pick up seeds from level surfaces. Figure 330 shows other types of bills especially adapted for securing the type of food used by the bird. The feet are no less adapted for its activities such as perching, wading, and swimming (Fig. 331).

B. Migrations.—Birds are not the only animals that migrate. The general subject of migrations is discussed in Chap. XLVI. However, it may be mentioned here that one of the most remarkable phenomena of bird life is their migrations. Not all birds migrate, but some do migrate great distances, as that recorded for the arctic tern (Fig. 338), which nests on the arctic shores, and, when the young are able to travel, migrates southward to spend the southern summer in the Antarctic, a distance of over twenty thousand miles, returning to spend the northern summer in the Arctic. They have one breeding season and nest in only one region. No satisfactory explanation has been offered as to how they find their way, even in the darkness, but several theories are offered, such as influence of temperature and food supply and a good sense of direction.

C. Songs.—Birds have various call notes, some birds being particularly gifted. In the South, the mockingbird is a good mimic and has a beautiful song of its own. Thrushes, cardinals, thrashers, many of the sparrows, warblers, and others too numerous to mention have characteristic and beautiful songs that may be recognized with a little care and patience. The nightingale, famed in poem and story for its song, does not live in the United States.

D. Nest Building and Care of the Young.—Birds exhibit an amazing variety of nest-building architecture. There are the hummingbird's delicately built nests of moss and lichens, lined with thistledown, the rude platforms of twigs of the mourning doves, and the barely scooped-out nests of some of the shore birds. Then there are the birds that not only do not build their nests but lay their eggs in the nests of other birds and have the eggs incubated by the owners of the nests. Examples of this type of behavior are the American cowbirds and the European cuckoo. Nests are usually hidden, and the eggs bear characteristic markings for each species. They vary in size from the ½-in. eggs of the hummingbird to the 3-lb. ostrich eggs. In some, the male and the female take turns, and in still others, as the ostrich, the male does most of the incubating.

As already noted, two general classes of young are recognized: those that are able to care for themselves as soon as hatched and others that are entirely helpless. These are watched over and fed by both male and female until they are able to care for themselves. For other adaptations of birds, see Chap. XLVI.



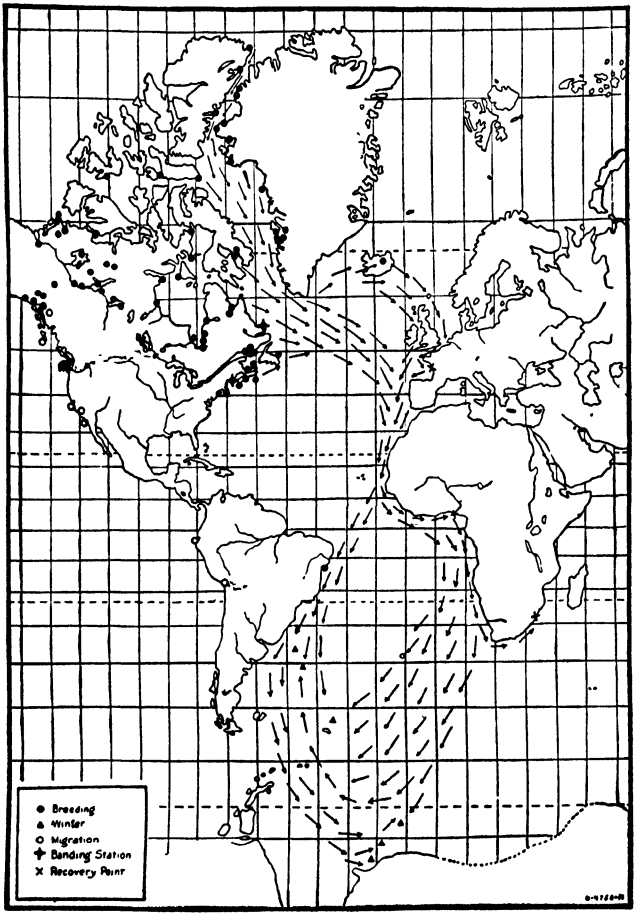


Fig. 338.—Distribution and migration of the Arctic tern, Sterna paradisaea. The route indicated for this bird is unique as no other species is known to breed abundantly in North America and to cross the Atlantic Ocean to and from the Old World. The extremes of summer and winter homes are 11,000 miles apart and the route taken is circuitous. These terns probably fly 25,000 miles each year. (From U.S. Department of Agriculture Circ. 363.)

VI. Importance of Birds

Besides furnishing food for man in the form of meat and eggs and furnishing feathers for ornamentation and for use in pillows, feather beds, and coverings, birds are very useful in destroying insect pests as well as many weed seed. They are truly friends of the farmer, and the good they do can hardly be estimated. In Salt Lake City is a monument to sea gulls. In 1848–1849 the crops of Mormon pioneers were threatened by a scourge of crickets, but the gulls arrived and saved the day. The beneficial effect of most birds of prey in destroying mice, rats, ground squirrels, etc., has been mentioned.

In certain regions of the world are deposits of guano, the excrement of sea birds, useful for fertilizer. Peru has valuable deposits.

Bird songs give an esthetic pleasure. The hobby of studying birds is a good one, since not only is it interesting but it takes the student outdoors.

VII. The Orders of Birds

Ornithologists do not agree to the classification of birds. More than fourteen thousand species of living birds have been described. They are not so sharply separated into groups as are the other classes. About 25 orders are recognized. Many of these are represented in Fig. 51; others are illustrated by photographs.

Subclass II. NEORNITHES (page 480).

Division I. *Ratitae* (L. *ratis*, a raft) (page 480). Young are precocious.

Order 1. *Struthioniformes* (L. *struthio*, an ostrich; *forma*, appearance). Terrestrial birds that have lost the power of flight; naked head, neck, and legs; *African ostrich* (Fig. 339).

Order 2. *Rheiformes* (L. *Rhea*, the genus of American ostrich). *Ostrich-like*, flightless birds with naked head, neck, and legs; *American ostrich.*

Order 3. *Casuariiformes* (L. *casuarius*, a cassowary). Ostrich-like birds with small rudimentary wings; *cassowary, emu.*

Order 4. *Apterygiformes* (Gr. *a*, not; *pteryx*, wing). Small birds with hair-like feathers and rudimentary wings; *kiwi* (*Apteryx*).

Division II. *Carinatae* (L. *carina*, a keel). Birds with keel on breastbone, to which muscles are attached.

Order 5. *Crypturiformes* (or *Tinamiformes*). Flying terrestrial birds with short tail; no pygostyle; related to the Ratitae, but breastbone is keeled.

Order 6. *Sphenisciformes* [Gr. *spheniskos*, a little wedge (wing shape)]. Flightless marine birds with small scale-like feathers; wings modified as paddles; *penguins.*

Order 7. *Gaviiformes* (*Gavia*, the loon). Aquatic birds with legs far back on the body and webbed feet; *loons.*

Order 8. *Colymbiformes* (Gr. *columbus*, a diver). Aquatic birds with legs far back on the body, toes lobed; *grebes.*

Order 9. *Procellariiformes* (*Procellaria*, the stormy petrel). Marine birds with webbed feet and powers of great flight; *albatrosses* and *petrels*.

Order 10. *Pelecaniformes* (L. *pelicanus*, a pelican). Swimming birds with webbed toes; *pelicans* and *cormorants*.

Order 11. *Ciconiiformes* (L. *ciconia*, a stork). Stork-like, long-legged, wading birds; *herons*, *ibises*, *flamingos* (Figs. 340 and 341).

Order 12. *Anseriformes* (L. *anser*, a goose). Goose-like birds: aquatic; beak covered with soft, sensitive membrane and edged with horny lamellae; feet webbed; *geese*, *swans*, *ducks*.

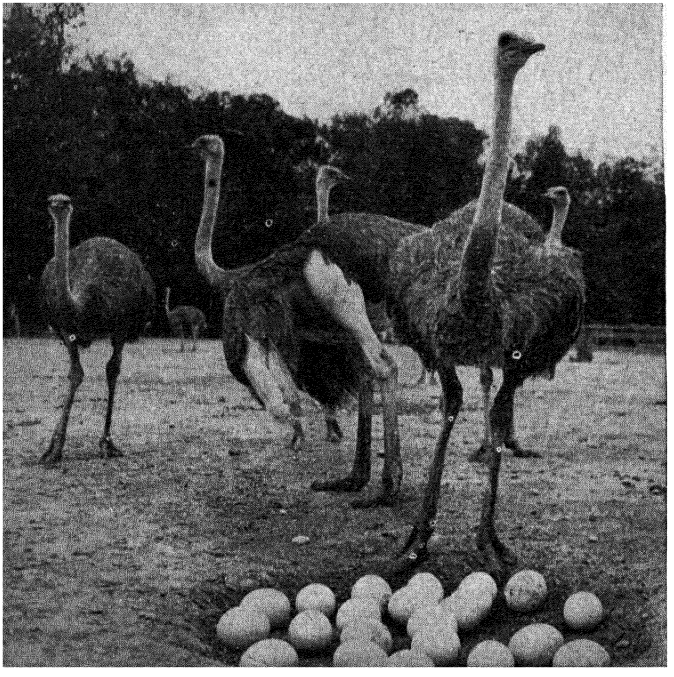


Fig. 339.—Ostriches, Struthio, and their eggs. (Courtesy of the California Zoological Society.)

Order 13. *Falconiformes* (L. *falcon*, a falcon). Falcon-like birds; carnivorous; curved beak, hooked at the end; sharp claws on feet adapted for perching and seizing prey; *eagles*, *hawks*, *vultures*.

Order 14. *Galliformes* (L. *gallus*, a cock). Fowl-like birds; terrestrial or arboreal birds with feet adapted for perching and scratching; *pheasants*, *quail*, *domestic fowls*.

Order 15. *Gruiformes* (L. *grus*, crane). Crane-like birds; mostly marsh birds; wading birds with feet not webbed; neck extended in flight; *cranes*, *rails*.

Order 16. *Charadriiformes* (*Charadrius*, a genus of plover). Plover-like birds; small shore birds, usually long-legged and long-billed; *plovers*, *gulls*, *terns* (Fig. 342*A*).

Order 17. *Columbiformes* (L. *columba*, a pigeon). Pigeon-like birds; birds with short bill and short wing; *pigeons*, *doves*.

Order 18. *Psittaciformes* (L. *psittacus*, a parrot). Parrot-like birds; four toes, two in front and two behind; heavy hooked bill; *parrots*.

Order 19. *Cuculiformes* (L. *cuculus*, a cuckoo). Cuckoo-like birds; perching birds with two toes in front and two behind; long compressed bill; long tail; *cuckoo.*

Fig. 340.—Egret, Herodias egretta, and their nests in Egret Sanctuary, Avery Island, La. (Courtesy of E. H. McIlhenny.)

Fig. 341.—White ibis, Guara alba, in flight. (J. C. Dickinson.)

Order 20. *Strigiformes* (L. *strix*, a screech owl). Owl-like birds; bill hooked; eyes large; claws sharp; *barn owl* (Fig. 343*B*).

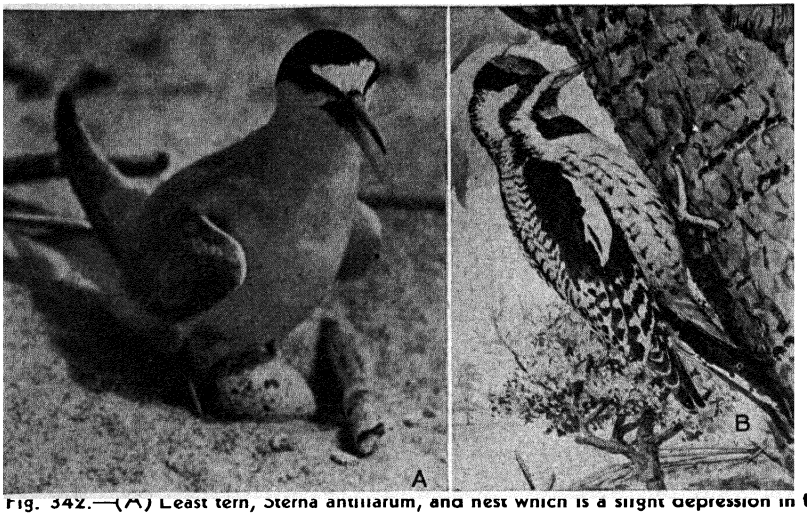


Fig. 342.—(A) Least tern, Sterna antillarum, and nest which is a slight depression in the sand. (Don Eyles.) (B) Yellow-bellied sapsucker, Sphyrapicus varius varius. The tail feathers of this woodpecker are especially stiffened so that it may be used as a prop. The toes of the feet are especially adapted for climbing and the chisel-like bill is also especially adapted for its work. (Courtesy of U.S. Biological Survey.)

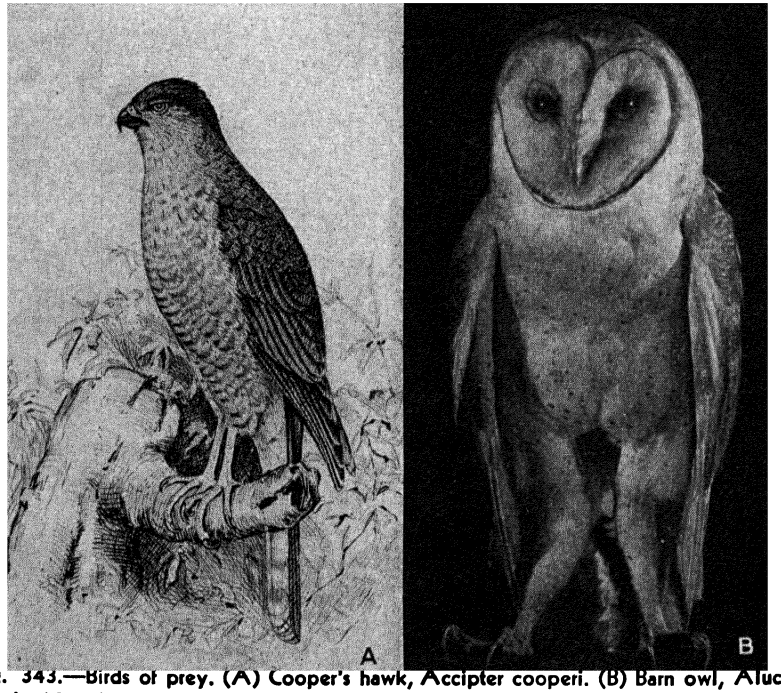


Fig. 343.—Birds of prey. (A) Cooper's hawk, Accipter cooperi. (B) Barn owl, Aluco pratincola. Note long claws on these birds. [(A) Courtesy of U.S. Biological survey, and (B) The American Museum of Natural History.]

Order 21. *Caprimulgiformes* (Caprimulgus, generic name for European goatsucker). Goatsucker-like birds; short-billed, wide-mouthed birds with long, pointed wings; *nighthawk; whippoorwill.*

Order 22. *Micropodiformes* (Gr. *mikros*, small; *pous*, foot). Swift-like birds with small feet; either with long bills, as the hummingbirds, or short bills and wide mouths, as the swifts.

Order 23. *Coraciiformes* (Gr. *corax*, a crow). Kingfishers, etc. In some species the bill is straight, pointed and long; legs small; *kingfishers, hornbills* (not crows).

Order 24. *Piciformes* (L. *picus*, a woodpecker). Woodpecker-like birds; climbing birds with heavy pointed bills and stiff tail feathers used for propping body against tree; *woodpecker* (Fig. 342); *toucan.*

Order 25. *Passeriformes* (L. *passer*, a sparrow). Sparrow-like birds; small or medium-sized; large group containing more than half the known species of birds; the common perching birds or songbirds; *larks, swallows, crows, jays, starlings, wrens, nuthatch, creepers, blackbirds, tanager, sparrows*, etc.

VIII. Interesting Birds

A few birds are so interesting as to be worthy of special mention. Only some of the forms frequently mentioned in song and story, which have some very unusual features, can be included here.

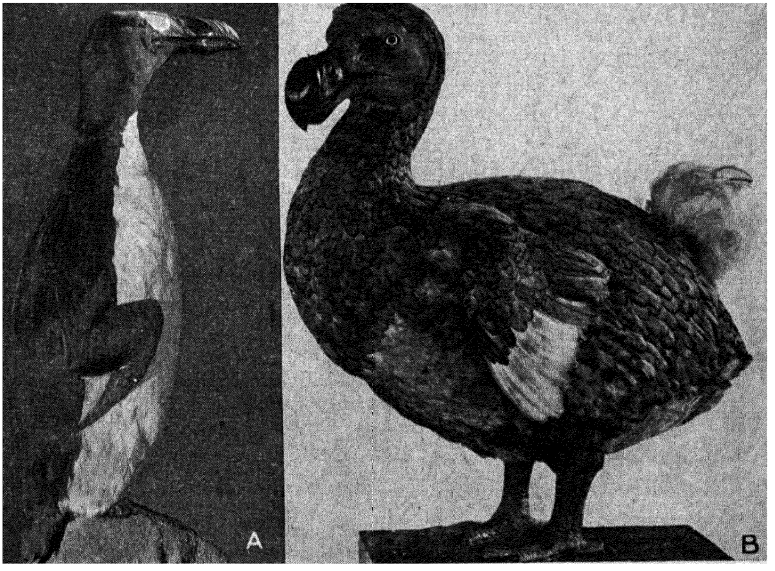


Fig. 344.—Two birds which have recently become extinct. (A) The great auk, Plautus impennis, extinct since 1842. (B) Dodo, Didus ineptus, now extinct, though seen alive as late as 1681. (Courtesy of The American Museum of Natural History.)

A. Dodo (Fig. 344*B*).—In Portuguese, the word *dodo* means simpleton. The bird was so named because the Portuguese sailors who found it on the island of Mauritius found it sluggish. It was flightless and easy to capture and was last seen alive about 1681. "Extinct as a dodo" is an expression often used.

B. Lyre Bird (*Fig 345*) —This famous bird is famous for its tail, shaped like an ancient lyre It is developed in the male bird and is a secondary sexual characteristic The, are about the size of chickens

C Birds of Paradise —The plumage of the male birds of paradise is magnificent and well deserves its reputation as the most gorgeous in the bird tribe. They are not large birds, many of them being not more than 6 or 8 in long

D The Great Auk, or Garefowl (*Fig 344A*) —This bird has become extinct within the last hundred years It was unable to fly, and large numbers nested on the coasts and islands in the North Atlantic. The eggs were used for food the birds for meat, and the feathers for pillows and feather beds This is another case of extinction due to man

The great auk has many relatives, the auks, which are diving birds, forming much of the bird life of the Arctic seas They nest on cliffs, a female laying a single egg on the rocks, no nests are made

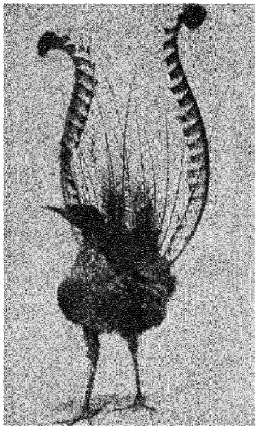


Fig 345 —Lyre bird, Menura superba (Courtesy of The American Museum of Natural History)

E Pelicans —These birds usually live in companies They have peculiar pouches hanging from the lower bill, which may be 18 in long and 6 in deep It may serve as a scoop net for catching fish

F Egrets, or Snowy Herons (Fig 341) —One of the most beautiful of the herons is the egret It faced extinction because its nuptial plumes, the aigrettes, long, white plumes like spun glass, were prized for ornamentation of ladies hats These plumes grow out from the back of the birds during the nesting season and can be obtained only by shooting the birds Since they live in rookeries they are easy to capture Laws protecting these birds have saved them from extinction, and their former rookeries in Florida are being reestablished

G The Albatross Even long ago sailors considered it unlucky to kill the albatross And anyone who has read Coleridge's Lay of the Ancient Mariner is not likely to forget instead of a cross, an albatross around my neck was hung ' The albatross is famous for its marvelous powers of flight and for its long, narrow wings, which may reach a length of 3 ft or more

H Flamingos *Flamingos* nest in large colonies There is a colony now established at Miami They are beautiful in color being scarlet or pink They have peculiar bills sharply curved black on the end yellow at the base and orange in the middle

They build very curious mud nests about 1 ft in height 18 in in diameter at the base and about 1 ft at the top The egg that is laid in a hollow at the top of this structure is thus protected from rising water

I Swans White swans are pure white except for a black bill with a yellow spot at the base, black feet and eyes with a brown iris There is a black species also The young when hatched, are called *cygnets* They are grayish brown but their plumage changes to white as they grow older

J Secretary Bird — This curious-looking bird from South Africa gets his name from the feathers on the head, which can be raised when the bird is excited, giving it the appearance of a pencil behind the ear of a clerk or secretary They are long-legged, awkward birds, protected because they kill snakes

1. What are some of the reasons for thinking that birds have reptilian ancestors?
2. Describe the reptilian characters of the *Archaeopteryx*. Why is it classed as a bird?
3. Do any living birds have teeth? Name some toothed birds.
4. Are there any peculiarities in the neck of an owl? What is the role of the neck of birds in flying?
5. What are the peculiarities of the wings of a bird? Why would you say that they had been greatly modified since the time of the *Archeopteryx*?
6. Describe the types of feathers. What is the role of each type? Do they grow evenly on the body?
7. How is color produced in birds? Do you know any cases of protective coloration? Is the usual more sober coloration a protective device? Explain.
8. Name at least three secondary sexual characters of roosters.
9. How is the voice of the bird produced?
10. What are some of the peculiarities of the skeleton of the bird? How is this related to the flying habit?
11. Describe the digestive organs of birds.
12. Compare the power of coordination of the bird and that of other lower animals. How is it possible for birds to fly so quickly among branches?
13. Where are the eggs fertilized in birds? What is the state of the bird egg when it starts down the oviduct? What parts are derived from the oviduct? What is the state of the egg when laid?
14. How long must a hen's egg be incubated before hatching? At what temperature must hen's eggs be kept?
15. Describe ten types of birds' nests.
16. Describe some migratory birds.
17. Why should most birds be protected? Why are birds spoken of as "the farmer's friend"? Do you know any birds that are scavengers?
18. Discuss some adaptations and special activities of birds.
19. Name at least two birds recently extinct.
20. What are some interesting types of birds?
21. Define, as related to birds: cere, talon, molt, crop, syrinx, germinal disk.

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CHAPTER XXXIII

MAMMALIA

When Nature, her great masterpiece design'd
And fram'd her last, best work, the human mind,
Her eye intent on all the wondrous plan,
She form'd of various stuff, the various Man.
—BURNS.

I. Mammals in General

The mammals (L. *mamma*, breast) are the highest group in the animal kingdom. This position is justified on account of the great development of brain power. Since man, who belongs to the *primate* (L. *primus*, first) group, has some primitive features, the primates are placed by some authorities somewhere near the middle of the series of orders.

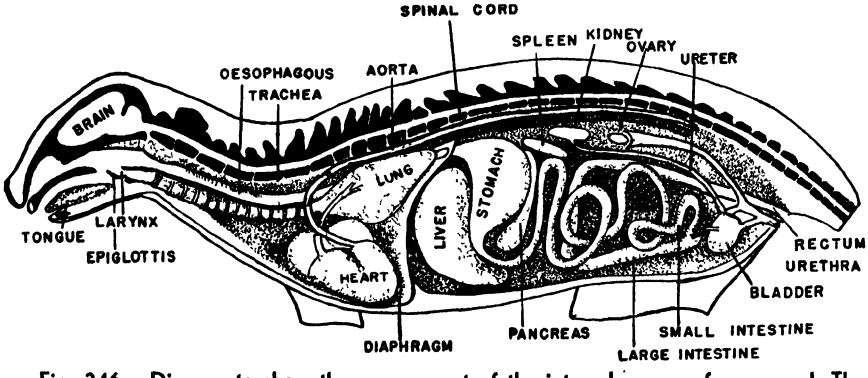


Fig. 346.—Diagram to show the arrangement of the internal organs of a mammal. The heart is pulled away so as to show the origin of the aorta and the pulmonary artery. The membranes around the heart and lungs have been omitted. In most instances the urethra of mammals is an excretory duct close to, but distinct from, the reproductive duct. (B. Shamos.)

The mammals vary widely in size from the small field mouse to the largest animal now living, the whale. Here, too, are included familiar cats, dogs, and many other animals that serve man as beasts of burden and for food.

There are about 4,000 species of living mammals, and about 3,500 fossil species have been found. The living mammals are fitted to live in practically every type of environment; in water, as whales; in the air, as bats; the great majority on land, as deer, lions, tigers; in trees, as pumas and monkeys; and, finally, under the surface of the earth, as moles.

In a general course of biology, there is usually little time for a thorough study of a typical mammal, but often one or more laboratory periods are spent in demonstration of the typical mammalian features as opposed to the features of the frog. The animals usually used in this work are the guinea pig, the rabbit, the white rat, the cat, and, more lately, the foetal pig. The last-named is easy to get, and the 8- to 10-in. sizes furnish excellent material for the demonstration of the mammalian features. Figure 346 shows a generalized vertebrate. Since Part IV of this book is largely concerned with mammalian anatomy and physiology, only a summary of these features is included in this chapter.

II. Ancestry of the Mammals

The Age of Mammals was the Cenozoic era, but mammals arose long before that time, probably in the Lower Permian or the Triassic times. The primitive mammals had some characteristics possessed by a group of primitive reptiles, the cynodonts. Perhaps their most important feature was the type of teeth. The type of dentition was heterodont, incisors, canines, and molars being present. The cynodonts also had paired occipital condyles.

III. Mammalian Features

The monotremes have many reptilian features and differ from typical mammals in that they lay eggs, have mammary glands without teats, and have only one opening for the urinogenital and digestive systems. The other mammals have separate anal and urinogenital openings and bring forth their young alive.

Except for the monotremes, the features most characteristic of the mammals are:

1. The body is more or less covered with *hair*, though this may be reduced to a few bristles, as in the whales.

2. There are *oil*, or *sebaceous glands*, which keep the hair and the skin pliable; *sweat glands*, connected with the heat-regulating mechanism, and *mammary glands*, reduced in the male, well developed in the female. These secrete milk for the nourishment of the young.

3. There is some form of external *ear*, or pinna, and the eyes have movable upper lids. The nose may be variously modified into a snout and may take over the functions of a tactile organ (mole) or prehension (elephant).

4. Except in aquatic forms, there are *cheeks* and *fleshy lips*.

5. The body cavity, or *coelom*, is divided by a muscular *diaphragm* into thoracic and abdominal cavities.

6. The *heart* is four-chambered and the sides separate. There is one aortic arch, the left.

7. The *red blood corpuscles*, circular, except in camels, are without nuclei. They are short-lived and are produced regularly in the red bone marrow.

8. There is a *vasomotor system* connected with the sweat glands, which helps in maintaining a constant body temperature ranging from 74 to 104°F. (24 to 40°C.).

9. There are *two sets of teeth*, temporary or milk teeth, which are replaced by permanent teeth. The teeth are of four kinds, incisors, canines, premolars, and molars (heterodont dentition).

10. Except for *monotremes*, the young are born alive, viviparous (L. *vivus*, alive; *parere*, to bear). The *placenta* is developed in the *Eutheria* and furnishes a means of nourishment of the young until they are born. As in the reptiles, embryonic membranes are present.

11. The *germ cells* of the eggs are microscopic, and they have little yolk. *Cleavage* is holoblastic.

12. There is great *development of the brain*, the cerebrum being much larger in proportion to the size of the animal. In the higher mammals, it is much convoluted, thus greatly increasing the cerebral cortex. The corpus callosum is greatly increased in size, and there is a complex well-developed cerebellum.

13. There has been a *simplification of the skeleton*, though the bones are not so fused as in the birds. The old quadrate of the reptiles becomes the incus of the ear, and the articulare becomes the malleus.

14. The skull articulates with the vertebral column by two occipital condyles, as in the Amphibia, and not with one, as in the reptiles and birds.

15. The bones of the *lower jaw* have fused to form a single bone that articulates with the skull.

16. The *ribs* articulate both with the vertebrae and with the sternum and so allow contraction and expansion of the thoracic cavity in breathing.

17. Three types of *foot posture* (page 650) are shown by the mammals: (1) *plantigrade* (L. *planta*, sole of the foot; *gradus*, step), or walking with the whole sole on the ground, as bears and man; (2) *digitigrade* (L. *digitus*, finger; *gradus*, step), as shown by the cat and dog; (3) *unguligrade* (L. *ungula*, hoof; *gradus*, step), as shown by cows, horses, etc. (Fig. 435).

Tracks of Mammals.—Hunters and fur trappers are able to trail their quarry by means of their tracks. Figure 347 shows the tracks of some native mammals. Observation shows that when a rabbit jumps, the hind legs are placed in front of the front legs. This is indicated in 9 of Fig. 347. The track tells the story of the structure of the foot and gives information as to how the animal walks or runs.

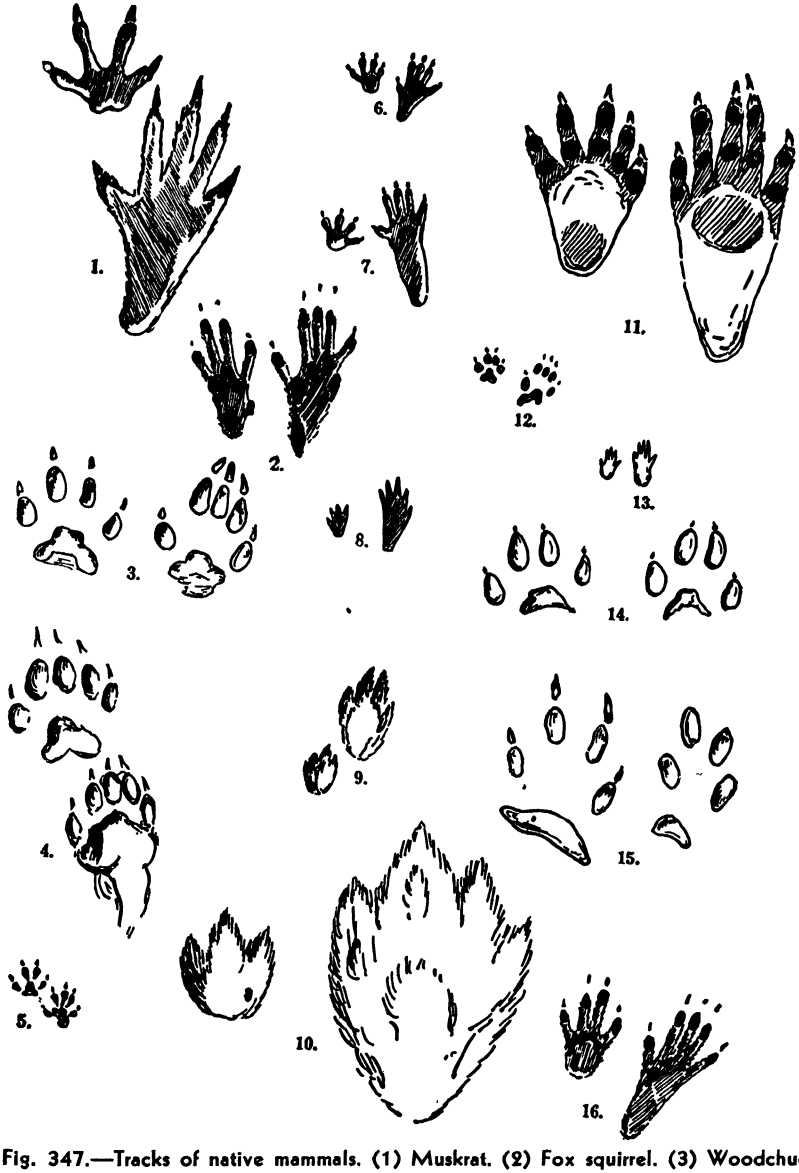


Fig. 347.—Tracks of native mammals. (1) Muskrat. (2) Fox squirrel. (3) Woodchuck. (4) Skunk. (5) Meadow mouse. (6) Deer mouse. (7) Brown rat. (8) Weasel. (9) Rabbit. (10) Varying hare. (11) Raccoon. (12) Little chipmunk. (13) Shrew. (14) Mink. (15) Fox. (16) Red squirrel. (From Williams, The Living World, The Macmillan Company.)

IV. Some Activities and Adaptations of Mammals

A. Migration.—The migrations of the birds in the spring are well known, yet among the mammals there is a case of migration almost as famous. Great heards of seals arrive at the Pribilof Islands in the Bering Sea at approximately the same time every spring and remain there from about May 1 to Sept. 15 (Fig. 348). During this time, the young are born. After leaving the islands, they go on their long sea migrations. They live on the seacoasts and islands of the northern regions; other herds are in the cold regions of the south. The seals furnish us with valuable fur and are protected by law in many countries. The three-year-old "bachelors" are killed for their fur. Other mammals that migrate are the red bat, whales, and elk.

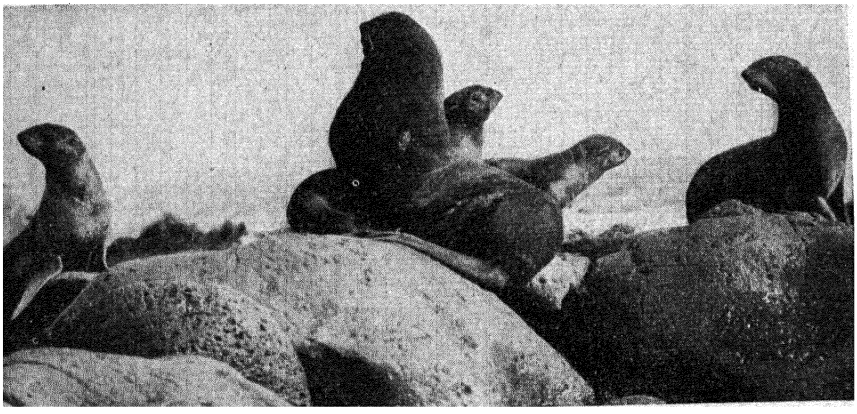


Fig. 348.—The fur seal, Callorhinus alascanus. The fur seals arrive at the Pribilof Islands off the coast of Alaska at approximately the same time every year for the breeding season.

B. Hibernation.—Many groups of animals go in for a long sleep or hibernate (page 457). Among the mammals, the ground squirrels, woodchucks, bats, and jumping mice hibernate. The bear becomes very fat before he goes into a cave or other sheltered place and goes to sleep. Since the sleep is somewhat intermittent, it is not true hibernation. He seems hardly to breathe, and all activities are at a low ebb. When the bears come out of their dens in the spring, they are quite thin, having used up their fat while asleep. The cubs, usually two in number, are born in midwinter.

Hibernation is often thought of as winter sleep, and most animals do hibernate in winter; but some begin their long sleep before cold weather.

C. Home Building.—Many mammals make little effort to build permanent homes, but there are others that do. Shallow caves, hollow trees, or any sort of shelter often provide temporary homes. But beavers (Fig. 349) and muskrats build intricate homes or lodges. Nests are built

by mice, fox squirrels, and many others. Burrows or dens are built by woodchucks, prairie dogs, and ground squirrels. Some of these have places for food storage and some nests for rearing young.

D. Secondary Sexual Characters.—Secondary sexual characters are shown in mammals by the larger size in some forms, especially large horns and antlers, or beards, as shown by the bison (Fig. 29). Large fur-seal bulls may weigh 500 lb., and the females weigh from 50 to 100 lb. Scent glands are often more prominent in the male.

E. Coloration.—While many mammals are very conspicuously colored, many show a protective coloration that enables them to remain inconspicuously in their environment. Even the striped tiger is incon-

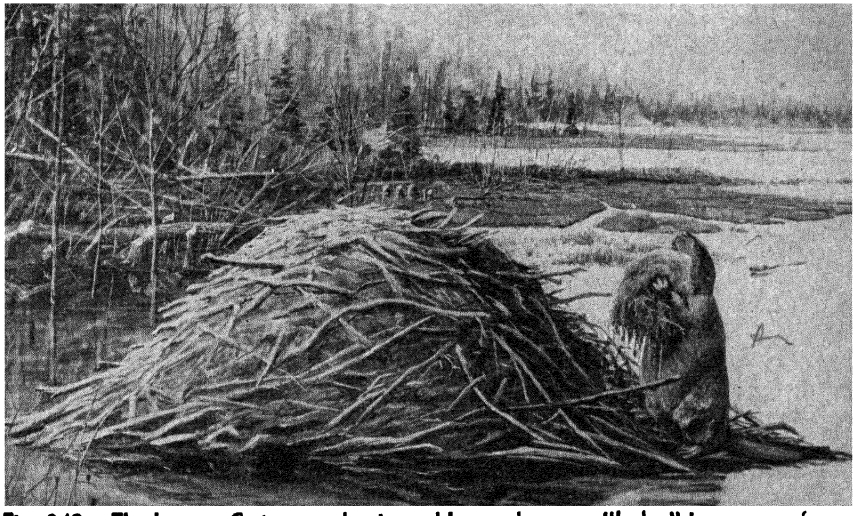


Fig. 349.—The beaver, Castor canadensis, and beaver house or "lodge" in process of construction. (Courtesy of U.S. Biological Survey.)

spicuous in the jungle. In the arctic regions, many animals are colored white during the winter season, as the arctic fox, snowshoe rabbit, weasel, etc., changing their color to spotted or brown during the summer (Fig. 502).

V. The Importance of Mammals

The relations of the mammals to man are complex and varied (page 830). They have served as beasts of burden since the dawn of history, and prehistoric man certainly used them for food and their hides for clothing. The value of domesticated animals to man cannot be estimated. Flesh and milk are used for food, and leather is made from the hides of many mammals. Other important articles of commerce are musk from the glands of certain mammals, ivory from the tusks of walruses and ele-

phants, oil from the fat of whales, and ambergris, a product of the intestinal tract of whales, which is used in making perfumes.

Millions of dollars' worth of furs are sold every year. Formerly the supply came from trapped animals, but now there are large silver-fox (Fig. 537) farms and other farms for mink, marten, and other fur-bearing animals.

Many mammals are predators and do much damage. Domesticated animals will be killed by predatory animals like lions, wolves, and other wild animals in countries where these animals are plentiful. The rabbit will do damage to green crops, rats will eat corn and other stored food, foxes will kill chickens, and house cats destroy millions of birds annually.

VI. Classification

Class. MAMMALIA.

Subclass I. *Prototheria* (Gr. *protos*, first, *therion*, mammal). The egg-laying mammals.

Order 1. *Monotremata* (Gr. *monos*, single; *trema*, opening). Examples are the *duckbill* and the *spiny anteater* (*Tachyglossus*), primitive mammals that lay eggs. These are

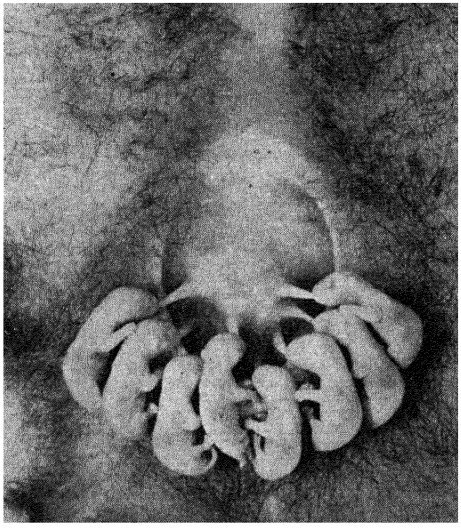


Fig. 350.—Brood pouch of opossum, Didelphis virginiana, showing attachment of the young embryos. (Courtesy of the General Biological Supply House.)

the only ones that have a cloaca. They lay eggs, and the young are nourished by a secretion from mammary glands. The duckbill, *Ornithorhynchus anatinus*, is found in Australia and has curious webbed feet, a duck-like snout, and is covered with hair.

Subclass II. *Metatheria* (Gr. *meta*, beyond; *therion*, mammal). The pouched mammals.

Order 1. *Marsupialia* (L. *marsupium*, a pouch). Mammals with no well-developed placenta. The young are born in a very undeveloped state and place themselves in a pouch, the marsupium. In this pouch are teats to which the young animals attach themselves by mouth; they remain there until developed. There are seven families of

marsupials. Examples are the *kangaroo, opossum, wombat, bandicoots.* The only representative in the United States is the opossum, *Didelphis virginiana.* The young remain in the pouch of the mother until they are fairly well developed (Fig. 350) and after that often ride on her back. They remain with her about two months.

Subclass III. *Eutheria,* (Gr. *eu,* true; *therion,* mammal). Most of the mammals, including man. All mammals with placentae through which the young are nourished before birth; *deer, dog, monkey,* etc.

Section *A. Unguiculata* (L. *unguis,* claw). Clawed mammals.

Order 1. *Insectivora* (L. *insectus,* cut off; *vorare,* to devour). *Moles* and *shrews.* These animals feed mainly on insects. They have rudimentary eyes, no external ears, and their forelimbs are adapted for digging. The common mole, *Scalopus aquaticus,* is a good example (Fig. 32*A*).

Order 2. *Dermoptera* (Gr. *derma,* skin; *pteron,* wing). *Flying lemurs* (not true lemurs). These animals resemble the insectivores in structure of skull and in the canine teeth. The two known genera are found in Malaysia and the Philippines.

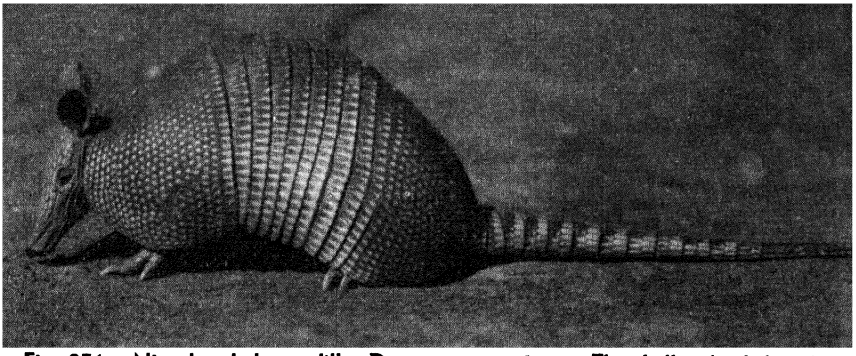


Fig. 351.—Nine banded armadillo, Dasypus novemcinctus. The shell is hard, but the animal can roll up into a ball when attacked. (Courtesy of The American Museum Natural History.)

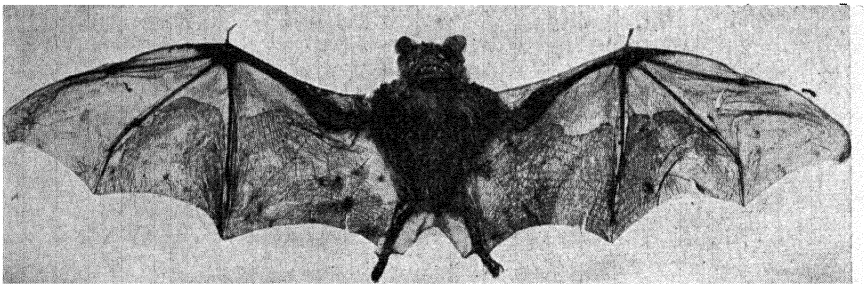
Order 3. *Edentata* (L. *edentatus,* rendered toothless). *Giant anteaters, sloths, armadillos.* The giant anteater has no teeth, but the other representatives of this group have modified teeth. The giant anteater opens an ant hill with its claws and takes up the ants with a long prehensile tongue. The representative of this group that lives in the United States is the *nine-banded armadillo,* which lives as far north as Texas. The hair has been replaced by bony plates. If disturbed, the animal rolls up in a ball. The tail is long and is covered with overlapping rings. He has a small head, large ears and powerful claws for digging. The tongue is long, sticky, and protrusible, designed to entangle insects after they have been dislodged by powerful claws (Fig. 351). One interesting feature of reproduction is that *each* egg produces *four young.*

Order 4. *Pholidota* (Gr. *pholis,* scale). The *scaly anteaters.* These are clawed animals lacking teeth. The tongue is long and protractile. An example is the pangolin, *Manis.*

Order 5. *Rodentia* (L. *rodere,* to gnaw). One of the largest of all the mammal groups. The teeth of rodents are especially modified for gnawing. There is one pair of incisors in the upper jaw. Rodents eat plants mostly and cause great damage. Examples are *beavers, guinea pigs, squirrels,* etc.

Order 6. *Lagomorpha* (Gr. *lagor*, hare; *morphe*, form). This order is often included in the order Rodentia, the animals in the two groups being very similar. Rabbits and hares have four instead of two upper incisors. Examples are *rabbits*, *hares*.

Order 7. *Chiroptera* (Gr. *cheir*, hand; *pteryx*, wing). *Bats* or *flying mammals*. The bat wing is quite different from the wing of a *bird* (Fig. 352). The forelimbs and



hastatum. (Courtesy of The American Museum Natural History.)

fingers are extended; the skin is stretched between them and connected with the hind feet; also, usually, with the tail. When at rest, bats usually grasp a perch by the hind legs and hang head down. They are nocturnal, and caves are favorite retreats for them. They are widely distributed. Some are fruit-eating; the *vampire bats* live on the blood of horses, sheep, cattle, and occasionally attack sleeping human beings. The skin is cut by the front teeth, and the blood is lapped up as it oozes out.

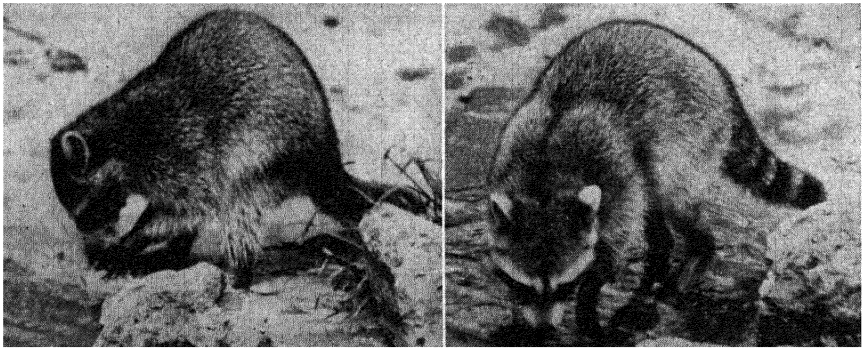


Fig. 353.—Raccoon, Procyon lotor. This mammal has the habit of washing its food before eating it if possible. (Courtesy of U.S. Biological Survey.)

Order 8. *The Carnivora* (L. *carnivorus*, flesh eating) (page 536). *Lions*, *tigers*, etc. Although most of the animals in this group eat flesh, some are omnivorous, as *bears*. The canine teeth are well developed, the incisors small; the premolars adapted for cutting are fitted for crushing. Carnassial (L. *caro*, flesh) peculiar to this group are the fourth premolar above and the first molar below. These bite on one another like a pair of scissors.

The terrestrial carnivores (suborder Fissipedia L. *fissus* cleft; *pedis* foot) have feet fitted for walking, whereas the aquatic carnivore (suborder Pinnepedia L. *pinna*, feather; *pedis* foot) have feet fitted for swimming.

There are eight well-known families belonging to the terrestrial Carnivora. Among the most important of these is the family Canidae, which includes *dogs*, *raccoons* (Fig. 353), *coyotes*, *foxes*, and *wolves;* the family Felidae, including *cats*, *tigers*, *leopards*, *mountain lions*, etc.; and the family Ursidae, the *bears*. Among the important representatives of the aquatic Carnivores, the Pinnipedia, are the *seals* and *walruses*.

Section *B. Ungulata* (L. *ungula*, nail). Hoofed mammals.

Order 9. *Perissodactyla* (Gr. *perissos*, odd; *daktylos*, finger). Odd-toed hoofed mammals. *Horses*, *tapirs*, *rhinoceroses*, all mammals with an odd number of hoofed toes. These may vary in number from the one toe of a horse to the *tapir*, which has three on the back feet and four on the front.

Order 10. *Artiodactyla* (Gr. *artios*, equal; *daktylos*, finger). Even-toed hoofed mammals. A very large group, including many of the familiar game mammals. Here are included cattle, *Bos;* camels, *Camelus;* llama; pigs, *Sus;* deer, *Cervus;* bison, *Bison* (Fig. 29); hippotamus, *Hippotamus;* giraffe, *Giraffa;* and many others.

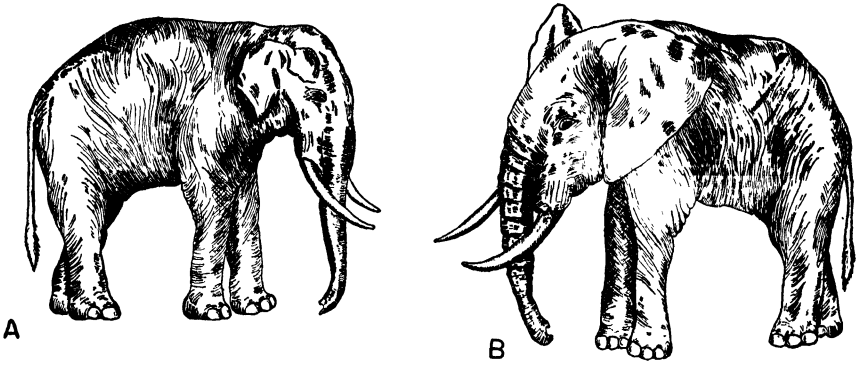


Fig. 354.—(A) Indian elephant. (B) African Elephant. Difference in these animals include shape of back, size of ears, folds of skin on the trunk, etc. The tusks are incisor teeth. (L. Runyon.)

The name *ruminant* (L. *rumen*, throat) is given to the members of this group, which, like the cattle, swallow their food with little mastication and later regurgitate it and chew it thoroughly. These animals have stomachs with four chambers.

The bison, *Bison bison*, once existed in great numbers on the Western plains, but with the advent of the white man and the building up of the country, they were threatened with extinction. However, a small herd placed in one of the national parks is now increasing (Fig. 29).

Order 11. *Proboscidea* (Gr. *proboskis*, trunk; L. *forma*, shape). The *Elephants*. There are only two living genera of elephants, each with one species, the African elephant, *Loxodonta africanus*, and the Asiatic elephant, *Elephas indicus* (Fig. 354). Some of the differences between the two are that the African species is larger, has larger ears and a hollow back; the Indian elephant has smaller ears and a bounded back. Both are covered with a loose, thick skin, much wrinkled. From the character of this skin, the elephants are often called *pachyderms* (Gr. *pachys*, thick; *derma*, skin). The long, muscular proboscis, used as a prehensile organ, has the nasal openings at the tip. The tusks, often present in the males, are the prolongations and enlargement of the incisor teeth. These furnish the ivory of commerce. Elephants are used as beasts of burden in some countries. They are said to be intelligent.

Order 12. *Hyracoidea* (Gr. *Hyrax*, shrew mouse). *Coneys* or *hyraxes*. Rodent-like mammals with short ears, reduced tails, and primitive plantigrade feet. There are three toes on the front limbs and four on the hind limbs. An example is *Procavia* (Africa). The *Procavia syriaca* is the coney of the Bible.

Section *C. Aquatic mammals.*

Order 13. *Sirenia* (Gr. *seiren*, a sea nymph). Sometimes included with the whales but quite different from them. They are herbivorous, of large size, without hind limbs or external ears. Examples are *sea cows*, *manatees*.

Order 14. *Cetacea* (Gr. *ketos*, whale). *Whales* and *dolphins*. In some classifications, this order is represented in two orders:

Order *Odontoceti* (Gr. *odon*, tooth; *ketos*, whale). *Toothed whales*, *porpoises*, *sperm whales*. Whales are warm-blooded, the body heat being retained by a layer of fat beneath the skin. The forelimbs are modified as paddles, the head is large, eyes small, and there are no external ears. They are air-breathing, the nostrils

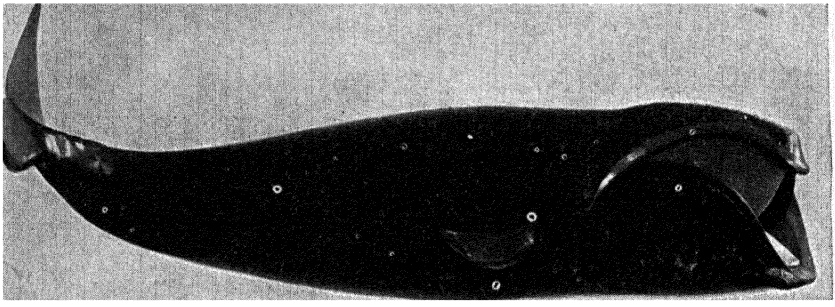


Fig. 355.—The whalebone whale, Balaena mysticetus, one of the largest of living mammals. (Courtesy of The American Museum of Natural History.)

having a single opening. A whale is said to "spout" when the air is forced out of the "blow hole," the moisture of the breath condensing in the air.

Order *Mystacoceti. Whalebone whales.* Whales without teeth except in the embryos. Plates of whalebone, frayed at the edges, or baleen, form a sort of strainer by which the food is strained out of the water. The largest of the whales, the sulphur-bottom whale, belongs to this group. These may reach a length of 103 ft. and weigh 294,000 lb. They are the *largest living animals* (Fig. 355).

Section *D. The primates* (page 799). Mammals with nails.

Order 15. Primates. *Lemurs, apes, monkeys, man.* The members of this group have some primitive characteristics, and for this reason some authorities place them about in the middle of the series of mammal orders. On account of their superior mental power, however, they may well be called the *climax group*. Since this group is especially interesting on account of man's place in it, the suborders and families are listed.

Suborder 1. *Lemuroideae.* Lemuroids.

Family 1. *Chiromyidae.* The aye-aye.

Family 2. *Lemurideae.* True lemurs.

Suborder 2. *Tarsioideae.* Tarsiers.

Suborder 3. *Anthropoideae.* Monkeys, apes, man.

Series 1. *Platyrrhini* (broad nose). New World monkeys.

Family 1. *Cebidae.* Capuchins, howler monkeys, spider monkeys, etc.

Family 2. *Hapalidae.* Marmosets.

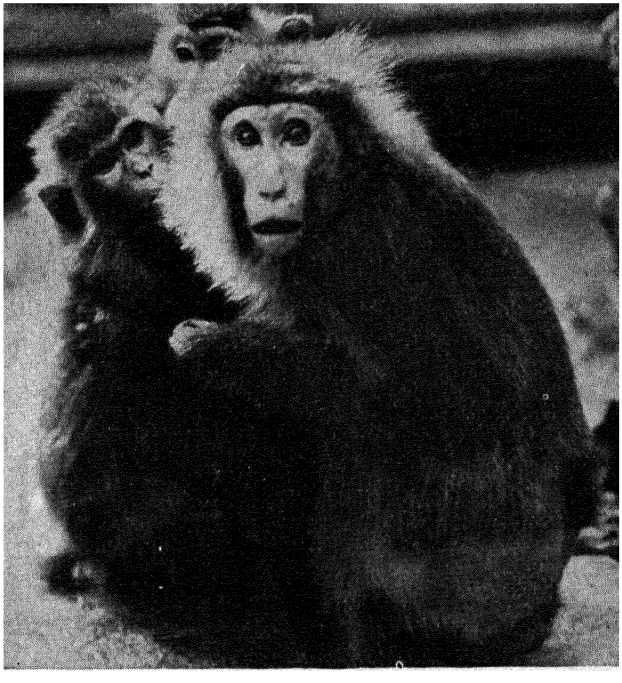


Fig. 356.—Japanese macaques, Macaca fuscata. (Courtesy of The National Zoological Park.)

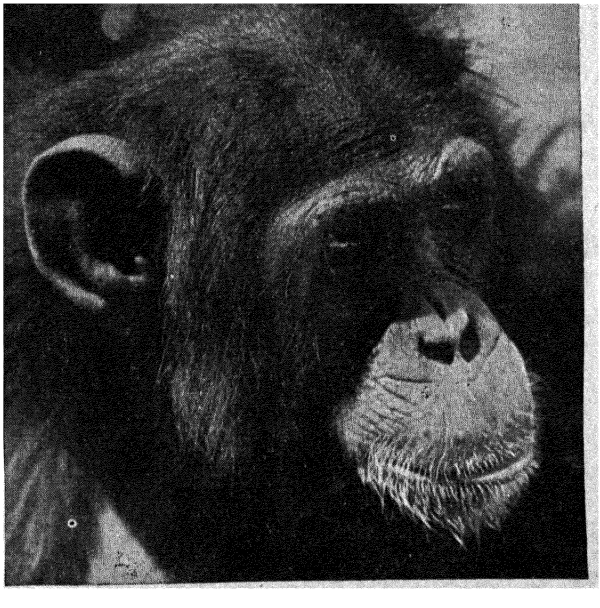


Fig. 357.—Chimpanzee, Pan (Anthropopithecus troglodytes). The chimpanzee is ranked next to the gorilla in the primate group of animals.

Series 2. *Catarrhini* (nostrils close together). Old World monkeys, apes, men
Family 3. *Cercopithecidae.* Baboons, macaques (Fig. 356), mandrills, etc.
Family 4. *Hylobatidae.* Gibbons.
Family 5. *Pongidae.* Apes, orangutans, chimpanzees (Fig. 357), gorilla (Fig. 358).
Family 6. *Hominidae.* Man.

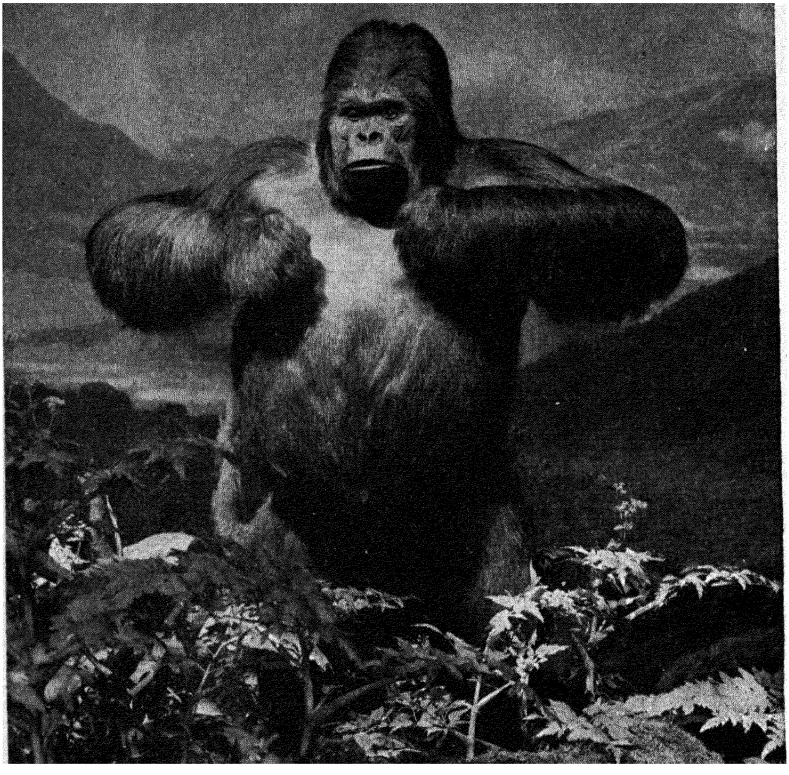


Fig. 358.—Gorilla gorilla. Large male gorilla (Belgian Congo) from the gorilla habitat group in Akeley African Hall, The American Museum of Natural History (Courtesy of The American Museum of Natural History.)

The tailless apes often have bipedal locomotion. The forelimbs are longer than the hind limbs and rest on the ground on their knuckles, helping to preserve the equilibrium.

Man dominates all other animals on account of his mental development. On account of this same development, he is able to fit himself to live in most situations.

Questions

1. What characters separate mammals from other groups?
2. What mammals lay eggs?
3. Describe some mammal migrations.
4. Why is the hibernation of a female bear especially interesting?

5. What are the three types of foot posture shown by mammals?
6. Describe at least 10 widely different (in appearance and size) mammals, and state what characters they all have in common.
7. Discuss (*a*) home building by mammals; (*b*) secondary sexual characters, (*c*) coloration.
8. Define, as related to mammals; digitigrade, unguligrade, plantigrade, marsupium.

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Part IV. General Biology:

ORGANS, SYSTEMS, AND THEIR FUNCTIONS; THE BIOLOGY OF MAN

CHAPTER XXXIV

FOODS, THE FUEL OF LIVING ORGANISMS

For it's rare that a man thinks of anything so seriously as his dinner!
—BEN JONSON.

I. The Role of Green Plants in Food Manufacture

Every living thing must obtain food and assimilate it or suffer death. Animals are not able, as are the green plants, to manufacture their own food. Even animals that live on meat alone, such as the Carnivora, are indirectly dependent upon plants, since the animals that they eat use plants for their food. For example, lions eat zebras, but zebras are herbivorous and eat plants. In every case, the original source of the food supply of animals is the green plant.

Because they manufacture the food for the entire living world, green plants are often spoken of as the "food factories of the world." They manufacture the three classes of food, carbohydrates, proteins, and fats. Many types of each of these three classes of food are known. The fundamental process of the manufacture of sugar by green plants, or *photosynthesis* (page 128), may be illustrated by the following formula:

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy} = \underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2}$$

In other words, six atoms of carbon dioxide plus six atoms of water, with the aid of the energy from the sun, will make one molecule of glucose and six molecules of oxygen. The manufacture of glucose by green plants is not so simple as that indicated in the foregoing reaction but doubtless involves several steps. The formation of glucose by the green plant is not fully understood, but the essential facts are that the green plant is able to take carbon dioxide from the air, water from the earth, and, with the aid of the energy from the sun, manufacture glucose. The green coloring matter of plants, *chlorophyll* (page 32), is the substance in the plant that does this work. Certain plants, such as mushrooms, do not possess chlorophyll and are therefore incapable of photosynthesis.

In the foregoing description of the synthesis of carbohydrates by green plants, it is shown that the elements of oxygen and carbon are derived from the air in the form of carbon dioxide, but the source of hydrogen was not accounted for. This element must come from water, since there is no

hydrogen in the air and the plant has no other means for obtaining it. If the formula for glucose, $C_6H_{12}O_6$, be examined, it will be evident that hydrogen and oxygen are present in the same proportion as they are in water, namely, two parts of hydrogen to one of oxygen. If one molecule of water be removed from glucose, the formula becomes $(C_6H_{10}O_5)_n$, which is *starch*, the form in which the plant stores the carbohydrate that it has manufactured. Starch is relatively insoluble and exhibits other properties that make it a favorable substance for storage purposes (page 140).

II. Foods

A. Types of Foods. 1. CARBOHYDRATES.—All carbohydrates are made up of three elements, carbon, hydrogen, and oxygen. Ordinary water is made up of two of these, hydrogen and oxygen, in the proportion of 2 parts of hydrogen to 1 part of oxygen, H_2O. A carbohydrate has, in addition, carbon. If water is removed from a carbohydrate, carbon will be left.

2. PROTEINS.—Proteins also contain carbon, hydrogen, and oxygen but, in addition, nitrogen is always present and often sulphur and phosphorus. Proteins have very complex chemical formulas. But although there are many kinds of proteins, they consist of fairly simple building blocks, the *amino acids*. These always contain one or more of the amino or NH_2 groups and at least one carboxyl radical, COOH. The amino radical acts as a base and the carboxyl radical as an acid.

The starting point of the world's food supply is the manufacture of carbohydrates, or carbohydrate synthesis. In protein synthesis, the building blocks are the amino acids. Three of the materials of which protein is composed (carbon, hydrogen, and oxygen) are supplied by the synthesis of carbohydrates, whereas the nitrogen for the NH_2 radical is taken by the plant from the soil. More than twenty different kinds of amino acids are known, and these are capable of almost infinite combinations. This accounts for the great variety of proteins. Although light is necessary for the manufacture of carbohydrates in green leaves, it is not necessary for protein synthesis. Proteins have large complex molecules—$C_{758}H_{1181}N_{207}O_{210}S_2Fe$ is the formula for hemoglobin (horse), which gives an idea of the complexity of a molecule of this protein.

3. FATS.—Fats are made up of the same elements as those that form carbohydrates, but in fats these elements are combined in different proportions, being especially poor in oxygen. The chief fat of olive oil is *olein*, which has the formula $C_{57}H_{104}O_6$. This formula shows that this fat contains an enormous number of hydrogen atoms, a small number of oxygen atoms, and a large number of carbon atoms. Fats are spoken of as "concentrated food." They are readily oxidized, thus liberating heat. Not all fats are the same in nutritive value. For example, butterfat is superior

to most brands of oleomargarine for human nutrition. However, some modern oleomargarine is equal to butter; and some butter is very poor.

B. Role in Nutrition of the Three Types of Food.—All three types may supply energy. Proteins as a result of oxidation may produce *energy* and *heat* but are also absolutely necessary for the *building* up of protoplasm, either for purpose of growth or for rebuilding living substance that

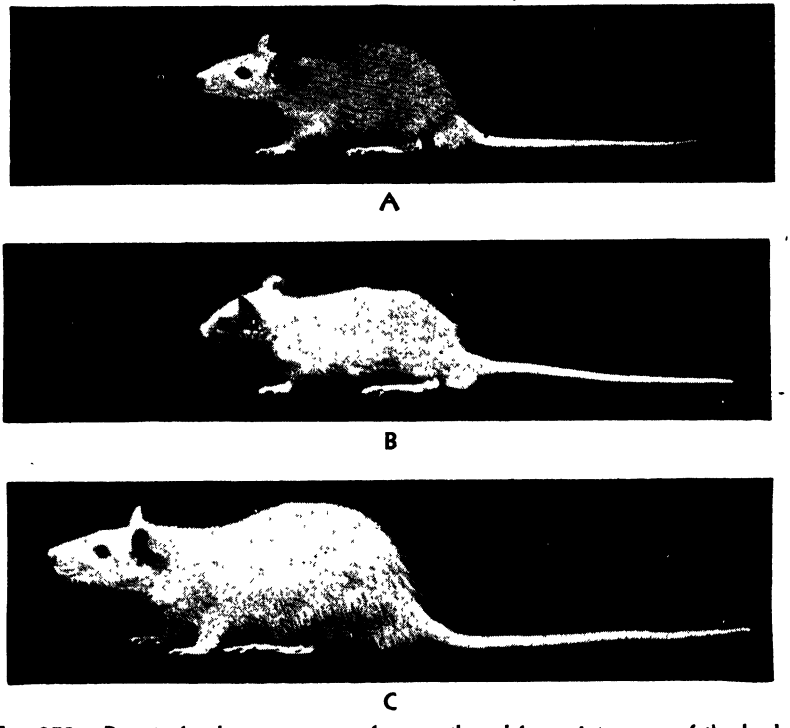

Fig. 359.—Protein foods are necessary for growth and for maintenance of the body in health. (A) (B) (C) Rats from the same litter, 11 weeks old. (A) Rat that had good protein but not enough. (B) This one had enough protein but of a poor kind. (C) Rat that had good protein and plenty of it. (Courtesy of U.S. Bureau of Home Economics.)

has worn out. Not all proteins, however, are of the same value. Figure 359 shows the effects of good and bad proteins.

Carbohydrates, when oxidized, furnish *heat* and *energy*. The digestion of carbohydrates and the excretion of wastes resulting from this digestion require less work on the part of the body than these processes do in the case of proteins; hence carbohydrates are preferred to proteins for the production of energy. Carbohydrates also serve another function; they are "protein sparers," since they furnish heat and energy that would otherwise have to be secured from proteins. Even though fats possess a greater

energy content than carbohydrates, experiments seem to prove that carbohydrates are better "protein sparers" than are the fats. Fats, however, may be stored and thus furnish a reserve food supply.

C. Accessory Foods. 1. WATER.—Included among the accessory foods are water, mineral salts, and vitamins. Most organic substances contain considerable quantities of water, although the amounts may vary tremendously in various animals and tissues, being as low as 3 per cent in certain tissues and as high as 98 per cent in jellyfish. Living things cannot exist for very long without water. They can live without food longer than they can without water. Water is capable of dissolving more different substances than is any other liquid. It holds these substances in chemical solution so that they can be transported throughout the body and can pass through membranes. Without water, the colloidal state of protoplasm would not be possible. Water may exist in the protoplasm in the "free state," or it may enter into the chemical composition of compounds. It is necessary for protoplasmic movement.

2. MINERAL SALTS.—Mineral salts are present in all protoplasm. They are concerned with diffusion and osmosis; they have something to do with controlling the acidity of the body fluids, and they are important in other ways. For example, *calcium* and *phosphorus* are important in the formation of the bones and teeth of vertebrates. In many invertebrates, calcium is important in the formation of the skeleton. Calcium is also necessary for the coagulation of the blood. Figure 360*A* shows the short, stubby body of the rat that was not given enough calcium; this condition was due to poorly-formed bones. Quite a contrast is presented by the rat that was supplied with plenty of calcium. Milk is the best source of calcium, although other foods also contain this mineral. Calcium and phosphorus are both necessary for good growth in plants (Fig. 361).

Iron is a constituent of hemoglobin, which is the red-colored substance in the red blood cells. This substance has an affinity for oxygen and is important for this reason. Not a great deal of iron is present in the human body—about 2½ g.—but this is essential. In some people the blood is deficient in hemoglobin, giving rise to the disease of anemia; treatment with iron relieves this condition. Certain plant and animal foods are rich in iron (see Appendix, page 873). Iron is necessary for the formation of chlorophyll in plants, although it is not known just why. *Magnesium* is also necessary for this purpose; it is a part of the chlorophyll molecule itself. Other necessary salts are those of *sodium*, *sulphur*, *potassium*, *chlorine*, *iodine*, *boron*, and (for plants) nitrogen (Fig. 361).

Unless the diet is quite specialized, it is likely to contain all the minerals needed. The only exception is iodine, which is necessary for the normal secretory activities of the *thyroid gland* (Chap. XXXIX). In some parts of the country where the soil contains very little iodine and where

sea foods, which contain iodine, are not commonly eaten, it is necessary to supplement the diet with small amounts of iodine. This may be done by

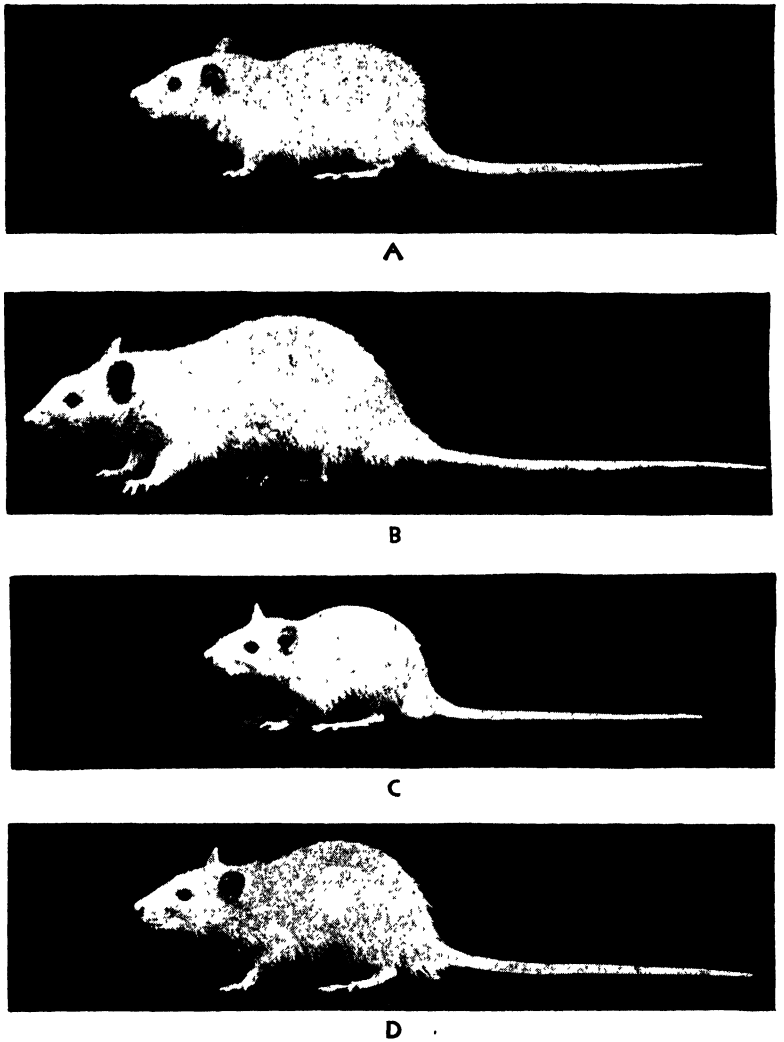

Fig. 360.—The role of minerals, calcium and phosphorus in nutrition. (A) (B) Two rats from the same litter, 22 weeks old. A did not have enough calcium. Body is short and stubby, owing to poorly formed bones; B had plenty of calcium and its bones are well formed. (C) (D) Rats from the same litter 9 weeks old. C did not have enough phosphorus and grew slowly; D had plenty of phosphorus and is well grown. (Courtesy of U.S. Bureau of Home Economics.)

requiring the use of iodized table salt. Too much iodine is dangerous, since it brings about serious disturbances in metabolism.

Eleven minerals—Na, sodium; K, potassium; Ca, calcium; Mg, magnesium; Cl, chlorine; Fe, iron; I, iodine; P, phosphorus; S, sulphur; Cu, copper; and Mn, manganese—are necessary for an adequate diet in higher animals.

3. VITAMINS. *a. Vitamins in General.*—Other accessory food elements, the vitamins, are not only important but absolutely necessary for normal nutrition and growth. The chemical nature of many of the

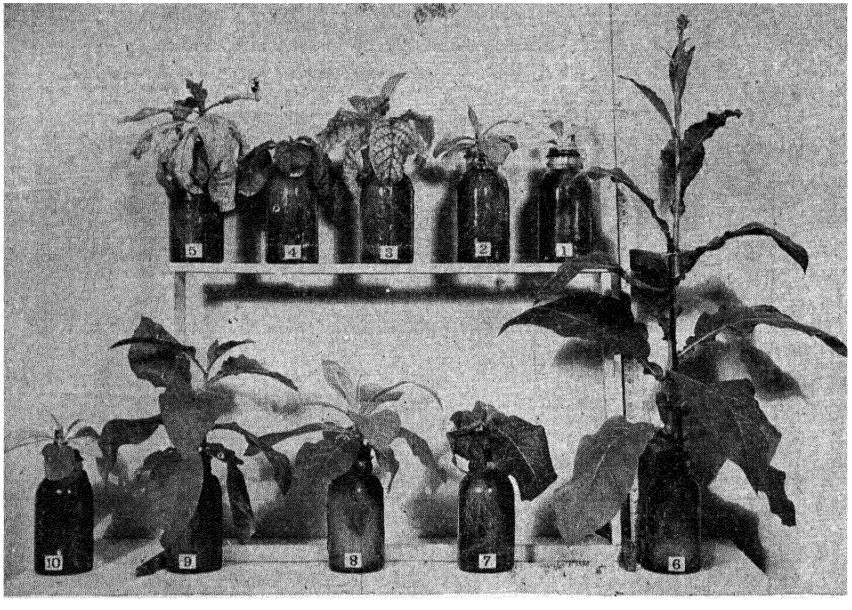

Fig. 361.—The use of minerals by plants. (6) Tobacco grown in a complete nutrient solution. (1) Without nitrogen. (2) Without phosphorus. (3) Without potassium. (4) Without calcium. (5) Without magnesium. (7) Without boron. (8) Without sulphur. (9) Without manganese. (10) Without iron. (From U.S. Department of Agriculture Technical Bulletin 340, 1933.)

vitamins has been determined, and their effect on the body has been discovered experimentally by feeding animals, especially rats, on diets that excluded certain of these substances. Years ago, when sailors spent long periods at sea, they came down with a disease known as scurvy, a disease caused by lack of vitamin C in the diet.

Recent experiments indicate that vitamins are just as essential to plants as they are to animals. Plants, in general, are much better able to synthesize vitamins from simpler substances; hence vitamins need not be present in the soil in order that plants may grow well. However, the amount of vitamins produced in a plant depends on such factors as the variety of plant, the presence or absence of fertilizer in the soil, and the

character of the climate. For example, more vitamin A has been found in wheat grown on manured land than in that grown on unfertilized land.

Vitamins as well as other food elements are received by the roots from the rest of the plant. If roots are detached from the rest of the plant, they can be grown in bottles of water to which salts, sugar, and vitamins have been added.

The name *vitamin* (Gr. *vita*, life; *amine*, a chemical radical NH_2) was proposed for these substances by Funk in 1912. He fed pigeons on a diet deficient in vitamin B. They soon became so weak they were unable to

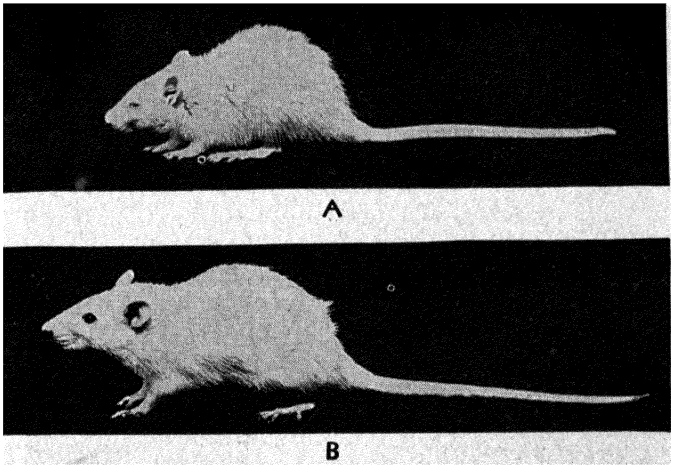

Fig. 362.—Vitamin A, primarily a growth-promoting substance which also has an effect upon epithelial tissues. (A) (B) Two rats from the same litter 11 weeks old. A had no vitamin as evidenced by infected eye, rough fur, and lack of vigor. B had plenty of vitamin A as shown by bright eyes, sleek fur, and vigor. (Courtesy of U.S. Bureau of Home Economics.)

hold up their heads. It was found that they could be cured quickly and easily by feeding them with a substance extracted from bran. For this reason, the substance responsible for the cure was given the name *vitamin*. Vitamins are designated by letters, A, B, B_1, B_2, C, D, E, G, K, etc. Three of these, A, D, and E, are soluble in fats and occur in oils and fats; three, B, C, and G, are water-soluble and occur commonly in the juices of vegetables and fruits.

b. Vitamin A.—This vitamin is widely distributed in plant tissues, especially those that contain yellow pigment such as carrots, sweet potato, squash, etc., and in animal fats such as those of butter, egg yolk, and cod-liver oil. Carotene, a yellow pigment, is transformed into vitamin A ($C_{20}H_{30}O$). The lack of this vitamin in the food is serious, because it regulates the secreting power of epithelial tissue. When vitamin A is absent the epithelium becomes dry, as shown in the eyes of the rat in

Fig. 362. Here the tear glands do not keep the eye moist, and a disease of the eye known as *dry eye, xerophthalmia,* results. A lack of visual purple in the eye, or *night blindness,* is associated with a lack of vitamin A.

c. Vitamin B.—This is spoken of as the *antineuritic vitamin.* Lack of it causes a disease known as *beriberi,* which is a sort of paralysis due to the degeneration of the nerves. Besides this, the heart muscle and the central nervous system are affected and enlargement of various organs takes place. Vitamin B was the first of the vitamins found. A Dutch investiga-

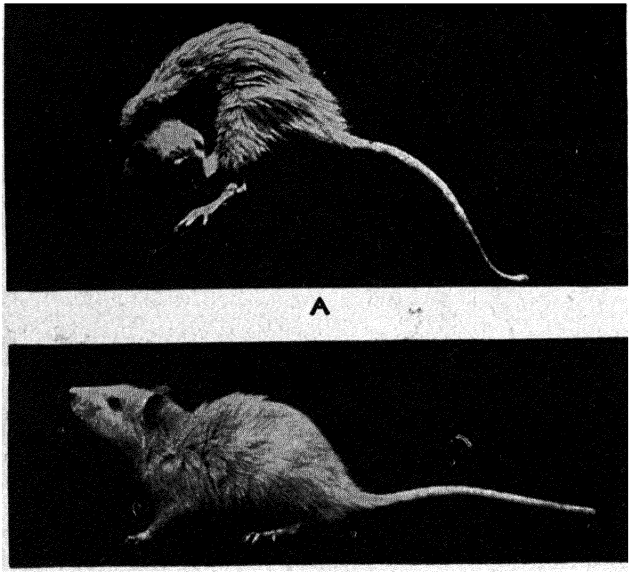

Fig. 363.—Vitamin B complex has several functions. Its use prevents development of pellagra. Vitamin B_2 is sometimes called vitamin G; it promotes bodily well being. (A) Female rat 24 weeks old which did not have enough vitamin B. The lack of muscle control is called spastic paralysis. (B) The same rat 24 hours later, after receiving a food rich in vitamin B. Muscle control has already been recovered. (Courtesy of U.S. Bureau of Home Economics.)

tor, Eijkman, working in Java, found that bran coats or hulls of cereals contained a substance that would prevent the disease beriberi. Figure 363 shows that the experimental rat, which had been fed on a diet lacking in vitamin B, recovered muscular control within 24 hours after being fed with food rich in this vitamin. Many foods contain vitamin B. It is especially abundant in the wheat germ and in yeast (see page 193 in the Appendix for a further list of foods containing this vitamin). Vitamin B has been found to be complex and has been subdivided into B_1, B_2, B_3, B_4, B_5, etc. B_1 is thiamin chloride. The *antipellagra* factor is *nicotinic acid.*

This was identified in 1937. Not all the other fractions have been surely identified.

d. Vitamin C (Ascorbic Acid).—Vitamin C prevents *scurvy*. This disease involves a partial destruction of the walls of the capillary blood vessels and is responsible for troubles with the teeth and the gums. The rat illustrated in Fig. 364 was fed on a diet deficient in vitamin C and was suffering from scurvy. Fresh fruits, tomatoes, and fresh vegetables are sources of this vitamin.

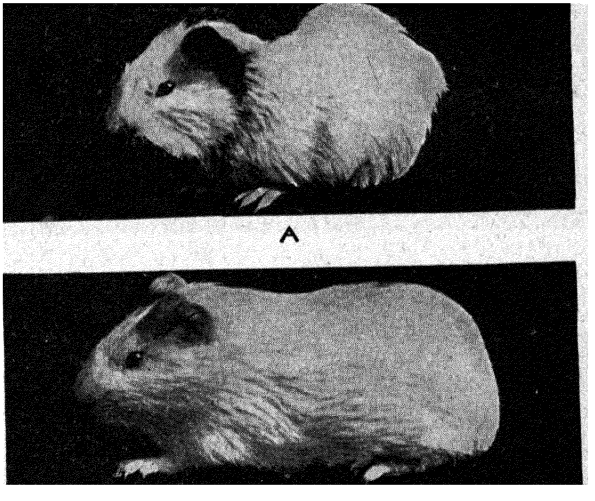

Fig. 364.—Vitamin C, essential for the maintenance of normal conditions of connective tissues of the body, as well as healthy bones and teeth. Lack of this vitamin causes scurvy. (A) (B) Guinea pigs of the same age. (A) This animal had no vitamin A and developed scurvy. Note rough fur and crouched position due to sore joints. (B) This one had plenty of vitamin A. It has sleek fur and is healthy and alert. (Courtesy of U.S. Bureau of Home Economics.)

e. Vitamin D (Calciferol), or the Antirachitic Vitamin.—Rickets (lack of mineral matter in the bones) is a disease of the bones that leads to deformities. It is due to an insufficient amount of vitamin D in the food. Lack of this vitamin also increases the possibility of decay of the teeth. Vitamin D is sometimes called the *sunlight vitamin*, because sunlight seems to affect the fats beneath the skin in such a way that they produce the vitamin. Ultraviolet light will accomplish the same result. The livers of certain fish, particularly of the *cod*, *halibut*, and *mackerel*, are rich in this vitamin. Figure 365 shows the bowlegs and short body of a rat that was fed on a diet deficient in vitamin D. Other foods besides fish oils contain large amounts of this vitamin, especially milk, cream, butter, and eggs. Vitamin D was discovered by McCollum in 1921. It has been recently

shown (Waddell, 1935) to exist in two forms. For example, by irradiating milk after it is drawn from the cow, the *cholesterol type* of vitamin D is formed. This cholesterol type occurs also in cod-liver oil. The second type of vitamin D is obtained in milk by feeding the cows yeast known to contain *ergosterol.* This milk is known as *metabolized milk* and is of the *ergosterol type.*

Only minute quantities of vitamins are needed to ensure normal development. Crystals of pure vitamin D are so powerful that to prevent rickets in a rat, only 1/10,000 mg. a day is necessary.

Fig. 365.—Vitamin D, sometimes called the "sunshine" vitamin, is essential for good bones and teeth. (A) (B) Rats from the same litter, 20 weeks old. (A) This rat had no vitamin D. Note short body and bowlegs, typical signs of rickets. (B) this one had plenty of vitamin D. Its bones are strong and straight. (Courtesy of U.S. Bureau of Home Economics.)

f. Vitamin E (Tocopherol) the Antisterility Vitamin.—Rats deprived of vitamin E remain sterile. The gonads of the male do not function properly. The gonads of the female rat are not injured, but the embryo rats die in the uterus. This vitamin occurs in wheat germ, lettuce, and watercress. Evans isolated it in 1935.

g. Vitamin G (B_2).—This is the *antipellagra vitamin.* In 1937, the antipellagra fraction of the vitamin B complex was isolated as nicotinic acid. Pellagra, a dread disease, affects the skin and nervous system. It is prevalent wherever the diet is not varied enough to include foods containing vitamin G.

The discovery of new vitamins may be expected in the future as progress is made in the study of nutrition. Other accessory foods, such as tea and coffee, will be discussed later (page 551).

D. Food Requirements for Normal Nutrition; How Determined.—The method usually employed is to feed animals on different types of diets and observe the effect they produce. In many laboratories, rats are used for this purpose. The amount of food required by any animal depends primarily upon three things: (1) the size of the body, (2) the amount of work done, and (3) the quantity of heat necessary to keep the body at its normal temperature.

The fuel value of any food may be determined by burning a given amount in a calorimeter. When the food unites with oxygen, heat is given off; hence the unit used in measuring the amount of heat given off is called a *calorie*. The large calorie used in determining fuel values is the amount of heat necessary to raise the temperature of 1 kg. (1,000 g. or 2.2 lb.) of water 1°C. To determine the amount of food an individual needs, one must take into account size, habits, and age. A rat does not need the same amount that a rabbit does, nor does an office worker need the same amount of food as a day laborer. The latter needs much more on account of his greater physical activity. People that live in cold climates need more food than those that live in hot climates, and growing organisms need more in proportion to their size than do organisms that are fully grown. (For the table of calorie requirements for human beings, see page 549.)

E. Preparation of Foods.—All animals except man eat their food raw. Cooked food is unknown to animals unless given to them by man. Cooking renders some foods more easily digestible, and many foods are improved in flavor and appearance. Starch grains swell up and burst so that the digestive juices can reach their contents easily; the cellulose fibers of plants are softened, as well as the fibers of meat; bread becomes porous or "light" as a result of the presence of baking powders or yeast and is cooked in that state (page 193). Foods are thus changed so that they are easier for the digestive system to break up into substances suitable for absorption.

Incidentally, harmful bacteria are destroyed by the high heat necessary for cooking. However, cooking may also do harm. For example, vitamins may be destroyed. This has been observed in the case of milk. When boiled, milk is changed in many ways and is less valuable as a food. Milk is often treated by a heating process known as *pasteurization*, which destroys bacteria. In this process, the heat is regulated so that it kills nearly all pathogenic bacteria but does not alter the food value of the milk.

F. The Pure Food Laws.—Before the passage of the Pure Food and Drug Act in 1906, food was often preserved by the use of harmful chemicals. Also, food was adulterated, for substances were added that reduced the value of the food in question. An example was the practice of adding

water to milk or chalk to flour. Sometimes substances were added that were actually harmful. The law requires that all substances added either for preservative purposes or for increase of the bulk for any reason be printed on the label. In this way the citizen is protected if he reads the label. Harmful preservatives, colors, flavors, etc., are forbidden.

TABLE OF THE COMPOSITION OF FOODS.—The table on the composition of foods, in the Appendix, page 873, has been compiled from various sources. It offers easy reference possibilities.

Questions

1. What is a food?
2. Why are green plants spoken of as the "food factories of the world"?
3. What is an amino acid? Why are they spoken of as the building blocks of proteins?
4. Compare the composition of carbohydrates, proteins, and fats. What is the role of each in nutrition?
5. Are all proteins of the same value in nutrition? Fats?
6. Discuss the importance of water to living things.
7. Why is calcium in the diet important? Phosphorus?
8. How is iron used in plants? In animals?
9. Discuss the general importance of vitamins to plants and animals. What advantages have the plants over animals in securing vitamins?
10. What led to the discovery of vitamins? Who was Eijkman?
11. Who proposed the name *vitamin*? When? What experiment was performed by the discoverer of the same vitamin?
12. Discuss the role of each of the following vitamins: A, B, C, D, E, F, G (B_2). Include in this discussion the normal function and the results of deficiency of each one.
13. For what disease is nicotinic acid now prescribed?
14. "C. Hopkins CaFe Mg NaCl = C. Hopkins Cafe mighty good if taken with a grain of salt" is a phrase suggested to aid students in remembering the minerals important in the diet. What are these minerals? How is each one used in the body?
15. Discuss tea, coffee, and cocoa as foods. To what is their stimulating action due?
16. Is alcohol a food? Explain.

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CHAPTER XXXV

NUTRITION IN PLANTS AND ANIMALS

Now good digestion, wait on appetite,
And health on both!

—SHAKESPEARE.

I. Nature and Necessity for Digestion

Although nutritive processes are the same in all the higher animals, they naturally differ in details because of differences in feeding habits. Inorganic nutrients, such as minerals, may be absorbed without change, but organic foods must be changed into simpler substances by the action of *enzymes*. Carbohydrates, such as starches and complex sugars, cannot be absorbed until they are changed into simple sugars. Similarly, proteins and fats must be changed into relatively simple substances before they can be absorbed. Foods that are insoluble cannot be used by living organisms, either plants or animals. Digestion in plants is the same sort of process as digestion in animals. Similar agents act upon proteins, carbohydrates, and fats in plants and animals, though the plants are not provided with highly specialized digestive systems as animals are.

Role of Enzymes.—An enzyme is a *catalyst* (page 23); *i.e.*, it accelerates a reaction without itself being changed or used up in the process. Not very much is known about enzymes. One of their most interesting properties is the fact that they are specific in their action; *i.e.*, one enzyme acts on only one type of substance. For instance, *sucrase*, acts only on *sucrose* (cane sugar); and *pepsin* acts only on *protein*. Another characteristic is that their action is *reversible*. For example, they are responsible for changing the sugar manufactured by the plant into starch suitable for storage, yet when the plant needs the starch for food, this insoluble form is changed again to the soluble sugar by the same enzyme. It is evident that the conditions under which the enzyme works determine what type of reaction will take place, but these conditions are not fully understood. It should be noted here that stored in seeds are enzymes ready to transform materials needed by the young developing plant. These include enzymes for the digestion of protein, carbohydrates, and fats. Some seeds are oily, some starchy; but all contain some of all three food types and, presumably, their specific enzymes.

II. Digestion in Plants

No special digestive organs are present in plants such as are found in animals (Fig. 366). In the simpler plants, especially the Fungi, digestion may take place outside the cells through the agency of enzymes that are secreted by the plants.

A. Carbohydrates, Fats, Proteins. 1. CARBOHYDRATES.—In the higher plants, starch is formed mainly in the leaves from glucose. This starch is insoluble in water and nondiffusible. Before it can be used by the plant, it must be changed into a soluble, diffusible form. The enzyme that does this work is *diastase.* It may be that this is not a simple enzyme but a combination of two or more enzymes working together. Some authorities believe that one of these two enzymes, *amylase,* converts the starch into a sugar, dextrin, and that the other enzyme, dextrinase, transforms this dextrin into maltose. Another enzyme, maltase, then changes the maltose sugar into a still simpler sugar, glucose. Glucose is soluble and can pass through the cell wall into the cell protoplasm. Here it is used by the protoplasm, either to furnish energy or as building material.

2. FATS.—As starch must be changed to a soluble form that is diffusible, so must fats and proteins be changed, also. The *lipases* are the enzymes that are instrumental in changing the fats into fatty acids and glycerol. This process has been studied in the germination of seeds containing a large amount of fat or oil, the castor-oil seed *Ricinus.* The lipases are the same enzymes that cause the synthesis of fats in plants. Whether synthesis or digestion takes place seems dependent upon the amount of water. When the water is decreasing, the fat synthesis takes place; when the water is increasing, as in the conditions suitable for the germination of the seed, digestion takes place.

3. PROTEINS.—The study of the digestion of proteins is not so easy to study in plants, because proteins are not stored in large quantities as are starches and fats. Three classes of enzymes act upon the proteins: (1) The protinases, which act upon the proteins and split them into albuminoses and peptones. These compounds, derived from the proteins, are complex substances themselves and are not ready for assimilation by the cells. (2) Peptidases, which act upon the albuminoses and peptones and, by hydrolysis, split them into amino acids. (3) The amidases, which liberate ammonia from the amino or amido compounds. Each of these is specific, and one cannot do the work of the other.

B. Fate of the Products of Digestion.—The final products of digestion are carried to all parts of the plant for assimilation and use by the cells. They may be *oxidized* (during respiration) and furnish the energy needed for growth and other physiological activities of the cell; they may be *assimilated, i.e.,* used to build more protoplasm needed for repair or

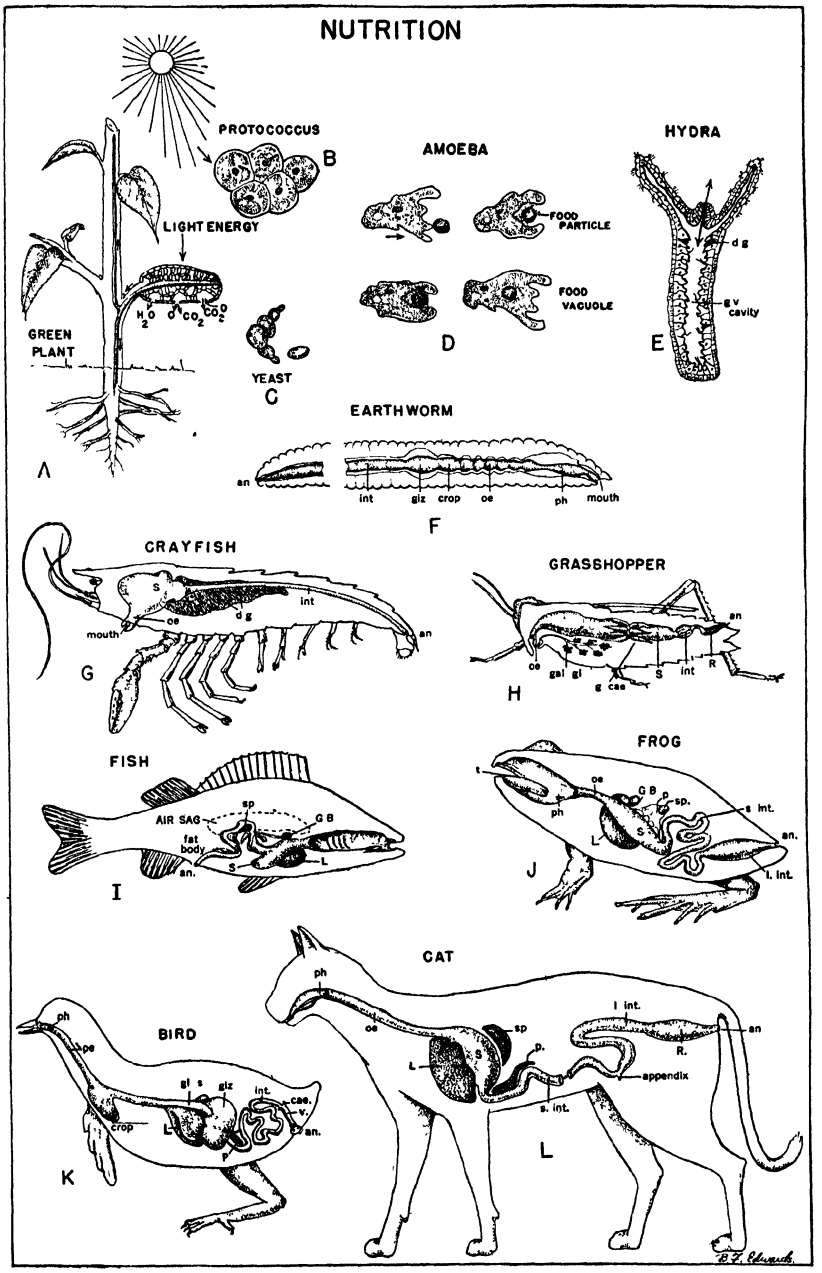

Fig. 366.—Mechanisms for digestion in plants and animals. (B. F. Edwards.) (an) Anus, (cae) caecum, (d. g.) digestive gland, (G. B.) gall bladder, (g. v.) gastrovascular cavity, (gl. s.) glandular stomach, (l. int.) large intestine, (L.) liver, (oe) oesophagus, (p) pancreas, (ph) pharynx, (R) rectum, (sal. gl.) salivary gland, (sp.) spleen, (s. int.) small intestine, (s) stomach.

growth; they may be *resynthesized* into any one of three types of food and stored; finally, they may be used in the synthesis of new compounds.

C. Carnivorous Plants.—A few plants are carnivorous and depend upon a certain amount of animal food for their nutrition. They grow in bogs or in poorly drained soil where there is a shortage of available nitrogen compounds. Nitrogen is one of the essentials for building up protoplasm. Carnivorous plants solve the problem of securing enough nitrogen by digesting animal food. When adequate soil nutrients are available, these plants thrive without animal food.

To secure this animal food, mainly insects, carnivorous plants have developed cups, sticky hairs, and other devices for securing the animals. The pitcher plant, the sundews, and the Venus's-flytrap are good examples of carnivorous plants. If cups and pitchers contain water, insects are drowned in it; then enzymes are poured into the water from the leaves, and so digestion and then absorption take place. The Venus's-flytrap, after capturing the insect (Fig. 103), pours out upon it the enzymes necessary for digesting it; after digestion is completed, the leaves open and discharge the indigestible remains (Fig. 103*F*).

III. Digestion in Animals

The digestive systems of animals are of many types, though in all of them the fundamental processes of digestion are the same as in plants. The one-celled creatures possess no special digestive organs, yet the processes of digestion, assimilation, and growth occur in these creatures as well as in the highest and most specialized of digestive systems.

A. Digestion in Invertebrates. 1. PROTOZOA.—Protozoa secure their food in various ways; the *Amoeba*, by sending out protoplasmic processes and surrounding it (page 271); in the case of the *Paramecium* (page 278), it is swept into the gullet by the action of cilia. In both cases, a food vacuole is formed. Into this the surrounding protoplasm pours digestive juices, which dissolve the food particles. The digested food is then absorbed into the protoplasm. The parasitic *Endamoeba histolytica* digests its food outside the body. It pours digestive juice on the tissues surrounding it, dissolving them, and then absorbing the digested food (*extracellular digestion*).

2. HYDRA.—The coelenterate group, of which *Hydra* is a good representative, exhibits both *intracellular* digestion and *extracellular* digestion. The cavity into which the mouth opens, the gastrovascular cavity, is lined with flagellated cells to keep a current moving and cells that digest food in the same manner that the *Amoeba* does, *i.e.*, inside the cell (*intracellular digestion*). In addition, digestive juices are poured into the cavity, and most digestion takes place there (*extracellular digestion*). The products of digestion are passed on by diffusion in *Hydra;* in some

of the higher coelenterates, there are gastrovascular canals (*Aurelia*, page 306).

3. EARTHWORM.—The earthworm shows a great advance over the *Hydra* in having a definite digestive system and a circulatory system.

When the food reaches the esophagus, it is mixed with the secretion of three pairs of calciferous glands; this secretion is alkaline and serves to neutralize the acid nature of the food. The *crop* is a storage organ, and the food remains in it until it passes into the gizzard and is broken up into fine pieces in preparation for digestion. The walls of the stomach intestine contain gland cells that secrete digestive enzymes (page 337) of three types: (1) *amylase*, which converts carbohydrates to simple

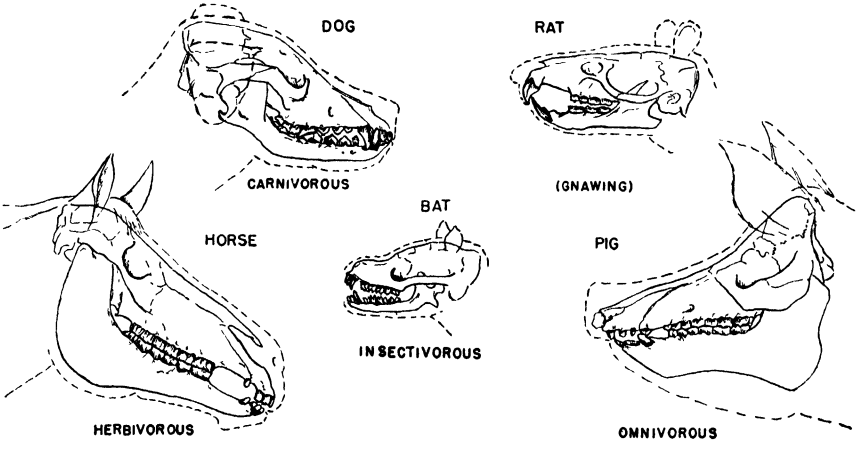

Fig. 367.—Teeth of various types of animals. Food habits of animals are shown by their teeth. (B. F. Edwards.)

sugars, (2) *trypsin*, which changes proteins to peptones and amino acids, and (3) *lipase*, which splits the fats into fatty acids and glycerine.

Absorption of digested food is through the walls of the intestine and takes place by *diffusion and osmosis* (page 39). The surface of the intestine is increased by an infolding, the *typhlosole* (page 336). After absorption, the food is carried to all parts of the body by the *coelomic fluid* and the *blood*.

It will be seen from the preceding that the earthworm represents a transition from the gastrovascular type of digestive system to that of the higher animals. The flatworm has a very much branched intestine but does not show the transportation system characteristic of the earthworm.

B. Digestion in Vertebrates.—Digestion in the vertebrates is more specialized than in the invertebrates. The digestive processes have been studied more thoroughly in this group and are better understood. In the

different groups of the vertebrates, the digestive systems are similar, though modified according to the activities of the animal and the kind of food that they eat.

1. Digestive Organs of Vertebrates. *a. Teeth.*—Food is ingested by means of the mouth. Usually glands are present in the mucous membranes of the mouth cavity of land animals that secrete lubricating substances that make the food easy to swallow.

Nearly all vertebrates possess teeth (Fig. 367), which are for grasping, grinding, or cutting food. There is a wide difference between the grinding teeth of the herbivorous animal whose food is coarse grass and the sharp, pointed teeth of the carnivorous animal (Fig. 367). The character of the teeth is definitely related to the type of food the animal eats.

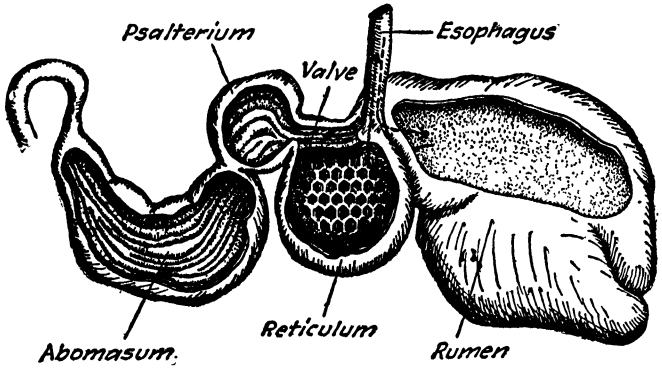

Fig. 368.—Diagram of the stomach of a cud-chewing animal (ruminant). (From Wolcott, Animal Biology.)

b. Tongues.—Among the vertebrates, tongues vary greatly in size, shape, and function. The woodpecker, for example, possesses a tongue that is modified as an effective instrument for dragging insects out of holes in trees, whereas the tongue of the cow is adapted for grasping wisps of grass that are cut off against the lower teeth. The cow has no canines or incisors in the upper jaw. In the higher animals, the sense of taste is located on the tongue.

c. Types of Food Tubes.—The alimentary canal is modified according to the use to which it is put. For example, the stomach of the cow, a herbivorous animal, is very complicated (Fig. 368). The arrows in the figure show the path of the food that is swallowed, regurgitated into the mouth, chewed again, and then swallowed again, the finer food going into a different part of the stomach.

Herbivorous animals possess digestive tubes that may be twenty times the length of their bodies. This is necessary because the coarse, bulky food they eat contains cellulose, which takes a long time to digest.

The intestines of carnivorous animals, on the other hand, are from three to five times the length of their bodies, whereas those of omnivorous animals are about ten times the length of their bodies. Various modifications for increasing the surface of the intestines for absorption of digested food are by folding, coiling, formation of pouches, and *villi* (L. *villus*, shaggy hair). The villi, characteristic of birds and mammals, are finger-like processes (Fig. 369) that make the lining of the intestine look like

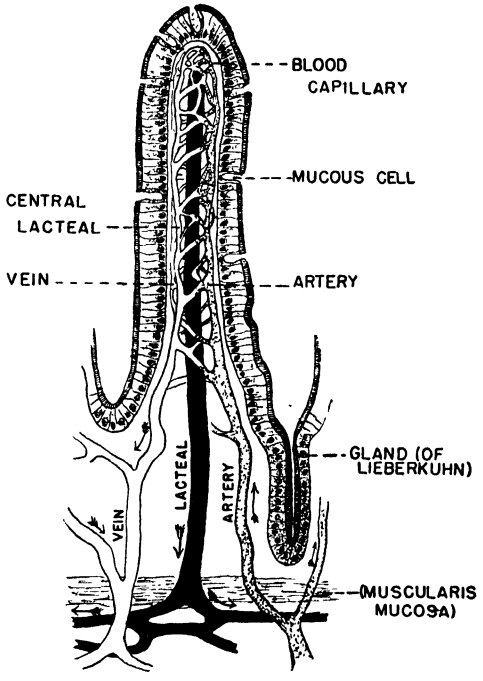

Fig. 369.—Diagram of an intestinal villus. The 4–5 millions of these villi in the intestine greatly increase the absorbing surface.

velvet. A microscope is required to see these small projections, yet they increase the surface enormously.

d. Glands.—In the lower invertebrates, the digestive glands consist mostly of a single cell. In the higher invertebrates, they may be multicellular, as the digestive glands of the crayfish which function both as liver and pancreas. Most vertebrates possess *salivary glands*, which open into the mouth, *gastric* glands, which open into the stomach, and *intestinal* glands, which open into the intestine. These are of various types (Fig. 370). A large gland, such as the liver or pancreas, consists of many units.

e. Special Functions of the Liver and the Pancreas.—The liver is the largest gland in the body and one of the most important. Not all its work

is concerned with digestion. *Bile* is mainly a waste product, made up of worn-out blood cells and other wastes. Yet the bile performs the important functions of helping to make the intestinal juice slightly alkaline and of emulsifying fats, *i.e.*, it mixes with the fats so that they become finely divided into droplets. In this state, the fats can be acted upon by digestive juices. Some substances in the bile are said to aid in the absorption of fats. The bile also stimulates the wave-like peristaltic contractions of the intestines. Some physiologists think that the bile has a slight antiseptic action in the intestine.

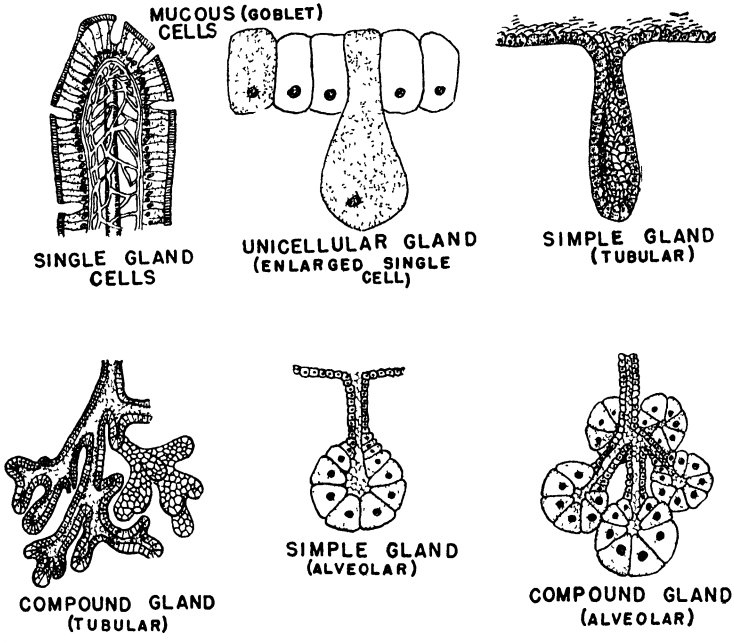

Fig. 370.—Some types of glands. There are many modifications of these types. (B. F. Edwards.)

One of the important functions of the liver is the collection of *urea*, a waste product of protein digestion. Urea is largely formed in the liver and is then carried by the blood to the kidneys, where it is excreted. The liver forms and stores *glycogen* as a reserve food. The portal circulatory system (page 562) carries blood that is rich in food substances from the stomach and the intestine. This blood passes through the liver before it reaches the general circulation. Glucose is taken out of the blood by the liver, transformed into glycogen, an animal starch, and stored until energy is needed; it is then converted into glucose.

The *pancreas* secretes three enzymes: (1) *amylopsin* for splitting carbohydrates, (2) *trypsin* for splitting proteins, and *steapsin* (lipase) for

splitting fats. In addition, it contains patches of tissue, the *islands of Langerhans*, which secrete *insulin*. This is not an enzyme but a *hormone* (page 618), as the secretions of ductless glands are named (page 263). If insulin is not present in the blood, a disease known as *diabetes* occurs.

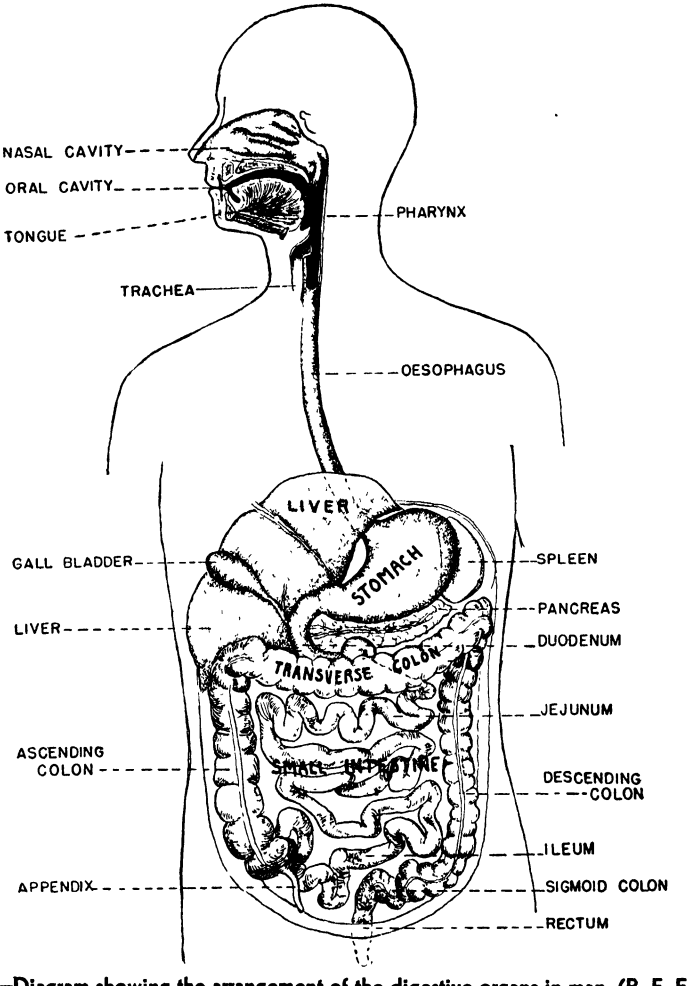

Fig. 371.—Diagram showing the arrangement of the digestive organs in man. (B. F. Edwards.)

2. Digestive Organs and Digestion in Man.—The processes concerned with nutrition are essentially the same in man as they are in other living things. Naturally, there are special requirements of the human body. As an example of digestive processes of the lower *vertebrates*, the frog may be taken (page 234), and the example will not be repeated here. Some differences in the digestive organs of other lower animals are mentioned above.

In man, the alimentary canal consists of the *mouth*, *pharynx*, *esophagus*, *stomach*, *small intestine*, and *large intestine* (Fig. 371). Together, these constitute a tube about 30 ft. long. A mucous membrane, which secretes mucus, lines the entire tract. Food will move easily over a surface covered with such a slippery substance as mucus.

In addition to the *liver* and *pancreas*, on the outside of the digestive tract, but connecting with it through ducts, there are many glands in

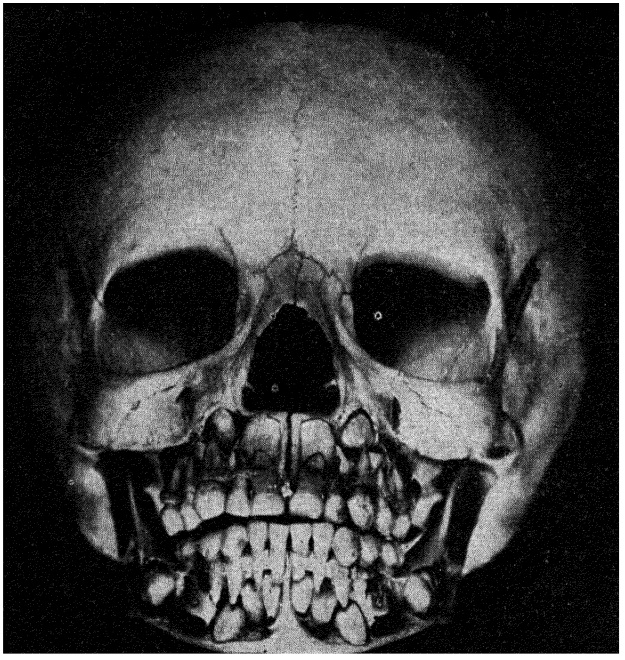

Fig. 372.—Teeth and jaws of a six-year-old child. The permanent teeth, enamelled, but yet without roots, are ready to begin displacing the temporary teeth. (Courtesy of U.S. Department of Agriculture Extension Service.)

the stomach and the intestines that are concerned with various phases of the process of digestion (see the table on page 543).

a. The Teeth. (1) STRUCTURE.—Teeth may be called *accessory organs of digestion.* Each tooth consists of a crown, a neck, and one or more roots. The roots lie in the sockets in the jawbone. The hardest substance in the body is the enamel that covers the crown of the tooth. Dentine lies just under the enamel and forms the bulk of the tooth. Although dentine is not so hard as enamel, it is harder than the most compact layer of bone. In the middle of the tooth is the pulp cavity, a little chamber containing nerves and blood vessels that enter the pulp cavity through canals in the roots.

(2) TYPES.—These are *incisors* (L. *incisus*, to cut), the "front teeth," which are flat and sharp for biting off food; *canines*, on either side, which in man, aid in biting, though in the dog and other flesh-eating animals, they are more or less well-developed tusks for fighting and tearing flesh; the *bicuspids* (L. *bis*, twice, *cuspis*, point); and the *molars* (L. *mola*, mill), which possess wide surfaces for grinding food and mixing it with saliva.

(3) TEMPORARY AND PERMANENT TEETH.—Figure 372 is a photograph of a six-year-old child. The milk, or temporary teeth, cover the permanent teeth that will later take their places. The 20 "milk" teeth are as many as the small jaws of a child can accommodate. There are 32 permanent teeth, the wisdom teeth appearing sometime between the eighteenth and thirtieth year. In some cases, wisdom teeth do not appear at all.

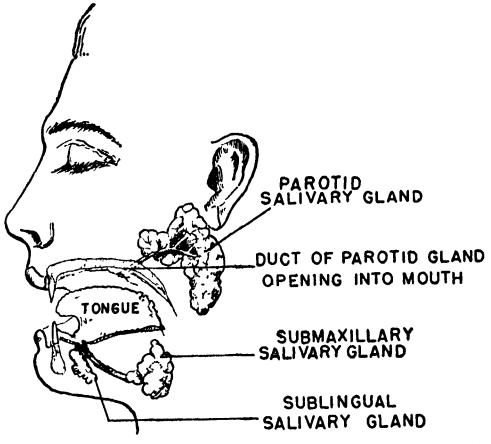

Fig. 373.—Diagram showing the location and openings of the salivary glands. (B. F. Edwards.)

The character of the diet has great influence on the development of the teeth. Vitamin D and phosphorus are important in regulating the structure of the teeth, and vitamin C is necessary for the structures around the teeth. If the teeth are not kept clean, the fermentation of starchy food that becomes lodged between them may cause the formation of acids, which dissolve away the substance of the teeth and thus form cavities. For a table of foods showing their calcium and phosphorous content, as well as the presence of vitamins C and D, see pages 524 to 528.

b. The Salivary Glands and Saliva.—Three pairs of salivary glands are present in man: the *sublingual*, under the tongue; the *submaxillary*, under and behind the corners of the lower jaw; and the *parotid*, in front of the ears (Fig. 373). The parotids become inflamed and swollen when one has the *mumps*. These six glands secrete the saliva. The ducts of the submaxillary and sublingual glands unite before they reach the mouth,

whereas the ducts from the parotids open on the inside of the cheeks opposite the second molars of the upper jaw.

Ptyalin, a starch-splitting enzyme, is present in human saliva. Saliva moistens the food so that it may be tasted; the mucus in it also lubricates the food so that it may be easily swallowed.

Salivary glands are absent in aquatic forms. In the land forms, they perform the same function as in man. Carnivorous mammals do not have ptyalin secreted by their salivary glands, but all other mammals do.

c. The Stomach. (1) STRUCTURE AND FUNCTIONS.—The stomach is a muscular organ; its walls contain three layers of muscles: an outside layer, *longitudinal*, a middle layer, *oblique*, and a third layer, *circular*. The muscle fibers in these three layers run in different directions and by their activity produce the "churning movements" that thoroughly mix the gastric juice with food. An important function of the stomach, aside from the secretion of the gastric juice, is to serve as a storehouse for food so that enough can be eaten at one time to serve the body for several hours. In the lining of the stomach are the openings of many glands that secrete the gastric juice.

(2) DIGESTION IN THE STOMACH.—The cardiac part of the mammalian stomach is located nearest the heart; the lower end is the pylorus. Certain glands in the stomach secrete *mucus;* other glands produce the *gastric juice;* hydrochloric acid is secreted by other cells in the stomach wall. The gastric juice, which is acid, contains the enzyme *pepsin*. This acts on protein foods, causing them to split into simpler substances, peptones and proteoses. The glands that produce the pepsin are located near the middle of the stomach. Lower down in the pyloric section, *rennin*, an enzyme that coagulates milk, is secreted. If the milk were not coagulated, it would not remain in the stomach long enough to be acted upon by the gastric juice.

The digestion of starch begins in the mouth and continues to a certain extent in the stomach. The digestion of protein is begun in the stomach and completed in the intestine. Some physiologists believe that a certain amount of fat is digested in the stomach by an enzyme, *gastric lipase*. This is questionable. The stomach mixes the food and enzymes together by a sort of churning motion. Wave-like contractions also occur that force the food along when it is to be passed on into the intestine.

d. The Small Intestine. (1). DIVISIONS.—The small intestine is divided into the duodenum (page 234), the jujenum, and the ileum. The last two are fastened to the dorsal abdominal wall by connective tissue, the mesentery. The arteries, veins, and nerves reach the intestines through the mesenteries (Fig. 383).

(2) DIGESTION IN THE SMALL INTESTINE.—After the digestive processes are completed in the stomach, the food is in a liquid condition,

called the *chyme*. It now enters the *duodenum*, the part of the small intestine next to the stomach, through a valve, a little at a time. *Ducts* from the *liver* and from the *pancreas* also enter the duodenum. The acid chyme changes prosecretin, a hormone secreted by glands in the intestinal wall, to secretin. This substance is carried to the pancreas by the blood and causes the secretion of pancreatic juice. The three enzymes in the pancreatic juice are *amylase*, which acts on starch, *trypsin*, which acts on proteins, and *lipase*, which acts on fats. They do their work in an alkaline medium. The acid chyme is made alkaline by the bile from the liver and the pancreatic juice.

Starches are first acted upon in the mouth by ptyalin, and the work is continued in the small intestine by amylase. The intestine itself secretes three enzymes that act upon the sugars remaining from digestion in the mouth, stomach, and small intestine. The *maltase* acts upon malt sugar; *invertase* acts on cane sugar; and *lactase* acts on milk sugar. The products are simple sugars like glucose. These three are sometimes called the *inverting enzymes*.

Proteins are acted upon by *pepsin* in the stomach; by *trypsin* in the small intestine; and, finally, by *erepsin*, which is secreted in the small intestine and changes peptides to amino acids.

Fats are first melted by the heat of the body and then emulsified by the bile (page 538). *Lipase* then brings about the change of fats into *fatty acids* and *glycerol*. Below will be found a table of digestive enzymes.

Source	Location of enzyme	Secretions	Enzymes	Substances changed	Intermediate products	Products ready for absorption
Salivary glands	Mouth	Saliva	Ptyalin	Starch	Maltose	
Gastric glands	Stomach	Gastric juice	Pepsin	Protein	Proteoses	
			Rennin	Protein of milk	Peptones Casein	
Pancreas	Pancreas	Pancreatic juice	Amylase	Starch	Maltose	
			Lipase	Fats		Fatty acids and glycerol
			Trypsin	Proteins		Amino acids
Glands of small intestine	Small intestine	Intestinal juice	Erepsin group	Proteoses		Amino acids
				Peptones		Amino acids
				Casein		Amino acids
			Maltase	Maltose		Simple sugars
			Sucrase	Cane sugar		
			Lactase	Milk sugar		

The small intestine exhibits two types of movements: (1) waves of contraction, or *peristalsis* (Gr. *peri*, around; *stalsis*, constriction), which forces the food along, and (2) contractions of the intestinal segments. The second type of contractions makes the intestine look somewhat like a string of sausages (Fig. 374).

e. The Large Intestine and Its Functions.—About nine hours after eating, the last of the digested food has entered the large intestine from the small intestine through a valve, the *ileocaecal* valve. At the junction of the small and large intestine is the *caecum*, which is joined on to the *vermiform appendix* (Fig. 371). The caecum, or the blind portion at the beginning of the large intestine, is only about 2½ in. long in man. In some herbivorous animals, such as the rabbit, it is quite large.

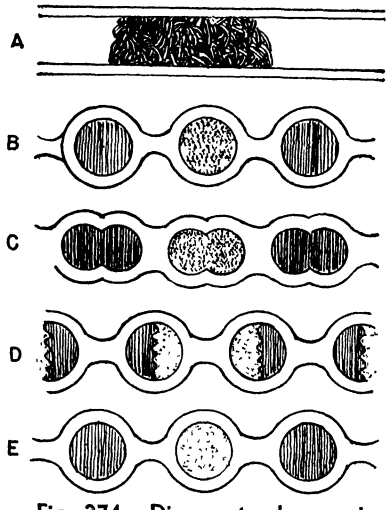

Fig. 374.—Diagram to show peristalsis in the small intestine. Each bolus is split by constriction and the halves of the adjacent boluses are reunited, thus insuring a thorough mixing. (B. Shamos.)

The food entering the large intestine a little at a time from the small intestine through the *ileocaecal* valve is liquid; the valve prevents any of the material from passing back into the small intestine. The large intestine at this point is the ascending colon, so that the materials must travel upward to reach the *transverse colon;* from the transverse colon it goes through the *descending colon* to the *rectum.* The work begun in the small intestine continues to some extent. Also, *bacteria* live in the large intestine, and these may act upon certain proteins that have escaped digestion. This type of bacterial putrefaction occurs normally in the large intestine. Some authorities believe it to be harmful; others believe that, although it is not beneficial, the harmful effects are neutralized by the body normally.

The material in the large intestine consists of many kinds of substances: undigested food, products of digestion, bacteria, secretions, and the like. In addition, the lining of the large intestine secretes large quantities of mucus, and this aids in eliminating the intestinal contents. After the liquid food reaches the large intestine, water is absorbed from it, and the material assumes the more solid character of feces. The movements of the large intestine are somewhat similar to those of the small intestine, and thus the intestinal contents are moved along by peristalsis, being expelled as feces once or twice a day.

The various movements of the alimentary tract are under the control of the sympathetic nervous system.

f. Time Required for Digestion of a Meal.—This depends somewhat upon the character of the food. Liquid food remains in the stomach only

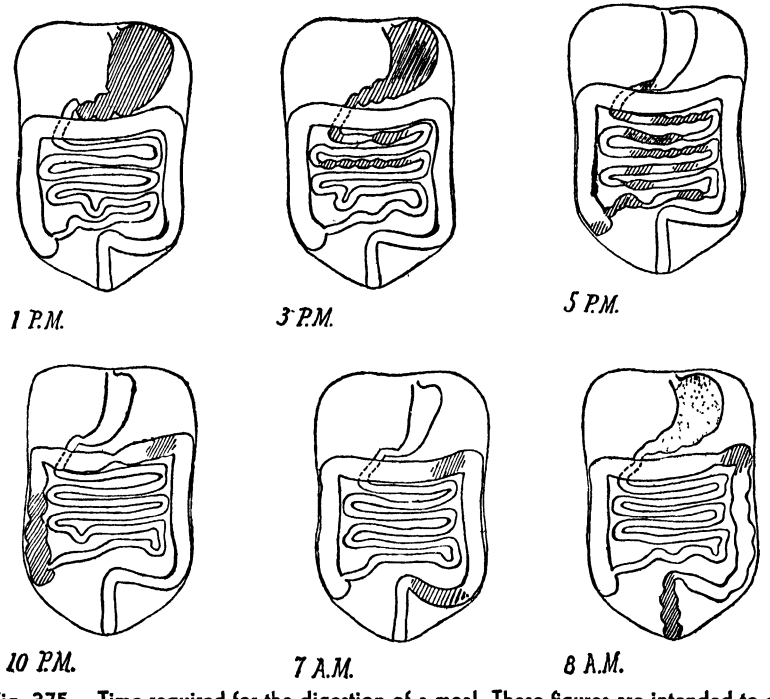

Fig. 375.—Time required for the digestion of a meal. These figures are intended to show the probable advance of the food during the next few hours after dinner. For the sake of simplicity the tract is represented as free from food taken previously and no supper is eaten. The course of the small intestine is diagrammatic.

At 1 p.m. the stomach is full and active.

At 3 the stomach is smaller, having forwarded part of its contents to the small intestine.

At 5 the stomach is about empty and digestion is in progress at intervals all along the small intestine.

At 10 the small intestine is clear. There is antiperistalsis in the ascending colon. The foremost portion of the material is near the spleen. The mass now consists less of food than of associated secretions.

At 7 a.m. the chief accumulation is in the sigmoid flexure. The lagging part is near the spleen.

Breakfast is eaten, the lower part of the tract wakes to activity at the same time as the stomach, and at 8 the sigmoid has thrust its contents to the rectum. This is the occasion for defecation. (From Stiles, Human Physiology, W. B. Saunders Company.)

a very short time, whereas fats remain there longer than any other food. It follows that foods coated with fats or fried remain in the stomach longer than they would if they were prepared in some other way. In

general, food remains in the stomach from 2 to 4 hours, then passes little by little into the small intestine. Owing to the length of the small intestine, about 20 ft., the greater part of digestion takes place there. It requires about 9 hours from the time of eating until the last of the meal has passed from the small to the large intestine (Fig. 375).

3. Absorption and Assimilation. *a. Process and Place of Absorption.*—Before absorption can take place, food must be in condition to pass through a membrane. The purpose of digestion is so to change food that it will be absorbed through the intestinal membranes into the blood stream and carried to the millions of cells in the body. Absorption is essentially the same in all vertebrates, the differences being related to the type of food and the requirements of the animal. In man, most of the absorption takes place in the small intestine. The inside layer of the small intestine is thrown up in small finger-like projections, the *villi* (Fig. 537), which increase the surface available for absorption. The relations of artery, vein, and lymph vessels in a villus are shown in Fig. 369.

b. Routes of the Absorbed Foods to the Cells. (1) Carbohydrates and proteins.—The products of the digestion of starches, which are the simple sugars, and the products of protein digestion, which are the amino acids, are absorbed into the blood vessels of the portal system (Fig. 376). When the portal vein reaches the liver, it breaks up into capillaries, and from these the liver absorbs a part of the simple sugars, converting them into *glycogen* (Gr. *glykys*, sweet), an animal starch, which is a reserve food supply. The blood leaving the liver enters the hepatic veins, and these, in turn, empty into the large ascending vena cava, which enters the right auricle of the heart. From the heart, the blood is pumped to every portion of the body, finally reaching the cells.

(2) Fats.—Fats go by a different route, through the *lymph vessels*, for a part of the journey. The products of digested fats pass into the lymph vessels of the villi and then into the vessels leading to the *thoracic duct* (Fig. 376). Because absorbed fat products are emulsified, they look like milk, and so the lymph vessels running through the mesenteries of the intestine look milky and are called *lacteals*. The thoracic duct empties into the base of the jugular vein at its junction with the innominate vein to form the descending vena cava, which enters the right auricle of the heart. From here the blood containing the fats is distributed by way of the general circulation to all cells of the body.

c. Fate of Absorbed Foods.—When the absorbed foods reach the cells, they are used to produce energy to carry on the activities of the cell and to build up protoplasm.

(1) Carbohydrates.—Carbohydrates enter the blood as simple sugars. The normal amount of sugar in the blood is 0.1 per cent, *i.e.*, there is 0.1 g. in 100 cc. of blood. After a starchy meal the quantity may

rise to from 0.12 to 0.14 per cent. If it rises above 0.14 per cent, some of it is excreted by the kidneys and is thus lost. Usually, however, some of it is stored in the liver as glycogen before this level is reached. This makes a reserve supply of food that may be called for between meals. When the glycogen is needed, it is reconverted into sugar by the action of enzymes.

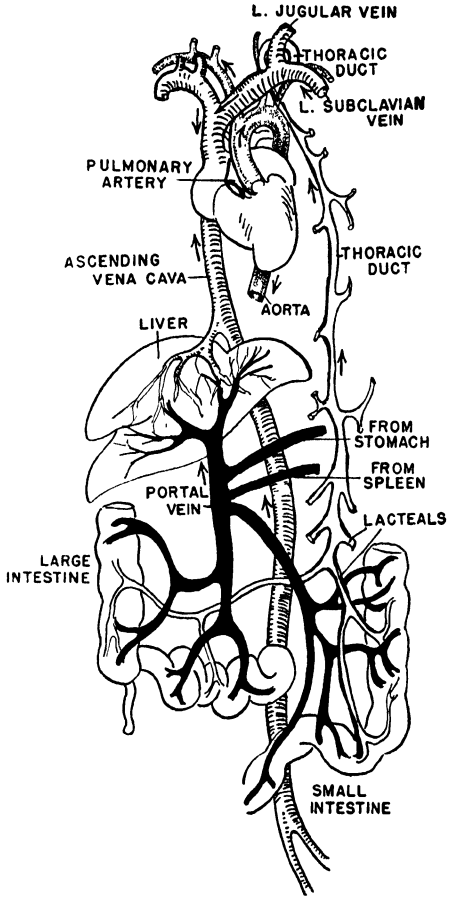

Fig. 376.—Diagram to show route of absorbed foods. Carbohydrates and proteins enter the general circulation by way of the portal vein; fats by way of the thoracic duct. (B. Shamos.)

The process is quite complex, since it works both ways; *i.e.*, the glucose is changed into glycogen, and the glycogen changed back to glucose as needed. In this process, insulin from the pancreas plays an important part as well as *glycogenase*, an enzyme from the liver. Storage of carbohydrates in the liver is important for two reasons: (1) it would be excreted by the kidneys and so lost if the level of sugar rose too high in the blood,

and (2) it furnishes a reserve food supply that can be drawn upon between meals.

The energy for the activities of cells must come from the breaking up of glucose or some other food substance (page 522). We may return to the formula (page 156):

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} \rightarrow \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy}$$

The process is not so simple as shown by the reaction. If the glucose were burned outside the body, energy would be liberated, but it could only be burned at high temperatures. In the body, the glucose can be "burned" at low temperatures because of the action of enzymes.

(2) FATS.—Fats enter the blood stream in a finely divided condition. Evidence exists that fats cannot be properly oxidized unless carbohydrates are present; *i.e.*, "fats burn in the flame of carbohydrates." Fats and fat-like bodies are built into the structure of protoplasm, especially into cell membranes. They are important here because they are concerned with a very important characteristic of the membrane, namely, permeability. Some of the fat is stored in specialized cells. For example, a "layer of fat" lies just under the skin. By this is meant that fat is stored in specialized cells generally distributed under the skin. Here it serves as an "insulator" to conserve the body heat. Other portions of the body may also contain fat in storage. This stored fat resembles glycogen in that it is a food supply to be "tapped" in times of need. Like glucose, fat, when burned, releases energy and becomes carbon dioxide and water.

(3) PROTEINS.—Proteins (page 520) furnish the building blocks for the construction of protoplasm. They may be utilized in the cells for building up tissues during growth or for rebuilding tissues that have been broken down by the activities of the animal. No work is done by any living things without the breaking down of some tissue that must be rebuilt. Proteins are also used as sources of energy (page 521).

The combustion or oxidation of the amino acid in the cell liberates energy, as does the oxidation of carbohydrates and fats. Before this takes place, however, the amino acid becomes changed, mainly in the liver. The *portal vein* carrying the absorbed foods travels through the liver. In addition to storing up glycogen, the liver changes the *amino acid molecule* so that *urea* is formed and extracted by the kidneys.

Storage of both carbohydrates and fats occurs in the body, but very little storage of proteins. If the stores of fats and carbohydrates are consumed, the proteins of the tissues are themselves used for energy. The body literally "burns itself up." Naturally, this cannot continue very

long. But as long as the body remains alive, it must have energy to carry on its activities.

One of the most interesting facts about the three classes of foods is that they are all *chains of carbon atoms*. As already stated, plants manufacture glucose, and this can be converted into fats (oil in seeds, etc.); also, with the addition to the glucose of salts from the soil, amino acids may be formed (page 151). Animals are unable to manufacture protein from starch and salts. They must be synthesized or built up from the amino acids obtained either directly from the plant food or indirectly from meat whose proteins were obtained from plants. But other transformations do take place. It is a matter of common knowledge that carbohydrates can be transformed into fat within the animal body. The farmer takes advantage of this fact in feeding livestock. Hogs to be fattened are fed on corn, which contains large quantities of carbohydrates. Also, a part of the proteins and a part of the fats may be converted into glucose. This was discovered as a result of feeding animals a carefully controlled carbohydrate-free diet and then estimating the amount of glycogen in the liver. Since no carbohydrates were fed, the glycogen must have come from the other food elements.

4. The Food Requirements of the Human Body.—Food requirements of organisms vary according to their manner of living; the same is true of the human body. Exposure to cold, physical exercise, growth, and other factors influence the food requirements for the maintenance of normal health.

a. Basal Metabolism.—When the body is in a resting state, some activities continue to take place, and thus a certain amount of metabolism occurs; this is *basal metabolism; i.e.*, there is a minimum amount of breaking down and building up of substances; otherwise, life activities, such as breathing, the beating of the heart, etc., could not continue. There must, of course, be enough food present to carry on this basal metabolism.

b. Measurement of Food Requirements.—In addition to the amount of food necessary for basal metabolism, there must be enough present for other activities, which are due to exercise, exposure to cold, growth, and repair of protoplasm. Naturally an inactive worker, such as one doing office work, will not need as much food as one who does active outdoor work, a lumberman, for example.

Food requirements are measured in large calories (page 529). The requirements range from 1,000 cal. for the sedentary individual to from 7,000 to 8,000 for those who do hard physical work. There are 4.1 cal. per gram in carbohydrates, about the same in proteins, and 9.1 cal. per gram in fats. It is possible, therefore, to measure within small limits what is needed by the human body in the way of calories. It is not so

simple as it might seem, however, because certain substances are required in the diet. For example, corn contains a protein called *zein*. If this is the only protein fed to an animal, no matter how much carbohydrate and fat it receives, death will occur. Zein is lacking in two of the essential amino acids. If these are added to the diet, the proper balance is restored, and the animal remains alive. By experiment it has been determined that 9 of the 23 amino acids that have been obtained by the breaking down of protein molecules are essential for life; that certain of the fatty acids must be present; that carbohydrates are the best energy producers; and that they aid in the metabolism of fat as well as being protein sparers. How much protein is needed depends upon how much of the other foods are eaten. A well-balanced diet for a person requiring about 2,700 cal. daily is as follows:

Food	Grams	Calories (approximate)
Proteins....	100	400
Carbohydrates	400	1,600
Fats.....	75	675

This seems to be a good proportion for people in temperate climates. The Eskimos, however, live on a diet composed exclusively of animal food. Stefansson, the arctic explorer, found that health could be maintained on such a diet.

All the proteins that one needs may be obtained from plants. An entire group, the herbivores, eat plants only. However, man must eat a greater variety of food if plants are his sole source of proteins. It may be possible for individuals to maintain health on 25 g. of protein a day; it is probably wiser to ingest from 50 to 100 g. daily. For a table of food values, see page 873.

Not all food substances necessary for health furnish energy. *Water*, for example, is indispensable for cell life. Without it, the colloidal condition of protoplasm would not be possible. Water is more necessary for life than any other substance.

c. Accessory Foods. (1) MINERALS (page 22).—Eleven minerals are necessary for adequate diet in higher animals. These are listed on page 522. *Calcium* is important, together with *phosphorus*, in building up bones and teeth; it is concerned with heart action, maintaining muscle tone (page 623), and in the clotting of blood (page 568). *Iron* is present in all cells in minute amounts and takes part in the composition of hemoglobin, the substance in the blood that has an affinity for oxygen (page 522). *Iodine* is necessary for the secretion of the thyroid gland, *thyroxin*.

In certain regions of the country, especially in the region of the Great Lakes and other inland regions, very little iodine is present in the soil, so that the foods that grow there are lacking in iodine. This lack results in the development of goiter in many individuals. The addition of a small amount of iodine to the table salt or other foods prevents the disease. It is dangerous to add iodine to foods except on the advice of physicians; too much causes as much trouble as too little (page 622). Other minerals are necessary for good health, but the role they play is too complex to go into here. Raw foods, green foods, meats, and many other foods contain enough minerals to maintain the body in health. Refinement of foods—for example, the manufacture of white flour, the polishing of rice, etc.—may lead to a deficiency in the mineral supply needed.

(2) VITAMINS.—These are as important for health in man as they are in animals and plants. (For list of vitamins and their uses, see pages 524 to 528.)

(3) ALCOHOL AS A FOOD.—Alcohol is oxidized in the body, but, although it produces heat, it also increases the loss of heat from the body due to the rush of blood to the capillaries of the skin. It has a narcotic action on the nerves and other harmful effects. This is more fully discussed on page 852.

(4) TEA AND COFFEE.—These are among the least harmful of the substances taken for a "lift" when one is tired. Both contain caffein (page 809). People differ from one another, and tea and coffee affect different people in different ways.

(5) COCOA AND SOFT DRINKS.—Cocoa contains a drug somewhat similar to caffein, *theobromine*, which is a stimulant (page 810). Many "soft drinks" contain a small amount of caffein.

(6) FLAVORS AND CONDIMENTS.—These may have no nutritive value but may increase the secretion of the gastric fluid and so indirectly aid digestion.

5. SOME DISORDERS OF THE ALIMENTARY TRACT. *a. Indigestion.*—The term *indigestion* may mean a slight disorder or a serious ailment. It may be only temporary discomfort. Often, however, it is associated with acute inflammation of the alimentary tract brought on by overindulgence or "gorging" with food or by drinking beverages containing alcohol. So-called *acid stomach* is a condition that may not be related to acid. Gastric juice is normally acid and in health must be acid. However, in cases of gastric ulcer, the normal acid of the gastric juice irritates the sore spot. In this case, treatment involves neutralizing the acid to give the ulcer time to heal.

b. Cancer.—Cancers may grow in almost any part of the alimentary canal. They are not caused in the same way as ulcers. A group of cells, for some unknown reason, but usually where there is continued irritation,

begin to grow very fast and destroy the cells around them. The growth mechanism seems to be upset in some way, and the cells "run wild." The cells may pass into lymph spaces or into the blood and be carried to other parts of the body, where they settle down and begin to grow. Surgical treatment is the only method employed for cancer of the alimentary canal. In some cases, if found in time, radium and X rays are effective.

c. Appendicitis.—Appendicitis is due to inflammation of the appendix from infection. The infection may destroy the walls of the appendix, liberating germs into the body cavity and causing a serious condition known as *peritonitis*. Removal of the appendix is an operation easily performed and usually leads to complete recovery.

d. Dysentery.—Other organisms may invade the alimentary canal and be responsible for certain diseases. The best known of these is dysentery caused either by *Endamoeba histolytica* (page 814) or by a bacillus, *Bacillus dysenterae.*

e. Gallstones.—Bile is collected in the gall bladder between meals. While it is there, water is absorbed from it, and this renders it more concentrated. Sometimes some substances are precipitated out of the bile and form gallstones. They may do no harm if they remain in the gall bladder, but if they pass into the bile duct they obstruct the passage of the bile and must be removed by a surgeon.

f. Allergy.—Allergy may be a sensitiveness to certain types of food. It is very different from the usual type of digestive upset.

g. Irritating Substances.—Sometimes irritating substances in the lower intestine cause trouble in other parts of the alimentary canal. One effect is the reversal of peristalsis that stimulates the waves to run in a direction opposite from normal; *i.e.*, toward instead of away from the stomach. The result is nausea or a general feeling of illness.

h. Influence of the Mental States on Digestion.—Fear, anger, pain, and hunger tend to affect digestion. This is because secretions of the stomach, intestines, and glands are interfered with. After fits of temper, one often has a headache, feels mentally dull, or suffers from gas production. It is good practice to see that mealtimes are pleasant for everyone. Any unpleasant emotion interferes with digestion.

A healthy individual seldom realizes that he has a stomach. Sometimes fear of a particular food or class of foods may and often does interfere with digestion.

Questions

1. Discuss digestion of foods in plants. Include in this discussion a mention of the plant enzymes and the role of each.
2. What is the fate of the digested foods in plants?
3. How does digestion take place in carnivorous plants?

4. Distinguish between intercellular and intracellular digestion.
5. Show how absorbing surface is increased by root hairs and villi.
6. Is there any advantage in having the intestine long and narrow?
7. Compare the teeth and alimentary tracts of the carnivorous and herbivorous animals. How is the type of food used by these animals related to difference in teeth and digestive tracts?
8. How is each of the three types of food prepared for digestion? Why must it be so prepared?
9. What are the parts of the human digestive tract?
10. Compare the milk and permanent teeth of man as to structure, number, etc.
11. Where are valves found in the alimentary tract? What is their function?
12. Give an account of digestive enzymes concerned in human digestion, stating where each is produced and what work is done by each. What character do these enzymes possess in common?
13. What is sucrase? Maltase? Lactase? Erepsin? Insulin? Where are these found?
14. What is the source of the bile, and what role does it play in digestion?
15. Describe the changes undergone by the three types of food during digestion in man in the following places: the mouth, the stomach, the small intestine, the large intestine.
16. Is there any advantage in the coagulation of milk in the stomach?
17. In what form are the carbohydrates when they are absorbed from the digestive tract? Proteins? Fats?
18. What principles are involved in the absorption of these foods?
19. Discuss the absorption of foods from the alimentary canal. What are the routes from the intestine to the cells of the three types of foods?
20. What is the fate of the absorbed products of the carbohydrates? Proteins? Fats? How do the cells use each of these foods? Is it possible for the body to transform glucose into fats? Fats into glucose? Proteins into either of the other two types of foods? How do plants transform glucose into proteins?
21. What is peristalsis? Where does it occur? What happens when it is reversed?
22. How long does it take to digest a meal?
23. What are some special functions of the liver and the pancreas?
24. How are the energy requirements of the human body estimated?
25. Name some disorders of the alimentary canal. What ones are preventable?
26. Define: peristalsis, oxidation, catalyst, ingestion, egestion, allergy, lacteal, emulsion.

Suggested References

NOTE: The following references will be useful for Chaps. XXXIV through XL.

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CHAPTER XXXVI

CIRCULATION

I finally saw the blood, forced by the action of the left ventricle into the arteries, was distributed to the body at large, and its several parts, in the same manner as it is sent through the lungs, impelled by the right ventricle into the pulmonary artery, and that it then passed through the veins and along the vena cava, and so around to the left ventricle . . . which motion we may be allowed to call circular.

—HARVEY, 1628.

I. Definition of Circulation

The term *circulation*, as applied to living things, means the process by which a liquid carries substances throughout the organism. The liquid may or may not be enclosed in blood vessels. The problems of circulation in the single-celled organism are simple compared with those of the complex organisms with billions of cells. Substances must reach all these cells, and wastes must be taken away; and so elaborate systems of circulation have been developed.

II. Types of Circulation

There are three types of circulatory systems: (1) the nonspecialized type, as in *Amoeba*, *Elodea*, and *Hydra;* (2) the *open type*, as in plants and the crayfish; and (3) the *closed type*, as in the earthworm and the higher animals.

A. Circulation in the Lower Organisms. 1. STREAMING.—The lower plants and animals do not possess systems of vessels, yet a definite circulation takes place in them. This is evident in the streaming of the protoplasm in *Amoeba* (page 271) or in the cell of *Elodea*. As a result of this streaming, the absorbed food substances are carried to all parts of the body.

2. CYCLOSIS.—In *Paramecium*, the movements of the food vacuoles follow a definite path, thus allowing an absorption of the food materials by the cytoplasm in all parts of the cell. This is *cyclosis* (Fig. 189).

B. Transfer of Materials in Plants.—Beginning with the ferns, definite systems for the transfer of water and food, *vascular systems*, are present in all plants. The processes of transfer of food in the phloem (page 124) are not so well known as the transfer of the water in the water tubes of xylem. Even this is not fully explained. The *osmotic* action (page 108) occurring both at the end of the root and in the leaf explains it

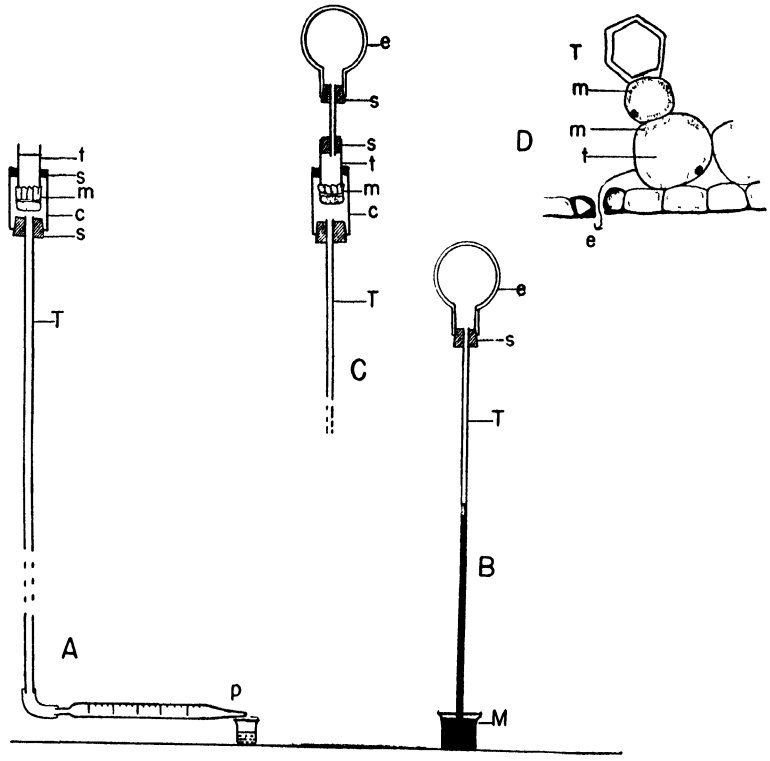

Fig. 377.—Experiments to illustrate osmosis and evaporation as they take place in a plant. (Courtesy of Dr. E. H. Runyon.)

A. Osmosis alone. (t) Tube of water closed at one end with m, membrane, permeable to water but not permeable to sugar. (s) Rubber stopper. (c) Glass cylinder (bottle with bottom broken out may be used). (T) Long glass tube ending in a graduated pipette, p. T corresponds to the stem of a plant.

Experiment. Fill t, c, and T with water excluding all air bubbles. The water slowly filters through m and drips from p. Sugar is now added to t, making the water less concentrated in t than in c, so osmosis begins; water rises in t and air is seen to enter the end of p.

B. Evaporation alone. (e) A porous cup from which water evaporates.

Experiment. Fill the tube T and the porous cup, e, with water so that there are no air bubbles. Invert over a beaker of mercury. As the water evaporates from the surface of the porous cup, the mercury M is pulled up, showing how tenaciously water adheres to the cup (as in the leaf cells).

C. Osmosis and evaporation working together. Here the porous cup evaporating surface e is joined to the apparatus of A so that rise of water in T (as in a stem) is caused by osmosis and evaporation working together. How will increasing the humidity affect the rate of rise of water in T?

D. Diagram of a small portion of a leaf showing parts corresponding to those of the apparatus. T, tracheid, corresponding to the tube of apparatus, is in direct connection with the stem and root, and t represents the sugar solution (the vacuole contains cell sap); and e, cell wall in contact with air space near stoma, represents the evaporating surface.

only in part. Figure 377 is a diagram of experiments easily carried out in the laboratory. The evaporation of the water from the bulb draws the water upward. In the leaf (Fig. 377*D*), the evaporation of water causes the sap to become more concentrated. The leaf cells are in direct contact with the water tubes of the leaf veins. Since the sap of the leaf cells is more concentrated than in the water veins, the principle of osmosis comes into play, and the water passes from the upper ends of the tubes into the leaf. The tubes are so small that the columns of water will "stick," or cohere, together; and so the water is drawn up.

Fig. 378.—William Harvey, 1578–1657.

C. Circulation in the Metazoa. The circulatory systems of the Metazoa may be of the open or closed type. The blood of animals having the closed type of circulatory system travels in a regular circuit. This fact has been known only a little more than three hundred years. William Harvey (1578–1657) (Fig. 378) studied circulation in animals for many years and then published his great discovery. Harvey did not actually see the capillaries, because really good microscopes had not yet been developed. It was a long time before his results were accepted.

If a piece of damp cotton is wrapped around the head of a small tadpole to keep it quiet and its tail is then examined under the low power of the compound microscope, circulation in the capillaries may be readily seen. The corpuscles move along rapidly in single file, and this gives an idea of the size of the capillaries.

1. The Invertebrates.—All types of circulatory systems are present in the invertebrates.

a. Hydra.—Movements of the liquid in the gastrovascular cavity are kept up by contractions of the body and by the flagella of the cells that line this cavity (Fig. 203). The animals of the *Hydra* group are built up of only two layers of cells; hence an elaborate circulatory system is not necessary.

b. Flatworms.—There is a much-branched intestine that ramifies through the body of the worm. This makes distribution of materials quite simple. Spaces, filled with fluid, are also present in the tissues. Contrac-

tions of the body aid in circulating the fluid through these spaces and so through the tissues.

c. Earthworm.—The circulatory system of the earthworm is of the closed type and represents a great advance over the other types thus far considered. It operates on the same principle as that of the higher animals: there are a pumping mechanism and a system of arteries and veins; the capillaries of the arteries are continuous with the capillaries of the veins. Through the thin walls of the capillaries, an exchange of materials takes place between the blood and the cells of the body. This exchange takes place according to the laws of diffusion and osmosis. (For details of the circulatory system of the earthworm, see Fig. 234.)

d. Crayfish.—The crayfish possesses an "open" type of circulatory system; *i.e.*, blood is collected in spaces in the tissues, the *sinuses*, in some

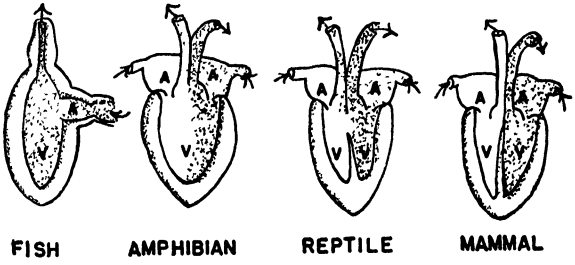

Fig. 379.—Diagrams of vertebrate hearts. Note relative simplicity of the fish heart. Note also that of the four diagrams shown, only the mammal shows complete separation of the right and left halves. A bird heart, not shown, also has complete separation of the two sides. (A) Auricle. (V) Ventricle.

places. There are a single pumping station, the heart, and a system of arteries and veins that, together with the sinuses, make up the circulatory system. The space around the heart is the pericardial sinus; here the blood collects and then enters the heart through openings, the *ostia*, rather than through blood vessels. The blood is prevented from flowing back by valves (Fig. 267).

e. Grasshopper.—This insect is an air-breathing arthropod with a very simple circulatory system of the "open" type (Fig. 280). A single muscular tube is present. In insects, the exchange of gases is taken care of by a special system of air tubes, the *tracheal system* (Fig. 281), and hence the blood of the insect does not perform the important function of exchanging oxygen and carbon dioxide that is taken care of by the blood of animals in other groups that have circulatory systems.

2. Vertebrates in General.—In the vertebrates, there is a well-developed *closed circulatory system.* The lymph system, which might be called a part of the circulatory system, is not entirely closed (page 563).

Many modifications of the general plan of circulation appear among the vertebrates.

The simplest heart among the vertebrate series is that of the fish. The auricle receives the blood, and the ventricle pumps it out (Fig. 379). Here only one auricle and one ventricle are present, and the ventricle receives only venous blood. This blood is carried through the ventral aorta to the different branchial arteries in the gills, where exchange of gases takes place. It does not then return to the heart, as is the case in the other types of vertebrates, but efferent vessels from the gills take it directly to the dorsal aorta, whence it is carried to all parts of the body.

The heart of amphibians contains two auricles and one ventricle. However, no great admixture of oxygenated and nonoxygenated blood takes place in the heart because of its peculiar structure (page 243). In most reptiles, an incomplete partition occurs in the ventricle of the heart. In the crocodile, however, there is a complete separation of the right and left halves of the heart.

In birds and mammals, the separation of the heart into two auricles and two ventricles is complete and no mixing takes place between blood that has been oxygenated and that which has not.

In the fish, a varying number of *aortic arches* is present, usually four; in the frog's there are two; in the bird, there is one, the right (Fig. 514); and in the mammal, there is one, the left (Fig. 514). The story of the origin and fate of the aortic arches is an interesting one (page 784), since it tells something of the evolutionary history of animals.

3. Circulation in Man.—The organs of circulation in man are the heart, arteries, veins, capillaries, and lymphatics.

a. The Heart.—The heart is a cone-shaped muscular organ about the size of the fist of the person to whom it belongs. It lies in the center of the chest cavity. Surrounding it is a double-walled membrane, the *pericardium.* The fluid that surrounds the heart is secreted by this membrane. As in birds and other mammals, the heart is divided into right and left halves by a partition or septum. Two auricles and two ventricles are present. The walls of the auricles are thin, whereas those of the ventricles are thick and muscular.

The *valves* of the heart direct the blood into the proper channels. They prevent "backing up," since they close after the blood has passed through them. Between the right auricle and the right ventricle is a valve with three flaps, the *tricuspid* valve (L. *tri*, three; *kuspis*, a point). Between the left auricle and the left ventricle is a valve with two flaps, the *bicuspid* (L. *bi*, two; *kuspis*, a point), sometimes called the *mitral valve*, from a fancied resemblance to a bishop's cap or miter. Both these valves open downward. The valves at the base of the arteries leaving the heart, the pulmonary and the aorta, open upward. These are pocket-like

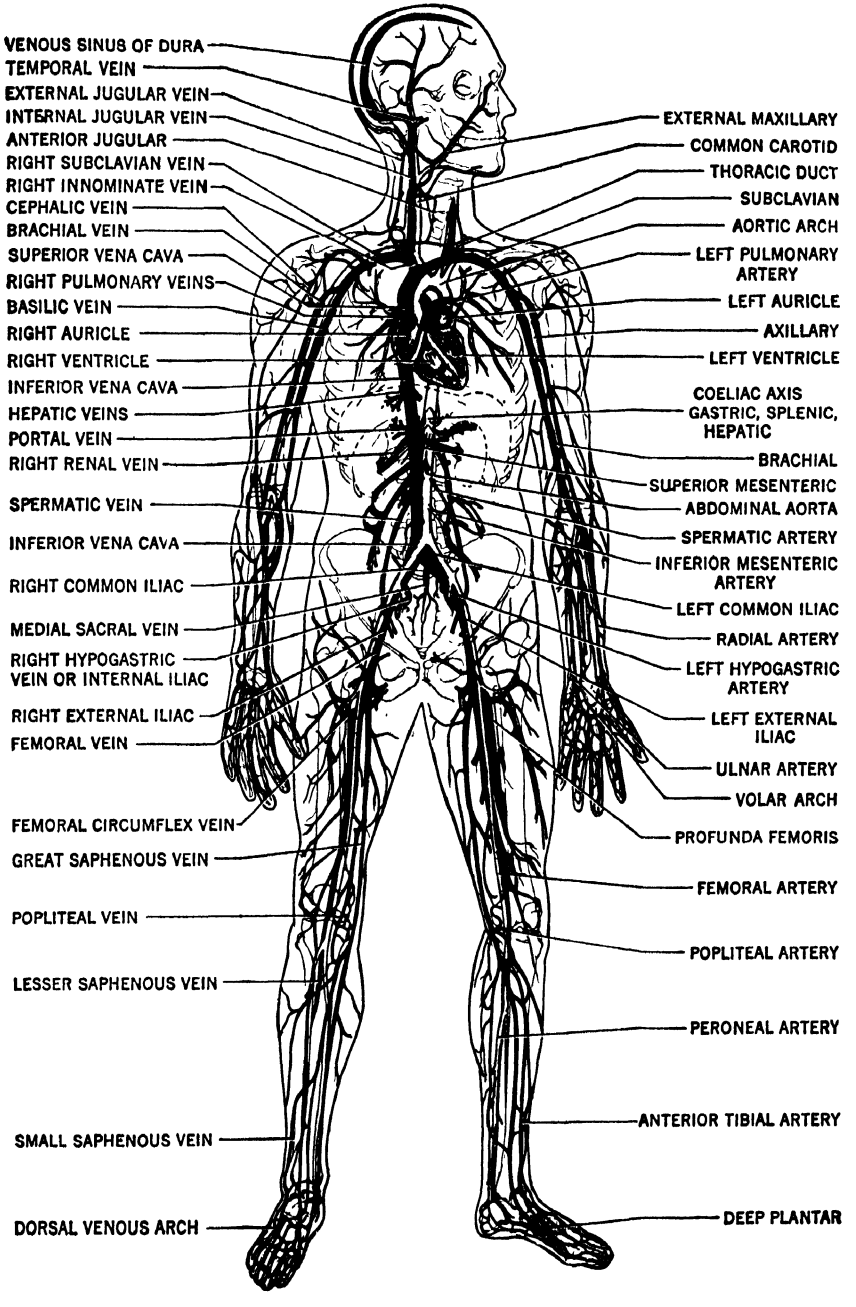

Fig. 380.—The circulatory system of man. (B. F. Edwards.)

valves in the shape of half-moons; hence the name, *semilunar valves* (L. *semi*, half; *luna*, moon). When the blood flows outward, the pockets lie close to the walls, but if it starts to flow backward, the pockets fill, and the valves close.

The heart serves as a living pump, its function being to keep the blood circulating through the body. It can rest only between beats. It does a

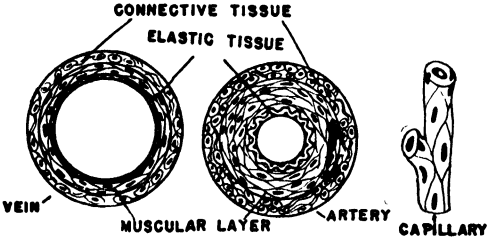

Fig. 381.—Diagram to illustrate the difference in structure of the walls of a vein, an artery, and a capillary. (B. Shamos.)

great deal of work at all times, and this work is greatly increased during exercise.

The *events of the heartbeat* are as follows: the two auricles contract together; this is followed by the contraction of the two ventricles. The auricles relax during the contraction of the ventricles, and the ventricles relax during the contraction of the auricles; the period of contraction is known as *systole*, the period of relaxation, *diastole*. This is repeated about seventy times a minute with great regularity. Some persons who are in good health have a little higher rate; others have a little lower rate. The work done by the heart in 24 hours is enormous. A large tree can lift over 100 gal. of water in a day, but the heart does enough work in 24 hours to carry a man weighing 150 lb. to the top of one of our tallest buildings.

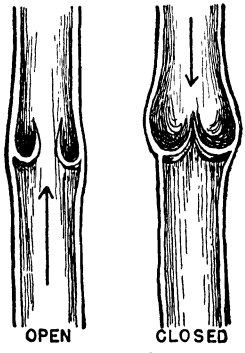

Fig. 382.—Diagram to illustrate the action of a pair of valves in a vein. The blood can flow in one direction only. (B. Shamos.)

b. Arteries, Veins, and Capillaries.—The arteries carry the blood from the heart to every part of the body (Fig. 380). They are elastic, muscular tubes with thick walls, strong enough to withstand considerable pressure (Fig. 381). They divide and subdivide until the resulting vessels are no larger than a hair. These are the capillaries, and they have very thin walls. Many millions of these fine tubes connect the arteries with the veins. It has been estimated that if united in a single line, the capillaries in one person would reach two and a half times around the earth. The

capillaries of the arteries are continuous with the capillaries of the veins. The veins into which the capillaries empty are small, but they unite, like the tributaries of a stream, to form larger vessels; these, in turn, join to form larger vessels until the great veins are formed. *Valves* are present in the veins and lymph vessels to prevent the backflow of lymph and blood (Fig. 382).

c. The Path of the Circulation. (1) SYSTEMIC CIRCULATION.—About 6 qt. of blood are present in an adult, the quantity depending somewhat on the size of the individual. This circulates through the body in from 20 to 30 seconds, or about three times a minute. This means that in 24 hours, the 6 qt. of blood pass through the blood vessels in all parts of the body from 3,000 to 4,000 times. Some routes are shorter than others. For example, the pulmonary circulation is a short circuit.

Many of the blood vessels are named in Fig. 380 for purposes of reference in understanding the paths of the blood in the human body as described below. The superior vena cava, or precaval vein, brings the blood from the head and shoulders to the right auricle; the inferior (here inferior means lower) vena cava, or postcaval vein, brings the blood from the part of the body below the heart to the right auricle. Both these large vessels are provided with valves to prevent the blood from flowing backward after it enters the heart. From the right auricle, the blood passes through the tricuspid valve to the right ventricle. When the ventricle contracts, the valve closes, and the blood is now forced into the pulmonary artery.

After the pulmonary artery leaves the heart (Fig. 380), it divides into two large branches, one going to each lung. In the lungs, the pulmonary arteries divide and subdivide until a network of capillaries is formed; then the capillaries unite to form the four pulmonary veins that pass to the left auricle. The capillary walls are thin, being only one layer of cells in thickness, and the air sacs of the lungs are very close to the capillaries, and they, too, have thin walls, only one layer thick. In the passage of the blood through the lungs, the exchange of gases takes place through these thin walls. The blood, a deep purple in color, carrying a load of carbon dioxide, passes through the capillaries and delivers the carbon dioxide to the air in the air sacs and receives oxygen. The gases diffuse through the moist membranes. A change in color now takes place, the oxygenated blood becoming bright red. The exchange of gases in the lungs is discussed in more detail later under the general subject of respiration (page 578).

The pulmonary veins carry the blood with its new cargo of oxygen to the left auricle. From here it passes through the bicuspid valve to the left ventricle. When the ventricles contract, the blood is forced into the aorta and then passes out through this great vessel and throughout its branches to every part of the body.

In the tissues, the blood in the capillaries gives up a part of its oxygen and receives carbon dioxide. Here, too, the blood carries to the cells the absorbed food products and takes away the carbon dioxide, as well as other wastes. The lymph is the medium of exchange here; it bathes the cells, taking oxygen, food, and other substances to them, and receiving the wastes.

The venous capillaries carry the blood to the smaller veins, and these, in turn, finally empty into the two large veins, the inferior and the superior

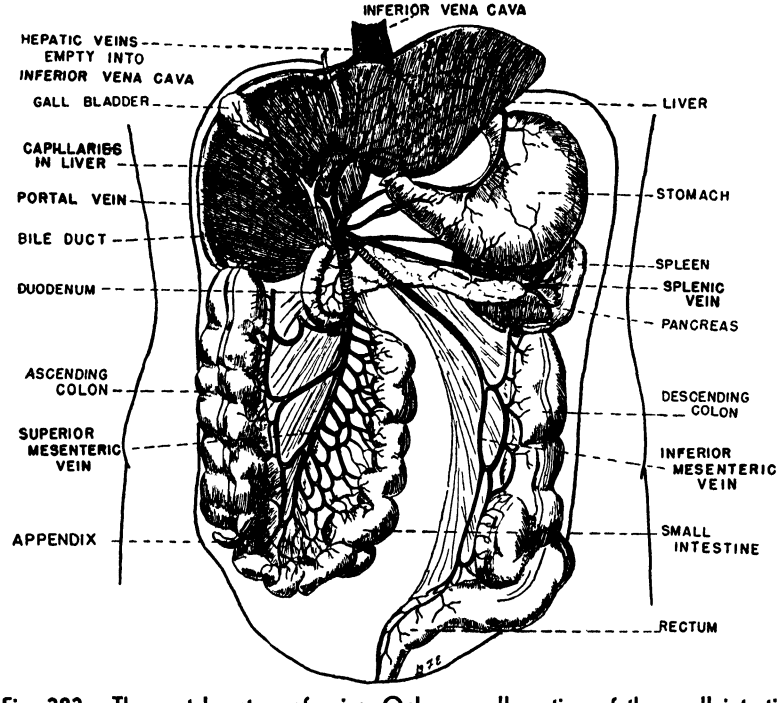

Fig. 383.—The portal system of veins. Only a small portion of the small intestine is shown, the transverse intestine is removed, and the liver is turned back in order to show the main portal vein. (B. F. Edwards.)

venae cavae (Fig. 380). These two large veins return the blood to the right auricle.

(2) THE PORTAL SYSTEM.—The portal vein and its branches constitute the portal system (Fig. 383). The work of the portal system was discussed under the general subject of nutrition (page 546). Briefly, the veins coming from the stomach, spleen, and intestines, carrying the absorbed products of carbohydrate and protein digestion, enter the liver and break up into capillaries. Here some of the sugar in the blood is transformed and stored as animal starch (*glycogen*), a reserve food supply.

The capillaries of the liver join to form the hepatic veins that leave the liver and connect with the inferior vena cava; the blood continues on through this vein to the right auricle of the heart. From here it follows the usual path of the circulation.

(3) THE PULSE.—When the heart beats, the "spurt" of blood forced into the aorta causes the elastic walls of the arteries to expand. This beat, or throb, observable in arteries, is due to the action of the heart. During exercise, the pulse rate quickens, since the rate of heartbeat is increased. Anger, fear, and other strong emotions cause the heart to beat faster, and hence the pulse rate increases.

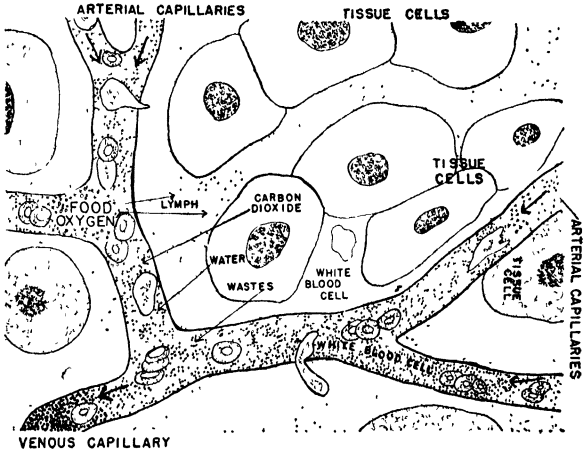

Fig. 384.—Relation of capillaries to tissue cells. The lymph bathes the tissue cells. As the blood flows in the capillaries, it brings food and oxygen to the cells and takes away wastes, the lymph acting as the "middleman." The red blood cells remain inside the capillaries but the white cells often migrate through the capillary walls. (B. Shamos.)

d. Blood Pressure.—When the blood is forced by the heart into the arteries, it is pushed against the walls of these blood vessels. This is known as *blood pressure.* Physicians use special methods of determining blood pressure. High and low blood pressures indicate certain types of disease.

e. The Lymph.—It has been mentioned that the lymph bathes the cells and serves as the "middleman" between the blood and the tissues (Fig. 384). There is only one route to the cells, and that is through the arteries to the capillaries and from the capillaries to the lymph that bathes the cells. The lymph may reenter the blood through the capillaries of the veins, or it may pass into lymph capillaries. These capillaries unite to form larger and larger vessels until two large ducts are formed (Fig. 385). The larger of these, the *thoracic duct,* drains the lower part of the body. It pours lymph and chyle into the left innominate vein at its

junction with the jugular vein. The other duct, the *right lymphatic*, drains the head and the right arm. It empties into the right innominate vein.

There are a large numbers of lymph *nodes* connected with the lymphatic system. These appear to serve two important functions. One type

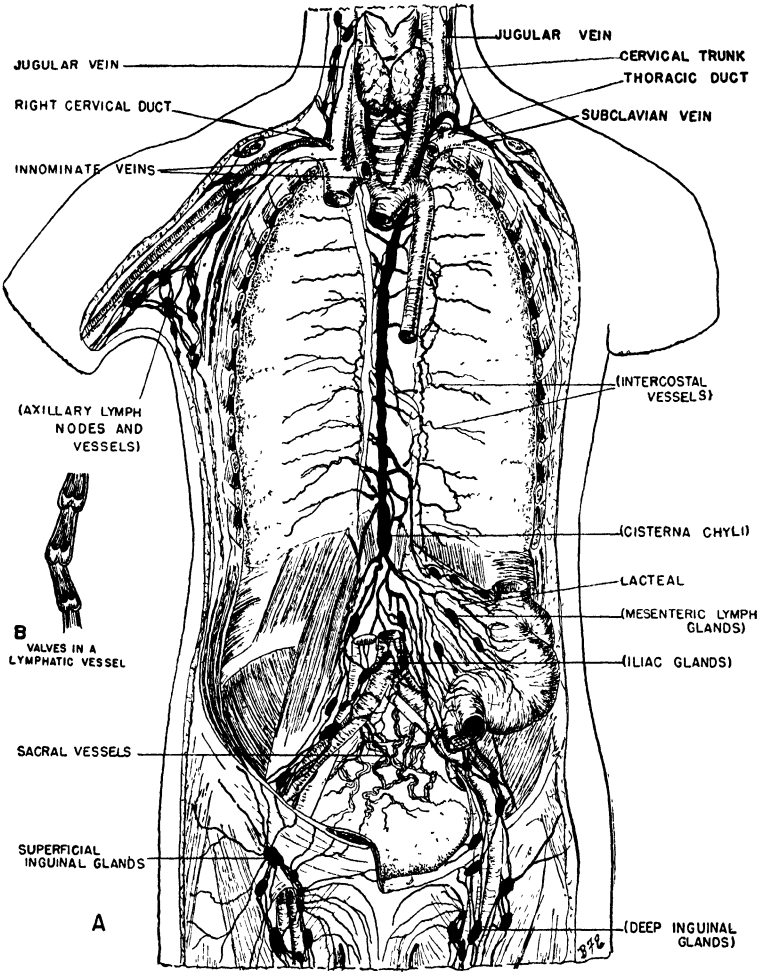

Fig. 385.—(A) Diagram of the lymphatic system of man. The two main lymphatic ducts empty into the innominate veins at the junction of the subclavian and jugular veins. (B) Valves in a lymphatic vessel. (B. F. Edwards.)

of white corpuscle, the lymphocytes, multiply here and are carried into the blood by the lymph; they are so constructed as to filter out solid particles and bacteria that find their way into the lymph. If the infection be too severe, the protective function may be overcome and the nodes themselves become focuses of infection.

In addition to the functions mentioned, the products of the digestion of fats are transported by the lymphatic system through the thoracic duct to the left innominate vein.

f. The Blood.—Blood is a complex substance. It has been called a *fluid tissue*, a good description. It is somewhat sticky, a little heavier than water, and is slightly alkaline (pH from 7.38 to 7.4). The quantity of blood in an adult is estimated to be about one-twentieth of the body weight. This amount may vary in health and disease.

(1) BLOOD PLASMA.—Blood plasma is straw or amber color and consists of about 90 per cent water with many substances dissolved in it. Some of these are merely substances being transported, but many of them are a part of the plasma itself.

a. Blood Proteins.—Three *blood proteins* are usually described in the plasma of the circulating blood (fibrinogen, serum-globulin, and serum-albumin).

b. Nutrients.—Many *nutrients*, the end products of digestion of food, are present. Normally, amino acids are present in small quantities; glucose and fats, in about the same proportion (0.08 to 0.18 per cent).

c. Salts.—Certain *salts* are always found, the most common being sodium chloride, or common salt. Other salts are those of potassium, calcium, magnesium, and iron.

d. Wastes.—*Waste* substances on their way to be excreted by the kidneys or other organs of elimination are present.

e. Oxygen.—Little *oxygen* is found in the plasma, for oxygen is carried mainly by the red blood cells; carbon dioxide, however, is transported mainly by the plasma.

f. Special Substances.—Substances such as the secretions of the ductless glands and enzymes are always present in the plasma.

g. Antibodies.—Antibodies, or substances that protect the body from invading organisms (see below), are a part of the blood plasma.

(2) RED BLOOD CORPUSCLES.—The blood contains two main types of corpuscles, red and white. Other small bodies, the *blood platelets*, occur in man and in some other vertebrates; these appear to be concerned with the clotting of blood.

The red blood corpuscles are red because they contain a protein, hemoglobin (Gr. *haima*, blood), which has an affinity for oxygen. When blood circulates through the lungs, it takes up oxygen, becoming bright red. Oxyhemoglobin is oxygen held in loose combination with the hemoglobin. When it reaches the tissues, it gives up the oxygen and the blood becomes purplish in color. Red corpuscles in vertebrates are circular or oval disks, varying widely in size. In man, they are biconcave circular disks about 0.0077 mm. in diameter. When the red cells of mammals are first formed, they have nuclei but lose them when they become mature

and enter the circulation (Fig. 386*A*). The groups below the mammals have red blood cells with nuclei. The red blood cells of the Amphibia are the largest; those of the musk deer, the smallest.

The red blood cells are formed in the red marrow in the ends of the long bones of the legs and arms and in the red marrow of the ribs and vertebrae. They probably live only from 30 to 90 days; hence millions of new cells must enter the blood stream daily. The number in man per cubic millimeter is about 5 millions for males and 4½ millions for females.

Functions of the Red Cells.—The red cells (erythrocytes) are the oxygen carriers because of the presence of *hemoglobin*. In the lungs, the hemoglobin takes up oxygen, forming oxyhemoglobin, which is taken to

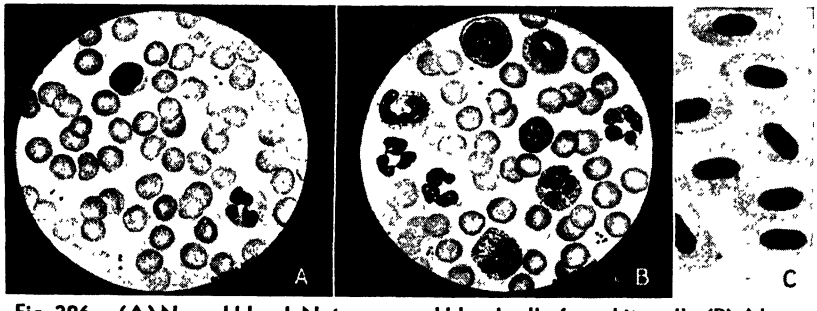

Fig. 386.—(A) Normal blood. Note many red blood cells, few white cells. (B) Abnormal blood. White blood cells greatly increased. This occurs in certain types of illnesses. (Drawn by H. E. Garver, From Kracke, A Textbook of Clinical Pathology, William Wood and Company.) (C) Red corpuscles of a bird, from a stained slide. (Courtesy of Dr. E. Gambrell.)

the tissues as the blood circulates. In the capillaries in the tissues, oxygen is given up to the cells, the hemoglobin becoming reduced hemoglobin. This returns to the lungs through the veins and takes up oxygen again. Other functions of the red cells have to do with maintenance of the alkalinity, viscosity, etc., of the blood.

(3) WHITE CORPUSCLES.—*a. Types.*—There are several varieties of white cells (Fig. 386*A* and *B*), which may be classified in many ways. There are large and small *lymphocytes* (20 to 25 per cent); *mononuclear* and *transitional monocytes* (3 to 8 per cent); the *granular leucocytes* are of three varieties, *neutrophils* (60 to 70 per cent), *eosinophils* (1 to 5 per cent), and *basophils* (.25 to .50 per cent).

b. Origin.—Some of the *lymphocytes* that arise in lymphatic tissue can act as phagocytes. The *neutrophils* have lobulated nuclei and are from 60 to 70 per cent of the *leucocytes*. They are formed in the marrow tissue and are able to ingest bacteria (Fig. 387). The *eosinophils* are thought to arise also in the bone marrow. They are a small group, only about 2 per cent of the leucocytes, but their numbers may increase in certain types of infections (Fig. 386*B*). *Basophils* are found in numbers (about ½ per cent). It is of value in diagnosis of disease for the physician to know the numbers and varieties of corpuscles present in the blood.

c. Functions.—On account of their protective work, the white blood corpuscles have been called the *policemen of the body*. Some of them are able to put out pseudopodia and engulf invading bacteria very much as an amoeba does. This process is called *phagocytosis*, and the white corpuscles that are able to do this are *phagocytes*.[1]

When injury takes place, the white blood cells migrate to the site of the injury in large numbers through the walls of the blood vessels. If the infection is severe, large numbers of the white cells are destroyed, and pus results (Fig. 445). If the infection is not severe, they destroy the *bacteria* (Fig. 387) and find their way back into the blood stream.

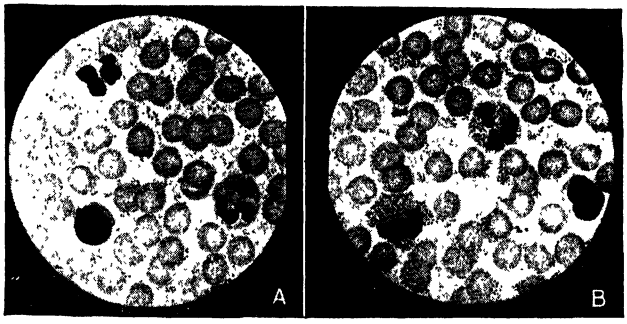

Fig. 387.—White blood cells ingest bacteria. (A) The organisms causing undulant fever were mixed with normal blood. (B) Note that the white blood cells have ingested many of the bacteria. (Courtesy Dr. E. Gambrell and Mrs. H. E. Garver.)

A summary of the main functions of the white corpuscles is as follows: (1) They protect the body from infections by engulfing the invading organisms (phagocytosis) or by producing substances that destroy pathogenic organisms. These substances, bacteriolysins, have the power of dissolving the organisms. (2) They aid in tissue repair and regeneration. (3) They aid in absorption from the intestines. (4) They help maintain blood proteins (see above). (5) They aid in the clotting of the blood.

(4) BLOOD PLATELETS OR THROMBOCYTES.—These are small, round bodies thought to be connected with the clotting of the blood. There are about 300,000 per cubic centimeter of blood. When removed from the blood, they disintegrate rapidly (see also below).

(5) CLOTTING OF BLOOD.—*a. Nature of the Clot.*—If a small amount of blood is collected in a test tube, it will remain liquid for a short time, about 7 minutes. Then it forms a clot somewhat like the "setting" of gelatin. At first it is a firm red mass, but in half an hour or so a straw-colored liquid, the *serum*, will begin to separate from the mass. If a blood clot is examined under the microscope, it will be seen that long, thin

[1] In the blood serum are substances, *opsonins* (Gr. *opsonein*, to buy victuals), which render invading cells, as bacteria, more susceptible to the action of phagocytes.

threads run through it; this is *fibrin*, which was formed when the blood clotted. By contraction, the fibrin threads cause the separation of the clot and the serum. Most of the blood corpuscles remain entangled among the threads of fibrin. The blood does not clot in the blood vessels, because of substances present in the blood that prevents it.

b. Howell's Theory.—Howell's theory of the coagulation of the blood is that there is present in the blood two substances, *antithrombin* and *antiprothrombin* (*heparin*), which prevent the clotting of blood in the blood vessels. Calcium salts, fibrinogen, and prothrombin are also normal constituents of the blood. Howell's idea is that when blood is shed, the exposure to the air causes the blood cells and platelets to disintegrate. Tissue fluid from these and injured tissue cells contains a substance known as *cephalin.* This will neutralize the antithrombin and antiprothrombin. From prothrombin and other substances, in the presence of calcium, thrombin will be formed. Thrombin then reacts with the fibrinogen to form the fibrin fibers characteristic of blood clots. There are other theories that formulate a somewhat different chain of events.

c. Prevention of Clotting.—Clotting may be prevented by (1) adding a chemical such as sodium oxalate; (2) adding the extract from the head of a leech, *hirudin;* (3) adding *heparin*, an extract from the liver; (4) whipping the blood to remove the fibrin. It may be delayed by placing the blood in vessels that have been greased. In order to make certain tests of the blood of ill people, it must be prevented from clotting.

d. Function of Clotting.—The clotting of blood is a protective adaptation. If it were not for this property of blood, all the blood of the body would ebb away, drop by drop, from even a slight wound.

Sometimes people are born without this protective mechanism, and the disease of hemophilia, which is definitely inherited, occurs (see below).

(6) HEAT-REGULATING MECHANISM.—Cold-blooded animals do not possess a heat-regulating mechanism; warm-blooded animals have a heat-regulating mechanism under the control of a center of the medulla oblongata of the brain. The blood plays an important part in the regulation of heat in the body. When the air is cold, the heat-regulating center in the brain causes the contraction of the blood capillaries just under the skin; when the air is warm, the capillaries are stimulated to expand, which results in a supply of blood to the skin and a radiation of heat. Evaporation of perspiration also causes a "cooling off" of those animals which possess sweat glands (page 666).

(7) IMMUNITY.—Immunity (L. *immunis*, free) may be briefly described as resistance to infections from organisms that cause disease. It may be natural (inherited) or acquired.

a. Natural Immunity.—It has long been known that some people are more susceptible to certain diseases than others. This fact is brought out in every epidemic of influenza; some people with only slight exposure

contract the disease; others live with it and do not take it; *i.e.*, they are immune. There is also *racial immunity*. The Eskimos are resistant to many infectious diseases; Negroes are said to be quite susceptible to tuberculosis. Another type of immunity is that which comes from age; *i.e.*, so-called *children's diseases* are not generally contracted by adults, though there are always exceptions.

b. Acquired Immunity.—Immunity may be acquired by having a disease like smallpox. A patient recovering from this disease and from some others is immune from it for life. *Artificial immunity* is acquired through inoculation of a serum, vaccine, or antitoxin.

Other terms are *active immunity*, the kind one has after recovering from a disease, and *passive immunity*, the same as artificial immunity.

c. Building of Immunity.—The exact mechanism of the formation of substances in the building of immunity is not known. It is known, however, that when the body is invaded by foreign proteins, either plant or animal, certain protective substances, to which the name *antibody* has been given, are formed. Several classes of substances produce antibodies, and these are called *antigens* (Gr. *anti*, against; *genes*, born). An antigen is a substance that stimulates the production of antibodies, which are named according to what they do. For example, *precipitins* are antibodies that cause precipitates; *agglutinins* cause a clumping together, or agglutination, of cells, etc.

Vaccines and antitoxins are now known that will induce immunity in the case of certain diseases. Some of these may be injected in the blood stream. The difference between a vaccine and an antitoxin is that the vaccine is usually prepared from dead bacteria of the type that causes the disease to be fought, *e.g.*, typhoid fever, whereas antitoxin (Gr. *anti*, against; *toxikon*, poison) is for neutralization of a poison, such as that produced by organisms causing a disease such as diphtheria.

Various kinds of antibodies produce their effects in various ways. Just how they are formed is not known.

(8) THE BLOOD GROUPS.—It has been determined that blood of all individuals is not alike. In certain cases, such as loss of blood from accident, hemorrhage, or other causes, it is a practice to give blood transfusions to replace the blood lost. Medical men had long noted that the transfusions were not always helpful, indeed, might cause death. This was because the mixture of some bloods caused an agglutination of red corpuscles. In working with this problem, Landsteiner found that there are four types of human blood, according to the presence or absence in red blood corpuscles of certain agglutinating substances designated as *A* and *B*. Some persons have both these substances, and their blood is typed as *AB*; some have *A* only; some have *B* only, and still others have neither, and their blood is typed as *O*. There are also two agglutinable substances in the blood plasma, alpha (*a*) and beta (*b*). Both of these

are present in the plasma of Group *O*, alpha in the plasma of Group *B*, beta in the plasma of Group *A* Agglutination will occur when the substance *A* in the corpuscles of the donor comes into contact with alpha in the plasma of the recipient, or when substance *B* in the corpuscles of the donor comes into contact with beta in the plasma of the recipient From this it follows that serum of type *A* will agglutinate corpuscles of *B* and *AB*, serum of type *B* will agglutinate *A* and *AB*, serum of *AB* will not cause agglutination of corpuscles of any type, serum of *O* will agglutinate *A*, *B*, and *AB* Since the corpuscles of *O* contain neither *A* nor *B*, *O* may act as universal donor type and since serum of *AB* contains neither alpha nor beta substances, *AB* may act as the universal recipient type The following table summarizes the results

Serums of groups	Red cells of groups*			
	O	*A*	*B*	*AB*
O (*a*, *b*)	−	+	+	+
A (*b*)	−	−	+	+
B (*a*)	−	+	−	+
AB (*o*)	−	−	−	−

* − shows no agglutination + shows agglutination

The type of blood in an individual remains the same all through life and is definitely inherited Most hospitals now keep blood of various types in refrigerators to be used for emergency cases The test to determine the proper group to which a person's blood belongs, known as *typing*, can be done in a few minutes

g Some Disorders of the Circulatory System (1) THE HEART.—The contracting power of the heart may be reduced through various causes Infectious diseases, such as rheumatic fever, may affect the muscles of the heart, or poisons (toxins) produced by bacteria may also affect the muscles The valves may lose their power to close normally, in which case there is "leakage" of the valves Sometimes the blood vessels that supply the heart become plugged up, usually with a blood clot, the heart, deprived of food and oxygen in this way, soon ceases to beat

(2) HARDENING OF THE ARTERIES.—The blood vessels may lose their elasticity, this is a condition associated with age Since they cannot expand, the blood pressure rises, and rupture of the blood vessels may occur Even the rupture of a small blood vessel in the brain may cause paralysis People who stand a great deal are sometimes troubled with a condition known as *varicose veins* (L. *varix*, a dilated vein) In this disease, the blood vessels become enlarged, probably because of loss of elasticity

(3) HEMOPHILIA.—Sometimes the blood lacks the elements necessary for clotting This may be a result of disease or may be hereditary Hemophilia is a sex-linked character and affects males more often than females

(see page 736 for explanation of mechanism of inheritance). Females may be carriers but are not often affected themselves.

(4) ANEMIA.—When the red blood cells are greatly reduced in number through disease, loss of blood, etc., a condition arises known as *anemia*. Pernicious anemia is a severe type of this disease. If it is severe enough, the patient dies, because there are not enough red blood cells to carry sufficient oxygen for life activities. A diet of liver or treatment with liver extract increases the number of red cells in a manner not understood, but which is little short of marvelous. Death is thus prevented.

(5) LEUCOCYTOSIS.—There may be more than the normal number of white cells, a condition known as *leucocytosis* (Fig. 386*B*). As stated before, in cases where there is an infection, the number of white cells increases and assists the body in overcoming the disease. The white cells are thus protective. In certain cases, the white blood cells increase greatly in number without any known cause. This brings about a condition known as *leukemia*, which usually terminates fatally. The cause of this disease is not understood.

(6) LEUCOPENIA.—Sometimes the number of white blood corpuscles is below normal, a condition known as *leucopenia*. This is a characteristic symptom of certain diseases such as typhoid fever and tuberculosis.

Questions

1. Discuss the three types of circulation and give examples of each type.
2. Describe circulation in the lower organisms, *Elodea*, *Amoeba*, and *Hydra*.
3. Discuss transfer of materials in plants.
4. Describe circulation in *Hydra* and flatworms.
5. Compare the circulation of the earthworm with that of the crayfish. What are the peculiarities of the circulation of insects?
6. Who discovered the circulation of the blood and when?
7. What are some differences in the hearts of fish, Amphibia, reptiles, birds, and mammals?
8. What would be the path of a blood corpuscle from the right lung of man back to the same right lung?
9. Trace the route of the products of the digestion of a ham sandwich made with butter from the digestive tract to the cells of the body.
10. Compare the veins, arteries, and capillaries with regard to structure and function.
11. What is the source of glycogen in the liver?
12. What is the function of the blood plasma? How do the red corpuscles of man differ from those of a frog? What are the functions of the red corpuscles? The white corpuscles? Are the white corpuscles all alike? In what part of the blood is oxygen carried? The carbon dioxide? Where in the body do the white corpuscles originate? The red corpuscles?
13. Give an account of exchange of gases in the capillaries of the lung.
14. What is lymph? Is there a special lymphatic system? Explain. What is the function of the lymph? What is a lymph node? What are its two functions? Where does the lymph enter the venous system?
15. Why does blood not clot in blood vessels? What would happen if the blood did not have the power of clotting?

16. Describe the events in the formation of a blood clot. What is Howell's theory of the clotting of the blood?
17. What is the role of the blood in the mechanism of heat regulation of the body?
18. What are some functions of the blood aside from transportation of materials? What is natural immunity? Acquired immunity?
19. What are some disorders of the circulatory system? Which of these are preventable?
20. Define: fibrin, leucocyte, lymphocyte, hemoglobin, antibody, antigen, antitoxin, vaccine agglutinin, precipitin, varicose vein, renal corpuscle.
21. Describe the four types of blood groups. Why may group *O* act as a universal donor? Why may group *AB*. act as a universal recipient?

CHAPTER XXXVII

RESPIRATION

This being of mine, whatever it really is,
Consists of a little flesh, a little breath and
That part which governs.
—MARCUS AURELIUS.

I. The Respiration Process

All living cells must take in oxygen in order to carry on chemical processes, and every cell must get rid of carbon dioxide, which is a waste product of the oxidation of substances within them. The taking in of oxygen and the giving off of the carbon dioxide, CO_2, occur according to the law of diffusion of gases. According to this law, molecules will pass from places of high concentration to places of low concentration. It is interesting to note that the molecules of each gas behave independently. This is why oxygen can be taken in and carbon dioxide given off at the same time. In the blood, a greater concentration of CO_2 exists than in the air; hence CO_2 is diffused out through the moist surfaces of the cells of the lungs into the air in the cavities of these organs. The air is composed of about 20 per cent oxygen and 80 per cent nitrogen. The blood that reaches the lungs from the tissues is poor in oxygen; hence oxygen is taken into the blood from the air in the lungs.

Among the chemical changes that take place in the cell is the breaking down of absorbed food into its final products. Such chemical changes are necessary in order to release the energy stored in these foods. The energy in the glucose manufactured by the plant came from the sun and was stored up during the process of food manufacture. Without energy organisms could not live. The work of the cell then is to transform energy stored up in the food that is absorbed by the cell (potential energy) into active energy or energy that is available for the use of the cell (kinetic energy).

Scientific knowledge of breathing was not possible until the discovery of the circulation of the blood by William Harvey in 1628. Not until a hundred years later, however, was the real foundation for the study of respiration made possible by the discovery of oxygen by Priestley (1733–1804) and the recognition by him of its importance to all living matter. Lavoisier (1743–1794) made extensive studies and demonstrated that respiration is a chemical process, a process in which oxygen of the air is used and carbon dioxide is produced. Before this time, however, Robert

Hooke demonstrated before the Royal Society of London, in 1667, that a dog, to be kept alive, "must have a supply of fresh air." A little later John Mayo became convinced that air contained something necessary to life. He called this *spiritus nitro aereus*, which was the substance later proved to be oxygen.

II. Types of Respiration

There is a distinct difference between *respiration* and *breathing* as the word *breathing* is commonly used. Breathing is pulmonary, or *external* respiration, whereas the exchange of gases in the cell is *tissue*, or *internal*, respiration.

A. Tissue or Internal Respiration.—The oxidation of food within a cell is often compared with the burning of fuel. Energy is always released during the processes of oxidation, and this is true whether food or wood is burned. But important differences exist between the burning of coal or wood and the oxidation of food within the cell. It is true that carbon dioxide, water, and kinetic energy are the final results in both cases, but certain differences may be noted.

Wood or coal are oxidized only at very high temperatures; light is produced in burning these substances. In living things, oxidation takes place within cells at temperatures that vary from the temperatures of plants and cold-blooded animals living in cold countries to temperatures of plants and cold-blooded animals living in hot countries and warm-blooded animals. Another important difference is that respiration occurs in the protoplasm. Protoplasm is largely water. It would not be possible to carry on the process of combustion outside a living organism in water. But this process does occur in living things. Certain enzymes are present in the cell that are necessary for combustion, either directly or indirectly. The difference between respiration and ordinary combustion may be accounted for, in part, at least, by the *activity of the enzymes*. This subject is discussed here because the respiratory process is so often compared with "burning," or combustion. It is known what materials are used and what wastes are produced in respiration, but just how the changes are brought about is somewhat obscure. It is also known that stored food is used up and that heat is produced. Sometimes fires are caused by moist grain stored in warehouses or other places; respiration as a result of germination of the grain produces so much heat that the grain may catch on fire. Like all other chemical processes, the process of respiration is influenced by environmental factors. For example, heat, moisture, etc., influence the rate at which respiration takes place.

B. Aerobic and Anaerobic Respiration.—Aerobic respiration (page 156) takes place in the presence of free oxygen; *anaerobic* (Gr. *an*, without; *aer*, air) does not require oxygen. The products of these two types of

respiration are different. In aerobic respiration, oxidation is completed, and the end products are carbon dioxide and water; in anaerobic respiration, intermediate products are formed, such as lactic acid and alcohol. There are two ways in which oxidation can take place in the absence of oxygen: (1) by the rearrangement of the atoms in the molecules (*e.g.*, of alcohol) without any additional oxygen; and (2) oxygen is used, but it must be obtained by the breaking down of the other components of the cell, since no other source of oxygen is available. Of course, a substance formed under anaerobic conditions (such as alcohol) can later be oxidized by free oxygen to carbon dioxide and water.

III. Respiration in Plants

In Fig. 102, the exchange of gases in the plant is shown. Respiration in plants should not be confused with the process of *photosynthesis*, or food manufacture (page 140). Plants respire both day and night or they could not live, whereas photosynthesis can take place only in the presence of light. In the chapter on The Leaf (page 143) is a full account of the processes of respiration and photosynthesis.

Plants do not possess the elaborate machinery for carrying on respiration that the animals do, but the process within the cell is exactly the same. The plant stores up foods; the air enters through the stomata (page 133) and passes to spaces between the cells; oxygen is taken in by the cell; oxidation of stored food occurs, and energy is released. In this process, wastes are formed; these are carbon dioxide and water. The chemical reaction is expressed by the familiar formula:

$$\underset{\text{glucose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} = \underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{6H_2O} + \text{energy}$$

To bring all this to pass, certain enzymes must be present. The fundamental process of respiration is the same for all living things, plant or animal.

IV. Respiration in Animals

A. Organs of External Respiration, or Breathing. 1. CELL SURFACES. Elaborate systems for carrying on pulmonary, or external, respiration are present in many animals. In the Protozoa, however, all that is necessary is the gaseous exchange through the body surface.

2. SKIN.—In the earthworm (page 339), the moist skin is an organ of respiration. Under this moist skin are many capillaries; the absorption of oxygen and the giving off of carbon dioxide take place between the blood in these capillaries and the outer air through the skin. These two gases act

independently of each other (page 339); the oxygen will pass from a place of high-oxygen pressure to a place of low-oxygen pressure; the carbon dioxide will do the same. In this case, the air has a higher oxygen content than the blood in the capillaries; hence oxygen will diffuse through the skin into the blood. The blood has a higher carbon dioxide content than the air; so the carbon dioxide diffuses out through the skin.

In the frog, the skin is used as a supplementary respiratory organ, the *lungs* being present also (page 246).

In higher animals, the oxygen load is carried by a protein substance, the *hemoglobin* (page 565). The hemoglobin attracts oxygen and forms a loose combination with it, *oxyhemoglobin*. The combination is so loose that the oxygen is easily given up when it reaches the tissues. In the earthworm and some other invertebrates, the hemoglobin is dissolved in the plasma of the blood; in the frog and higher animals, it is carried by the red cells (page 237).

3. GILLS.—Many invertebrates that live in water respire by means of gills. Here the oxygen dissolved in the water flows over the gills, which have a good supply of blood capillaries. The exchange of gases takes place here just as it does through the skin of the earthworm.

In certain vertebrates, gills are present. The fish take in water through their mouths. In the wall of the pharynx are pouches that open to the outside. Attached to the walls of the pouches are gills. The water taken in by the fish passes through its mouth and flows over the gills; the oxygen dissolved in this water passes through the gills into the capillaries. At the same time, the carbon dioxide brought by the blood to the gills by the capillaries is given up. In fish the hemoglobin is in the red blood cells that carry the oxygen.

4. TRACHEAE.—In insects, there is a special system of air tubes, the *tracheae* (Fig. 281), which carry the oxygen directly to the tissues. These tubes branch again and again until minute tubules reach every part of the tissue. Carbon dioxide diffuses through the walls of the tracheae and is expelled to the outside from the tubes through the *spiracles* (page 400). The air is circulated in insects by a "pumping motion" of the abdomen, which contracts and expands the spiracles. Because of the tracheae, the blood of insects is relieved of the duty of transporting gases. In other groups, the circulatory systems, when present, serve to transport the gases of respiration.

5. LUNGS.—The organs of respiration of the higher animals are the trachea and lungs. These differ in certain details in different animals. In the frog, the lungs are simple (page 247), and no diaphragm is present. In the birds, there is no diaphragm, and the lungs extend far back into the body (Fig. 334). They connect with air sacs, usually nine in number. The air passes through the lungs into the air sacs, and aeration is quite

efficient (page 487). The lungs of birds are not simple sacs like those of the frog but are highly developed and contain many air chambers.

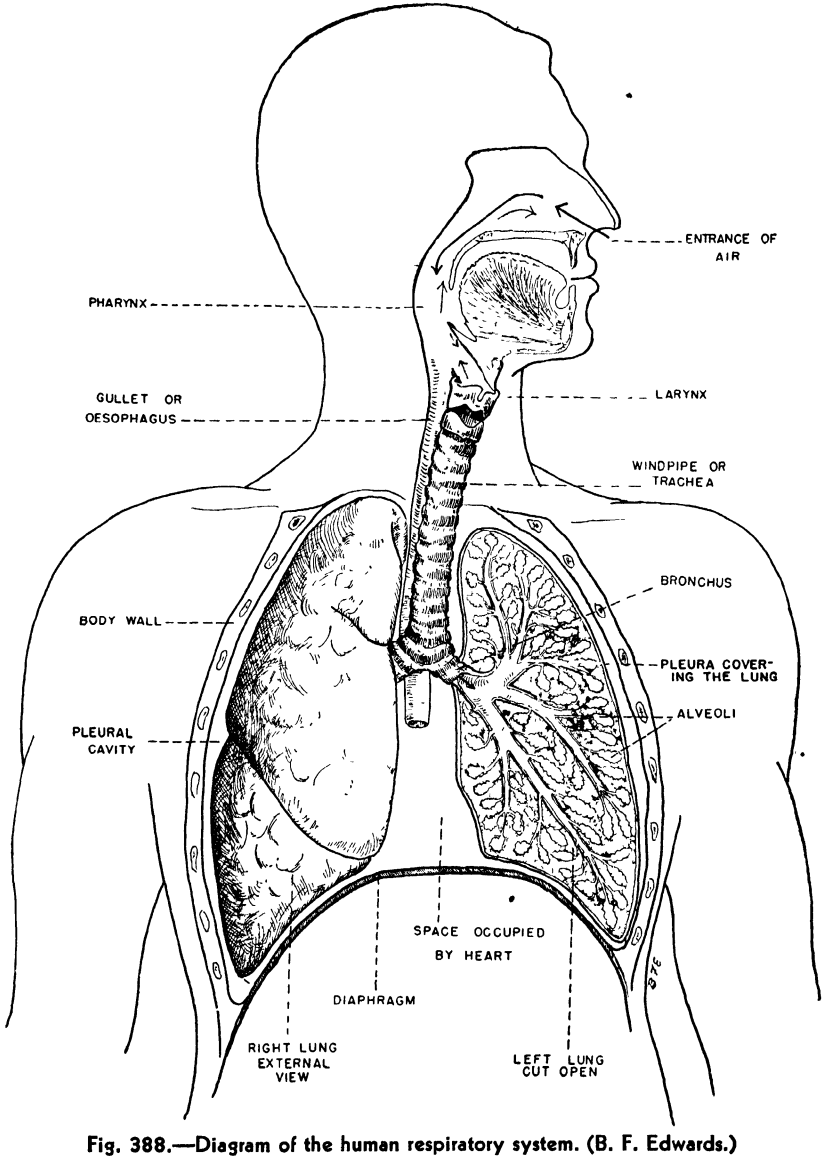

Fig. 388.—Diagram of the human respiratory system. (B. F. Edwards.)

B. Respiration in Man.—In man, the skin has almost lost its respiratory function, and the lungs are more developed than in the lower animals,

since they must bear the entire burden of external respiration, or exchange of gases with the environment.

1. The Organs of External Respiration.—The organs of external respiration are the nose, trachea or windpipe, and the lungs. The passage of air is through the nose to the throat, through the glottis into the larynx and then through the tracheae, into the branches of the tracheae, to the sacs of the lungs. During this journey, the air becomes warm, gathers moisture, and is freed from dust by the hairs in the nose.

a. Trachea and Bronchi.—The two branches of the trachea are termed the *bronchi*, and one leads to each lung. These divide and subdivide until they reach a size just visible to the naked eye. These small twigs, *bronchioles*, widen at the end so that each forms a thin-walled sac

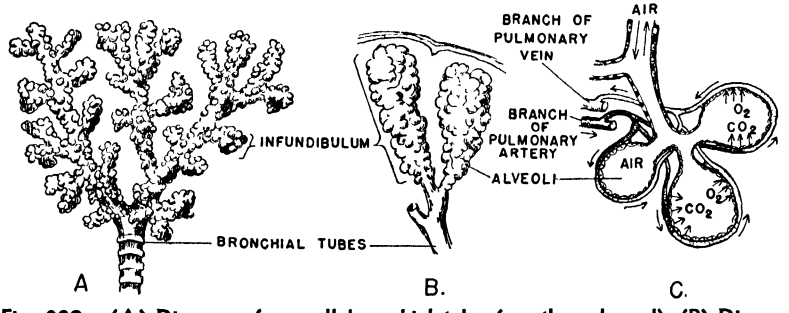

Fig. 389.—(A) Diagram of a small bronchial tube (greatly enlarged). (B) Diagram of one of the branches (still more enlarged). (C) Diagram to show the relations of the blood vessels, and the exchange of gases in the alveoli. (B. F. Edwards.)

(alveolus) (Fig. 388). The trachea does not collapse because of rings of cartilage in the walls.

b. Lungs.—The lungs are in the thoracic cavity. Surrounding each one is a thin, two-walled sac, made up of the *pleurae*. One pleura lines the walls, floor, and roof of the chest; the other covers the surfaces of the lungs. When the lungs are inflated, the pleural membranes covering them are in contact with the pleural membranes lining the thoracic cavity, but when the lungs are only partially inflated, there is a space between the two membranes, the pleural cavities (one for each lung). Infection of the pleural membranes is known as *pleurisy*.

Because the lungs contain air, even after as much air as possible has been forced out of them they will float in water.

The walls of the alveoli are very thin and are composed of cells one layer thick. Each of these alveoli is surrounded by capillaries, which also possess thin walls. The red cells that pass along in the capillaries are therefore separated from the air supply by only two membranes of the greatest possible thinness. An exchange of gases takes place here easily by diffusion (Fig. 389).

c. Diaphragm.—The thoracic, or chest, cavity is separated from the abdominal cavity by the *diaphragm.* This is a thin sheet of muscle and is dome-shaped (Fig. 388).

2. Mechanism of Breathing. *a. The Respiratory Center.*—It is possible to hold one's breath for a time, but the process of breathing is not a voluntary one. It is controlled by a respiratory center in the medulla oblongata. This is proved by the fact that if one particular spot in the medulla, the "vital knot," is cut, all breathing stops immediately. Just how the automatic and rhythmic breathing is controlled is not well understood. Carbon dioxide appears to play some role.

During muscular exercise, the rate and depth of breathing are increased. This is associated with a number of changes. A reduction of oxygen in the blood occurs, because this gas is now being used by the active muscles at an increased rate; an increase in the amount of lactic acid and carbon dioxide also takes place. Carbon dioxide, or something closely associated with it, stimulates the respiratory center. An experiment will prove this. Suppose one breathes air from a small closed chamber and allows the expired air, but no fresh air, to return to the chamber. If the carbon dioxide is removed from the expired air and the air is rebreathed until all the oxygen is gradually taken up, the ratio of breathing is very little accelerated. But if the same experiment is repeated, except that carbon dioxide is not removed but is allowed to accumulate to be rebreathed again, breathing becomes markedly accelerated, and extreme discomfort results. The waste that should be eliminated stimulates the breathing center and thus hastens the removal of that waste. The carbon dioxide is, therefore, instrumental in adjusting the respiratory rate to the varying degrees of the activity of the organism.

b. Inspiration and Expiration.—The taking in of air is *inspiration* (*L. in,* in; *spirare,* to breathe), or inhalation, and the breathing out of air is exhalation or *expiration* (*L. ex,* outside; *spirare,* to breathe). The chest cavity is a completely closed box (Fig. 390I), and the lungs are in communication with the exterior through the air passages. Before air can enter the lungs, the size of the chest cavity must be increased. This is accomplished in two ways: muscles lift up the ends of the ribs, widening the cavity of the chest, while other muscles, by contraction, draw the diaphragm downward, thus increasing the depth of the chest. This enlargement causes the air to rush into the lungs and to expand them until they fill the pleural cavity. During expiration, the ribs and sternum fall, chiefly by their own weight, and the diaphragm is pushed up by the stomach and the liver. The lungs are elastic, and the stretched walls of the air sacs return to normal, thus forcing the air out. In Fig. 390II, the stretched rubber on the bottom of the bell jar represents the diaphragm and the rubber tubes represent the lungs. When the rubber sheet

is pulled down, the size of the space inside the bell jar is increased, and the air from the outside fills the balloons; when the rubber sheet is contracted back to normal, the size of the space inside the jar is made smaller, and the air is forced out by the collapsing of the walls of the balloons. In making this experiment, the trachea and lungs of a freshly killed animal may be used. The total surface of the respiratory epithelium of an adult man is nearly 100 sq. m. or about fifty times the area of the skin. The importance of such a large area for effecting rapid gaseous exchange is obvious.

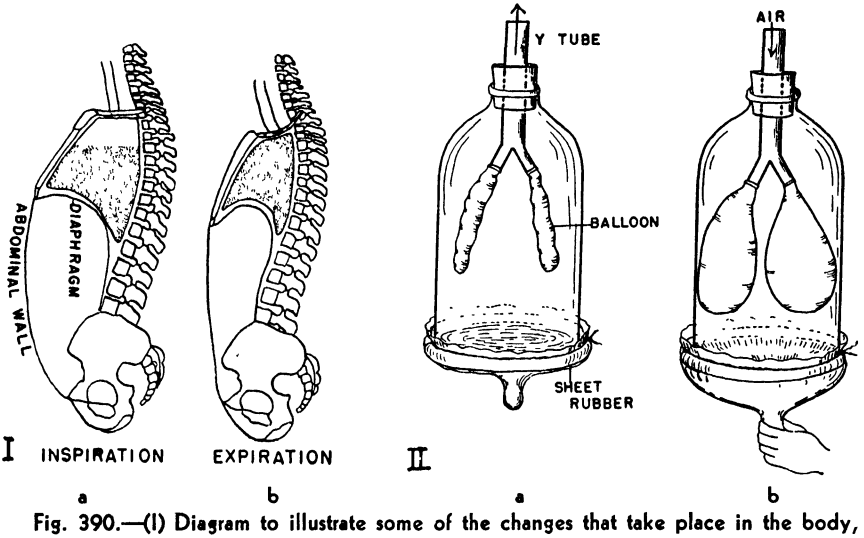

Fig. 390.—(I) Diagram to illustrate some of the changes that take place in the body, (a) during inspiration and (b) during expiration. (II) Experiment to illustrate the role of the diaphragm in breathing. (Adapted from various sources by L. Runyon.)

c. Vital Capacity.—In man at rest, about 16 breathing movements take place per minute, and at each breath about 500 cc. of air are inspired and expired. But by forced expiration one can breathe out about 1,600 cc. more. Even after this, some air still remains in the lungs.

The various types of air may be designated as follows: *Tidal* air is the air that is breathed in and out during ordinary, quiet respiratory movements (about 500 cc.). *Complemental* air is air that is taken in with a very long, deep breath or that can be inspired after the tidal air by taking a very deep breath (about 1,600 cc.). *Supplemental* air is the amount that can be breathed out by forcible expiration after a quiet expiration (about 1,600 cc.). *Residual*, or minimal, air remains after the most forced expiration (about 1,000 cc.). This air causes the lungs to float when they are removed from the body and placed in water. Vital capacity is the amount of air that can be breathed out after taking the deepest breath

possible. It is a rough measure of lung capacity. It varies with the size, age, and sex of the individual. In the average adult man it is about 3,700 cc. but may vary from 2,400 to 6,200 cc. Naturally, the tidal air (about 500 cc.) plus the supplemental air (about 1,600 cc.) plus the complemental air (1,600 cc.) is the vital capacity.

3. Changes in Respired Air; Ventilation.—The air breathed in is, of course, of the same composition as the air on the outside, but it loses oxygen and takes up carbon dioxide in its journey through the lungs. However, not all the oxygen is taken out of the air during respiration. About three-fourths of the oxygen in the air taken in is still present in the air when it is expired. The concentration of carbon dioxide in expired air is not very high. Expired air can, therefore, be breathed over again and deliver oxygen to the lungs. The nitrogen of the air is not used by the body in any known manner. As much is inspired as is expired.

Changes in the Gaseous Content of Inspired and Expired Air

	N	O	CO_2
Inspired.....	79	20 96	0.04
Expired.....	79	16 02	4 38
	0	4.94 lost	4.34 gained

The older theories regarding the ill effects of overcrowded rooms were that these effects were due partly to the accumulation of carbon dioxide and partly to the removal of oxygen. Carbon dioxide is present in pure air in only 0.03 per cent and oxygen in about 21 per cent. Accurate measurements seem to prove that the discomforts due to "bad" air are not caused by these two factors but are the result of odors, high temperature, a large amount of moisture, and stillness. When the air is saturated with moisture, it cannot take up moisture from the skin, and hence its cooling power is limited. Although fanning oneself is a cooling process, the fan does not bring cooler or less humid air; it does bring a greater amount of air in contact with the skin.

The Black Hole of Calcutta.—In Calcutta, 146 persons were imprisoned on a hot night in a room about 20 ft. square. There was a small window in the wall of the room open to the air from the outside, yet in the morning all but 23 were dead. In this case the deaths were due not to an excess of carbon dioxide or to a lack of oxygen but to the other factors noted above.

Ventilation.—In recent years a large number of public buildings as well as private homes have been air-conditioned; *i.e.*, the outside air is drawn into a conditioning room, where it is washed, warmed, or cooled

as desired, moisture added if required, and then distributed by a system of fans to all parts of the building. Circulation is provided for by use of force and suction.

4. External and Internal Respiration Compared.—Although breathing is necessary for respiration, it is not respiration itself. To differentiate it from the cellular respiration of the tissues, it is often called *external respiration.*

In the small air sacs, more oxygen is present than in the blood; hence the oxygen diffuses into the blood, and the hemoglobin of the red blood corpuscles attracts it and forms a temporary combination with it, the oxyhemoglobin. The hemoglobin can absorb enormous quantities of oxygen. The blood that enters the lungs contains more carbon dioxide than there is in the alveoli; hence carbon dioxide diffuses out of the capillaries into the alveoli and passes out of the lungs in the expired air. Just the reverse of this is true when the blood reaches the tissues. More oxygen is present in the arterial blood than in the tissues; hence oxygen diffuses out of the blood into the tissues. Since the cells produce carbon dioxide, in high concentration this gas diffuses into the capillaries. In both cases, the exchange takes place through moist membranes. It is all a matter of the concentration of the gases and the process is that of diffusion. Apparently the cells take no active part in the transfer.

5. Artificial Respiration.—In cases of near drowning, coal-gas poisoning, or in other cases where the breathing machinery fails, it is often possible to cause breathing to begin again by the administration of certain methods. There are several machines that are useful in these cases, but they are not always available. The Schafer "prone-pressure" method requires no apparatus and seems reliable.

Figure 391 shows the position of the operator and the victim. The operator places his hands over the lower ribs of the victim and throws the weight of his body forward, pressing against the lower ribs of the patient from 12 to 15 times a minute. This forces air (or water) out of the lungs. As the operator gradually brings his body to a more erect position, the pressure is relaxed, then applied again. It may take half an hour or more for normal respiration to begin.

An apparatus called an *artificial lung* has been invented; sufferers from paralyzed lungs may be placed in this machine and their lungs artificially ventilated for weeks at a time if necessary.

6. Defense Mechanisms against Bacteria.—The hair that lines the nasal cavities filters out many foreign bodies; some bacteria and other particles are trapped by the mucus that covers the mucous membrane. Many bacteria are expelled by coughing and sneezing. The mucous membrane is covered with cilia that moves the mucus, with any bacteria that it may contain, back to the throat, where it is coughed up or swallowed.

7. The Voice.—The breathing apparatus also produces the voice. The *voice box* is the *larynx* (Fig. 392II), located at the upper end of the trachea. The *vocal cords* are two thin membranes or bands lying within the voice box. They are fastened to the front wall of the larynx and to two cartilages (arytenoid) in the back. Small muscles move the cartilages. Figure 392II illustrates how the cords are brought to the mid-line during

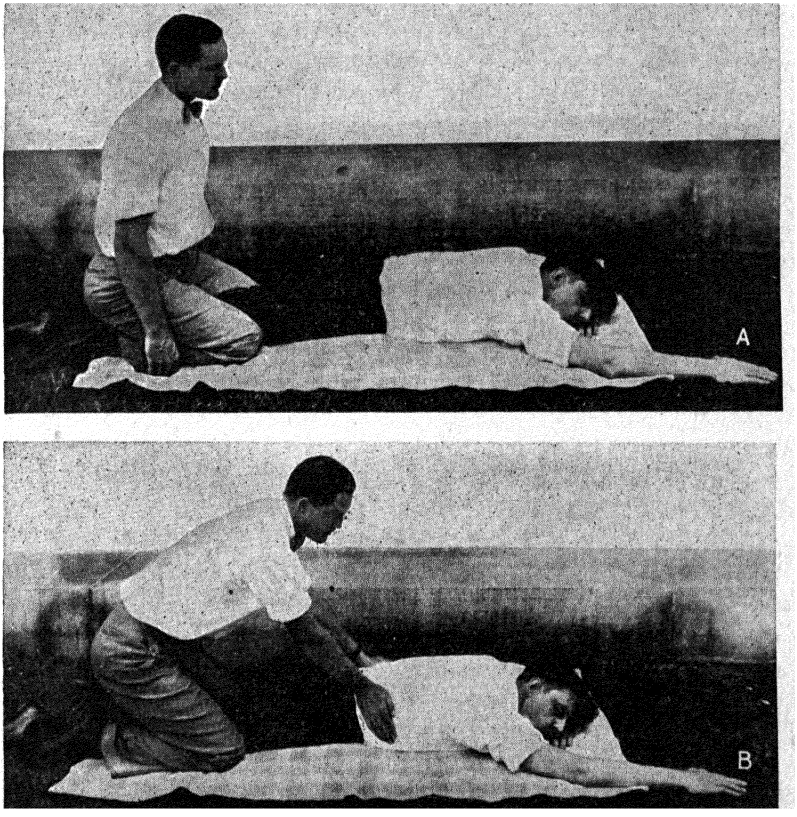

Fig. 391.—Artificial respiration. (A) First position. (B) Second position. (Courtesy of the American Red Cross.)

speech and how they are swung out from each other at ordinary times. When not in use, these cords lie against the wall of the larynx, and hence no sound is produced during ordinary breathing.

Volume or loudness can be modified by changing the force of the air current. Pitch depends upon the length and tightness of the cords as well as upon the number of times they vibrate per minute (frequency). Women and children possess short vocal cords, and their voices are, therefore, high-pitched. In men, the vocal cords are longer, and the voice is deeper.

The quality of the voice depends upon many factors, such as the size of the throat and the character of the trachea and chest.

Coughing and sneezing result from the irritation of the lining of the respiratory tract. Yawning, sighing, snoring, and hiccoughing are other examples of modified respiratory acts, the mechanism of which is imperfectly understood.

8. Some Disorders of the Respiratory Tract. *a. Diseases of the Trachea and Lungs.*—The respiratory passages are warm and moist and therefore offer ideal places for the growth of microorganisms. Some of

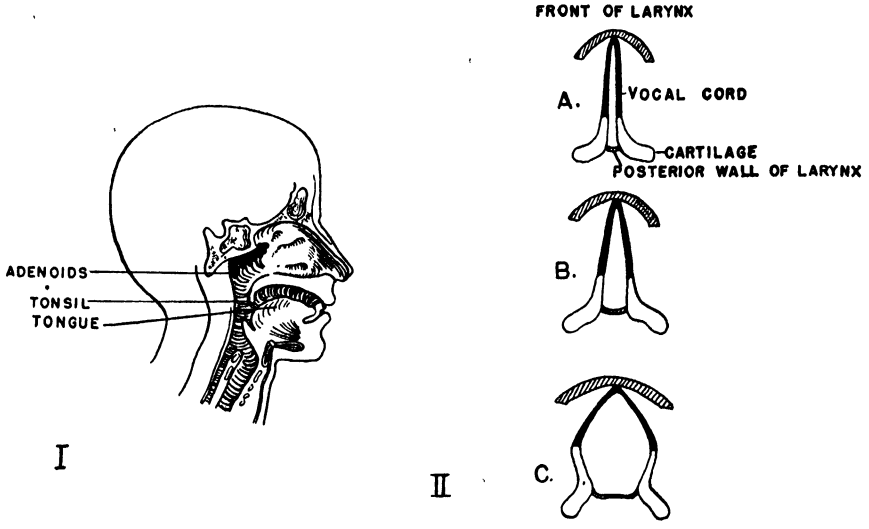

Fig. 392.—(I) Adenoids. Schematic diagram of the head and neck showing the location of adenoids and one tonsil. (II) Vocal cords, viewed from above. (A) Position while singing a high note. (B) Position in quiet breathing. (C) Position during a deep inspiration. The cords are fastened in front to the larynx and to two cartilages, arytenoid, in the posterior. (B. Shamos.)

these produce symptoms and are named after the place infected. Inflammation of the nose is called *rhinitis*, of the pharynx, *pharyngitis*, and of the larynx, *laryngitis*. These diseases may all be variations of the common cold. The real cause of the common cold has never been determined. It may be due to a submicroscopical substance, a *filterable virus* (page 13). Infections of this type may spread to the middle ear or to the sinuses, which open directly into the nasal cavity. Serious illnesses may follow. Tonsils may become badly infected and spread their infection to other parts of the body. Infection of the bronchi of the trachea may give rise to *bronchitis*. *Pneumonia* is due to the infection of the alveoli. *Tuberculosis* may extend into the deeper tissues of the lungs.

b. Allergy.—Certain troubles of the respiratory tract are not due to infections but to sensitiveness, or allergy, to certain substances, such as dust and pollen that float about in the air. *Hay fever* and *asthma* are diseases of this type.

c. Occupational Diseases.—Some occupations, such as polishing metals, pottery making, and cotton spinning, lead to injury of the lungs. The inhalation of metal or mineral dust injures the lungs and leads to pulmonary diseases, such as *bronchitis* and *tuberculosis*. *Silicosis* is a disease caused from the inhalation of silicon (sand) or quartz dust.

d. Adenoids.—Sometimes adenoid tissue, which is connective tissue, grows larger than is normal and partially closes the air passage (Fig. 392I). Children with adenoids usually are "mouth breathers." Enlarged adenoids affect the general health and hinder proper development of the mouth. The lower jaw may recede, and the hard palate may become narrow and highly arched. Also, more bacteria gain entrance through the mouth than through the nose. The number of bacteria that enters the tubes is greatly increased by breathing through the mouth.

e. The Effects of Barometric Pressures.—High air pressure is experienced in submarine work, diving, etc. Workers subjected to high air pressure sometimes suffer if they are not returned to normal pressure gradually. If released from high pressure suddenly, gases in the blood, particularly nitrogen, are liberated in the form of bubbles that may block the capillaries. As a result, pains in the muscles and joints, and other symptoms may appear.

On the other hand, low air pressure is of interest in connection with aviation, life at high altitudes, etc. Some people are affected unpleasantly by altitudes of 9,000 ft. or more. The symptoms include headache, nausea, weakness, and other discomforts. The term *mountain sickness* is sometimes applied to disturbances due to high altitudes. The results noted are not clearly understood; a deficiency of oxygen may account for some of the symptoms.

V. Summary

Respiration takes place in all living things. In the one-celled organisms, it takes place through the cell membranes, no special respiratory organs being present. Plants respire both day and night. Air reaches the air spaces through the stomata, and exchange of gases is through the cell walls. In the lower animals, the organs of external respiration or breathing may be the *skin*, as in the earthworm, the *skin* and *lungs*, as in the frog, the *gills*, as in crayfish and fish, *trachea*, as in the insects, or, in the higher animals, the *trachea*, *bronchi*, and *lungs*. The process of external respiration is exactly opposite from internal respiration. In the former, oxygen from the air is taken into the lungs or their counterpart and absorbed by

the blood in the capillaries; at the same time, the carbon dioxide in the blood in the capillaries diffuses into the air spaces and goes out with the breath. In internal respiration, the oxygen is brought to the cells by the blood. It enters the cells by diffusion, and carbon dioxide diffuses from the cells to the blood. Just how oxygen is used by the cell in oxidation processes is not known.

Questions

1. Distinguish between breathing and respiration; external and internal respiration.
2. Why must all living things have oxygen? How do anaerobic organisms get their oxygen? How is it possible for foods to be oxidized in the body at low temperatures?
3. Compare respiration in the earthworm with that in the crayfish. What are the peculiarities of the respiratory systems in insects?
4. Compare respiration in the fish and frog. Why is it possible for a frog, though an air breather, to stay under water for a long time?
5. Compare gills and lungs as respiratory organs.
6. What peculiarities of the respiratory system in birds are related to their mode of life?
7. Describe the respiratory organs of man.
8. Give an account of the events of inhalation and expiration.
9. Discuss the exchange of gases in the lung. How is it possible for oxygen to be absorbed by the blood and carbon dioxide given up at the same time?
10. What are some protective devices in the respiratory tract?
11. Explain why breathing is automatic and rhythmic. Where is the breathing center located?
12. Describe the vocal organs. How is the voice controlled?
13. Explain the relationship between the circulatory and respiratory system in animals (except insects).
14. Discuss some disorders of the respiratory tract. Which of these is preventable?
15. What are some effects on respiration of barometric pressure? Why do you think that pilots in "dive bombers" should be young?
16. Define: vital knot, vital capacity, oxidation, aerobe, anaerobe, alveolus, pleura, allergy, adenoid.

CHAPTER XXXVIII

EXCRETION

Find out the cause of this effect. . . .
—SHAKESPEARE.

I. Wastes

Chemical changes take place in all living cells. These changes include the general processes of metabolism that involve growth and repair. Some of the compounds formed during metabolism are not used for purposes of growth and repair but are classed as wastes. Wastes may be harmful, and their accumulation may mean death to an organism; or they may be harmless and in some cases useful. In order to get rid of wastes, the organism, plant or animal, has developed various methods of *excretion* (L. *ex*, out, *cernere*, to sift). These methods may be fairly simple, or they may involve elaborate systems of organs.

II. Excretion in Plants

Carbon dioxide and water as excretory products have been mentioned many times (Fig. 393). Thousands of other compounds that are formed by plants may be classed as wastes; one author has listed over 4,000. These include essential oils, gums and resins, organic acids, tannins, alkaloids, pigments, and minerals. Many of these are of use to man.

Plants do not possess the well-developed excretory systems such as those that occur in animals. Wastes in plants may be eliminated by diffusion from roots or by secretions from surface glands. The dropping of various parts like bark, leaves, and twigs disposes of certain wastes. Often wastes are not excreted at all but stored up in some part of the plant. This accounts for most of the substances mentioned above. The carbon dioxide produced during respiration may be used by the plant for the manufacture of food, or it may take part in photosynthesis (page 140). In the dark, the carbon dioxide diffuses out of the plant as a gaseous waste, or it may combine with water to form carbonic acid, and this may diffuse out of the roots and aid in dissolving mineral salts so that they may be absorbed by root hairs. Roots excrete other substances, some of which may be beneficial to the growth of plants; others are toxic or harmful.

The general subject of water loss from plants involves *guttation* (page 147). This is not to be confused with transpiration, which is giving off water in the form of vapor. In guttation, the water is exuded from special

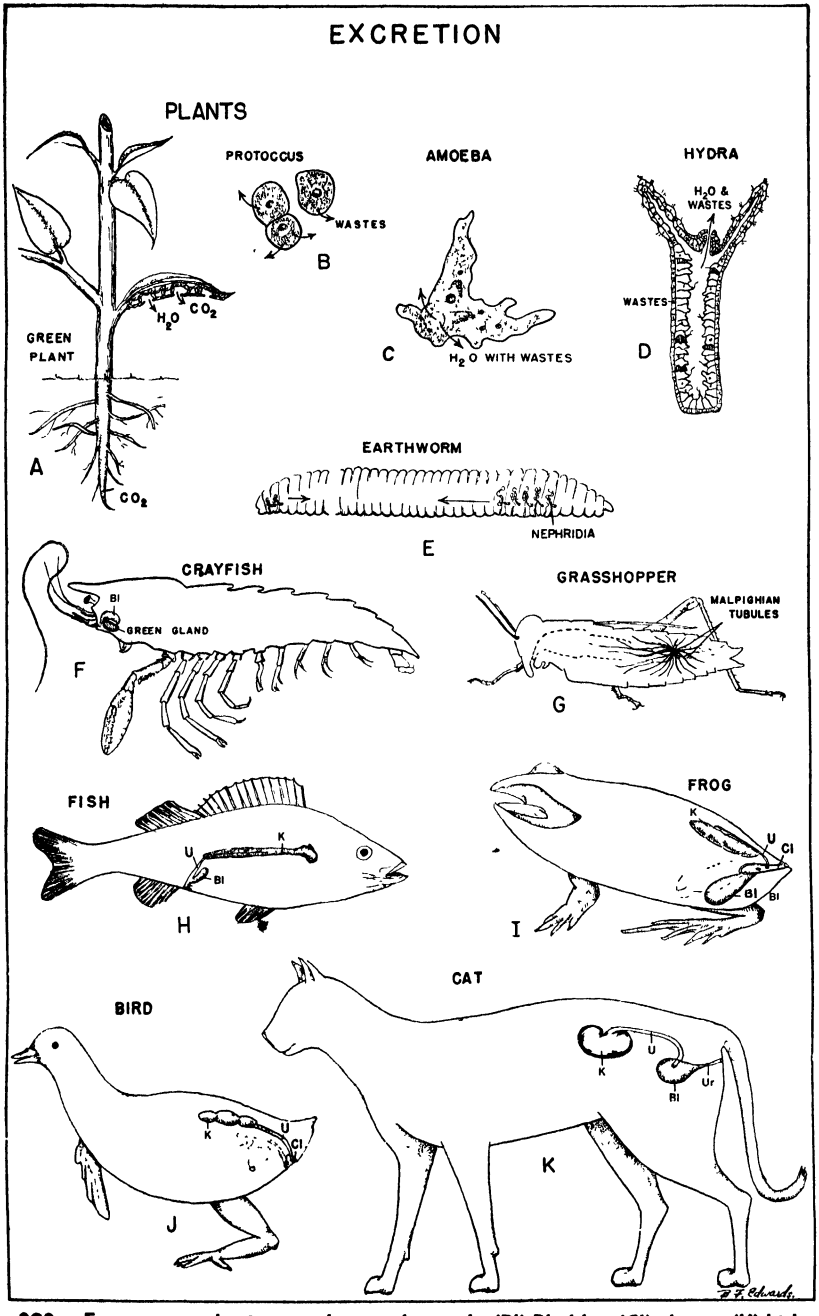

Fig. 393.—Excretory mechanisms in plants and animals. (Bl) Bladder, (Cl) cloaca, (K) kidney, (U) ureter, (Ur) urethra. (B. F. Edwards.)

structures connected with the vascular system. The drops lie along the edges of leaves and are sometimes mistaken for dew (Fig. 100).

III. Excretion in Animals

A. Types of Wastes and Their Elimination.—Except for the Protozoa and a few other types of lower invertebrates, animals possess definite excretory systems. Animal wastes may consist of the indigestible remains of food or of unabsorbed food. These are often spoken of as feces and are cast out of the alimentary canal. Usually, however, by excretion is meant the waste products of cell activity. In this class are carbon dioxide, urea, and many other substances. Another class of wastes includes cast-off materials, such as dead flakes of skin in man, the scaly outer covering in snakes, the exoskeleton of insects, crayfish, and other animals, the feathers of birds during molting, and nails and horns in certain mammals. Since these are not the result of metabolic processes, they represent a different type of waste from that produced during metabolism.

Elimination is getting rid of wastes more or less mechanically, as from the intestine and bladder; *excretion* is extracting wastes from a circulating medium, the body fluids, and passing them to a temporary depot such as the bladder, lungs, and alimentary tract.

B. Excretory Organs and Their Functions. 1. INVERTEBRATES. *a. Cell Surfaces.*—In the Protozoa, excretion takes place through the cell walls by diffusion and through the contractile vacuole if one is present. Many Protozoa do not have contractile vacuoles, particularly the salt-water forms. In the coelenterates, sponges, and ctenophores, there are no special excretory organs, and elimination takes place through the body surfaces by diffusion (Fig. 393).

b. Protonephridia.—In flatworms and nemerteans, the "flame cell" (page 314) is a simple type of excretory organ. The motion of a tuft of cilia suggests the flickering of a flame; hence the name. These cells are connected with coiled tubes that fuse to form a system of canals that open to the surface of the body by excretory pores. The wastes in the surrounding tissues diffuse in the flame cells and leave the body by the excretory pores.

c. Nephridia.—The earthworm possesses a pair of excretory organs in each of its segments, except the first three and the last; these are nephridia (Fig. 235). Each nephridium consists of a funnel and a much-coiled tube (page 339). The funnel opens into the body cavity and the tube opens to the exterior by way of pores.

d. Green Glands and Malpighian Tubules.—In the crayfish (page 363), the excretory problem is taken care of by *green glands;* in insects *Malpighian tubules* are the excretory organs (page 400).

2. VERTEBRATES IN GENERAL.—There are three types of chief excretory organs, or kidneys, in the vertebrates: (1) *pronephros*, (2) *mesonephros*, (3) *metanephros*.

a. Pronephros (Gr. *pro*, before; *nephros*, kidney).—The pronephros type of kidney is functional in cyclostomes, young fish, and young amphibians, but only in the embryos of other groups. It is situated near the head in the coelom and, for this reason, often called the *head kidney.* It may consist of from 1 to 13 tubules, each with a funnel-like ciliated nephrostome. Each tubule is something like the nephridium of the earthworm. A collecting duct, the pronephric duct, leads to the cloaca.

b. Mesonephros (Gr. *mesos*, middle; *nephros*).—This type of kidney is functional in fish and amphibians and is referred to as the *middle kidney.* It is situated in the coelom, further down than the location of the pronephros. It is more complicated in many ways than the pronephros. Each uriniferous tubule ends in a Malpighian body, which consists of a knot of blood vessels, the glomerulus, enclosed in a capsule, Bowman's capsule.

The blood supply of the mesonephros of the frog is from the renal portal system. The mesonephros removes urea and other wastes to be eliminated from the blood. This material, the urine, is gathered by the collecting tubules, which empty into the mesonephric duct. This, in turn, empties into the cloaca. The urine may be stored in a bladder if one is present, as in the frog, and return to the cloaca for elimination to the outside through the anus. The *nephrostomes* of the tubules usually open into the coelom.

c. Metanephros (Gr. *meta*, after; *nephros*), *or Posterior Kidney.*—In this type of kidney, there are no nephrostomes opening into the coelom, and a new duct makes its appearance, the ureter. This leads directly from the kidney to the cloaca in some forms; in man, it leads to the bladder. The blood supply is from the aorta, and the renal veins connect with the posterior vena cava. The renal portal system, which supplies the mesonephros in the amphibians, is not present in the amniotes. The renal corpuscle, or Malpighian body, is the same in the metanephros as it is in the mesonephros.

In embryonic development of the amniotes, the pronephros appears first; then the mesonephros replaces this; and finally, the metanephros takes over the functions of the kidney. This is one of the examples often used as illustrating the *biogenetic law* (page 391), that the development of the individual recapitulates the development of the race.

Because of the close association of the excretory and reproductive systems, they are termed together the *urinogenital system.*

d. Bladder.—The bladder is a storage organ for urine; it is not found in all vertebrates. Some fish have a diverticulum from the cloaca called a *bladder;* in other fish, a bladder is formed from the fused ends of the Wolffian ducts. In some Amphibia, as the frog, there is a small bladder connected with the cloaca (Fig. 165). Urine is stored here but goes again to the cloaca before going to the outside. A bladder is missing in snakes,

crocodiles, and birds (Fig. 393*J*). In some reptiles and in all mammals, a bladder for the storage of urine is formed from the base of the allantois. In mammals, the ureters pass directly from the kidneys to the bladder; the urine is expelled to the outside through a tube, the urethra (Fig. 393*K*).

3. Excretion in Man.—The excretory organs of man are the skin, lungs, liver, kidneys, ureters, bladder.

a. Role of the Skin in Excretion.—The skin in man performs important functions in the process of excretion. It may excrete about 600 cc. of water during an ordinary day; on a hot day it may excrete as much as 2,000 to 3,000 cc. But in spite of this apparently great amount of water, the total solids excreted by the skin are not very great. It is to be borne in mind that the chief function of the sweat is to keep the body cool. If the water is not needed for this purpose, it is not secreted from the blood by the sweat glands; excess water in the body is eliminated by the kidneys.

b. Excretion and the Lungs.—In the process of breathing, water containing carbon dioxide and small amounts of organic substances is given off or eliminated. The amount of water lost from the body in this way is estimated variously from 200 to 300 cc. daily and the amount of carbon dioxide, from 12 to 14 cu. ft. The lungs are, therefore, very important in the elimination of wastes, especially carbon dioxide (see also page 579).

c. Excretion and the Liver.—Bile is a waste product, though it performs a useful function in aiding in the absorption of fats (page 538). There are certain cells in the liver, *Küpfer* cells, which are said to be concerned in the destruction of red blood corpuscles. The spleen and the bone marrow are also said to aid in destroying worn-out red corpuscles. The products of these destroyed red cells form a large part of the bile that is formed in the liver.

Urea is formed in the liver and carried by the blood to the kidneys to be excreted. The formation of urea is complex and involves many processes not well understood. It is known that certain of the liver cells work in association with certain enzymes that are specific for some split products of protein metabolism. There may be several steps in the process and several enzymes active. One method of the formation of urea is by deaminization. If an excess of amino acids, products of protein metabolism, occur in the blood, the liver splits off the NH_2 radical of the amino acid and converts the remainder into glycogen, or animal starch, a carbohydrate that is a reserve food. The NH_2 is then changed to NH_3 (ammonia), which is combined with carbon dioxide to form urea and water.

$$2NH_3 + CO_2 = \underset{\text{urea}}{CO(NH_2)_2} + \underset{\text{water}}{H_2O}$$

This goes by way of the blood stream to the kidneys to be eliminated.

d. Excretion and the Kidneys.—As in the frog, the kidneys in man lie at the back of the abdominal cavity. They are bean-shaped, brownish in color and are from about 4 to 4½ in. in length. A longitudinal section through the middle of the kidney reveals three regions: (1) the outer *cortex*, (2) the *medulla*, containing the *pyramids*, which are made up of tubules, and (3) the pelvis, which is the enlarged end of the ureter (Fig. 394). At the apex of the pyramids are the papillae, and the tips of each

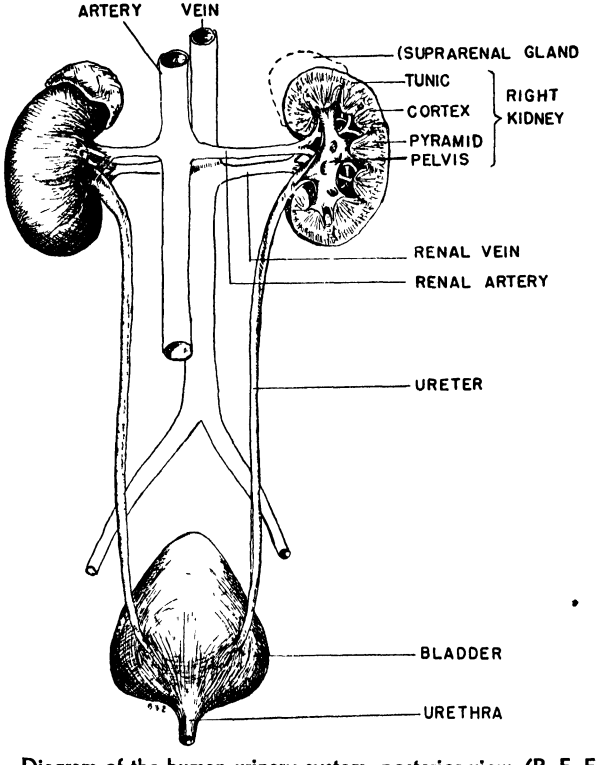

Fig. 394.—Diagram of the human urinary system, posterior view. (B. F. Edwards.)

papilla are the openings of the collecting ducts that are formed by the union of several uriniferous tubules. The ureter leads directly from the kidney to the bladder. From the bladder, an unpaired duct, the urethra, leads to the outside (Fig. 394). The various parts of the kidney tubule have different functions. The terminal part of the tubule, which lies in the cortex, is the *Malpighian tubule*, or renal corpuscle. The corpuscle has a double-walled capsule in which is a knot of blood vessels, the *glomerulus* (Fig. 395). The rest of the tubule is a much convoluted portion leading to the loop of Henle, and this, in turn, is connected with a

collecting tubule that empties into the pelvis of the kidney, which is the enlarged end of the ureter.

The blood is brought to the kidneys by a pair of renal arteries, which are branches of the dorsal aorta. In each kidney, these break down into small afferent arteries, which enter the glomeruli. The blood brought by an afferent artery circulates through the glomerulus, leaving by an efferent artery (Fig. 172). After leaving the glomerulus, the efferent artery breaks up into a capillary network over the convoluted surface

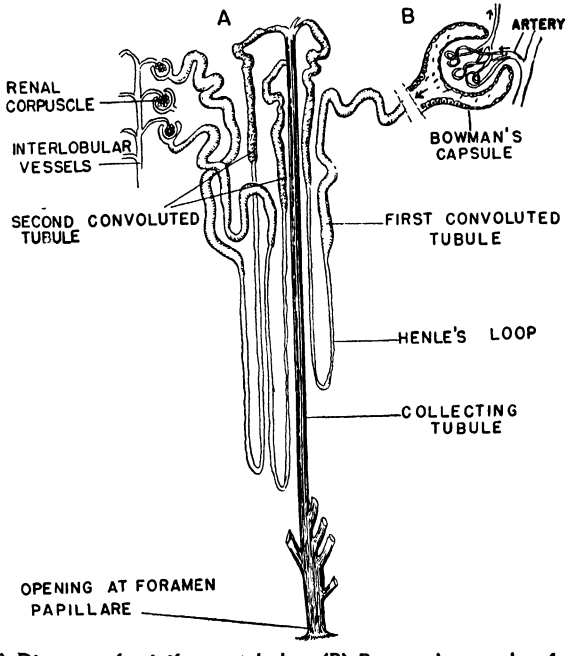

Fig. 395.—(A) Diagram of uriniferous tubules. (B) Bowman's capsule of a single tubule, greatly enlarged. See also Fig. 172. (B. F. Edwards.)

of the tubule. The work of the kidney is believed to be partly filtration and partly secretion. It is probable that since the walls of Bowman's capsules are thin, water and inorganic salts are filtered out into the lumen. This filtration is probably brought about by a difference in pressure in the blood vessels and the lumen (Fig. 172). The urea, uric acid, and other materials that make up the urine are probably secreted from the blood in the second set of capillaries by the cells of the convoluted tubules. There is also a certain amount of reabsorption of materials—sugar, for example—by the tubules (see also Fig. 172).

e. Other Functions of the Kidneys.—The kidneys have other important functions than those connected with secretion and elimination of urine.

(1) REGULATION OF THE COMPOSITION OF THE BLOOD. (*a*) Sugar Content.—In health, the concentration of glucose in the blood plasma is maintained between the limits of about 0.08 to 0.14 per cent, averaging about 0.1 per cent (page 546). The liver helps regulate the sugar in the blood by storing up glycogen (page 538), which is used when the blood sugar falls below the normal level. The kidneys also play a part in maintaining the blood-sugar level. In the filtrate from the glomerular portion of the tubule, there is a considerable amount of sugar. In health, none of this appears in the urine; it is, therefore, reabsorbed by the tubules and returned to the blood stream. But in cases where the amount of sugar is very greatly increased in the blood, as, for example, in diabetes, the tubules are unable to reabsorb the sugar, and so it is excreted with the urine.

(*b*) Volume of Blood.—The kidneys tend to regulate the volume of blood, since they excrete excess water; the urine thus becomes dilute and is increased in amount. After loss of blood, as the result of hemorrhage, water is conserved, and the volume of urine becomes diminished.

(*c*) Salt Content.—This is also regulated to some extent by the kidneys by altering the ratio of salt to water produced in the urine. This depends upon the amount of salts and water taken into the body.

(2) OTHER ACTIVITIES OF THE KIDNEYS.—These include syntheses of certain acids and other chemical reactions too complex to go into here.

f. The Bladder and Excretion.—The bladder in man is a muscular organ capable of much expansion. The kidneys work all the time, and the secretion, the urine, goes to the bladder through the ureters, drop by drop. The flow down the ureters, which are about 12 in. long, is accomplished partly by gravity and partly by peristaltic action of the ureters themselves. The ureters enter the posterior wall of the bladder, and each is guarded by a valve. The urine may be retained in the bladder until there is about ½ pt. The bladder is emptied by relaxation of a valve which guards the urethra and by contraction of the abdominal muscles. This function is somewhat under the control of the will. About 1,500 cc. of urine are excreted by a normal adult over a period of a day.

g. Some Disorders of the Excretory System.—Many disturbances may occur in the activities of the kidneys. Some of these are due to infectious diseases. Disease-producing bacteria may enter the kidneys from the blood and bring about destruction of tissue. Or sometimes *toxins* produced by bacteria may enter the kidney and injure it. For example, diphtheria germs that are located in the throat may do great harm to the kidneys. *Kidney stones*, like stones in the gall bladder, are caused by the precipitation of some solids in the urine. They may block the flow of urine from the kidney; as a result, the kidney may degenerate. Fortunately, one kidney can perform all the necessary functions; hence the removal

of a diseased one often leads to recovery and health. *Bright's disease* is associated with high blood pressure. In this disease, the tissue of the kidney is injured.

C. Summary.—*Elimination* is getting rid of wastes mechanically; *true excretion* is extracting the end products of metabolism, the wastes not used by the organism, from a circulating medium, and passing them to temporary waste depots such as the lungs and the bladder, to be eliminated.

The invertebrates have various types of excretory organs. In Protozoa and the coelenterates, the *cell surfaces* serve as excretory organs. In the flatworms, there are "*flame cells*," which are primitive excretory organs; in the earthworms, the *nephridia* are more complex. A pair of nephridia is situated in every segment of the earthworm except the first three and the last. *Green glands* take care of excretion in the crayfish, and *Malpighian tubules* are the characteristic excretory organs of the insects.

Kidneys are the chief excretory organs of the *vertebrates*, the accessory organs being the skin, the lungs, and the liver. Three types of kidneys occur: the *pronephros* of the cyclostomes; the *mesonephros*, as in the frog; and the highly complex, remarkable structures, the *metanephros* of the higher animals, including *Man*.

Questions

1. Distinguish between excretion and elimination. Why are the solid wastes in the intestine not considered in the same class as the waste products of metabolism?
2. Give an account of excretion in plants.
3. Compare excretion in *Hydra*, earthworm, crayfish, and grasshoppers; in frog and man.
4. Distinguish between pronephroi, mesonephroi, and metanephroi.
5. Which animals have functional pronephroi; mesonephroi; metanephroi? Is there any significance in the appearance of pronephroi and mesonephroi in the embryonic stages of the higher animals possessing metanephroi?
6. Where is urea formed? How is it excreted?
7. What are the regions of the kidney?
8. Discuss the structure of a Bowman's capsule, and state the work done by each part of it.
9. Compare the function of the bladder in the frog and in man.
10. Discuss the work of the kidneys as a whole. Besides excretion, what other important functions are taken care of by the kidneys?
11. What is the role of the skin in excretion? The lungs? The liver?
12. Explain how infections in any part of the body may cause injury to the kidneys.
13. How are kidney stones formed, and what harm may they do?
14. Define: ureter, urethra, renal corpuscle, "flame cell," guttation, nephridium, cloaca, Malpighian tubule, glomerulus, pronephros, mesonephros, metanephros.

CHAPTER XXXIX

COORDINATION

Memory, the warder of the brain.
—SHAKESPEARE.

I. Stimulus and Response

One of the most characteristic properties of living things is that they can receive stimuli and that cells, tissues, organs, even the entire organism itself can respond, each in its own way, to stimuli. The stimulus may come from the outside or the inside of the organism; *i.e.*, it may be internal or external. In a biological sense, a stimulus is something that "excites the body to activity." Many kinds of stimuli affect living things, such as change in the concentration of light, various chemicals, electrical currents, changes in osmotic pressure, changes in temperature, etc.

The response of living things to various kinds of stimuli is called a *tropism* (Gr. *trope*, a turning) or taxis (Gr. *taxis*, arrangement).

A. Types of Tropisms.—Responses to stimuli are of two types, positive and negative. For example, a *Euglena* will swim toward a weak light; *i.e.*, it will respond positively to the light; but the same *Euglena* will avoid bright light or respond negatively. A list of the various types of tropisms is placed here for reference.

Response to light, *phototropism* (Gr. *phos*, light; *trope*, turning).
Response to water, *hydrotropism* (Gr. *hydro*, water).
Response to gravity, *geotropism* (Gr. *ge*, earth).
Response to heat, *thermotropism* (Gr. *therme*, heat).
Response to chemicals, *chemotropism* (Gr. *chemeia*, a mingling).
Response to electric current, *electropism* (Gr. *elektron*, shining, the sun)
Response to touch, *thigmotropism* (Gr. *thigma*, touch).
Response to currents, *rheotropism* (Gr. *rheos*, current).
Response to color, *chromotropism* (Gr. *chromos*, color).
Response to the sun, *heliotropism* (Gr. *helios*, sun).
Response to air currents, *anemotropism* (Gr. *anemos*, wind).

B. Responses of Organisms to Stimuli.—Only a few of the more familiar responses of organisms to various types of stimuli are mentioned below.

1. LIGHT. *a. Plants.*—Experiments that can be carried out in the laboratory will illustrate the amazing response of plants to the stimulus of light. For example, plants placed in a window tend to spread their

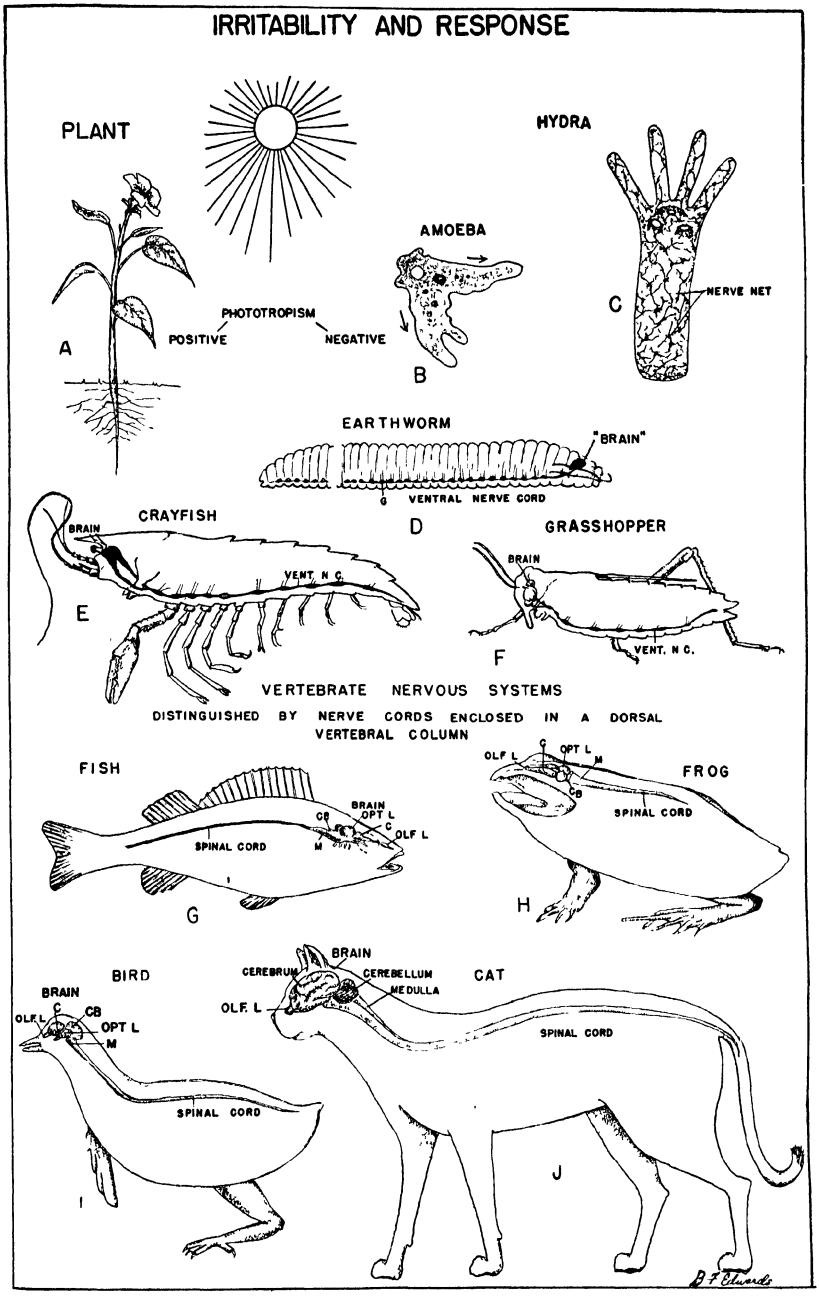

Fig. 396.—Mechanisms for irritability and response in organisms. (C) cerebrum; (CB) cerebellum; (G) ganglion; (M) medulla; (Olf) olfactory lobe; (Opt. L.) optic lobe; (Vent. N. C.) ventral nerve cord.

leaves to the light (Fig. 396). This is not always a slow turning of plants to light over a period of days. Figure 397 shows young sunflower plants that remained in a window for 1 day. At 10 o'clock on the second day, the pot was turned around so that the bent seedlings faced toward the inside of the room. In 1 hour they had changed their position and were already turning toward the light.

It has been shown that plants vary in the amount of light necessary for development and flowering. Thus, there are *long-* and *short-day plants.* By this is meant that some plants, such as *Gaillardia* (Fig. 398I) require a relatively long day to become mature and flower. As the figure shows, a plant, given 10 hours of light a day, does not develop nearly so well as a plant that has 16 hours of light a day. On the other hand, the mauve daisy (Fig. 398II) is a short-day plant. It does not require so much light for proper development, and if it is given more light than it needs for matur-

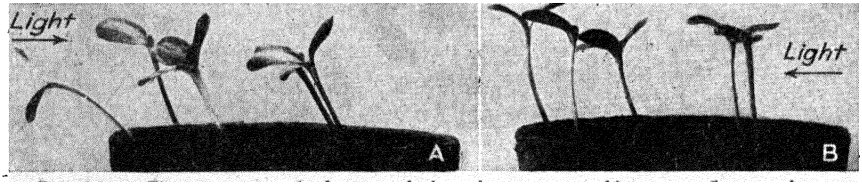

Fig. 397.—The response of plants to light, phototropism. Young sunflower plants set in window turned to the light. The pot was then turned around and in about an hour the plants had changed their position, turning toward the bright light.

ing and flowering, it may be stimulated to develop stem and leaf to such an extent that it will be prevented from flowering.

b. Animals.—Studies by Bissonnette, Benoît, Rowan, and many others indicate that the breeding or mating times of many animals, birds, mammals, and fish particularly, are also brought into relation to the seasons adapted to survival of the species by changing length of day and intensity of light. Spring breeders, like starlings, ducks, juncos, crows, pheasants, quail, grouse, ferrets, and raccoons may be induced to breed earlier by artificial increases in daily light time or even to breed in autumn if their days are increased in length to resemble those of spring and summer. Autumn breeders, like deer, sheep, and brook trout, mate when days are becoming shorter and produce their young in the spring or at some other time advantageous to the species. They may be made to mate in spring if hours of daylight are artificially shortened at that time. Other animals, like guinea pigs, rats, and man show little or no influence of length of day in this respect. Others, like field mice and hedgehogs, are affected similarly by other factors, food or temperature, instead of by light, or in addition to it. Many animals may therefore be said to have adapted themselves so that their times of mating are controlled or put

into action by such changes in their environment as in length of day, in temperature, or in food. Their young ones, therefore, tend to be brought forth at seasons which permit their survival and that of the race.

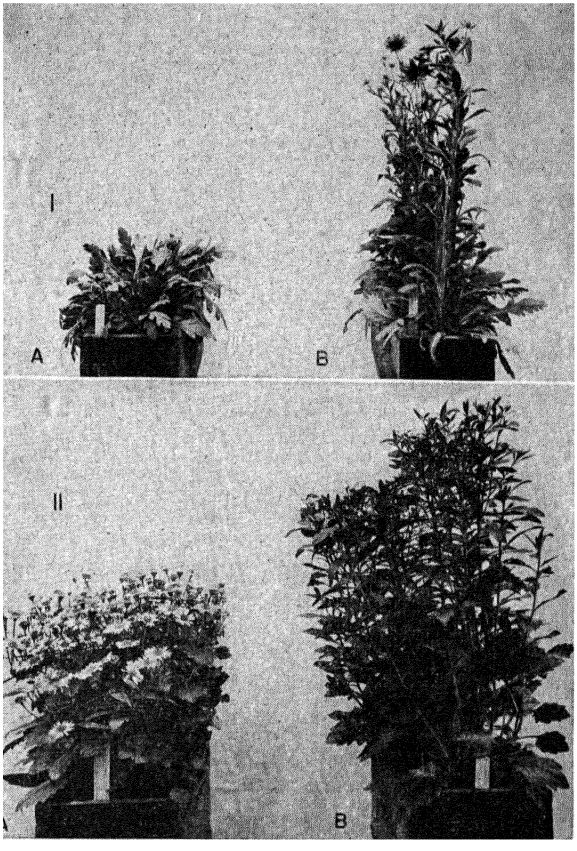

Fig. 398.—Long- and short-day plants. (I) Gaillardia, a long-day plant; it will not flower unless it has a certain number of hours of light. (A) Plant that has had 10 hours of artificial light daily. (B) Plant that has had 16 hours of artificial light daily. (II) Mauve cotton aster, a short-day plant; it will flower with a relatively small number of hours of artificial light daily. (A) Plant that has had 10 hours of artificial light daily; (B) Plant that has had 16 hours of artificial light daily. In this case, much light stimulated leaf and stem development but prevented flowering.

2. GRAVITY.—The response of plants to gravity is well shown by experiment with two young bean plants. Both were growing in a normal position. To exclude the influence of the light, the experiment was performed in a darkroom. One plant is slightly bent, because it had turned to the light a little. This plant was left in the normal position and kept as a control; the other was placed in a horizontal position. In about three

hours, the plant placed horizontally had altered its position so that the bud was almost in the normal position. Since this bending was "away from gravity," it represents an example of negative geotropism (Fig. 26). If a young corn, pea, or other seedling, growing normally, is turned upside down, the root will turn downward, and the stem will turn upward, as shown in Fig. 65.

3. WATER.—Roots appear to seek water (hydrotropism), though some are apparently more sensitive to the water stimulus than others. If a few seeds are placed in the bottom of a wire basket and covered with

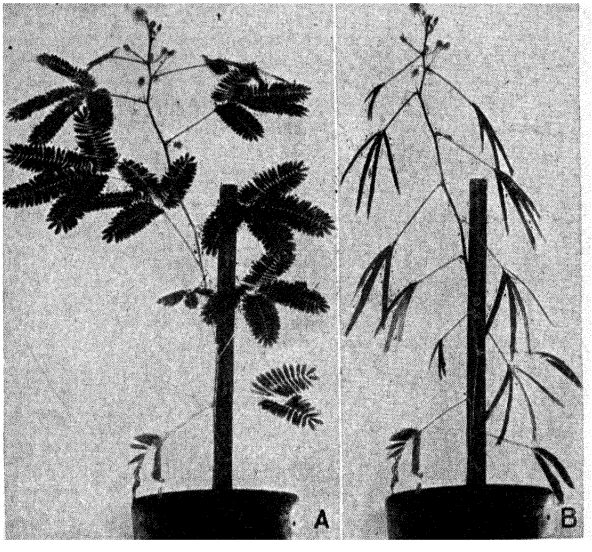

Fig. 399.—The "sensitive" plant, Mimosa pudica. (A) Before being touched. (B) After being touched. (Dr. E. H. Runyon.)

damp moss, the roots will grow out and try to respond to two forces, gravity and water.

4. CONTACT.—Plants that twine around a support respond to *contact* (rheotropism) by growing faster on one side than on the other. If a morning-glory is carefully untwined from its support, it will be impossible to straighten out the stem, since the inside of the "curl" is shorter than the outside.

5. CHEMICALS.—Most organisms will respond to various types of chemicals (chemotropism). A simple experiment is to place a drop of $\frac{1}{30}$ per cent acetic acid at the edge of a drop of culture containing *Paramecia*. The *Paramecia* tend to gather in regions of low acidity. It is interesting to note that the bacteria upon which *Paramecia* feed are likely to live in a medium that is slightly acid.

C. Nervous Systems and How They Operate. 1. RECEPTORS, EFFECTORS, ETC.—A *receptor* is naturally something that receives. In a biological sense, it is a structure fitted to receive stimuli. A *conductor* is something that passes on the stimuli received by the receptor. An *effector* is a structure that responds to a stimulus or, in other words, makes the stimulus effective; and an *adjustor* is something that makes possible the adjustment of the organism to its surroundings. Adjustment to the environment is taken care of in the higher animals by the central nervous system. This serves as a *coordinating center*, by means of which animals are adjusted to various kinds of stimuli and to their intensity, *i.e.*, to small or large amounts of the stimuli.

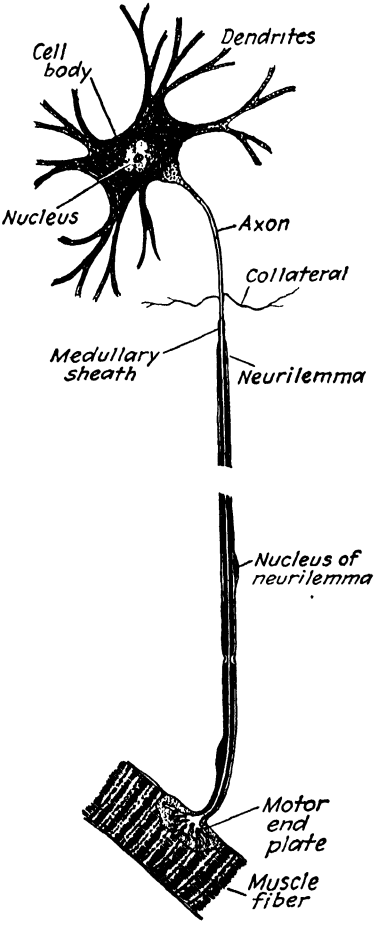

Fig. 400.—Diagram of a motor neuron. (From Wolcott, Animal Biology.)

Plants do not possess an elaborate system for receiving and responding to stimuli, yet one may touch a sensitive plant at one point and it will fold most of its leaves (Fig. 399). In the lower animals, such as the Protozoa, a single mass of protoplasm may serve as receptor, conductor, and effector. When *Amoeba* receives the stimulus of bright sunlight, this stimulus is carried to all parts of the cell by the protoplasm; then *Amoeba* moves away from the bright sunshine to a light of lesser intensity that is more favorable for its life activities. The nervous system of *Hydra* is in the form of a net (Fig. 396*C*). In this animal, one part of the cell contains the nerve, and another part of the cell contains contractile fibrils, which serve as an effector by contracting when stimulated. The earthworm, crayfish, and grasshopper all possess well-developed nervous systems (Fig. 396*D*, *E*, *F*). In each, a bilobed mass serves as a sort of brain; connectives pass from this to the ventral nerve cord, and branches from the nerve cord penetrate to all parts of the body. This machinery serves for the carrying out of reflex actions, which will be described a little later.

2. Nervous Tissue and the Neuron.—Nervous tissue is made up of *nerve cells* and a supporting tissue called *neuroglia*. This tissue has its origin in the ectoderm and is different from other connective tissue that is derived from the mesoderm. It is made up of cells and fibers.

The unit of the nervous system is the *neuron* (Gr. *neuron*, nerve), which consists of a cell body and its processes (Fig. 400). The cell body has a nucleus, a nucleolus, and cytoplasm. In the cytoplasm are small granules and fibrils. From the nerve cells extend two kinds of processes, the *dendrites* (Gr. *dendron*, a tree) and *axons* (Gr. *axon*, axis). There may

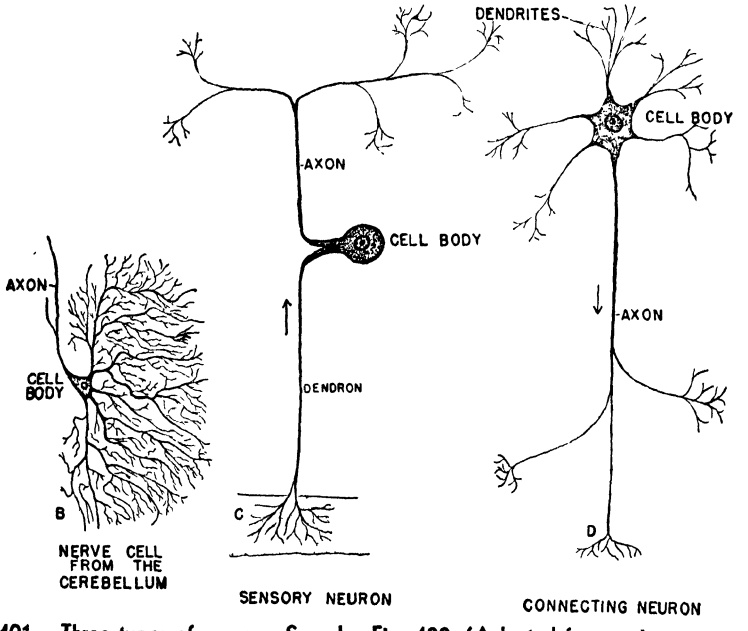

Fig. 401.—Three types of neurons. See also Fig. 400. (Adapted from various sources by B. F. Edwards.)

be one long dendrite, but there are usually many of these, which branch profusely. There is only one axon for each cell, though there may be several collateral branches. They may be long or short (Fig. 401), an example of a long axon being an axon from the spinal cord to the foot. When a nerve impulse passes from one neuron to another, it passes by way of the axon of the first across to the dendrites or cell body of the second. Sometimes the axon is surrounded by a sheath made up of a fatty substance, the *medullary* (L. *medulla*, marrow) sheath. Nerves with and without this sheath are spoken of as *medullated* or *nonmedullated*. If one includes the dendrites, some of the nerve cells are the longest cells in the body.

3. The Central, or Cerebrospinal, Nervous System.—This system is made up of the brain and the spinal cord (Fig. 402). The peripheral

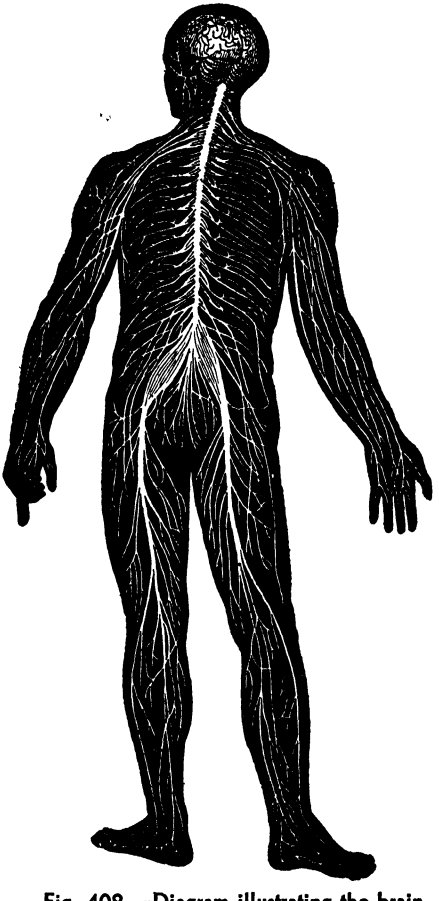

Fig. 402.—Diagram illustrating the brain, spinal cord, and spinal nerves of man. (From Kimber, Gray, and Stackpole, Textbook of Anatomy and Physiology, The Macmillan Company.)

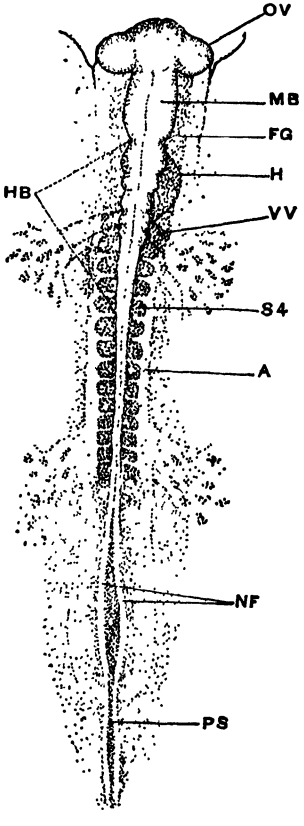

Fig. 403.—Chick embryo showing early development. (Ov) Optic vesicle, a lateral extension of the forebrain; (MB) midbrain; (HB) hindbrain; (NF) neural fold; (A) aorta; (PS) primitive streak; (S4) fourth somite; (FG) foregut. (From Wieman, An Introduction to Vertebrate Embryology.)

system, made up of cranial spinal and autonomic nerves, is considered as a separate system only because it is convenient to study it in that way. It is closely associated with the central nervous system, and the two

together constitute the coordinating mechanism of the animal body, both acting together, though with somewhat different functions.

a. The Brain.—Shortly after the anterior portion of the neural tube begins development of the brain in the embryo, three regions are noted: the *forebrain, midbrain,* and *hindbrain* (Fig. 403). These differentiate into the five regions shown in the diagram below. The forebrain develops two lobes: from the anterior of these, the cerebrum develops; from the posterior lobe, the "tween brain" is formed. The midbrain remains undivided, but from it develop the corpora quadrigemina, tegementum, and the crura cerebri. From the anterior lobe of the hindbrain are developed the cerebellum and the pons, and from the posterior lobe the medulla oblongata develops. The posterior part of the neural tube becomes the spinal cord.

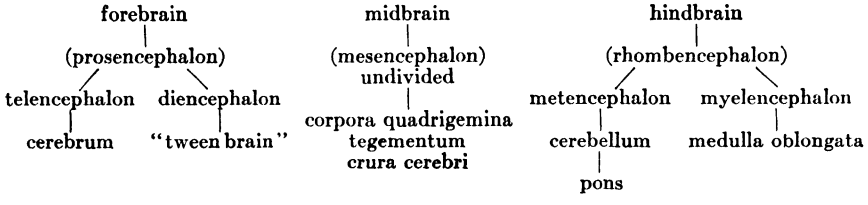

Figure 404 shows a series of brains from different types of vertebrates, arranged in order from fish to man. In the anterior portion are the olfactory lobes, concerned with a sense of smell.

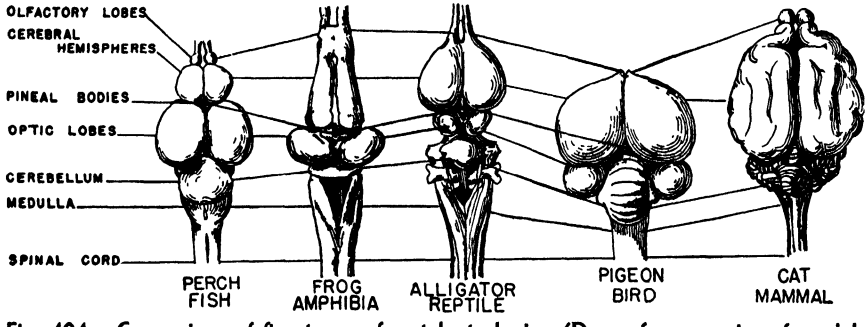

Fig. 404.—Comparison of five types of vertebrate brains. (Drawn from a series of models by B. F. Edwards.)

(1) THE CEREBRUM.—Except where noted, the following description is mainly of the human nervous system. The cerebrum in fish is poorly developed; it is somewhat larger in the amphibians, becomes more prominent in reptiles, birds, and mammals, but reaches a dominant place in man. Even in apes, the cerebrum is small in comparison with that in man. A human brain, four-fifths of which is the cerebrum, may weigh 1,350 g., whereas that of an adult gorilla weighs only about 430 g. In some animals,

the surface of the cerebrum is smooth; in others, quite wrinkled, or convoluted, thus greatly increasing the surface. If a groove is small, it is a *sulcus;* if deep, it is a *fissure.* In man, a layer of gray matter about ⅛ in. thick covers the cerebrum. This gray matter contains great numbers of cells and is the *cerebral cortex.* Beneath this lies the white matter in the

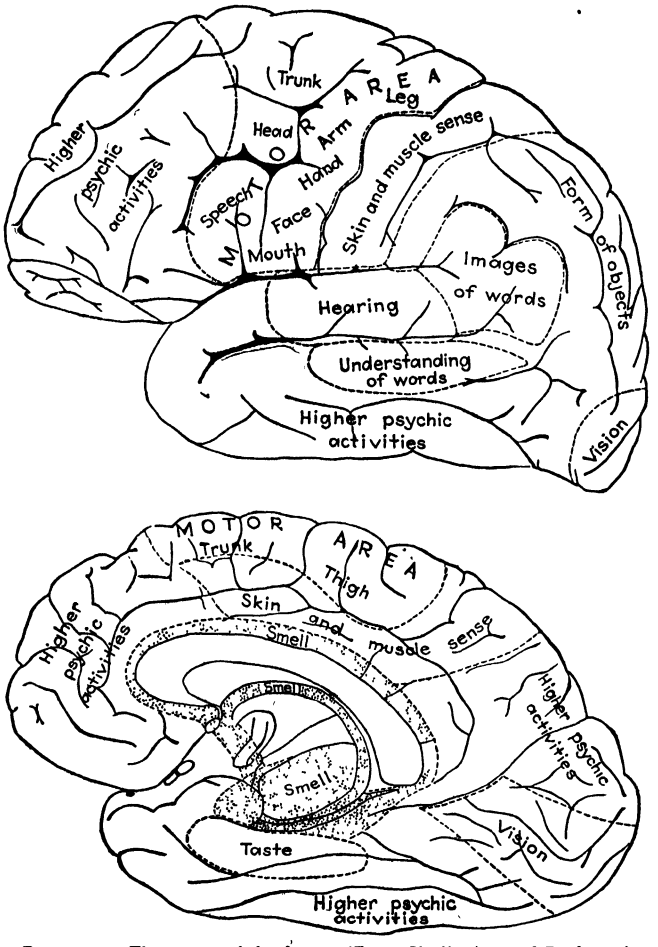

Fig. 405.—The areas of the brain. (From Shull, Animal Biology.)

interior. The white matter consists of countless numbers of nerve fibers. The dorsal and lateral walls of the cerebrum are called *pallium* or *mantle.*

A longitudidal fissure divides the cerebrum into two hemispheres, and in the higher animals, including man, these are joined by a bridge, the *corpus callosum.* Each hemisphere is divided into 5 lobes. The *frontal* and *parietal* lobes are separated by the *fissure* of *Rolando;* the *temporal* is

divided from the other two by the lateral *fissure* of *Sylvius;* the *occipital* is indistinctly separated from the parietal and temporal lobes by the posterior *parieto-occipital* fissure; the *insula* (island of Reil) is not seen from the surface of the hemisphere, being within the fissure of Sylvius and overlaid by the convolutions of the parietal and frontal lobes.

(*a*) Brain Tracts.—There are various connections among the parts of the brain. In the cortex are many nerve cells, and from these fibers pass to other parts of the brain and spinal cord. The fibers may be grouped in three main systems: (1) *association tracts,* with the function of association of memories, purposes, and acts; (2) the *commissural tracts,* which run in the corpus callosum between the two hemispheres and harmonize the actions of the two halves of the brain; (3) the *projection tracts,* whose fibers run from the cortex to the parts below, such as the cerebellum, the cord, etc. There are many important projection tracts, and the function of all the tracts has not been made out.

(*b*) Areas.—The brain has definite areas, in which are located special functions. The various tracts of the brain are connected with the cortex, which initiates or receives the impulses conducted over the separate tracts. By experiment, it has been shown that certain activities are controlled by certain regions of the brain. Figure 405 shows some of these regions. Recently experiments have demonstrated that these areas are not absolutely fixed. If certain of them are destroyed, another part of the cerebrum may, after a time, take over the function. Apparent exceptions are the auditory and visual centers.

(*c*) Functions of the Cerebrum.—The high development of the cerebrum is responsible for the dominance of man over the lower animals. The functions of the cerebrum may be summarized as follows:

1. It is the seat of intelligence and reasoning powers.
2. It is the seat of consciousness and of memory.
3. It interprets sensations.
4. Voluntary acts originate here.
5. It controls certain reflexes.
6. It is a reflex center.

(2) "TWEEN BRAIN," OR DIENCEPHALON.—The "tween brain" is comparatively inconspicuous. It is important, however, because of the pituitary gland, a part of which, the infundibulum, is an outgrowth of its ventral floor. The infundibulum meets and fuses with an ectodermal outgrowth from the mouth region, the hypophysis. The two form the *pituitary gland* (Fig. 406). This gland is connected with the brain by a small stalk and lies in a depression of the sphenoid bone, the Turkish saddle or *sella turcica.*

From the lateral walls of the "tween brain" grow the *optic stalks* essential for the development of the eyes, and from the dorsal surface, the *pineal gland* develops. The function of the pineal is problematical.

(3) THE MIDBRAIN, OR MESENCEPHALON.—This is a small region that forms a connecting isthmus between the other two divisions. On its ventral surface is the *crura cerebri*, a band of fibers providing communication between the cerebrum and the posterior parts of the nervous system.

In the lower forms, such as fish and Amphibia, the roof of the midbrain is expanded into the optic lobes (or corpora bigemina). In snakes and mammals, these become further divided into four centers, the corpora quadrigemina. The anterior pair of these sends fibers to the eyes; the posterior pair sends fibers to the ears.

(4) THE CEREBELLUM (L. dim. of *cerebrum*, brain; *pons* bridge).—This is formed from the dorsal part of the metencephalon, and the pons is formed from the ventral part. It has two lobes, which are connected by

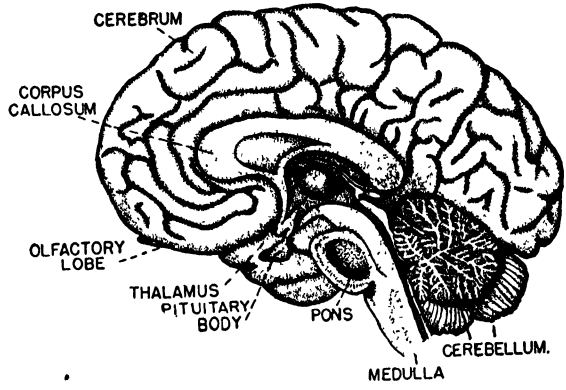

Fig. 406.—Diagram of half of a median section of a human brain. (L. Runyon.)

the central *vermis*.[1] The surface of the cerebellum is thrown into folds almost parallel to each other, thereby increasing the surface or cerebellar cortex. Like the cerebrum, there is a layer of gray matter forming this cortex. The cerebellum seems to have very little to do with consciousness, but certain evidence indicates that it controls the contractions of the body that regulate muscle tone, posture, and functions in the coordination of movements. It is highly developed in such forms as fish and birds. Birds exhibit excellent coordination. They can change their positions very abruptly yet maintain perfect equilibrium. This is shown by the fact that they can fly among the branches of a tree yet never strike even a twig! If the cerebellum of a bird is injured, this fine coordination is lost. The cerebellum is an important reflex center. The human cerebellum lies behind the cerebrum and is partially covered by it.

The cerebellum is attached to the rest of the nervous system by three pairs of cables or bundles of fibers called *peduncles*. They are the superior,

[1] Only the vermis (worm) corresponds to the cerebellum of the lower vertebrates.

connecting the cerebellum and the cerebrum; the middle, the transverse fibers mentioned below, connecting the cerebellum to the pons; and, finally, the inferior, connecting the cerebellum with the medulla, semicircular canals of the inner ear, and spinal cord. These connections are quite complicated.

(5) THE PONS VAROLII.—This structure develops from the ventral surface of the metencephalon. It contains many transverse fibers, which appear to partly surround and clasp the brain stem. In addition, there

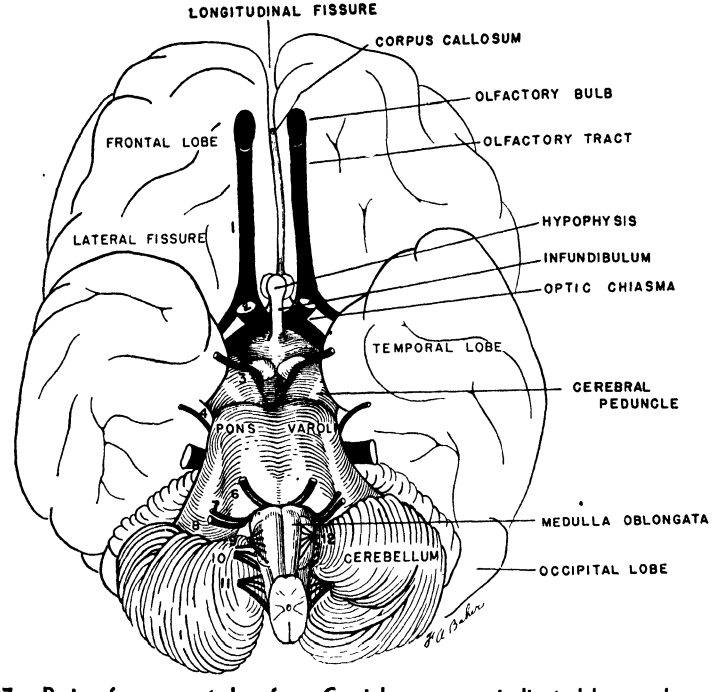

Fig. 407.—Brain of man, ventral surface. Cranial nerves are indicated by numbers 1 to 12. For names of the cranial nerves, see Appendix, page 872. (F. A. Baker.)

are many ascending and descending fibers. Some of the cranial nerves arise from the pons (Figs. 406 and 407).

(6) THE MEDULLA OBLONGATA.—This connects the brain with the spinal cord. In it are the centers that govern many vital activities, such as those of respiration, circulation, etc. If the cerebrum is lost, reason and memory are gone, but an animal may live; if the cerebellum is destroyed, all muscular control is lost; but if the medulla is destroyed, death comes at once, because breathing stops. Fibers in the medulla conduct stimuli to and from the higher parts of the brain. It is also a reflex center. The cavity of the medulla is the fourth ventricle.

(7) CAVITIES.—These are the *ventricles* of the brain and the canal of the spinal cord. In the vertebrate embryo, the central nervous system begins its development as a groove on the dorsal surface. The edges on each side of the groove roll up, meet, and fuse, forming the hollow neural tube (Fig. 403*NF*). Though much reduced, this hollow or canal persists through life as the central canal in the spinal cord. In the brain region, however, the canal is transformed into a series of irregular chambers, the four ventricles, which communicate with each other and with the canal of the spinal cord (Fig. 173*C*). There is one in each hemisphere, the first and second lateral ventricles; the third is at the base of the cerebrum in the "tween brain," and the fourth is in the medulla oblongata. In the midbrain is a lumen or canal[1] that connects anteriorly with the third ventricle and posteriorly with the fourth ventricle.[2] As pointed out, there is a space between the arachnoid membrane and the pia mater, the subarachnoid space. This is in communication with the fourth ventricle by three openings on the roof of the ventricle. From this it will be seen that the cerebrospinal fluid in the subarachnoid space is continuous with that in the ventricles and the canal of the spinal cord.

(8) FLEXURES.—In the frog, the brain has no bendings or flexures, and its axis is continuous with the spinal cord. As the brain becomes more complex, flexures appear. In man, there are three flexures. The most anterior of these is the *cephalic flexure* of the midbrain; the second, the *pontine flexure* in the metencephalon; and the posterior one is where the spinal cord joins the myelencephalon, the *cervical flexure*. These are more clearly shown in the developing brain.

b. The Spinal Cord. (1) FEATURES.—The spinal cord is joined to the *medulla oblongata*. It is made up of white and gray matter, the gray matter being on the inside in the form of the letter H (Fig. 408*B*). The spinal cord is the great highway for the transmission of impulses and is a great reflex center. The sensory, or afferent, fibers of the spinal nerves enter the dorsal side of the spinal cord, whereas the motor, or efferent, fibers of the spinal nerves emerge from the ventral side. Inside the cord are association fibers that transmit stimuli from one point to another in the brain. It is interesting to note that some of the nerve fibers cross over to the opposite side before they reach the cerebrum, so that the left side of the cerebrum receives sensory stimuli from neurons from the right side of the cord and the right side of the cerebrum receives stimuli coming from the neurons from the left side of the cord. The left side will transmit motor stimuli to the right side of the body, and the right side will transmit motor stimuli to the left side of the body.

[1] Aqueduct of Sylvius or iter.

[2] The fourth ventricle is connected posteriorly with the canal of the spinal cord.

The human spinal cord is about 18 in. long and about ¾ in. in diameter. In it are two deep grooves, dorsal and ventral. These grooves run the entire length of the cord. The cord has two enlargements, one in the cervical and one at the lumbar region at the levels with the arms and legs. These are associated with the increased nerve supply of paired appendages. From the spinal cord arise 31 pairs of spinal nerves (Fig. 402).

(2) FUNCTIONS OF THE SPINAL CORD.—The spinal cord performs two of the same functions as the medulla: (1) it conducts impulses to and from the brain, and (2) it acts as a reflex center. It may be called an important highway, since all the nerve impulses that come in by way of the spinal nerves pass through the cord and travel to the brain, to glands, and to muscles. If the spinal cord is cut across, all the parts of the body supplied by nerves below the cut are paralyzed, because there are then no pathways by which impulses may travel to and from the brain.

c. The Membranes.—In addition to the protection provided by the skull and the spinal column, the brain and spinal cord are further protected by three membranes, or *meninges*, and the *cerebrospinal fluid.* Inside the skull is a tough membrane, the *dura mater.* In the skull, this membrane also performs the function of the periosteum for the inside skull bones, but in the spinal column, the vertebrae have a periosteum of their own, and the dura mater forms a loose sheath attached only here and there to the spinal column. Next to the brain and closely following its folds is a more delicate membrane, the *pia mater.* This contains many blood vessels, which break up into small branches before entering the nervous tissue proper. Just below the dura mater is a third membrane, the delicate *arachnoid* membrane; between the arachnoid and the pia mater is the subarachnoid space, which is filled with cerebrospinal fluid. Inflammation of the brain membranes is called *meningitis.*

d. The Cerebrospinal Fluid.—This fluid, which surrounds the nervous tissue, in addition to the functions of bringing food to the nerve cells and taking away wastes, acts as a cushion and shock absorber. It is separated from the blood of the choroid plexuses of the third and fourth ventricles of the brain and differs chemically from the other tissue fluids. In man, about 200 cc., or nearly ½ pt., is separated out daily. It passes from the ventricles into the subarachnoid space through the openings in the fourth ventricle and is reabsorbed in the blood. If the openings are closed through disease, the fluid accumulates and causes a condition known as *hydrocephalus* (Gr. *hydor*, water; *cephale*, head).

4. THE PERIPHERAL SYSTEM.—The peripheral nervous system consists of 43 pairs of nerve trunks, 12 pairs arising from the brain, the cranial nerves, and 31 pairs from the spinal cord, the spinal nerves.

The autonomic system (see below) is essentially a part of the peripheral system. Since the autonomic system is adapted for certain functions, however, it is usually considered separately.

The peripheral nervous system is made up of nerves that form the connecting link between the central nervous system and the various organs and tissues of the animal body. Over these nerves, nervous impulses are conducted to and fro, the individual nerve fiber being a "one-way track," or conducting an impulse in one direction only.

a. The Cranial Nerves.[1]—In the frog and most of the other lower vertebrates, there are 10 pairs of cranial nerves, which have their origin in the brain; in man and most other mammals, there are 12 pairs. Three pairs of cranial nerves, the first, second, and eighth, are concerned with the special senses of sight, smell, and hearing. The fibers of the optic nerves cross to form the *optic chiasma* on the ventral surface of the diencephalon. The optic nerves transfer impulses that are interpreted by the brain as sight. These three pairs of nerves, as well as some others of the cranial nerves (page 872), conduct impulses in one direction only. A few of the cranial nerves are mixed; *i.e.*, they conduct both sensory and motor stimuli. The most important of these is the tenth, or vagus, which has both sensory and motor fibers and which supplies many organs of the animal body (page 872).

b. The Spinal Nerves.—There is a wide variation in the number of spinal nerves in *vertebrates;* as they issue from between the vertebrae, they are named accordingly. In the frog there are 10 pairs and in man, 31 (Fig. 402). Named according to location they are: cervical, 8; thoracic, 12; lumbar, 5; sacral, 5; coccygeal, 1. The spinal nerves are segmentally arranged; *i.e.*, the pairs are given off from the spinal cord at regular intervals. It is suggested by some authors that the segmental arrangement of the spinal nerves is correlated with the primitive segmented vertebrate body; that the cranial nerves, originally so arranged, have departed from the primitive arrangement because of the increased cephalization and specialization.

Each spinal nerve is a mixed nerve; *i.e.*, it has two roots, a dorsal root, arising outside of the cord in a spinal ganglion and a ventral root, arising in the ventral horn of the gray matter of the cord (Fig. 408).

The dorsal root contains only sensory neurons, conveying messages to the central nervous system; the ventral root contains motor or effector neurons conveying messages from the central nervous system to the muscles and glands. These two roots join shortly after leaving the cord to form the trunk of the spinal nerve. It is, therefore, a mixed nerve; *i.e.*, it has fibers that are both sensory and motor. A short distance from where the motor and sensory nerves join to form the trunk, four branches are given off: (1) a dorsal branch; (2) a ventral branch, larger than the dorsal; (3) a small branch to the membranes, the meningeal, and (4) the autonomic branch connecting with the autonomic ganglia (Fig. 410).

[1] For the names of the cranial nerves, their origin, distribution, and function, see Appendix, p. 872.

c. The Autonomic Nervous System.—This system, sometimes called the *vegetative* or *visceral nervous system*, is a special division of the peripheral nervous system.

(1) THE GANGLIA AND THEIR CONNECTIONS.—The autonomic nervous system is entirely involuntary and is concerned with the activities of the visceral structures, the intestine, heart, blood vessels, bladder, and reproductive organs. Most of the internal organs receive a double set of nerves from the autonomic system, one set stimulating and the other set inhibiting activity. The connection between the central nervous system and the organ innervated by the autonomic system is not direct but is through ganglia, which serve as relay stations.

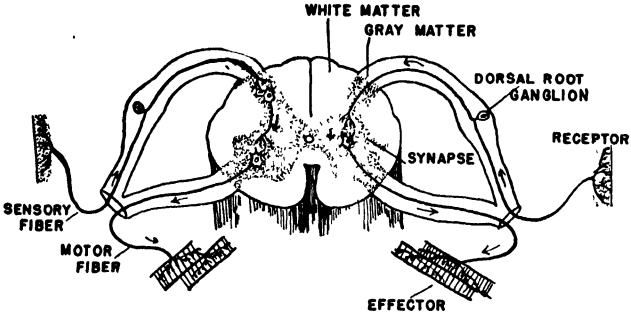

Fig. 408.—Diagram of a cross section of a human spinal cord, showing a simple reflex arc. See also Fig. 175. (B. Shamos.)

According to their location, the ganglia of the autonomic system may be placed in three groups: the *cranial, thoracicolumbar,* and *sacral.* The cranial and sacral ganglia together make up the *parasympathetic system,* whereas those of the thoracicolumbar region form the *sympathetic* (Fig. 409). The ganglia of the three divisions make connections with the brain and spinal cord, on one hand, and with the parts to be supplied, on the other. The fibers that go from the central nervous system to the sympathetic system are myelenated and are called the *preganglionic fibers;* those that go from the sympathetic system to the organ to be innervated are not myelenated and are called the *postganglionic fibers* (Fig. 410).

(2) THE SYMPATHETIC OR THORACICOLUMBAR SYSTEM consists of a double chain of ganglia, one on each side of the vertebral column (Fig. 409). These ganglia are connected with each other by nerve fibers and with the spinal nerves by branches, the *rami communicantes.* In the thoracicolumbar region, there are two of these for each ganglion, a *white ramus,* made up of preganglionic fibers, going from the spinal nerve to the sympathetic ganglion, and a *gray ramus,* made up of postganglionic fibers, going from the sympathetic ganglion to the spinal nerve (Fig. 410).

The neurons of this system are widely distributed, going to the eye, heart, skin, blood vessels, intestines, reproductive system, and some other parts.

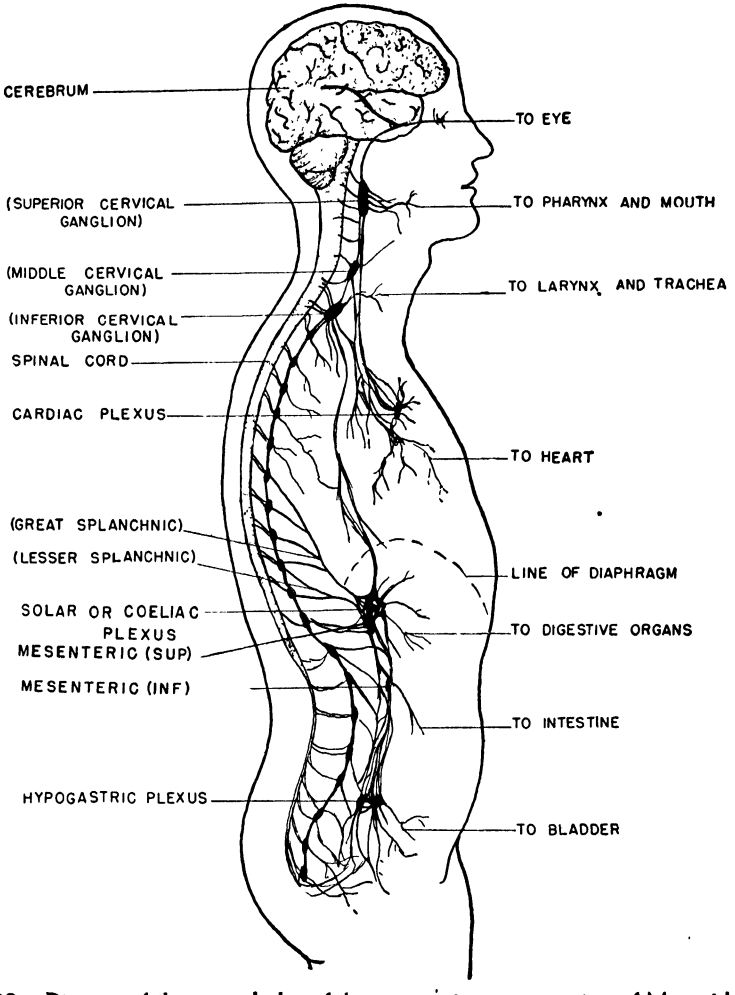

Fig. 409.—Diagram of the general plan of the autonomic nervous system of Man, side view. (B. F. Edwards.)

(3) THE PARASYMPATHETIC is made up of the cranial autonomic ganglia and the sacral autonomic ganglia. The former go to the eye, salivary glands, heart, bronchi, stomach, intestines, liver, pancreas, kidney.

The two systems are antagonistic in action. For example, the craniosacral contracts the pupils; the thoracicolumbar dilates the pupils; the craniosacral increases the secretions of glands; the thoracicolumbar

decreases the secretions of glands; the craniosacral increases the contractions of the gastrointestinal tract and relaxes sphincters; the thoracicolumbar lessens the contractions of the gastrointestinal tract and contracts sphincters, so on through a long list of activities.

(4) FUNCTIONS OF THE AUTONOMIC SYSTEM.—In summary, it may be said that the autonomic system is a division of the peripheral nervous system; that it has both afferent and efferent fibers, and that it is without

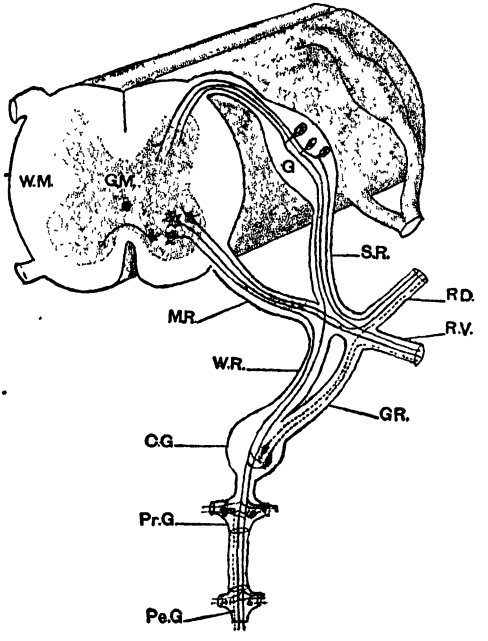

Fig. 410.—Diagram showing relation of spinal nerve to cord and sympathetic nervous system. (CG) Chain ganglion of sympathetic system; (RD) dorsal ramus of spinal nerve; (G) spinal ganglion, containing cell bodies of sensory neurons; (GM) gray matter of cord; (MR) motor spinal root, whose cell bodies lie in the ventral horn of gray matter of cord; (PeG) Peripheral sympathetic ganglion; (PrG) prevertebral sympathetic ganglion; (SR) sensory spinal root; (WR) white ramus of spinal nerve; (RV) ventral ramus of spinal nerve; (WM) white matter of cord. (From Wieman, General Zoology.)

any voluntary or conscious control. It is concerned with such vital activities as heartbeat, respiratory movements, movements of the bladder, intestines, stomach. The sympathetic or thoracicolumbar division of the autonomic system and the parasympathetic or craniosacral division are, in general, antagonistic in their action. Most of the internal organs receive a double set of nerves, one from each of the two divisions mentioned above, one set being excitatory and one set being inhibitory.

5. REFLEXES.—The manner in which the autonomic system operates has been described. The manner in which reflexes mediated through the

central nervous system operate depends, naturally, upon the way that nerves are connected with each other and with the central nervous system.

a. Reflex Arc.—Primitive nervous systems like that of *Hydra* do not include a central nerve cord but are simply nets of connected fibers (Fig. 396*C*). Reflexes in these lower animals are the result of interactions between the nerves, muscle fibrils, and the protoplasm. In the higher animals, the reflex arc, in its simplest form, includes a sensory neuron for receiving the stimulus and a motor neuron, which carries the impulse to the effector; the *effector* is often a muscle (Fig. 408). The connection between the sensory and the motor neurons is in the spinal cord. The brush-

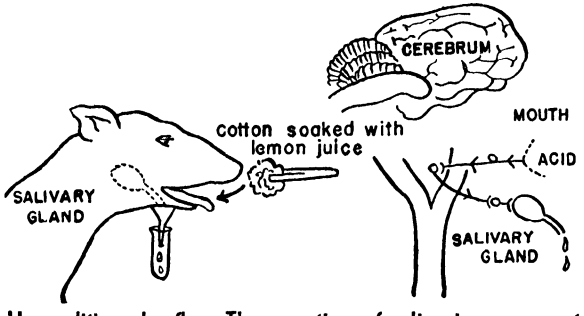

Fig. 411.—Unconditioned reflex. The secretion of saliva in response to acid (lemon juice) applied to the mouth is an unconditioned reflex, not involving the cerebrum. (Redrawn by B. Shamos from Crandall, An Introduction to Human Physiology, W. B. Saunders Company. After Dr. A. C. Ivey.)

like ending of the axon of one of these neurons comes near the dendrites of the other, forming a connection or *synapse* (Gr. *synapsis*, conjunction, union). Or there may be another neuron between the sensory and motor neurons, an *association neuron* (Fig. 408). The synapse is not a hard-and-fast connection such as occurs in the nerve net. The processes of the two neurons touch each other without being actually joined. Synapses are important because they govern the direction of the impulses. For example, if a nerve is struck at any particular point, impulses will travel away from this point in both directions. The impulse that travels in the direction normal for that nerve will pass through the synapse of the sensory to the motor nerve and reach the muscle, but the impulse that travels in the opposite direction cannot pass the synapse. Because of this characteristic of the synapses, the nervous mechanism is orderly in all its workings.

It is doubtful if the reflex arc is ever as simple as that just described. Figure 408 shows a diagram of a simple reflex action. Reflex movements may be complex and may well include movements of the whole body.

For example, a small insect passing the face might cause the winking of an eye, but a larger object, as a bat, would cause the movement of the whole body. The nervous system is furnished with a rich supply of connecting, or association, neurons; hence adjustment to changes in the environment is possible.

RATE OF IMPULSES.—Experiments have shown that an ordinary motor nerve of a mammal transmits impulses at the rate of about 120 m. per second.

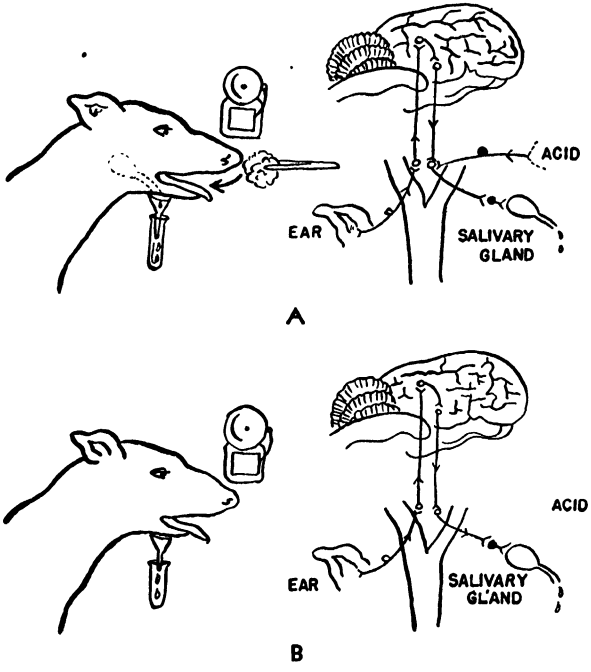

Fig. 412.—(A) Development of the conditioned reflex. The association of the sound of the gong with the application of lemon juice opens up a new pathway involving the cerebrum. (B) Conditioned reflex. After gong and acid reflex have been repeated together 50 times, the salivary gland is conditioned or taught to secrete when only the gong is sounded. The new pathways that have been opened up are adequate to produce a secretion of saliva when the gong is sounded. (Redrawn by B. Shamos from Crandall, An Introduction to Human Physiology, W. B. Saunders Company. After Dr. A. C. Ivey.)

b. Conditioned and Unconditioned Reflexes.—Two types of reflexes are recognized: (1) those just described (Figs. 408 and 411), or *unconditioned reflexes*, and (2) *conditioned reflexes* (Fig. 412). A conditioned reflex is an act repeated until it becomes a habit. One worker who has contributed greatly to our knowledge of conditioned reflexes was Pavlov, the great Russian physiologist. He performed many experiments with dogs. One was to offer food and at the same time to ring a bell. Food

stimulates the flow of saliva. After a time, the salivary juice of the dog would flow when the bell was rung without the presentation of the food.

It is believed that many adjustments made by animals are due to simple external stimuli such as light; for example, the moth flies toward a flame because of stimulation due to light waves. The robber fly normally flies toward a light in a straight line but will fly in a spiral path if one eye is blackened. In this case, the light stimulus acts on only one side. Many complications are encountered in explaining animal tropisms, and authorities are not in agreement as to the details of many of the responses observed. It is difficult to draw a sharp line between tropisms, reflexes, and instincts.

6. Habit Formation.—The formation of a habit is dependent upon learning. An animal may learn by the "trial-and-error" method and thus modify its behavior by experience. Jennings' famous experiment with *Paramecia* illustrates this very well. As Fig. 194 illustrates, when *Paramecium* strikes an obstacle, it backs away. Then it swims forward again, but after several "trials," it will find its way around a small obstacle. The "error" is that it could not find its way around the obstacle the first time. Higher animals learn rapidly. For example, a rat will learn to go through a maze after a few trials, and a monkey will soon learn to open a door. A higher type of learning is that characteristic of man and, to a lesser extent, of apes, namely, *working with ideas* rather than with objects.

7. Instincts.—A bird will build its first nest according to a definite pattern, and the spider will spin its web the way its forbears did, though the bird has never seen a nest built, nor has the spider seen a web spun. Ducks will "take to water" even though their eggs are hatched under a hen. This type of behavior is called *instinctive.* Instincts are more complicated than tropisms, yet there are situations in which it is difficult to distinguish between tropisms and instinctive behavior. It is a question whether a fly lays her eggs in a dead frog's open mouth because there is a chemical attraction to the dead meat or whether this is an instinctive action to provide the young larvae with food. In any case, it is convenient at present to refer to many activities of both higher and lower animals as instinctive.

8. Sleep.—In all living things, periods of activity alternate with periods of rest. For example, the position of *Oxalis*, the coffee plant, and other plants changes when it becomes dark. It is not known whether periods of rest correspond to sleep in animals or not.

In the human body, certain tissues—for example, the gland cells—undergo periods of activity followed by periods of rest. During sleep, the brain and other tissues rest; it is a time of recuperation. Shakespeare

speaks of "sleep that knits the raveled sleeve of care." Many theories have been expressed regarding the cause of sleep.[1]

Physiological Changes during Sleep.—Respiration is deeper and slower during sleep; secretions appear to be diminished; all metabolic activities are slowed up, and the power to perform conscious movements is lost. It is interesting to note that the sense of hearing is the last to be lost when one goes to sleep and the first to be regained upon waking.

Hypnotic Sleep.—This is a condition brought about by suggestion. It is not natural sleep. The blanched appearance of the skin under the influence of hypnotic sleep is due to the constriction of blood vessels. In natural sleep, the condition of the blood vessels is the opposite of this; *i.e.*, they dilate. Hypnosis is not well understood.

9. Behavior.—The sum total of the reactions of an organism to its environment is called its *behavior*. Behavior has been described in a general way in connection with tropisms and conditioned and unconditioned reflexes. The types of behavior may be summarized under four general heads: (1) tropistic behavior, (2) reflex behavior, (3) instinctive behavior (chain-reflex behavior), and (4) habitual behavior.

a. Tropistic Behavior.—These include familiar types of tropisms (page 596) such as turning to the light, etc. Tropisms explain behavior in plants and lower organisms, particularly the Protozoa (page 283).

b. Reflex Behavior.—Reflex behavior is characteristic of animals with nervous systems. Even *Hydra* possesses a simple nervous system and exhibits reflexes. Examples of reflexes in man are the knee jerk, which follows striking the knee just below the kneecap, and expansion of the pupil of the eye in the dark or contraction of the pupil in strong light.

c. Instinctive Behavior.—Instinctive behavior differs from a simple reflex in that it calls for the response of the animal as a whole and not in part. Instinctive behavior has never been satisfactorily explained.

d. Habitual Behavior.—The three types of behavior mentioned above are inherited; habitual behavior is acquired and is often called a *conditioned reflex* (page 616). Habits grow by practice. They are brought into existence by education and by training.

II. Chemical Regulators; Hormones

A. Chemical Coordination.—In addition to the coordination of the animal body accomplished by nervous systems, there is another sort of coordination, which may be termed *chemical coordination*. This is quite as important as nervous coordination and is concerned with the processes of the body that take place slowly. The substances responsible for chemical coordination are hormones (page 263), which are manufactured by the ductless glands and certain specialized cells. They share with the

[1] See Howell, "Textbook of Physiology," pp. 268–278 (1933).

nervous system the functions of coordination in complex organisms. They are even present in the higher plants.

B. Plant Hormones.—That plants produce hormones that are responsible for certain of the plant activities is a comparatively recent discovery. It has been found that when gravity stimulates the tip of roots, a growth-regulating hormone is produced. This diffuses back to the region of response, causing unequal growth, which, in turn, causes curvature, or bending toward the earth. If the root tip is cut off and placed on sterile gelatin, the hormone will diffuse into the gelatin. If now this small block of gelatin is placed on the stump from which the tip has been cut, the hormone will diffuse back and cause bending toward the earth, or response to gravity. Gelatin blocks on which no root tips have been placed produce no effect when placed on the stump from which the root tip has been removed.

Various plant hormones have been isolated; in addition, it has been found that many organic compounds are growth-stimulating substances. Some of these have been placed on the market under various trade names, such as Hormodin, Auxin, Root Tone, etc., and are widely used in rooting cuttings. Vitamin B is also used to stimulate growth in plants.

C. Animal Hormones in General.—Internal secretions, or hormones, are numerous and important in animals. They are produced by certain specialized cells or by ductless glands and distributed by the blood stream in the higher animals. Little is known of their presence in the lower animals such as Protozoa, coelenterates, etc.

By experiment, it has been found that whereas each secretion has its own specific function, they also affect each other; *i.e.*, they form an "interlocking directorate." In general, the internal secretions are responsible, in part, at least, for metamorphosis in Amphibia, for the development of secondary sexual characters, for a considerable part of visceral control, for many phases of behavior, and, as shown by the following description of the endocrine system in man, many other activities of the animal body.

D. Hormones in Man.—The secretions of the ductless glands are poured directly into the blood stream. The specialized cells and the glands extract certain substances from the blood and make them over into the internal secretions. The glands receive a rich blood supply. Only a small amount of the secretions is necessary for health. Indeed, an unbelievably small amount often makes the difference between a normal and an abnormal individual.

1. THYROID. *a. Location and Functions.*—The thyroid (Gr. *thyroides*, shield-shaped) has been studied more thoroughly and is better understood regarding activity than any other gland. It has two lobes, one on either side of the trachea, or windpipe (Fig. 413). The secretion of the thyroid,

thyroxin, consists of 65 per cent iodine, which seems to be the active principle in the secretion. It helps to regulate (1) oxidation in the cells; (2) heat production; (3) growth; (4) mental development; and (5) it is concerned with sexual maturity.

b. Hypothyroidism (Gr. *hypo*, less than normal; + thyroid).—If there is not enough secretion of the thyroid, many abnormalities, depending upon the age of the individual, result.

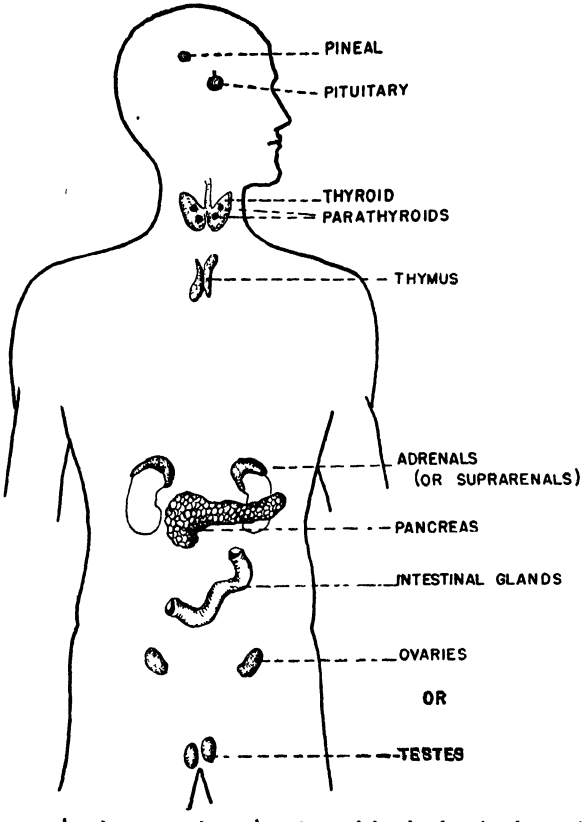

Fig. 413.—Diagram showing approximate locations of the ductless (endocrine) glands in man. (B. F. Edwards.)

(1) CRETINS.—Children whose thyroids are deficient and who do not develop normally either mentally or physically are *cretins*. Their skins are coarse, their hair scanty, their tongues may protrude, and their bodies may be puffy (Fig. 414). Feeding children of this type with extract from the thyroid glands or the glands themselves brings about normal development; the individuals are completely made over and will remain normal as long as they continue taking the extract of thyroid glands.

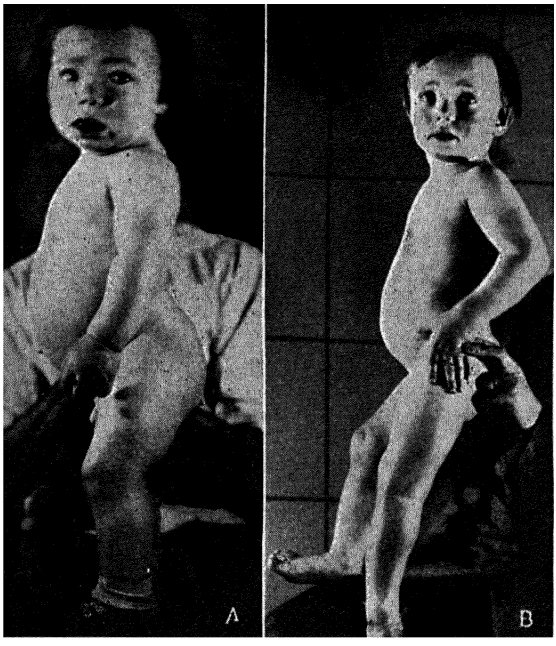

Fig. 414.—(A) A cretin, a child that had too little secretion (thyroxin) from the thyroid gland. (B) Same child after proper treatment. (Courtesy of the Good Samaritan Clinic, Atlanta, Ga.)

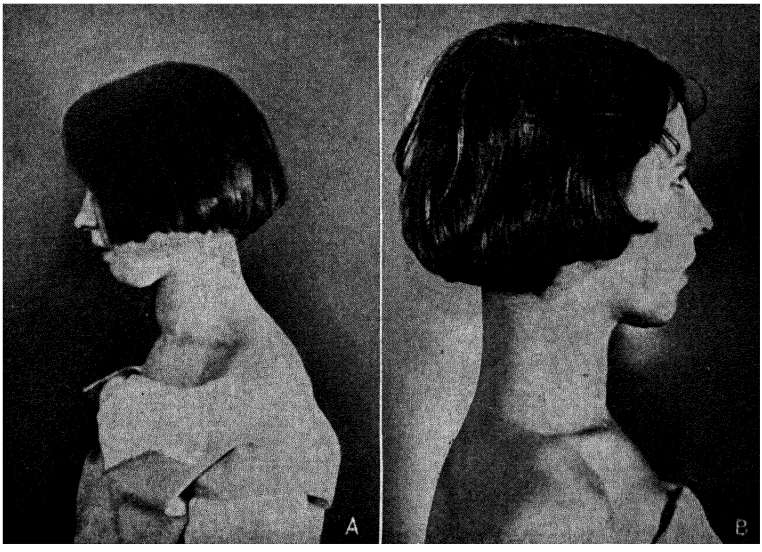

Fig. 415.—Goiter, an enlargement of the thyroid gland. (A) Girl with goiter. (B) Same girl after proper treatment. (Courtesy of the Good Samaritan Clinic, Atlanta, Ga.)

(2) GOITER.—Goiter is an enlargement of the thyroid gland (Fig. 415). If the body needs more thyroxin than is secreted by the thyroid, the gland may enlarge in an attempt to provide more secretion. Lack of thyroid secretion may be due to many causes, such as insufficient amount of iodine in the food or conditions that increase the need for the secretion. Two of these conditions are (1) low temperature and (2) the eating of much fat or protein food, thereby increasing the need for oxidation. Certain inland regions of the country are called *goiter belts*, because the lack of iodine in the food causes many people to be afflicted with enlarged thyroids (Fig. 415). Adding iodine to the food—for example, to table salt—cuts the percentage of inhabitants of some sections who suffer from goiter from an average of 35 to less than 1 per cent.

Fig. 416.—Myxedema, thyroid deficiency of middle age. (A) Case of myxedema. (B) Same woman after proper treatment. (Courtesy of the Good Samaritan Clinic, Atlanta, Ga.).

(3) MYXEDEMA.—Sometimes in middle life there is a deficiency of the thyroid secretion. Although this cannot affect growth the patient becomes sluggish, the skin puffy, usually there is a loss of hair (Fig. 416). The *myxedema* comes from the fact that the skin appears to have an abnormal quantity of water, *i.e.*, edema. The administration of the thyroid gland or the extract, thyroxin, is effective in correcting this condition.

c. Hyperthyroidism (Gr. *hyper*, over; + thyroid).—The thyroid may be over- as well as underactive. Too much thyroid secretion causes the metabolic rate to increase to such an extent that a loss in weight and an irritable disposition are likely to result. In some instances, a type of goiter develops known as ***exophthalmic goiter***. Persons thus afflicted are

"goggle-eyed"; *i.e.*, their eyes protrude. The cause of this disease is not well understood.

2. PARATHYROIDS (Gr. *para*, along side of; + thyroid).—The *parathyroids* are four small glands that are located, usually two in each lobe, in the thyroid gland. They are about the size of a grain of wheat, and the secretion from them is *parathormone*. They perform the important function of maintaining the normal level of calcium and phosphorus in the blood (see also vitamin D, page 527). Calcium is important in many physiological processes, such as the clotting of blood (page 567), maintaining muscle tone, and the health of the nerves. Calcium and phosphorus are both important in the formation of bones and teeth.

If the parathyroid glands are removed from certain animals, death follows in a few days. If there is too little of the secretion, the muscles twitch involuntarily (*tetany*), and spasms and convulsions occur. Injections of calcium bring about remarkable results; the convulsions cease within a minute, and the patient is restored to normal for a time.

3. PITUITARY (L. *pituita*, phlegm). *a. Location and Origin.*—The pituitary, about the size of a pea, is located in a small depression in the floor of the skull, the "Turkish saddle," or *sella turcica*. A narrow stalk attaches it to the brain. It has been appropriately called the *master gland*, because it affects the other ductless glands. If it is injured or removed, the thyroid, the adrenals, and the sex glands are all affected.

Embryologically, the gland is derived from two sources, the anterior part being an outgrowth from the ectoderm of the buccal region ("Rathke's pocket") and the posterior part, a downward growth from the underside of the brain nearest the throat (the *infundibulum*).

b. The Posterior Lobe and Its Secretions.—There are several parts to the pituitary gland, and each has a function of its own. The posterior lobe secretes two hormones, one of which affects *blood pressure;* the other is a *powerful stimulant* that brings about the contraction of certain muscles.

c. The Anterior Lobe.—The anterior lobe secretes several hormones. The best known is the one that affects growth.

(1) GIANTS AND DWARFS.—Too much of the growth hormone results in the development of a giant (Fig. 417); too little, in the development of a pituitary dwarf. The giants seen in circuses are individuals with too much of the secretion of the growth hormone. Often tumors are present in the gland that cause an oversecretion of the hormone. The pituitary dwarfs are well proportioned and are not to be confused with cretins or with achondroplastic dwarfs (Fig. 417). *Achondroplasia* is the lack of normal formation of cartilage, a condition sometimes called *fetal rickets*.

(2) ACROMEGALY.—Sometimes the excessive secretion from the pituitary gland does not begin until after the individual is grown. The

bones then enlarge, particularly the bones of the face, hands, and feet. This disease is known as *acromegaly* (Gr. *akron*, extremely; *mega*, large).

(3) GONAD-STIMULATION HORMONE.—If the tissue of the anterior pituitary is implanted in animals sexually immature, it will produce precocious sexual development. This condition is brought about by two hormones: one stimulates the growth of follicles in the ovaries of the

Fig. 417.—Two dwarfs and a giant. (A) Achondroplastic dwarf caused by a lack of cartilage development, (fetal rickets) in the embryo. (B) Midget, or dwarf with too little pituitary secretion. (C) Giant with too much secretion from the pituitary. (Courtesy of Keystone View Company.)

female, or the growth of seminiferous tubules in the testes of the males; the other stimulates the formation of corpus luteum in ovaries and the interstitial cells in the testes. In both males and females, there is a growth of the secondary sexual characters.

(4) PROLACTIN.—This is the lactation hormone and is produced by the anterior pituitary. It stimulates the secretion of milk in the mammary gland.

(5) FAT METABOLISM.—Since 1930, evidence has accumulated that there is a hormone in the anterior pituitary that governs fat metabolism. It may have some function in sugar metabolism.

(6) EFFECT ON OTHER GLANDS.—The secretion of anterior pituitary also has some effect upon the thyroid (thyreotropic hormone) and adrenal (adrenotropic) glands.

4. THE THYMUS.—The thymus is sometimes called *the gland of childhood*, since it reaches its greatest size in individuals of from fourteen to sixteen years of age. After that time, it generally decreases in size. It may have an influence upon early development and growth.

5. THE PINEAL GLAND (L. *pinea*, the cone of the pine).—Descartes believed the pineal to be the "center of the soul." It projects upward between the two hemispheres of the brain. In the lizard, *Sphenodon*, it is connected with a third eye (page 469). The removal of the gland appears to make little difference, though it may have some influence on growth.

6. THE ADRENALS (L. *ad*, to; *renalis*, kidneys).—These are sometimes called the *suprarenals*. An adrenal gland consists of an inner core, the *medulla* (L. *medulla*, marrow) and a *cortex* (L. *corium*, bark). In some fish, these two parts are separate glands. In man, although the two parts are united, they function separately, each producing a separate hormone.

a. The Medulla.—The hormone of the medulla is *adrenalin*, or *epinephrin* (Gr. *epi*, upon; *nephros*, kidney). Its function is to regulate blood pressure and the tonus of involuntary muscles. It has been called the *emergency hormone*. In times of stress, fear, or anger, the medulla is stimulated to pour adrenalin into the blood. This quickens the heartbeat, the blood sugar increases, and conditions are created that are favorable for an increase of strength. This explains "second wind" when one is exercising. It also explains why at times a man is said to "fight with the strength of ten men." Physicians use adrenalin as a drug to increase blood pressure, since it brings about constriction of the blood vessels.

b. The Cortex.—This portion of the adrenals produces an entirely different hormone, whose function is not well understood. In Addison's disease, degeneration of the cortex takes place, resulting in a lowering of the blood pressure, great muscular weakness, pigmentation of the skin, and other symptoms. Removal of the cortex of the adrenal is fatal. It may also control sex to some extent. Tumors and overactivity of the cortex may cause women to become bearded, and have deep voices.

7. ISLES OF LANGERHANS.—Drs. Banting and McLeod, of Canada, discovered that insulin is produced in certain patches of tissue in the pancreas known as the *Isles of Langerhans*. *Insulin* (L. *insula*, an island) is concerned with the storage of sugar in the liver and with the burning of sugar in the body; it functions also in the metabolism of fat. Fats burn "in the flame of the carbohydrates" (page 520), and when sugar

metabolism is upset, the fat metabolism is affected. If there is an insufficient amount of insulin, the disease *diabetes*, results. Patients feel hungry because the sugar is not available for food and energy; they are thirsty because of the large amount of water needed to eliminate excess sugar in the blood. Small amounts of insulin injected into the body enable diabetics to live in reasonable comfort.

8. Hormones in the Digestive Tract.—Glands in the lining of the digestive tract secrete hormones that aid in digestion.

a. Gastrin.—This hormone is produced in the *stomach* by *specialized cells*. Its function is to stimulate the production of gastric juice.

b. Secretin (page 543).—Certain cells in the mucosa of the small intestine are stimulated to produce *secretin* by the acidulated chyme as it comes from the stomach. It is carried to the pancreas by the blood stream and stimulates that gland to secrete pancreatic juice.

9. Endocrines Produced by the Sex Organs.[1]—In addition to producing eggs and sperm, the gonads produce certain hormones. The development of the sex organs is influenced by the pituitary.

a. Testes.—In mature testes of the male, *testosterone* is produced by the *interstitial cells*. This hormone, crystallized and synthesized in 1935, has to do with the secondary characters of the male, such as growth of hair, body proportions, etc. *Androsterone* is also found in the blood and testes.

b. Ovaries.—In the mature ovary, hormones are produced by the follicles. *Estrone* (or theelin), the female sex hormone, was isolated in crystalline form in 1929. It has a stimulating effect upon the lining of the uterus and the tubules of the mammary glands. When the egg ruptures from the follicle, the cells in the follicle differentiate into the corpus luteum, and these give rise to a new hormone, *progesterone*, which was first crystallized and prepared artificially in 1934. It appears to continue the work begun by estrone. The lining of the uterus is prepared for the implantation of the fertilized egg, and the mammary glands are further developed. The anterior lobe of the *hypophysis* appears to govern the secretion of milk by these glands, however.

E. Effects of Removal of Sex Organs.—Removal of sex organs leads to profound changes in animals. The mating instinct is greatly modified or lost, and there are often changes in the secondary sex characters. For example, antlers fail to develop in a male deer that has been castrated.

F. Transplantation.—If ovarian tissue is transplanted in castrated males of rats or guinea pigs, their hair and skeleton tends to become like those of the females; also, the mammary glands enlarge.

G. Freemartins.—Twins are often born to cows. If these are of a different sex, the female is usually sterile. Lillie discovered that in the calf twins there is a fusion of the embryonic blood systems so that there

[1] Male and female sex hormones are produced in both sexes, the sex of the animal determining whether a preponderence of male or female sex hormones will be secreted.

is an intermingling of the blood from each. The male gonads develop first and cause the suppression of the development of the ovary to such an extent that the female is usually sterile. She is known as a *freemartin.*

H. Placenta.—After the placenta is established, it is believed to secrete *emmenin*, a hormone which stimulates the uterus and mammary glands, as well as much of the theelin found in the urine of pregnancy. These hormones suppress the gonadotropic hormone of the pituitary. In addition, the placenta is said to be a source of supply of a blood coagulant and immune bodies.

I. Neurohumors.—So-called neurohumors are chemical mediators between nerve endings and the organs to which their nerve impulses are transmitted. Some authorities regard them as hormones.

Questions

1. Certain plants and animals do not possess nervous systems, yet they respond to the stimulus of light; explain.
2. In general, plants turn toward the light. Is there any exception to this? Explain the behavior of the prickly-lettuce plant, page 137.
3. Give examples of negative geotropism in plants. Of negative phototropism in animals.
4. Describe a neurone.
5. Where is the nerve cord of invertebrates located? Of vertebrates?
6. Compare the nervous systems of *Hydra*, earthworm, crayfish, and grasshopper.
7. What are the parts of the vertebrate nervous system?
8. Discuss the divisions of the central nervous system of man. Include in this discussion a full account of the functions of each division.
9. What is meant by the peripheral nervous system? The autonomic nervous system? What is the important work done by each of these?
10. What is the role of the three membranes of the nervous system?
11. Where is the cerebrospinal fluid found? Whence does it come? What is its function?
12. Where is the gray matter of the brain? Of the spinal cord?
13. Why is the increased surface of the brain (by convolutions) an advantage.
14. Compare a simple reflex action with a reflex of the autonomic system.
15. What types of reflex actions involve the following divisions of the central nervous system: the spinal cord, the medulla, the cerebrum, the cerebellum?
16. Distinguish between conditioned and unconditioned reflexes. Give examples of both types, other than those mentioned in the text.
17. Why is it said that a nerve impulse follows a "one-way path"? What governs the direction of the nerve impulse?
18. What are some plant hormones, and what role do they play?
19. How do the secretions of the ductless glands reach cells of the body?
20. Discuss the following glands with regard to location, secretion, and effects of over- and undersecretion:

pineal	pituitary	placenta
thyroid	posterior lobe	Isles of Langerhans
adrenal	anterior lobe	glands of the alimentary tract
medulla	ovaries	neurohumors
cortex	testes	

21. Define: tropism, taxis, receptor, effector, optic chiasma, acromegaly, freemartin, midget, cretin, achondroplasia.

CHAPTER XL

THE SPECIAL SENSES

What can give us more sure knowledge than our senses? How else can we distinguish between the true and the false?

—LUCRETIUS.

I. Sensations

The higher animals receive many sensations not included among the five conventional senses of smell, sight, touch, hearing and taste. Among these are included the sense that helps maintain an upright position, or equilibrium; a muscle sense; and, also, internal senses concerned with comfortable breathing, hunger, thirst, and the like.

Mention has already been made of effectors and receptors (page 601). These may also be called *end organs*. The end organs of reception are located at the outer end of certain sensory fibers; motor end organs are situated at the outer ends of motor fibers. Each sensory end organ is adapted to a specific kind of stimulus. For example, the retina of the eye is adapted to receive light stimuli; the ear, sound waves; etc.

II. Special Senses of Lower Animals

Exact information as to the sensations of lower animals is wanting. Most of the information that we have on this subject is based upon their behavior and what we know about the special senses of man.

A. Cutaneous Senses.—In the lower animals, many types of tactile organs are found. Included among these are the tentacles of the coral polyps, the antennae of insects, certain bristles of insects, and tactile hairs. The degree of sensitiveness to touch varies in different animals and on different parts on the surface of the animal body. In the vertebrates, practically the entire surface of the body is sensitive to touch. Regions of the body other than the surface that are sensitive to touch are the lining of the nasal cavities and the lining of the mouth.

By experiment, it can be shown that certain points of the skin are sensitive to heat; others to cold; still others to pain. Sense organs associated with some of these senses have been discovered.

B. Taste and Smell.—The receptors for the sense of smell are the *olfactory receptors*, and these are to be found in many of the lower animals. Experiments seem to show that they are located in the antennae of male moths and that there are about four thousand of them in these

large antennae. Apparently the male finds the female by means of the sense of smell.

In some animals the sense of smell is extremely well developed. A dog can detect smells that are beyond human power. In the higher vertebrates, the senses of smell and taste are located in or near the nose and mouth. It is of advantage to have these at the beginning of the respiratory and digestive tracts. In the catfish, taste organs are distributed over various parts of the body but are especially abundant on the filaments or "whiskers" around the mouth (Fig. 307*B*). Smell and taste in man are closely associated with the enjoyment of food. It is a common experience to be unable to taste anything when one's sense of smell has been impaired by a bad cold. The smell of certain foods is often associated with their taste.

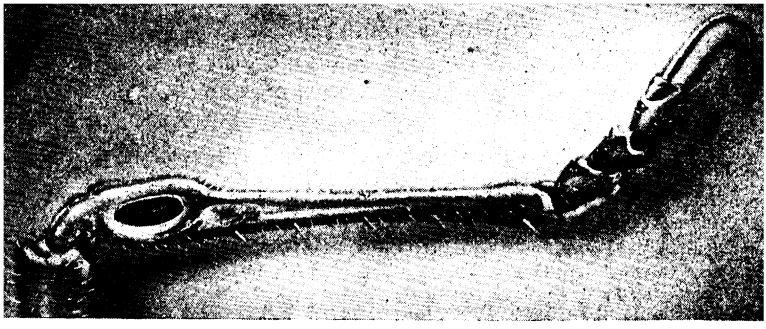

Fig. 416.— Ear, or hearing organ of the katydid. These organs are on the front legs, just below the "knee" joints. (F. A. Baker.)

C. Hearing and Balance.—A variety of structures is associated with the senses of hearing and balance. The *statocyst* of the crayfish (page 383), for example, is an organ that aids the animal in maintaining its equilibrium. The cavity of the statocyst is lined with sensitive hairs, and among these the crayfish places grains of sand. At each movement of the animal, the hairs are stimulated, and the position of the animal is automatically recorded. The statocyst may also function as an *auditory* organ.

Grasshoppers are provided with auditory organs on either side of the first abdominal segment (Fig. 278). This consists of a large membrane stretched over a cavity. The vibrations received by this membrane are transmitted to a small vesicle, which is connected with a nerve. Similar membranes are present on the forelegs of crickets and other insects (Fig. 418).

In the vertebrates, the sense organs of equilibrium and of hearing are often combined into a single structure. For example, no external ear is present in the frog, but semicircular canals, characteristic of all vertebrates, are present. These canals are filled with liquid, and when

the body moves, the liquid moves also, and a sense of position is communicated through the nerves to the brain.

The sense of hearing is associated with a drum-like *tympanic* membrane that can receive vibrations. In the frog, the tympanic membrane communicates with the inner ear by a bony *columella*. From the inner ear, the auditory nerve carries the impulses to the brain, where the sense of hearing is really produced. The inner ear is connected with the mouth by the Eustachian tube, which aids in equalizing pressures on the tympanic membrane.

Sounds are produced by *vibrations* in the air. The human ear cannot perceive vibrations above 30,000 per second or below 33 per second. For this reason, many sounds in nature are totally unheard by the human ear. Insects can detect some sounds that are unheard by the human ear. In the higher animals, the sound vibrations are collected by the outer ear and cause the drum to vibrate; these vibrations are transmitted to the inner ear by a *chain of small bones*, the hammer, the anvil, and the stirrup (malleus, incus, and stapes) and from there through the auditory nerve to the brain, which interprets the vibrations as sounds.

D. Sight.—Some of the lower organisms that possess no special sense organs are nevertheless sensitive to light. Tropisms have been mentioned (page 596) and the fact brought out that even in these cases some substance must be present to receive the light waves. Examples are eyespots in Protozoa, pigment cells in certain mollusks, etc. Lenses are often associated with such spots and are of value in focusing the light. There are many types of eyes among the invertebrates, both simple and complex.

1. Compound Eyes.—The eye of the crayfish (page 383) consists of a number of similar parts, which correspond to facets that are visible when one examines the surface of the eye with a hand lens (Fig. 269). These rod-like units (ommatidia) lie parallel to each other and may vary in number from a few to several thousand, the *crayfish* having about 2,500 and the grasshopper about 9,000. They are radially arranged with the rods tapering toward the base; each has a lens-like structure (*vitella*) and back of this, a crystalline cone. Sensory cells (*retinula*) are connected with the brain by nerve fibers. Finally, each of the units, or ommatidia, is screened from the adjacent units by a layer of pigment. For this reason, each unit receives a single impression from a different region of the object looked at, and therefore the image seen is a sort of *mosaic* (page 383). This type of vision is especially useful in detecting motion. Just how well insects see is not known. They are supposed to distinguish color in flowers, but this has not been proved.

The best developed eyes among the invertebrates are those that occur among the group of mollusks known as *cephalopods*, squids, nautili, etc.

2. The Vertebrate Eye.—The eye of man will be taken as a type of vertebrate eye (see below).

In fish, the eyes are lidless; in the frog, there is an upper eyelid, rather motionless, and a lower eyelid fused with a *nictitating* or third eyelid; in birds, there are three eyelids, an upper, a lower, and a *nictitating membrane* (page 481).

III. The Special Senses in Man

The organs of special sense in man are the same as those of the lower animals. They are classified as cutaneous senses, muscle sense, hunger, thirst, smell, taste, sight, hearing, and equilibrium.

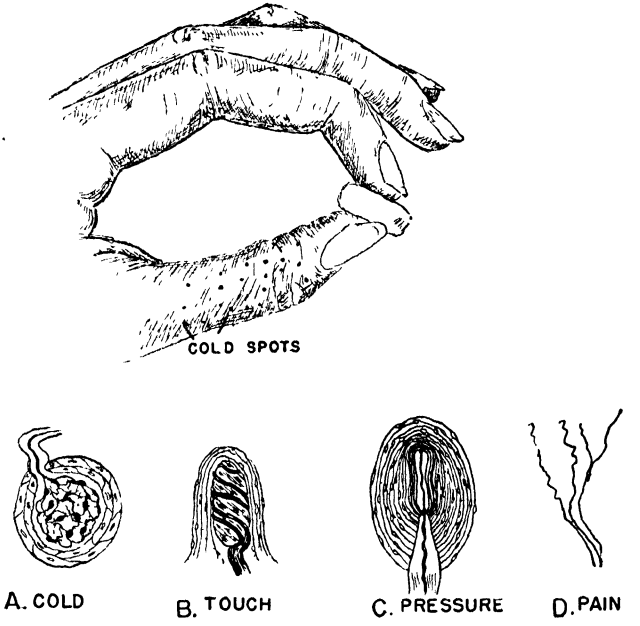

Fig. 419.—Cutaneous sensations. Cold spots are shown on the thumb. Hot, pressure, touch, and pain spots can be mapped in the same way. (B. F. Edwards.)

A. The Cutaneous Senses.—In this group are the senses of touch, heat, cold, pain, and pressure. The receptors for the cutaneous senses are widely distributed on the epithelium or in the connective tissue of the body. That they are distributed irregularly may be determined by experiment. With a stiff bristle or brush it may be determined if a point is sensitive to touch or to pain; by means of thin, cold, or warm metal rods it is possible to find the areas sensitive to heat or sensitive to cold. If a cutaneous nerve is treated with cocaine, the sensations disappear in the following order: pain, cold, heat, and touch. The smallest fibers

are the first to be affected by the cocaine. Lips and fingertips record the highest degree of sensitivity (Fig. 419).

It is estimated that for the whole cutaneous surface of the skin of man, there are something like from 3 to 4 million pain points, 5 million pressure points, 150,000 cold points, and 16,000 warm points.

1. PAIN.—This one of the most important of all the sensations and is more generally distributed over the skin and in the internal organs than any other sensation. Cutting the intestine or removing a tumor from the brain does not cause pain, but if the intestine is distended with gas or if a stone passes down the gall duct, great pain is felt. The reasons for this are not entirely understood.

2. REFERRED PAIN.—Pain arising in the visceral organs is often referred to certain areas on the skin. It is thought that this is brought about by the relationship of the nerves and the spinal cord; *i.e.*, the nerves that supply the skin area affected are in the same segment of the spinal cord with the nerves that supply the particular portion or organ affected.

3. PRESSURE.—Pressure is felt by special types of nerve cells that are differently spaced in different parts of the skin.

B. Muscular or Deep Sensibility.—In the muscles and tendons are special sensory end organs which may be simple or complex. From these, afferent nerve fibers carry impulses to centers in the brain, and these centers send out impulses along efferent nerve fibers to the muscles. This is the mechanism by which one has a certain consciousness of the condition of the muscles of all times, *i.e.*, the degree of muscular contraction, position of the body, and the like. This sense of position is necessary for voluntary movements; it aids in gauging the extent to which a muscle or group of muscles must contract to bring about certain results, and it is essential in recognizing the size and shape of objects. Without this muscular sense one could not learn to type by the sense of touch or to play the piano or the violin.

C. Hunger and Thirst.—Hunger is a sensation due to receptors in the stomach wall that are stimulated by contractions of the muscles when the stomach is empty. Thirst is a sensation associated with dryness and stickiness of the mouth, tongue, and pharynx. It may be local, caused by breathing hot, dry air, smoking, etc., by the inhalation of dust, by prolonged speaking, or by the eating of dry food; or the causes may be general, such as thirst after hemorrhage, after profuse sweating, or after greatly increased renal secretion, such as occurs in diabetes. In these cases, loss of water from the blood leads to deficient secretion of saliva and a consequent dryness of the mouth and pharynx. Because of its influence on the salivary center, fear may cause thirst.

D. Smell.—The sense of smell is probably better developed in the lower animals than in man. It is a familiar fact that a dog can follow the

footsteps of his master by the sense of smell. This animal has a large nasal cavity containing olfactory receptors.

In man, the receptors are located in the upper portion of the nasal cavity. In the section on Respiration, it was pointed out that the nasal cavity is divided by grooves and that the lowest are the paths of the air breathed in and out. The upper section is above this pathway. That is why one must "sniff" to fill the olfactory chamber and therefore "get a better smell." The olfactory receptors (Fig. 420) are not so highly developed as the taste buds. A moist membrane is necessary for smell.

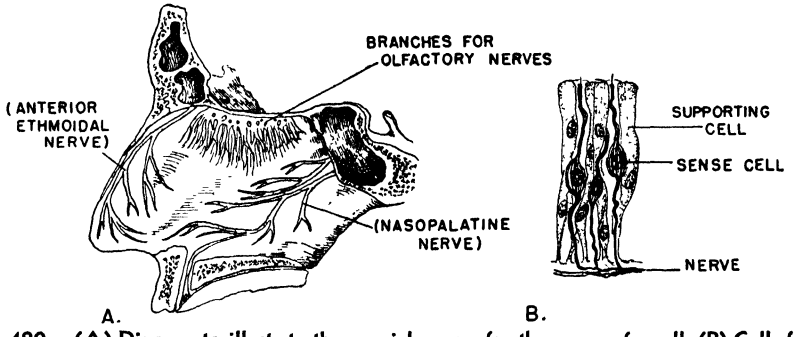

Fig. 420.—(A) Diagram to illustrate the special nerves for the sense of smell. (B) Cells from the olfactory epithelium of the human nose. (B. F. Edwards.)

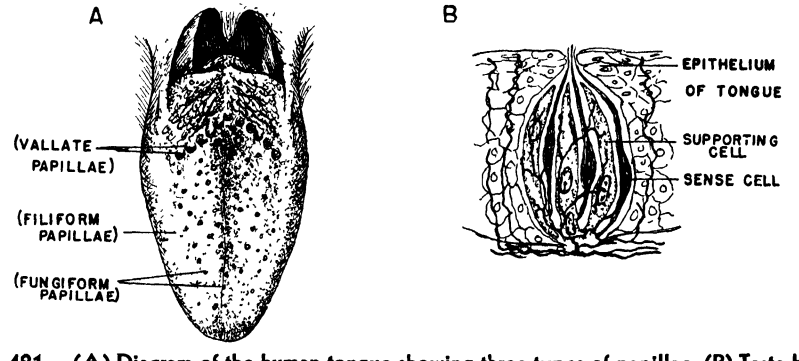

Fig. 421.—(A) Diagram of the human tongue showing three types of papillae. (B) Taste bud (greatly enlarged). (B. F. Edwards.)

The sense of smell is easily fatigued. Often, on entering a room, one may notice a smell; in a few minutes, it will not be noticed at all. Some smells are very penetrating. It is said that iodoform may be smelled when it is diluted 1 part to a million and that musk may be smelled when it is diluted 1 part to 8 million. A dry nasal cavity cannot be stimulated by aromatic materials.

E. Taste.—As previously noted, the senses of smell and taste are very closely associated. Figure 421*B* shows taste buds, one of several types,

and Fig. 421*A* shows the distribution of taste buds on the tongue. Others are present on the roof of the mouth and in the laryngeal region. A substance must be in solution before it can be tasted; a dry tongue is incapable of tasting.

Six fundamental tastes are recognized: salt, sweet, bitter, sour, alkaline, and metallic. Receptors for these are located as follows: Salt and sweet receptors predominate at the tip of the tongue. Bitter is localized on the posterior region of the tongue. Acid and sour are located along the sides of the tongue.

F. Vision.—The organs of vision and their method of operation are the same for man as for the higher vertebrates. More is known about the vision of man, however, than that of animals.

1. PROTECTIVE STRUCTURES OF THE EYE.—The eye lies in an eye *socket*, which is surrounded by bone. Pads of *fat* around the eye protect it from jars and pressures; *eyelashes* and *eyelids* keeps out the dust and protect the eye in other ways; *eyebrows* keep out perspiration. In addition, the surface of the eye is kept moist and washed by *tears*.

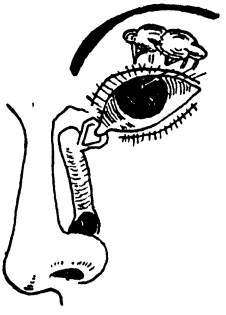

Fig. 422.—Lachrymal, or tear, gland and ducts. (B. Shamos.)

The glands that secrete the tears are located just above the eyeball (Fig. 422). They secrete tears constantly, and the winking of the eye spreads the moisture over the cornea and thus keeps it from drying out. If more moisture than is needed is secreted, it is collected by a duct that drains from the corner of the eye into a lower part of the nose. Only in crying, or when the duct is stopped up in some way, do the tears "overflow the eye." The edges of the eyelids help keep the tears from flowing over the lids. Tears also protect the eyes by removing irritating dust particles. A fatty secretion that comes from the glands (Meibomian) in the eyelids covers the edges of the eyelids.

2. MUSCLES OF THE EYES.—The eyes move very easily. Normal eyes are served by their muscles in such a way that both are moved at the same time, the same distance, in the same direction. *Six muscles*, arranged in pairs, are attached at one end of the bony socket of the eye and to the tissues of the eye at the other end. Normally, the muscles act in unison. When this occurs, the eyeballs are kept in proper relation to each other for normal sight. Sometimes, however, a muscle of one eye pulls more strongly than the corresponding muscle of the other eye; this gives rise to a condition known as "cross-eyes" (strabismus).

3. STRUCTURE OF THE EYE.—The eyeball is almost spherical. Its wall, as in other vertebrates, is made up of three layers or coats: (1) an outside

layer, the *sclera* or the *scleroid coat;* (2) a middle layer, the *choroid coat,* containing pigment and some of the vessels supplying the eye with blood; and (3) an inner coat, the *retina,* containing rods and cones, which

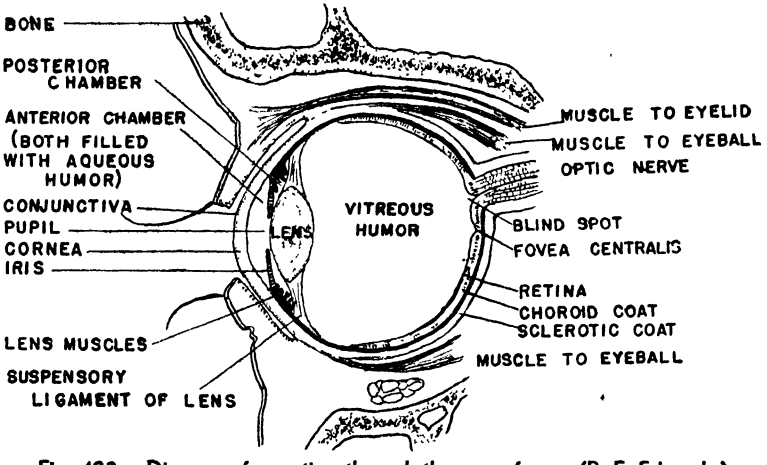

Fig. 423.—Diagram of a section through the eye of man. (B. F. Edwards.)

are specialized structures sensitive to light. These connect by means of neurones and synapses with the fibers of the optic nerve.

At the front of the eye, these three layers are modified. The scleroid coat is transparent in this region and becomes the *cornea;* the middle coat is the pigmented *iris* here and contains a central aperture, the *pupil.* The iris is made up of radial and sphincter muscles that regulate the size of the pupil and so regulate the amount of light entering the eye (Figs. 423 and 425). Just behind the iris is the *lens,* which is suspended in place by the ciliary muscles. The retina just reaches the attachment of the lens. Behind the lens is a large chamber filled with jelly-like, transparent material, the *vitreous* (L. *vitreus,* glassy) *humor,* and in front of the lens is another chamber filled with watery fluid, the *aqueous* humor.

Fig. 424.—Diagram to illustrate refraction of light. (B. Shamos.)

The *blind spot* in the human eye is the place where the *optic nerve* enters the eyeball. No rods or cones are present there.

The *yellow spot,* or macula lutea, is the spot of most acute vision and is in the center of the retina. In its center is a tiny pit, the *fovea centralis,* which is the region of most distinct vision. Only cones are present here.

4. MECHANISM OF SIGHT.—In addition to the perception of light, which is a primary requisite for seeing, there must be perception of form, color, depth, and distance. Special *light receptors* occur as far down in the animal series as the flatworms. It is possible that certain invertebrates, such as the bees, can distinguish colors. Perception of depth and distance is possessed by all vertebrates, but the highest development is in the primates, which possess *stereoscopic binocular vision.*

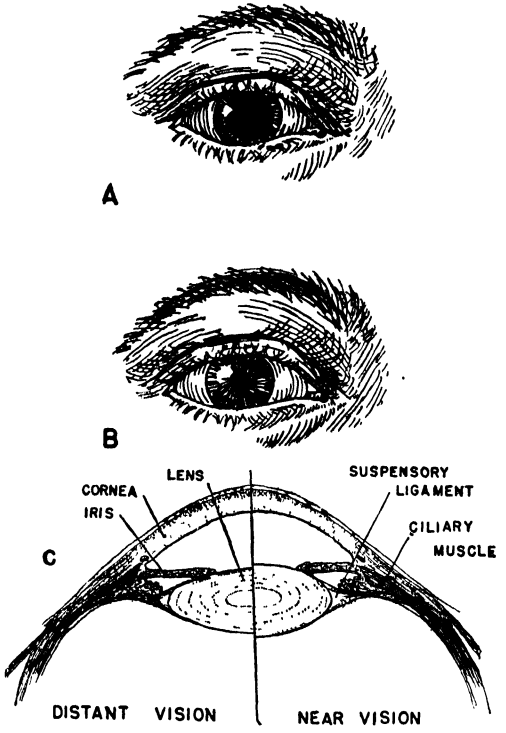

Fig. 425.—Accommodation mechanisms of the eye. (A) Pupil dilates when light is withdrawn or when eye is looking at distant objects. (B) Pupil constricts when eye is exposed to light or is looking at near objects. (C) Lens changes shape through action of ciliary muscle when looking at far and near objects. (B. Shamos.)

a. Formation of Images.—Rays of light become bent from their straight path when they pass from air into some other transparent material such as water, glass, etc. This is known as *refraction.* A simple experiment will illustrate this. If a glass rod is placed in a glass of water and then looked at from the side, it will appear broken at the point where the air and water meet (Fig. 424). The explanation is that the rays of light will be bent when they enter the water. The lens of the eye also bends the rays of light, as shown in Fig. 428. The surface of the cornea plays a role in the bending of the rays, but the lens can change the focusing power

of the eye by changing its curvature. The image is "upside down" on the retina, but the true position is *interpreted by the brain.*

b. Accommodation.—The eye has been likened to a camera. The camera contains a lens, a shutter (*pupil*), to regulate the amount of light coming in, and a sensitive plate (*retina*) to receive the image. The camera is focused by moving the lens and the sensitive plate closer together for the far objects and farther apart for the near objects to be photographed. In man, focusing is accomplished by changing the shape of the lens (Fig. 425). If near objects are to be viewed, the lens is thickened by the action of the ciliary muscles; if a far point is to be viewed, the ciliary muscles relax and the lens become flatter and thinner. In young people, the lens is more elastic and the ciliary muscle more contractile than in older people. For this reason, it is possible to focus the lens so that the images of the objects only a few inches from the eye will be formed. With age, the lens loses elasticity and the ciliary muscle becomes less contractile. Convex glasses are used to aid farsight of middle and old age.

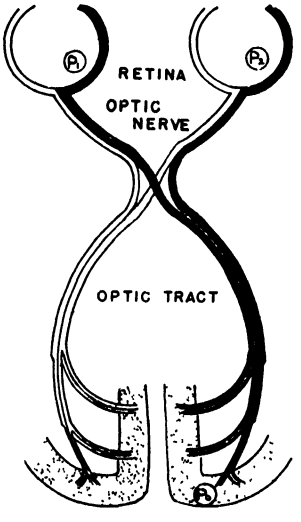

Fig. 426.—The optic pathways as seen in a horizontal section through the head. The right half of each retina sends fibers (shown in black) to the right occipital cortex. P_1 and P_2 are shown as a pair of corresponding points. Fibers from these two points presumably go to the same point in the visual cortex (P_0), since simultaneous stimulation of these two points causes a single sensation. If images of an object are formed on noncorresponding points, the object is seen double. See also Fig. 407. (Redrawn by B. Shamos from Carlson and Johnson, The Machinery of the Human Body, University of Chicago Press.)

c. The Visual Pathways to the Brain.—Images that fall upon the retina set up nerve impulses that are carried to the brain by the optic nerve. Here they connect with other fibers that end in the cortex of the occipital lobe of the brain. The two optic nerves meet a short distance behind the eyes, forming the *optic chiasma* (Fig. 426). As shown in the diagram, the fibers nearest the nose on each side cross over, whereas the rest of the fibers in each optic nerve continue straight backward. An object placed in front of the eyes creates an image upon the left half of both retinas or upon the right half of both retinas, never upon the right half of one retina and upon the left half of the other one so long as the eyes are in their true positions.

d. Perception of Light and Color.—Light waves are of varying length, those of light and color being from 0.0004 to 0.0008 mm. in length. When

these enter the eye, they bring about a chemical change in the rods and cones. These changes give rise to impulses that are carried by the optic nerve to the brain, which interprets or translates them.

e. Function of the Brain in Seeing.—The images that fall upon the retina start impulses in the eye, but these impulses must be carried to the brain before sight is produced. The center for sight is in the occipital lobe of the brain.

f. Binocular Vision.—If one gazes at an object with one eye, it appears somewhat different from the same object looked at with both eyes. This is because man possesses *binocular vision.* By this is meant that the two images falling upon the two retinas are fused in the brain. If an image is

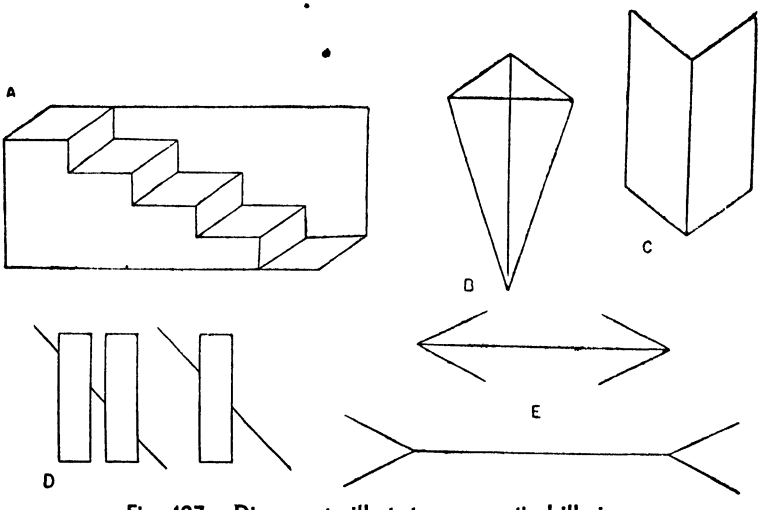

Fig. 427.—Diagrams to illustrate some optical illusions.

looked at first with one eye and then with the other, it will be realized that the image from one eye differs a little from that of the other eye, yet when the image is looked at with both eyes, a single image results; the two images have been fused in the brain.

The power of judging depth and distance is dependent upon several things. In looking at an object, one eye sees more of one side and the other eye sees more of the other side. One is not conscious of this, but one learns by experience and by handling that this slight difference in the sensations from the two eyes are produced only by solid objects. In looking at a near object, the muscles of the eye contract in one way; in looking at the same object farther away, the muscles contract in a different manner. Experience teaches that these different pulls indicate that the object is not flat but has depth.

g. Optical Illusions.—Things are not always what they seem, since judgment is sometimes deceptive. In Fig. 427*E*, for example, the two long

lines do not look as if they were of the same length because of the position of the lines at their ends. The result is a mistake in interpretation.

5. Some Defects of the Eye. The eyes of children are easily injured, because they are not yet mature. They are delicate organs, easily injured by overuse, by reading in a flickering or in a dim light or in a poor position, such as lying down or bending too low over a desk. Books for children should be printed with clear type on paper that is not glossy.

a. Nearsight and Farsight.—In a nearsighted eye (*myopic*), the eyeball is so long that images are formed in front of the retina instead of upon it; the result is a blurred image that can be corrected by concave glasses that focus the image directly upon the retina (Fig. 428*B* and *C*). Farsighted (*hyperopic*) eyes have just the opposite condition; the eyeball is short, and the images are formed behind the retina. Convex glasses will remedy this defect (Fig. 428*D* and *E*). Defects of this kind may, of course, be slight or pronounced.

b. Astigmatism.—This fairly common defect of the eye is due to the *unequal curvature* of the refracting surfaces of the eye. For example, the cornea may be more curved in a horizontal direction than in a vertical direction or vice versa. Glasses are easily fitted to correct this defect.

c. Cross-eye, or Strabismus. As explained, cross-eyes are due to the fact that the two eyes do not act in unison; the muscle of one eye pulls more strongly than the corresponding muscle of the other eye. Under these circumstances, the

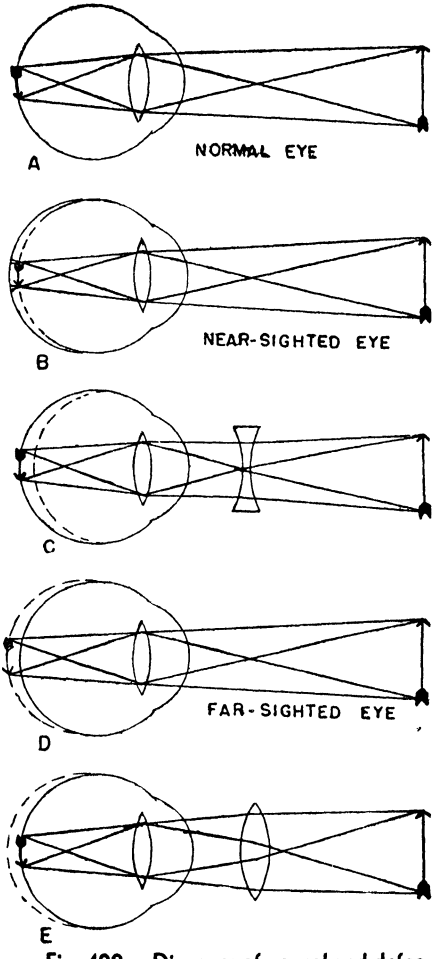

Fig. 428.—Diagrams of normal and defective eyes. (A) Normal eye; the image falls directly on the retina. (B) Nearsighted eye; the eyeball is usually longer than normal and the image is focussed in front of the retina. (C) Concave glasses correct nearsightedness. (D) Farsightedness; the eyeball is shorter than normal, and the image falls behind the retina. (E) Convex glasses will correct farsightedness.

images fall upon different regions of the retina. A person so affected learns to disregard the image of one eye.

d. Cataract.—Sometimes the lens of the eye becomes opaque, and the light rays are prevented from reaching the retina. There is no known cure for this condition except surgery. When the lens becomes too opaque, it must be removed. The light rays can then reach the retina, but all power of accommodation is lost.

e. Opaque Cornea.—Sometimes, through accident, the cornea becomes opaque. This is especially true if scar tissue is formed. The light rays cannot enter the eye through scar tissue.

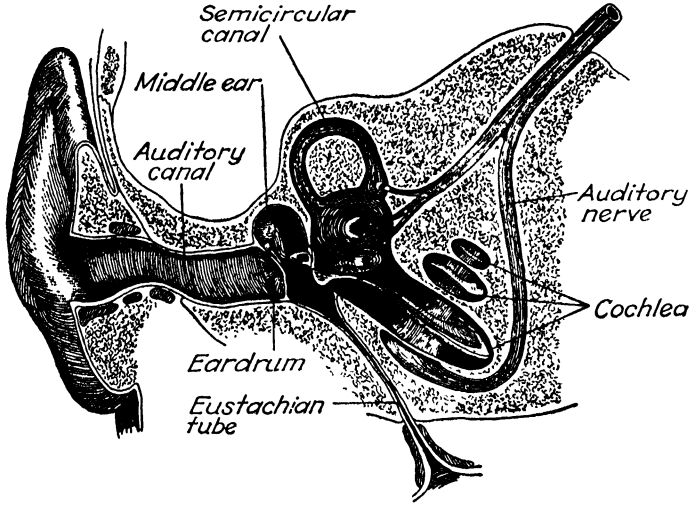

Fig. 429.—Diagram of the human ear. (After Czermak, from Haupt, Fundamentals of Biology.)

f. Color Blindness.—Inability to distinguish certain colors is called *color blindness*. There may be many forms and degrees of this defect. The most common form is *red-green color blindness*. For information regarding inheritance of color blindness, see page 736.

G. Hearing and Equilibrium.—The human ear, as are all vertebrate ears, is adapted for the reception of stimuli concerned with the senses of hearing and equilibrium. There are three parts, the external, middle, and internal ears.

1. The External Ear.—In man, the outer ear consists of cartilage covered with skin, the *pinna*. This is not so effective in collecting sound waves as the ears of certain of the lower animals. A horse, for example, can move his ears toward the direction of sound so as to gather in the sound waves. The other part of the external ear is the external auditory canal or *meatus*. This is the passageway for sound waves, and at the end of it lies the *tympanic membrane* (Fig. 429).

2. The Middle Ear.—The middle ear is a cavity filled with air, connecting with the pharynx through the Eustachian tube. This tube serves to equalize the air pressure in the middle ear with that on the outside.[1] Sound waves are transmitted across this cavity by three small bones, the *hammer*, the *anvil*, the *stirrup* (the *malleus*, *incus*, *stapes*). The first bone in the chain is the malleus, which is attached to the eardrum on one side and to the incus, or second bone in the chain, on the other side; the incus, in turn, is connected with the stapes, which is attached to the oval membrane (fenestra ovalis) of the middle ear.

The connections of the middle with the inner ear are through two small openings closed by membranes, the fenestra (window) ovalis (oval) and the fenestra rotunda (round).

3. The Inner Ear.—The inner ear is made up of bony and membranous parts and is protected by bone. In the inner ear are the receptors for hearing and equilibrium. Those concerned with hearing are inside the *cochlea*, a curious, snail-shaped structure. The semicircular canals are concerned with the sense of equilibrium. On account of its shape, the inner ear is often referred to as the *labyrinth*. The *bony labyrinth* is a series of odd-shaped cavities in the temporal bone. These are (1) the *vestibule*, (2) the *cochlea*, and (3) the *semicircular* canals. The bony labyrinth encloses a *membranous labyrinth*, which, in general, follows the shape of the bony labyrinth. Between these two labyrinths is a fluid, the perilymph, which apparently has the function of transmitting vibrations received from the middle ear to a second fluid inside the membranous labyrinth, the endolymph.

a. The Vestibule.—This is the central cavity of the inner ear. It is connected with the middle ear by the two fenestrae mentioned above. The *membranous vestibule*, enclosed by the bony vestibule, does not conform to it in shape. It is made up of two small sacs: the *utricule* (L. *uter*, a little sac or bag made of skin), attached to the semicircular canals, and the *saccule* (L. *saccus*, a sac), attached to the cochlea.

In embryonic development, the first sign of the human ear is a small pit. Later, this pit is closed off as a small sac or vesicle (Fig. 403). In later development, this sac is divided into an upper portion, the utricule, and a lower portion, the saccule. From the utricule, the semicircular canals develop, and from the saccule, the organ of hearing, the cochlea, develops.

b. The *cochlea* (L. *cochlea*, snail).—This structure, forming the anterior part of the bony labyrinth, is coiled two and three-fourths times upon itself and resembles a snail shell in appearance (Fig. 429).

(1) The canals and the organ of Corti.—Within the bony cochlea is a complicated arrangement of three spiral *canals* or *scalae* (L. *ocala*,

[1] No equalization of pressure is possible if this tube is closed. Temporary deafness occurs when the tube is closed from inflammation.

ladder). The inner membranous canal (scala media) contains endolymph and also sensory cells grouped to form the spiral organ of Corti, the essential organ of hearing. This complex organ is equipped with sensory hairs, and the stimuli received by these hairs reach the brain through the auditory nerve.

(2) TRANSMISSION OF SOUND.—The sounds are collected to some extent by the external ear; they pass through the external auditory canal to the eardrum, which they cause to vibrate; the vibrations are transferred across the middle ear by the hammer and anvil to the stirrup bone, which fits into the fenestra ovalis of the inner ear; the perilymph of the inner ear receives the vibrations through the membrane stretched across the fenestra ovalis and transmits them to the endolymph inside the membranous labyrinth; the movements of this fluid stimulates the sensory hair-like structures of the organ of Corti and the impulses thus received reach the brain through the auditory nerve (the eighth).

Just *how* the organ of Corti analyzes the types of sounds, pitch, timbre, etc., is not known. Some evidence has accumulated, however, that high notes affect the region of the cochlea, where the membrane is narrowest, and that the low notes affect the region where the membrane is broadest.

(3) THE AUDITORY CENTER.—The auditory center is believed to be in the temporal lobe of the cerebrum. Removal of both temporal lobes causes complete deafness; removing one lobe impairs the hearing. For this reason, it is thought that some fibers cross to the opposite side and some do not, after the manner of the *optic chiasma.*

c. The Semicircular Canals.—These are concerned with the sense of equilibrium and balance. As noted, they are connected with the utriculus. The canals are placed in three planes roughly at right angles to each other. Each of the canals has an enlargement, a bulbous swelling, the *ampulla,* and inside of these are ridges with *hair-like processes* on their margins. Endolymph fills the canals, and when the position of the head is changed the fluid moves, and movements stimulate the sensory hair-like processes. The impulses so received are transmitted to the center for equilibrium and balance in the cerebellum by the auditory nerve. An animal is thus enabled to adjust its position with reference to the stimuli received through the influence of gravity.

Questions

1. Discuss the development of the special senses in the lower animals.
2. What are the cutaneous senses of man? What is meant by "referred pain"?
3. Why are the senses of taste and smell described as "chemical senses"? Describe the organs of taste and smell in man. Why do some things seem to lose their flavor when one has a cold?
4. Is it possible to taste food that is completely dry? Explain. Review other functions of the saliva.

5. Where on the tongue does one taste bitter? Sweet? Salty? Acid?
6. Explain what is meant by muscle sense.
7. Describe the structure of the eye of either the crayfish or the grasshopper. How do these animals probably see?
8. Describe the structure of the human eye. How does the eye move? How are images formed on the retina? What is meant by accommodation for far- and near-sight? What are some other defects of the eye? How may eye defects be corrected by glasses?
9. What is the function of the tear (lachrymal) glands? Do these glands secrete only when their owner is crying? What glands are present in the eyelids? What is their function?
10. The image that falls on the retina of the eye is upside down, yet things are seen in their upright position. Explain.
11. Give an account of the structures of the ear concerned with hearing. How do we hear? Compare the mechanism of hearing of the frog with that of man.
12. Describe the location, structure, and functions of the semicircular canals.
13. How is pressure in the ear regulated?
14. Can you explain why more can be done to aid defective eyes to see than can be done to aid defective ears to hear?
15. What is the function of the brain in seeing? Where in the brain is the auditory center located?
16. Name some animals with keener sight than man; with keener hearing; with keener sense of smell.
17. Define: ommatidia, facet, accommodation (of the eye), optic chiasma, optical illusion, binocular vision, nictitating membrane, Eustachian tube, organ of Corti.

CHAPTER XLI

SUPPORT, LOCOMOTION, PROTECTION

Man is all symmetrie,
Full of proportions, one limb to another.
—HERBERT.

I. Movement

The simplest animals move about from place to place by various means. *Amoeba* moves by means of pseudopodia; *Paramecium* swims by means of cilia. Either of these Protozoa can contract its body and "squeeze through" a very small space. The crayfish uses its tail for swimming, its legs mainly for walking; insects fly by means of wings; other invertebrates move in other ways. But except in the very lowest animals, locomotion depends upon two types of structures, skeletal and muscular.

II. The Skeleton

A. Exoskeletons and Endoskeletons.—Exoskeletons, characteristic of invertebrates, usually cover the outside of the body; endoskeletons, located inside the body, occur principally among the vertebrates.

B. Skeletons of the Invertebrates. 1. PROTOZOA.—Among the Protozoa, shells of various types are secreted. For example, *Arcella* secretes a shell of chitin; *Difflugia* constructs a covering of sand grains; the Foraminifera have skeletons of calcium carbonate, and the Radiolarians secrete skeletons of silica, which may be very complex and beautiful (Fig. 196).

2. SPONGES.—Sponges may have a framework made of calcium carbonate or more rigid silicious skeletons (Figs. 199 and 200), or they may secrete a substance akin to silk, *spongin* (Fig. 201), as found in bath sponges.

3. MOLLUSKS.—Mollusks produce the types of shells found in snails, clams, etc. In the bivalves, the two sides are fastened together with a membranous hinge (Fig. 252).

4. ARTHROPODS.—Crayfish and insects secrete a hard exoskeleton of chitin, which may be reinforced by mineral salts. These animals could not move if their exoskeletons did not have joints. Motion in them is dependent upon muscles that are attached to the inside of the exoskeleton. In order to grow, the arthropods must shed their skeletons from time to time (ecdysis) and secrete new and bigger ones (page 373).

C. The Vertebrate Skeleton.—The vertebrate skeleton is an endoskeleton derived from mesoderm. It is composed of living tissue, which may be of two kinds, cartilage and bone.

1. Cartilage and Bone.—Cartilage is made up of a more or less transparent elastic material, the *matrix*, in which are scattered cells. It often precedes the formation of *bone*, in which the matrix is made hard by the deposition of calcium carbonate and calcium phosphate. The scattered bone cells are in small cavities or lacunae (Fig. 430). These are arranged concentrically in irregular layers around a central cavity, the Haversian canal. Bone is rigid, nonelastic, and supports tissue. About two-thirds of the weight of a dry bone is mineral matter and about one-third animal matter. The bones of young animals contain less mineral

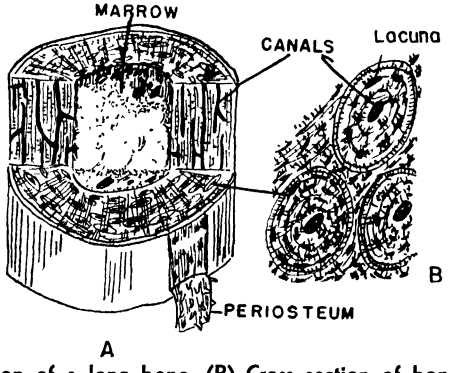

Fig. 430.—(A) Portion of a long bone. (B) Cross section of bone (highly magnified). (Modified from various authors by B. Shamos.)

matter than those of older animals, and for this reason their bones are less brittle. If bone is burned in the fire, the animal matter will be burned out and will then crumble and break easily; or if a bone is placed in any weak acid, such as 20 per cent HCl, or in strong vinegar and left there for a time, the mineral matter is dissolved out, and the bone becomes as limber as rubber and may be tied into a knot.

2. Types of Bones and Their Uses.—The bones in the human skeleton vary greatly in shape; they may be long, short, flat, cylindrical, or irregular. The *long* bones, such as those of the limbs, are of importance in rapid locomotion. *Short* bones, such as those of the wrists and the ankles, allow free movement over short distances. Where support is particularly needed, cylindrical bones are present, such as those of the limbs. Overweight in the long bones is avoided because of their peculiar structure; a thin layer of compact bone surrounds a central portion, which is spongy. In addition, these long bones contain cavities. A hollow cylinder is stronger than the same amount of material in solid form. The cylinder contains the same material, yet it supports the weight better.

Man uses this principle in constructing buildings. Grass stems or, better still, wheat stems that support heavy heads of wheat are good examples of the use of the hollow cylinder in nature.

The *flat* bones serve in two ways: either they protect delicate organs, as do the bones of the skull, or they afford a large area for the attachment of muscles, as do the hip bones. The vertebrae are irregular bones that (1) support the body, (2) protect the spinal cord, and (3) serve for the attachment of muscles. The spines of the vertebrae are especially adapted for the third function.

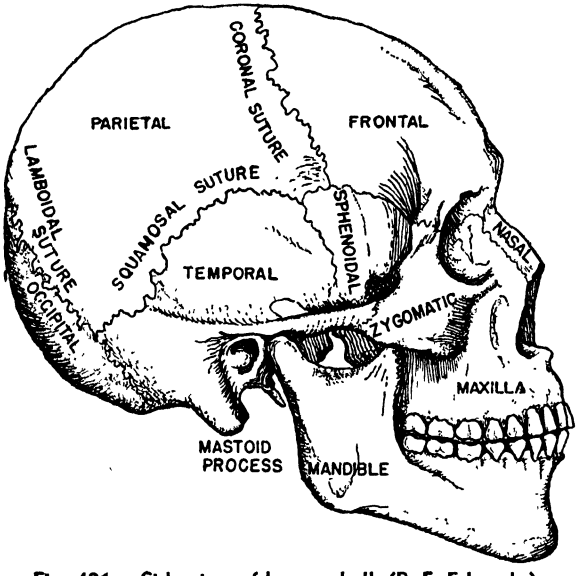

Fig. 431.—Side view of human skull. (B. F. Edwards.)

3. Bone Marrow.—There are two kinds of marrow in the cavities of the long bones: (1) *red marrow* in the spongy bone and (2) *yellow marrow* in the large cavities. The yellow color is due to the presence of large amounts of fat. In the red bone marrow, the *red blood corpuscles* are formed. Bone marrow also contains many blood vessels and nerves.

4. Joints.—Three types of movable joints occur in the skeletons of higher vertebrates: (1) the *hinge joint*, (2) the *gliding or pivotal joint*, and (3) the *ball-and-socket joint*. Figure 443 shows a hinge and a pivotal joint such as occur in the elbow. Ball-and-socket joints are present in shoulders and hips. Where bones meet in a joint, they are enlarged and covered by a layer of smooth cartilage. The membranes that enclose the joint secrete a fluid, the *synovial fluid*. This fluid lubricates the joints so that they work smoothly. The joints are held together by *ligaments* (L.

ligamentum, bandage). Immovable joints also occur as in the human skull (Fig. 431). Such skull joints are called *sutures*.

5. The Divisions of the Skeleton.—The skeleton is divided into three parts: (1) the *axial* skeleton, (2) the *appendicular* skeleton, and (3) the *visceral* skeleton.

a. The Axial Skeleton. (1) The skull.—The skulls of the cyclostomes and the elasmobranchs are cartilaginous (page 442). In the skulls of the bony fish, there are two kinds of bones, *cartilage bones* that develop from cartilage and *membrane bones* that develop from membranes. In the amphibian skull, some cartilage is retained in the skull. The frog skull

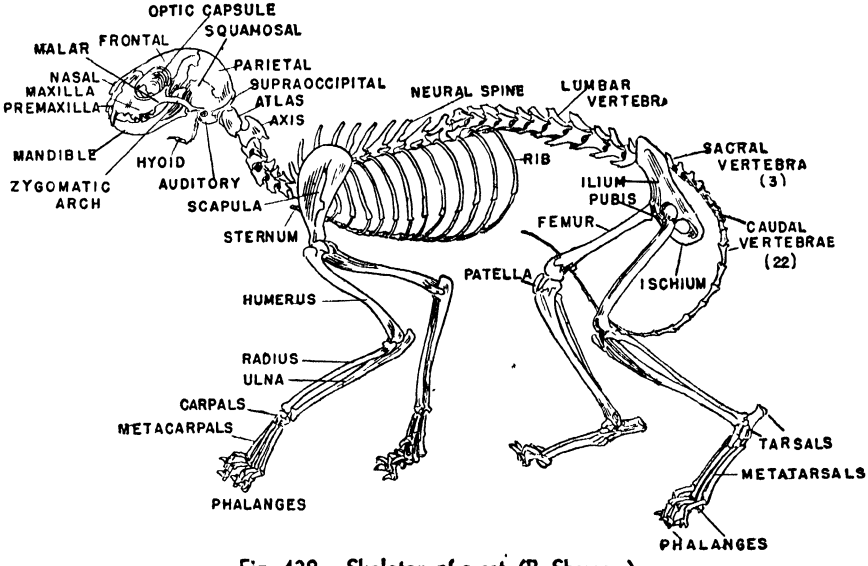

Fig. 432.—Skeleton of a cat. (B. Shamos.)

(Fig. 160) is broad and flat and has two occipital condyles, which articulate with the spinal cord. The reptile skull has but one occipital condyle and is more bony than the amphibian skull. One occipital condyle is present in the bird skull. The bird skull is composed of very thin bones that have completely fused. The mammalian skull has fewer bones; some have united; others have been lost. This skull is relatively wide and deep. There are two occipital condyles, as in the amphibians.

In spite of the differences noted, there is a surprising similarity in the bones to be found in a series of vertebrate skulls. There has been a process of simplification in the higher forms.

(2) The spinal column.—In the higher animals, neck vertebrae allow a turning of the head. A frog, for example, is able to roll its eyes but cannot turn its head to look backward. The number of vertebrae in the spinal column of vertebrates averages about 35, though they may

vary from 26 to 80. The upper region of the spinal column is the *cervical* region. In all mammals except four genera, there are 7 of these. Next is the *thoracic* region, and the number varies; the cat (Fig. 432) has 13; *man* has 12. The vertebrae in this region have *facets* for the articulation of the ribs. The largest vertebrae are those in the lumbar region, and the number of these varies from 2 to 9. In the sacral region, from 2 to 10 are fused to form the sacral bone; the number of *caudal* vertebrae varies greatly; in man, there are only 4 or 5.

Each vertebra consists of a *cylindrical* or *oval centrum;* dorsal to this is the *neural arch,* which encloses the nerve cord (Fig. 433). Three processes extend from the neural arch, a *dorsal neural spine* and two *lateral transverse processes.* Except on the first vertebra, these are separated by

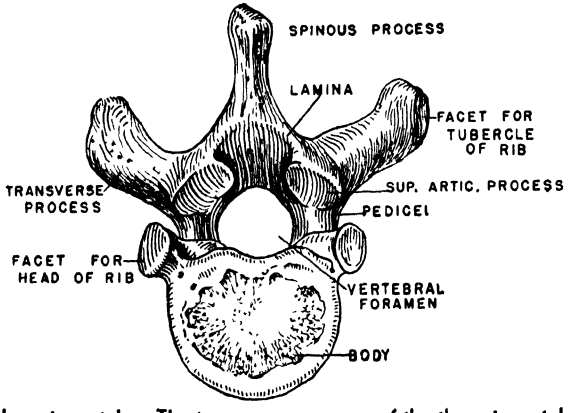

Fig. 433.—A thoracic vertebra. The transverse processes of the thoracic vertebrae give partial attachment for the ribs. (F. A. Baker.)

intervertebral disks of *cartilage* for the attachment of muscles. The individual vertebrae vary in various parts of the spinal column.

(3) STERNUM AND RIBS.—The breastbone is the *sternum,* and attached to it by *costal cartilages* are the first 7 pairs of ribs, designated as the *true ribs.* The next three pairs are called the *false ribs* and are attached to the costal cartilages, the lower pair are free and are known as the *floating ribs.* There are 12 pairs of ribs in man.

b. The Appendicular Skeleton.—The appendicular skeleton consists of the limbs, or appendages, and their supporting girdles. In fish, the appendages are fins, paired and median. In the higher vertebrates, there are two pairs of appendages and a pectoral and pelvic girdle (Fig. 432).

(1) THE PECTORAL GIRDLE.—This is made up of the *shoulder* bones, the *scapulae,* and the *collarbones,* or *clavicles.* Not all mammals have collarbones. The arms articulate with the scapulae.

(2) THE PELVIC GIRDLE.—This consists of two bones, each of which is made up of three bones, the *dorsal ilium*, which articulates with the *sacrum*, the *ventrial ischium*, and the *pubis*, united to form a single bone, the *innominate*. The two innominate bones are joined to each other in the front. The lower abdominal organs lie in and are partly supported by the *pelvis*.

(3) THE LIMBS.—Vertebrate limbs, in all forms above the fish, have a remarkable similarity of plan, even though they are used in very diverse ways. Typically, the limb is *pentadactyl* (Fig. 434). The *forelimb* of a typical land vertebrate consists of a single bone in the upper arm, the

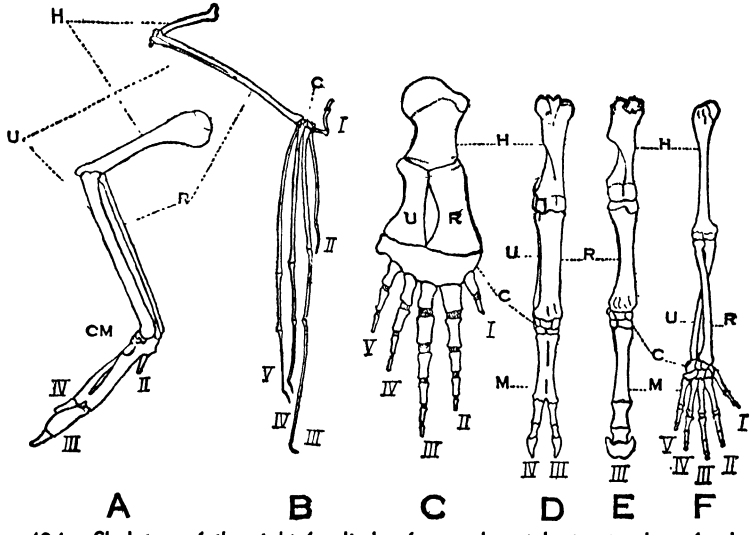

Fig. 434.—Skeleton of the right forelimb of several vertebrates to show fundamental similarity of structure. (A) Bird (raven). (B) Bat. (C) Whale. (D) Ox. (E) Horse. (F) Man. (C) carpals; (CM) carpometatarsal; (H) humerus; (M) metacarpals; (R) radius; (U) ulna; I—V, digits. (After Scott and Wieman.)

humerus, which articulates with the *scapula;* in the lower arm are the *radius* and the *ulna;* in the wrist there are nine small bones, the *carpals;* in the hand or palm, five *metacarpals;* and in each of the five fingers, or *phalanges*, there are usually three bones. The number of bones in these phalanges, or digits, varies but is usually quite regular in classes. The thumb or great toe is designated as digit I, and the others, in order, as II, III, IV, V. Knowing the phalangeal formula is a help in classification (Fig. 434).

The *hind limb* is on the same plan, a single upper bone, the *femur*, which articulates with the *pelvis;* two bones below the knee, the *tibia* and

fibula; the *ankle,* nine *tarsals;* the foot, five *metatarsals,* each bearing a phalange or digit.

The feet of animals show many remarkable adaptations correlated with the way they travel. Animals that travel at a high rate of speed have longer legs. There are three types of feet (page 504), the primitive flat-footed type, *plantigrade,* characteristic of bears and man; the *digitigrade,* characteristic of cats and dogs; and the *unguligrade,* characteristic of horses and cows (Fig. 435).

c. The Visceral Skeleton.—The visceral skeleton develops around the anterior part of the alimentary canal. In the lower vertebrates, especially the fish, it is a series of cartilaginous arches associated with the gill arches or the respiratory system. In animals adapted for life on land, these structures are transformed into other uses. In fish of the present

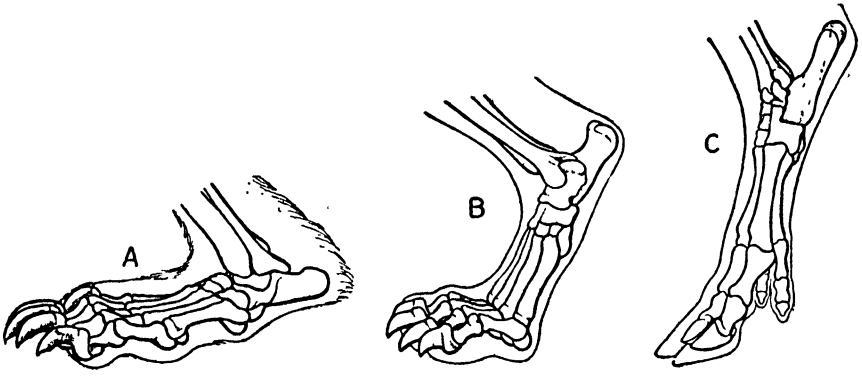

Fig. 435.—Foot postures of mammals. (A) Plantigrade. (B) Digitigrade. (C) Unguligrade. (After Pander and D'Alton. From Lull, Organic Evolution, The Macmillan Company.)

day, the visceral skeleton consists of the *upper* and *lower jaws,* the *branchial arches,* and the *hyoid arch.* In the higher land forms, the remnants of these bones are found in the larynx and trachea; some have become the ossicles of the ear, and the hyoid bones support the tongue.

6. The Functions of the Skeleton.—The vertebrate skeleton performs three functions: (1) *support,* keeping the body in shape and furnishing the framework to which the other parts of the body are attached; (2) *protection,* protecting delicate organs; for example, the brain is protected by the brain case or skull, the spinal cord by the vertebral column, and the lungs and heart by the chest and backbones; (3) *framework and levers,* for movement, although muscles are necessary to move the skeleton. The skeleton of the lower fish consists not of true bone but of cartilage. In the development of bony fish and higher animals, bone is at first either cartilaginous or membranous; it eventually becomes ossified or transformed into true bone.

As already stated, the skull protects the brain. But skeletal devices, such as pads of cartilage between the bones and arches and curves, prevent jarring.

D. Skeleton of Man.—Figure 436 is of the human skeleton and shows the relation of the bones to each other. The functions of the

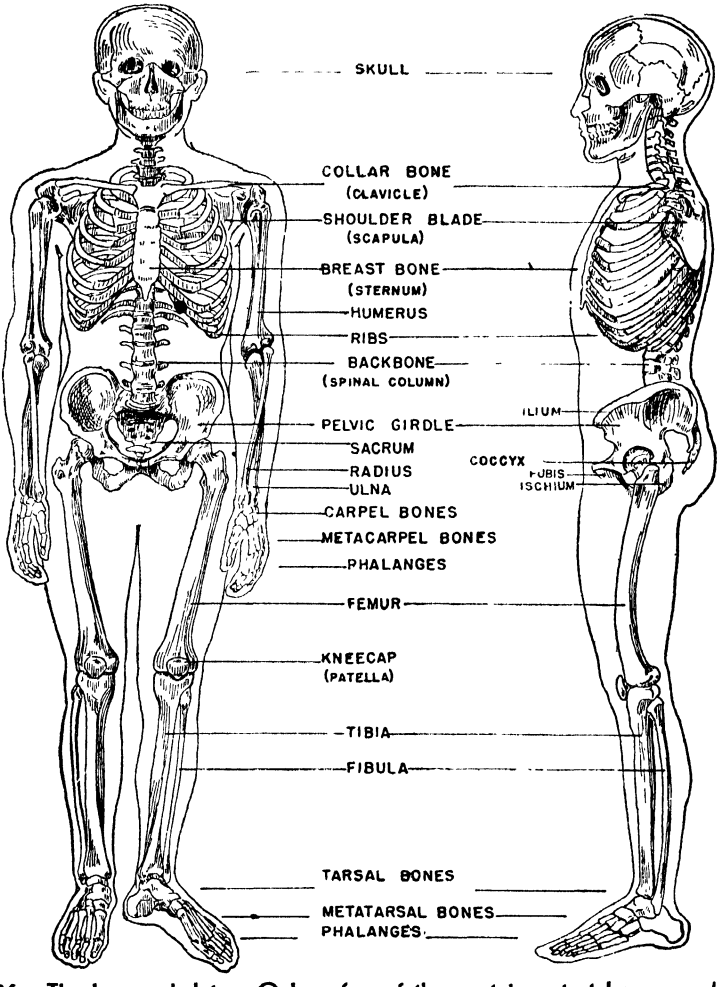

Fig. 436.—The human skeleton. Only a few of the most important bones are labelled. (B. Shamos.)

skeleton of man are the same as for other animals, *i.e.*, support, protection, and furnishing a framework and levers for movement.

1. The Number and Distribution of the Bones.—The fully matured skeleton consists of 206 bones, distributed as follows:

The head		
Cranium	8	
Face	14	
Ears	6	
Hyoid in the neck	1	29
The trunk		
Spinal column (vertebrae)	26	
Ribs	24	
Sternum (breastbone)	1	
Clavicles (collarbones)	2	
Scapulae (shoulder bones)	2	
Innominates (pelvic bones)	2	57
The limbs		
Arms	60	
Legs	60	120
Total		206

a. The Head Bones and Sinuses.—Eight bones are fused to form the brain case or cranium in the skull of man. The bones are named and the

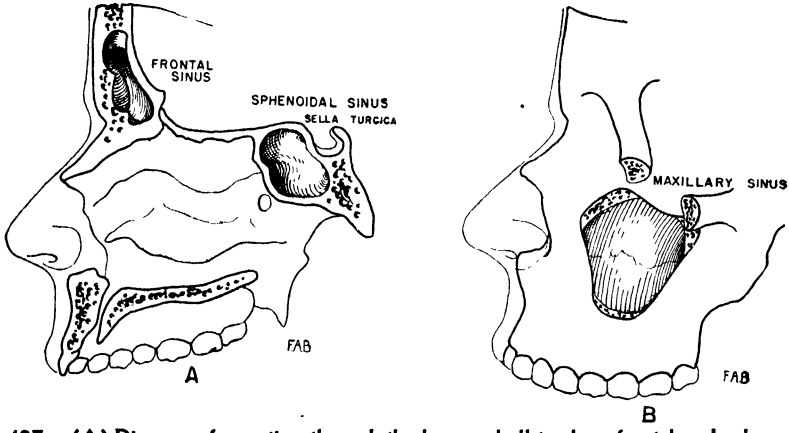

Fig. 437.—(A) Diagram of a section through the human skull to show frontal and sphenoidal sinuses. (B) Maxillary sinus. (F. A. Baker.)

sutures shown in Fig. 431. Fourteen bones make up the face, and there are three bones in each ear, the *malleus*, *incus*, and *stapes*. The *hyoid bone* supports the tongue.

Four sinuses are connected with each nasal cavity: the frontal sinus and ethmoidal (not shown in figure) open into the nasal cavity; the maxillary (antrum of Highmore) opens into the side of the nasal passage, and the sphenoidal sinus opens into the nasopharynx (Fig. 437*A* and *B*). These are lined with mucous membranes, and any inflammation in these spaces or sinuses is known as *sinusitis*. The cavities in the mastoid bone are also lined with mucous membrane and often become infected, thus causing *mastoiditis*.

b. The Trunk. (1) THE SPINAL COLUMN.—In mammals, including man, the typical number of cervical vertebrae, or those in the neck region, is 7. The first cervical vertebra is the *atlas*, so named because it is articulated with the head. Two occipital condyles rest on the two articular surfaces (Fig. 438*A*) of the atlas. The spinal cord passes through the posterior part of the ring of the atlas; in the anterior[1] part, the bony projection or odontoid process from the second vertebra, the *axis* or epistropheus, forms a pivot, around which the atlas rotates when the head is moved from side to side (Fig. 438*B*). Figure 433 shows the parts of a vertebra. They vary in different portions of the spinal column. In the cervical region, the spinous processes are short and often cleft into two. The 12 *thoracic vertebrae* are larger and have spinous processes directed downward; they also have articular surfaces for the 12 pairs of ribs.

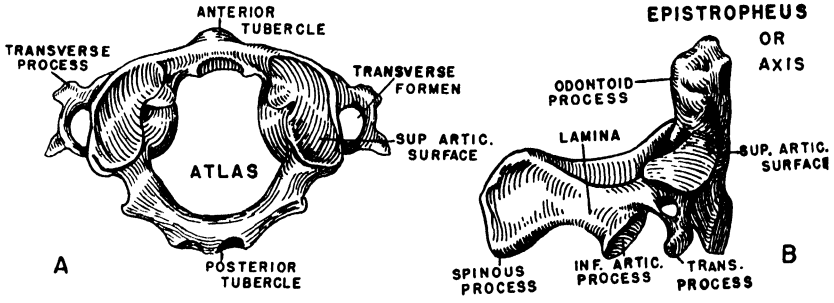

Fig. 438.—(A) Atlas: first cervical vertebra. (B) Epistropheus, or axis; second cervical vertebra. (F. A. Baker.)

Next to these are 5 vertebrae with prominent transverse processes, the *lumbar vertebrae*. In the adult skeleton, the next 5 are fused to form the *sacrum*, to which the pelvic girdle is attached, and, finally, 3 or 4 small bones, which form the *coccyx*, which is the vestige of a tail. The vertebrae are piled one on top of another and separated by disks of cartilage; they form a long flexible column. The spinal cord passes through the hollow cylinder formed by the arches of the vertebrae. Nerves and blood vessels pass through the transverse foramen of the vertebrae.

(2) THE STERNUM AND RIBS.—The breastbone is the sternum. Twelve pairs of ribs are present. Seven of the upper pairs of ribs are joined to the sternum and are called *true ribs*, whereas the five lower pairs joined to the cartilages of the sternum are called *false ribs*. The two lowest pairs of ribs are free at the front end and are called *floating ribs*. The collarbone is the *clavicle* and the shoulder bone, the *scapula*. The upper arm bone, the *humerus*, articulates with the scapula at the cup-like depression, the glenoid fossa.

[1] Anterior and posterior here refer to dorsal and ventral, respectively.

(3) THE GIRDLES. *a. The Pectoral Girdle.*—In man, the pectoral girdle is made up of the two collar bones, or *clavicles*, and the two shoulder bones, or *scapulae*. The coracoid is represented only by the *coracoid process*, which is attached to the scapula.

b. The Pelvic Girdle.—Each of the pelvic bones is made up of three bones, *ilium*, *ischium*, and *pubis*, fused to form a single innominate bone.

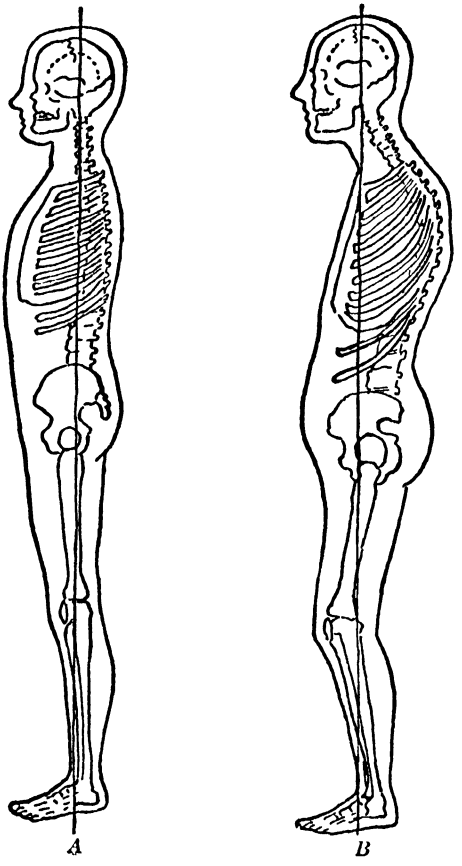

Fig. 439.—Posture. (A) Good body mechanics. (B) Poor body mechanics. (Courtesy of the Children's Bureau, U.S. Department of Labor.)

The two pelvic, or innominate, bones are fastened to the sacrum in the back and to each other in the front at the *symphysis pubis*. The pelvis is made up of the two *innominate bones*,[1] the *sacrum* and the *coccyx*. The lower abdominal organs lie in the bowl-shaped pelvis and are partly

[1] In youth, each innominate bone is made up of 3 parts: (1) *ilium*, the upper expanded portion, (2) *ischium*, lower strong portion, (3) pubis. The 2 pubic bones unite to form the front of the pelvis (page 649).

supported by it. The pelvis is an important part of the skeleton of man on account of his erect posture.

c. Limbs.—Each of the limbs contains 30 bones. The large bone in the upper part of the arm is the *humerus;* that in the upper part of the leg, the *femur*. The two bones in the lower part of the arm are the *radius* and *ulna;* those in the lower part of the leg, the *fibula* and *tibia*. The wrist contains 8 bones, the *carpals*, and the hand, 5 *metacarpals*, each bearing a finger or phalanx. The ankle consists of 7 *tarsal* bones; the foot contains 5 *metatarsal* bones, each bearing one toe or phalanx. From the foregoing, it is seen that there is 1 more bone in the wrist than in the ankle, but the kneecap, or *patella*, is an extra bone in the leg; hence the number of bones in the arm and leg is the same.

2. Functions of Arches and Curves.—In addition to the protection of the brain by the skull, various skeletal devices protect that important organ. The first of these is the arch of the foot. A side view of the arch of the foot (Fig. 436) shows that it is a real arch and that the axis of the body passes through the arch. In standing, therefore, the weight of the body falls on the arch, which acts as a sort of spring. The brain is also protected from jarring by the curves of the backbone (Fig. 430). If a straight stick is grasped in the hand and the floor struck with it, a jar will be felt, but with a curved stick, when the floor is struck, the jar will be much less severe than with the straight stick. The head of man is balanced at the top of the vertebral column. Pads of cartilage between the vertebrae give elasticity to the whole skeleton and serve to protect the brain from jars.

There are four curves, alternately convex and concave, in the vertebral column, and the vertebrae are bound together by ligaments.

3. Special Features in the Human Skeleton.—Although other vertebrates contain bones of the same types as those in man, distinct differences are evident. Only a few of these will be mentioned. Most of the peculiar features of the human skeleton are associated with the large brain and the upright position of the body. Some of the differences between the bones of apes and man are as follows:

1. The skull of man is larger in proportion to his size on account of the large size of the brain. The jaws of the ape are longer and heavier, and the front teeth slant forward.

On account of the upright posture of man, the head is balanced on top of the spinal column. This is possible because of the extra curve or backward turn at the top. When the ape stands up, his head extends forward.

2. Certain modifications of the pelvic bones are associated with an upright carriage. These bones are spread out so that balancing on two feet is possible.

3. The arms of the ape are longer, and he does not have a thumb

4. HYGIENE OF THE SKELETON. *a. Bones of Children.*—The bones of young children do not contain as much mineral matter as do those of adults; hence they bend more easily. Heavy loads will pull young shoulders downward and cause round shoulders. Books and other loads carried habitually on one side may cause a slight curvature of the spinal column.

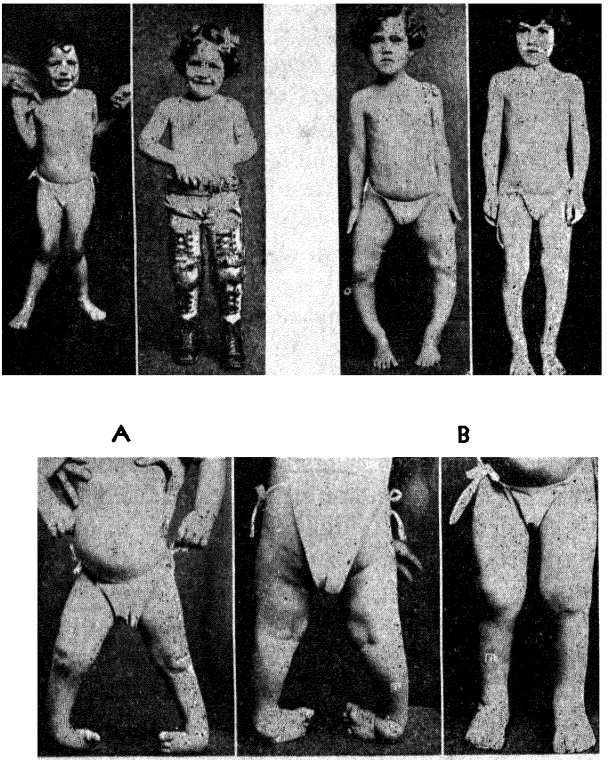

Fig. 440.—Some skeletal deformities which may be corrected by use of a special diet and proper braces. The figures on the right show limbs after correction of defect (no operation). (A) "Knockknees." (B) "Bowlegs." (C) Club feet. (Courtesy of Good Samaritan Clinic, Atlanta, Ga.)

Tight belts around the waist may cause an inward bending of the ribs. Posture will be more fully considered in the study of the muscles.

b. Broken Bones.—Bones that are broken will mend if proper care is given to them. The two broken surfaces must be placed together in the right manner, which only a physician is able to do. First aid consists of straightening out the broken limb. If the patient must be moved, a pillow may be tied around the limb, and a stiff support, such as a cane or umbrella, fastened to it to keep the limb from moving.

c. Fractured Bones.—Fractured bones are bones that may be completely broken. If ligaments around a bone are broken and the bone slips out of its socket, it is *dislocated. Sprains* are not so serious as dislocations. In the latter case, some of the ligaments are broken and torn loose, but the bone is not forced out of the socket.

d. Rickets.—A lack of minerals in the diet, or a disturbance in mineral metabolism so that proper calcification of the bones does not take place, causes rickets. This condition leads to the formation of bowlegs, knock-knees (Fig. 440*A* and *B*), and other malformations of the skeleton. Adequate amounts of calcium and phosphorus help correct this condition; also, cod-liver oil, which contains vitamin D, egg yolk, whole milk, and fresh vegetables.

e. Fallen Arches.—This occurs when the arches[1] of the foot, which are maintained in a normal condition by muscles, ligaments, and connective tissue, flatten out. Wearing improperly designed shoes will often bring about this condition.

f. Club Feet.—This is due to the contraction of tendons (Fig. 440*C*). There are several types of this malformation. They can be corrected by use of casts and surgery.

III. The Muscles

The skeleton plays a passive part in the movement of the animal body; the muscles play an active part. One of the chief characteristics of living things is their ability to move. In *Hydra*, one cell may contain both muscle and nerve elements, but in most animals, muscles form distinct tissues. They move the giant whale of the sea and also the lowly snail; they are responsible for the beating of the heart and for all the movements of the vital organs. Most of the discussion of muscles in this section refers to the muscles of the human body (Figs. 441 and 442).

A. Types of Muscles.—Three types of muscles are recognized: (1) *striated*, or voluntary, muscles, which are under the control of the will; (2), *smooth*, or involuntary, muscles, which are not under the control of the will; and (3) *cardiac*, or heart muscle, typical of the vertebrate heart.

1. Striated Muscle. *a. General Features.*—As its name implies, striated muscle is characterized by cross striations (Fig. 24). They are attached to the skeleton, and the movements accomplished by it are under the control of the will, *i.e.*, voluntary. For these reasons this type of muscle is often called *striped* or *voluntary* or *skeletal.* Because these muscles form part of the body wall, they are sometimes called *somatic.*

The muscle is made up of spindle-shaped fibers, each of which has a sheath (*sarcolemma*) enclosing the soft contractile substance. Each fiber

[1] The arches of the feet are: (1) *longitudinal* arch running from heel to toes on inner side of the foot (instep), and (2) *transverse* arch across the foot in the metatarsal region.

or cell has many nuclei, which are on the inner surface of this tubular sheath or sarcolemma. The individual fibers vary in length, number of nuclei, and in the number of fibrils of which they are made up. *Sarcoplasm* is the fluid material surrounding the fibrils (myofibrils) in a fiber or cell.

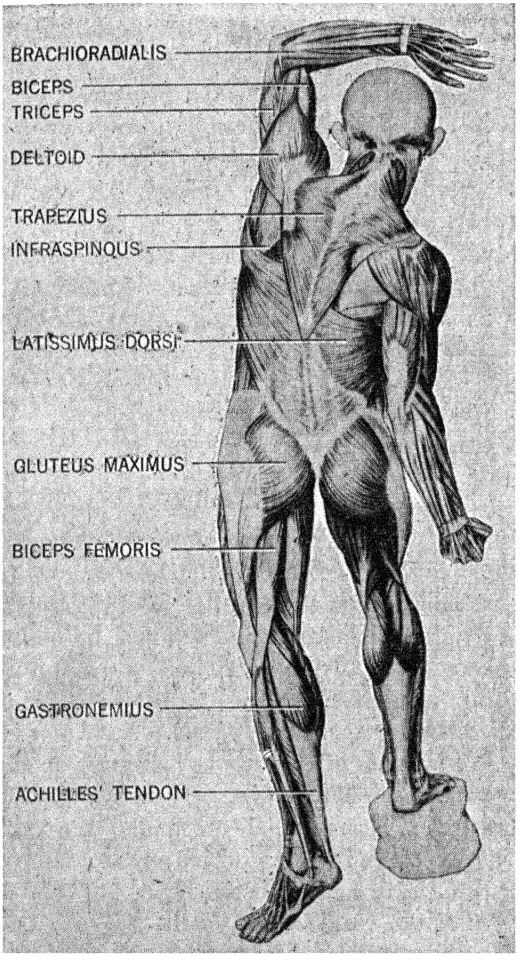

Fig. 441.—Muscles of man, back view. Simplified labelling by the author. (From Frohse Chart, Courtesy of A. J. Nystrom Company.)

There are two types of fibers, red and white. There may be both types of fibers in all skeletal muscles of man, but in the muscles that take care of slow movement the red fibers predominate, and in the muscles that take care of quick movements the white fibers predominate.

The muscle fibers are bound together in bundles, the *fasciculi*. Each bundle is surrounded by connective tissue; this tissue also binds the

smaller bundles into larger bundles. *Sheets* of it surround the muscle. This covering, or *fascia*, carries blood vessels and nerves. The bundles in a muscle may be observed in a piece of beef cut across the grain. Tendons fasten the muscles to the bones. These are dense white cords,

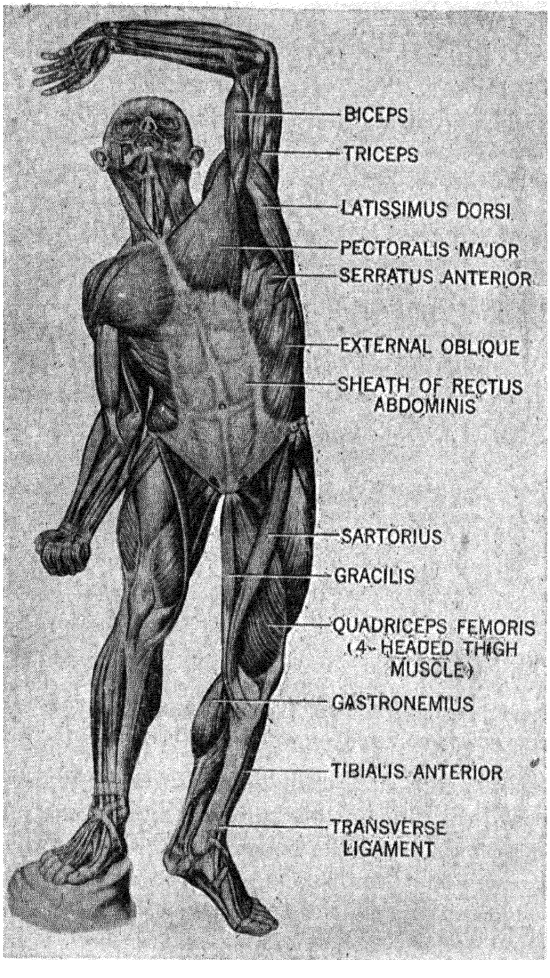

Fig. 442.—Muscles of man, front view. Simplified labelling by the author. (From Frohse Chart, Courtesy of A. J. Nystrom Company.)

found at the ends of the muscles; or they may be flattened, in which case they are called *aponeuroses* (Gr. *aponeuroun*, to pass into a tendon). Other terms connected with muscle study are *origin*, the end of the muscle attached to the less movable bone, and *insertion*, the end attached to the more movable bone.

b. Types of Skeletal Muscles.—Skeletal muscles are grouped according to the work that they do. They occur in pairs and "work against each other." Such action is said to be antagonistic (Fig. 443).

(1) EXTENSOR AND FLEXOR MUSCLES.—A muscle that bends one part of the skeleton more than another is a *flexor* muscle; one that extends a part, an *extensor*. For example, when the muscles in the front of the arm (*biceps*) contract, the elbow bends; while this is happening, the muscles on the back of the arm (*triceps*) relax. The muscles on the back of the arm may now contract and straighten the arm. The biceps is a *flexor* muscle, and the triceps an *extensor* muscle.

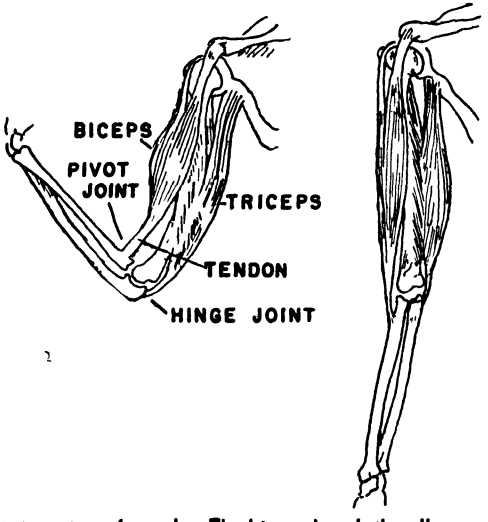

Fig. 443.—Antagonistic action of muscles. The biceps bends the elbow and is a flexor muscle; the triceps straightens the elbow and is an extensor muscle. (B. Shamos.)

(2) ADDUCTORS AND ABDUCTORS.—An *adductor* muscle will draw an appendage toward the mid-line of the body; an *abductor* muscle will move it away from the mid-line of the body.

(3) ELEVATORS AND DEPRESSORS.—As the name implies, an elevator muscle will elevate a part such as the lower jaw or the head; depressor muscles will lower a part.

(4) ROTATORS.—A rotator muscle will move one part over another, as the turning of the arm at the shoulder. There are two types, the *outward* rotators and the *inward* rotators.

(5) CONSTRICTORS, OR SPHINCTERS, AND DILATORS.—These are circular muscles, which close or open circular orifices, such as pupil of the eye, etc.

2. SMOOTH MUSCLE.—Smooth muscle is nonstriated, often called *involuntary*, because it is not under the control of the will, or *visceral*, because it is present in the visceral organs. The cells are spindle-shaped

and contain a single large nucleus (Fig. 24). The cytoplasm is differentiated into sarcoplasm and myofibrils. Though smooth muscle cells may occur as isolated small patches, they are usually arranged in two layers, an outside longitudinal layer and an inner thicker circular layer, as in the intestine. Connective tissue surrounds the muscles and carries the blood vessels and nerves. The peculiar characteristics of the smooth muscle are that they contract more slowly and are relatively slow in relaxation. The function of the smooth muscle is to carry on the necessary activities of the vital organs, as peristalsis, etc.

3. Cardiac Muscle.—Although the cardiac muscle is also striped or striated, the striations are less distinct than those of skeletal muscle (Fig. 24*C*). The fibers branch and unite by these branches with neighboring fibers. The single nucleated cells are smaller and are quadrangular in shape. These are arranged end to end. The continuous sheet thus formed is cut by intercalated disks, structures peculiar to heart muscle. They have no true sarcolemma. The action of cardiac muscle is involuntary.

B. Muscle Action.—The chief characteristic of muscle tissue is its ability to contract and relax (Fig. 443). It is this power that enables muscles to move the body.

1. Contraction and Tonus.—When a muscle contracts, it changes its shape. Each fiber becomes shorter and thicker, but the volume of the muscle as a whole is unchanged. This has been proved by experiment. Just what changes occur in the organization of the protoplasm when each fiber becomes shorter and thicker is not well understood.

Muscles are usually thought of in connection with movement. However, some muscles must be in constant contraction in order to maintain posture. For example, if one goes to sleep while sitting in a chair, the head will fall forward. To keep the head erect the muscles that support the head must be in a state of contraction, or *tonus*. A dead body will not stand erect but will collapse at the joints. It is therefore evident that standing erect, even though there is no movement, involves heavy work of muscles.

2. Relation of Muscle and Nerve.—There is an intimate relationship between the muscles and nerves, since all muscles are provided with nervous connections. If the nerve leading to a voluntary muscle is cut, the muscle becomes paralyzed and will not contract voluntarily; but such a muscle still exhibits some degree of irritability. It cannot be made to contract by voluntary effort, but a stimulus given to the muscle directly may result in a contraction. Smooth and cardiac muscles differ in this respect. They can continue some activity even though their nerves are cut. This is important, since the smooth muscle is concerned with vital activities and the heart, which contains cardiac muscle, must beat if the

animal is to continue to live. Just why these muscles differ from the skeletal muscles in this respect is not known, although it has been suggested that the difference may be due to the nerve cells that are present in such muscles.

Animal starch, or glycogen (page 546), in addition to being stored in the liver, is also stored in the muscles for future use. During the contraction of the muscle, some of the glycogen is changed to lactic acid, and in this reaction energy is liberated. Oxygen does not take part in this first reaction. Later, however, the lactic acid may be partially reconverted to glycogen, and for this process oxygen is necessary. Oxygen is brought to the muscle by the blood. Soon after the muscle begins to contract, an increased flow of blood takes place, which not only brings the oxygen but also takes away the excess lactic acid and wastes, especially CO_2. Soreness after too heavy exercise is said to be partly due to an accumulation of lactic acid in the tissues, though it may be due also to injury to the fibers.

The contraction of muscle, the formation of lactic acid from glycogen, and the reconversion of lactic acid into glycogen with the liberation of heat is a complex subject. It is known that these things happen, but there is some question as to exactly how they occur.

In addition to the relationship of glycogen and lactic acid, three other activities result from muscular contraction: (1) *increased production of wastes;* (2) *increased heat production;* and (3) *greater activity of the nervous system.* These, in turn, bring about other activities, such as an increased rate of the heartbeat, which results in a greater blood flow to the active muscles; and an increased rate of breathing, which brings a greater amount of oxygen to the lungs and eliminates a greater amount of CO_2 from the lungs.

3. FATIGUE.—When a muscle becomes fatigued, it does not contract readily; indeed, if the fatigue is great, it may not contract at all. This is probably due to the chemical changes associated with the accumulation of lactic acid. It is interesting to note that the site of the fatigue is at the connection of the nerve with the muscle. If a muscle showing signs of fatigue by reduced contraction be stimulated directly and not through the nerve, it will contract vigorously for some time longer. The cells will not recover if fatigue be carried to the point of absolute exhaustion. In this case, there is a coagulation of the protein of the fiber; the muscle dies and becomes rigid.

Fatigue is a very complex phenomenon. What we refer to as "being tired," or fatigued, is not always due to fatigue of the muscles. It may be due to mental states, lack of interest, laziness, etc. The sensation of fatigue is a protective reaction that occurs long before the danger point in the use of the muscles.

Rigor mortis is the rigid state of a body after death. This occurs from about 10 minutes to 7 hours after death and lasts from 1 to 6 days in the case of the human body. After this time, muscles again become soft and flexible.

4. EXERCISE.—Through exercise, the circulation is increased and, as a result, the materials are taken to and from the tissues more efficiently. A strong heart can be developed only by exercise suited to one's age and the type of life he leads.

If the muscles of respiration are strengthened by exercise, greater expansion of the chest takes place during breathing. This results in better ventilation of the lungs, and more oxygen is carried by the blood to the tissues. The processes of oxidation and the removal of wastes so necessary for health are thus carried on more efficiently.

Muscles not properly exercised become weak and flabby. On the other hand, too much exercise is harmful. "Athlete's heart," which causes the death of many fine atheletes, is due to overexercise, which results in certain structural changes in the heart, such as overdevelopment of muscle so that the valves do not close normally.

Shivering is a useful reflex. Muscular contractions occur during shivering that generate heat and make one more comfortable.

IV. The Skin

Contact with the outside world is mainly through the skin. From time to time, certain functions of the skin have been mentioned. These will be better understood after knowing something of the various structures of the skin.

A. Appendages of the Skin.—Briefly, some of the structures produced by the skins of vertebrates are as follows: The skin of fishes contains glands and pigment cells but are especially characterized by the presence of scales of various types; amphibian skin contains pigment and gland cells, and scales are present in one order only; Reptile skin produces horny scales, specialized structures such as rattles, spines, claws on the limbs, etc., and there are no glands; bird skin produces scales on the legs, claws on the feet, but the characteristic epidermal structure of the bird skin is the feather; mammal skin produces a wide variety of structures, horns, claws, hoofs, hair, and four types of glands (mammary, sweat, or sudoriferous, sebaceous, and scent). All these are concerned with the protection of the surface of the body. This is especially true of scales, feathers, and hair.

B. The Human Skin.—The human skin varies greatly in different races with respect to texture, color, and amount of hair; the native Australians are hairy, whereas the native Malays are beardless.

1. STRUCTURE.—There are two layers of the skin, an outside layer, the *epidermis*, and an inner layer, the *dermis*, or *corium* (Fig. 444).

a. The Epidermis.—The outside layer of the skin is made up of four layers, the upper three consisting of practically dead cells, and the lower layer (stratum mucosum or stratum germinativum) consisting of protoplasmic cells, which are constantly multiplying and adding to the three upper layers. These cells change in character as they are added to the upper layers; *keratin*, a waterproof substance, is added, and the cells change from a columnar shape to flat scales. The inner cells of the epidermis secure enough food to keep them alive, but the outer cells are dead and are continually being worn off or shed. These dead cells are the

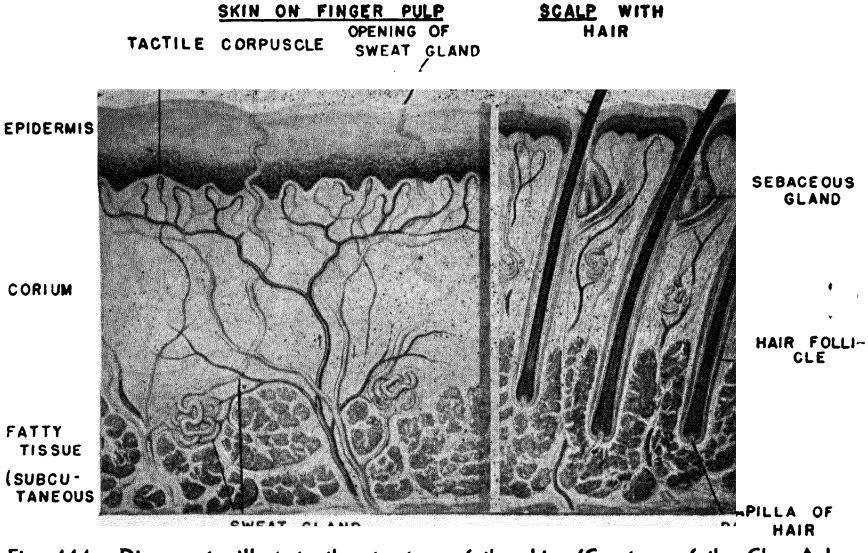

Fig. 444.—Diagram to illustrate the structure of the skin. (Courtesy of the Clay-Adams Company.)

"dead skin" on the body and "dandruff" on the head. The outer, horny layer of skin is especially thick on the palms of the hands and the soles of the feet. Most skin contains some color, and in animals this is sometimes arranged to form elaborate color patterns.

b. The Dermis.—The living part of the skin is the dermis. As shown in Fig. 444, it is thrown up into little ridges, the papillae, where it meets the epidermis. These are the ridges that show prominently in the fingerprints. Since no two fingerprints are exactly alike, such prints are useful in the identification of persons. It is routine practice to keep on record the fingerprints of criminals, for possible future identification. If records of the entire population were kept, they would aid in identifying persons suffering from a type of forgetfulness known as amnesia.

In the dermis are located nerves, glands, blood and lymph vessels, and connective tissue. Fat is stored in this layer, also (Fig. 444). Here, too, are certain nerve fibers that regulate the constriction and expansion of the blood vessels of the skin, thus helping regulate the heat of the body, and others, which go to the muscles, that cause the erection of hairs. Nerve fibers are also connected with the secretory glands, and, in addition, nerve endings are also present that are sensitive to touch, heat, cold, and pain. These sensations were referred to in the section on the nervous system (page 631).

c. Hair.—In Fig. 444, it will be noted that each hair is lodged in a small deep pocket in the skin, the *hair follicle.* At the bottom of the follicle is a mound of connective tissue, the papilla, on which the hair rests. The follicle is lined with cells that have been folded in from the epidermis, and the papilla is also covered with cells. The epidermal cells at the base of the hair multiply and push the cells upward, and so the hair grows. Hair, like the epidermis, contains neither blood vessels nor nerves. The papilla, however, have a rich blood supply, and the cells at the base of the hair receive an abundance of food.

Attached to the hair follicles are muscles. When these contract, the hairs "stand on end," as they do when one is badly frightened. The erection of hairs on a dog's neck or on a cat's back, when irritated, illustrates this point.

Dandruff consists of scales of dead epidermis. Such scales occur over the entire body. Certain diseases of the scalp, however, bring about an excess of dandruff. *Baldness* may be caused by disease germs; some types are inherited (page 746).

d. Glands. (1) SEBACEOUS GLANDS are of the compound type. Their function is to furnish an oily secretion for the hair to keep it soft and pliable. A modified sebaceous gland is found on the eyelid, the Meibomian glands of the eyelashes. The wax glands of the ear resemble sebaceous glands.

(2) SWEAT OR SUDORIFEROUS GLANDS are present in most mammals. Some exceptions are the echidna, the mole (*Talpa*), the aquatic Cetacea or whale family, and the *Sirenia* (sea cows). The sweat glands aid in maintaining body temperature (see below).

(3) MAMMARY GLANDS in some form are found in all mammals. In the monotremes, they are quite simple, but in the higher mammals, including man, they are of the compound type and secrete true milk.

e. Nails are modifications of the epidermis and grow chiefly from the base. The young cells that produce the nail are not as transparent as the older cells, hence there are "half moons" at the base of each nail.

2. FUNCTIONS OF THE SKIN. *a. General Functions.*—Some of the functions of the skin have been referred to in other chapters. (1) It acts

as a protective covering for the body; (2) it keeps the body from drying out; (3) it protects the delicate tissues beneath it from mechanical injury; (4) it protects the body from foreign organisms so long as it is unbroken (Fig. 445); (5) it contains several types of nerve fibers and nerve endings, as fibers to the blood vessels, fibers to the muscles, which cause erection of hair, fibers and nerve endings concerned with the sensations of touch, heat, cold, and pain, as well as fibers to the sweat and sebaceous glands; (6) it plays an important role in the maintenance of body temperature.

b. Body Heat.—Animals are divided into two classes, the cold-blooded, *poikilothermic* (Gr. *poikilos*, variegated; *therme*, heat) animals, whose temperature, like that of *frogs*, changes with the environment,

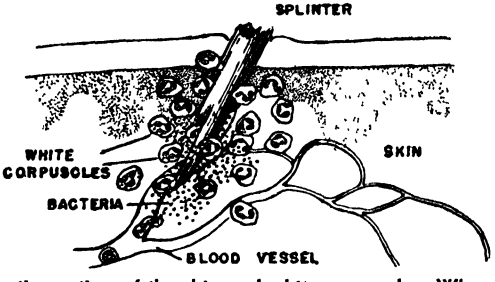

Fig. 445.—Protective action of the skin and white corpuscles. When the skin is broken, as when a splinter is imbedded in it, bacteria gain entrance to the body. Diagram shows bacteria entering capillary from splinter; also the white blood corpuscles which migrate to the focus of infection and engulf bacteria, dead tissue cells, etc. (See page 566.) (F. A. Baker.)

and the warm-blooded, *homiothermic* (Gr. *homos* same; *therme*, heat) animals, which have almost constant temperature. To the first class belong the fish, amphibians, and reptiles, and to the second, the birds and mammals, including man.

(1) PRODUCTION AND LOSS OF HEAT.—Oxidation processes in the cells, the reducing of complex to simple substances, liberates heat. The most important heat-producing organs are the muscles, through muscular activity. The heat is distributed to all parts of the body by the blood. Heat is lost from the body in the processes of respiration, the evaporation of sweat, radiation from the surface of the body, and in the wastes (urine and feces) thrown off.

(2) MAINTENANCE OF BODY HEAT.—The maintenance of heat in the human body depends upon many factors. There is evidence that there is a *heat-regulating center* in the brain. The *skin* plays an important role in the regulation of the body heat for several reasons: in the first place, it offers a large surface for heat radiation; in it is a rich network of capillaries, and they are able to hold a large part of the blood supply. The *nervous system* controls the expansion and constriction of these capillaries

so that heat is lost or conserved according to the environmental temperature In the skin, too, are the *sweat glands*, which are stimulated to activity by the nervous system when need for cooling the body arises The evaporation of the sweat from the skin has a cooling effect. Sweat may have an excretory function, also, but its main importance is in the elimination of heat The amount of sweat is increased by increased temperature or humidity of the atmosphere Because the air can take up only a certain amount of water vapor or moisture, high humidity of the air interferes with the evaporation of sweat Pain, nausea, mental excitement, as well as certain diseases (malaria, tuberculosis, and acute rheumatism) and drugs, also increase the amount of sweat

Decrease in the amount of sweat is brought about by certain diseases (fevers, diabetes, etc), cold, diarrhea, and the voiding of large quantities of urine Both the sweat glands and the blood vessels in the skin are controlled by the nervous system It follows that the amount of heat lost from the body is regulated by the nervous system

Other factors that affect the temperature of the body are age, clothing, individual differences, and hot and cold baths Children do not exhibit the same constancy of temperature as do adults Naturally, in the growing child, there is a large production of heat Also, there are individual differences in body temperature, which are related to size, shape, and the amount of fat present

(3) NORMAL AND ABNORMAL TEMPERATURES —The normal temperature of the human body is about 98⅘°F , or 37+°C The amount of blood that comes to the skin (page 568) helps regulate the body heat. The blood vessels in the skin are so abundant that they are capable of carrying a large portion of the blood of the body

Normal temperatures vary with different people, but within fairly small limits When the temperature reaches 102°F , the patient is said to be suffering with a warm fever. 104°F indicates a hot fever, a temperature 105°F is dangerous if it continues for a long time When the temperature rises to 109 or 110°F , death usually results On the other hand, a temperature of 91 or 92°F., if continued for a long time, will also lead to death

When heat is produced as a result of violent exercise, the body soon cools off naturally But in the case of fever, not enough heat is lost Often the sweat glands do not function Sponging with tepid water helps cool the body in cases of slight fever, rubbing with alcohol has the same effect

A chill, or a feeling of chilliness, may occur in various types of illness when the blood vessels of the skin become constricted Under such conditions, the skin contains no warm blood, and the patient feels cold

(4) BATHS.—Baths affect the circulation and therefore the body heat. *Tepid baths* do not affect the circulation to any great extent. They are beneficial in that they remove body wastes, dust, etc. *Cold baths* cause contraction of blood vessels in the skin; the return of blood to the skin after the bath gives a feeling of warmth. Rubbing helps stimulate this reaction. If the bather is not in good physical condition, this reaction may not follow, and the individual is left chilled and shivering. *Hot baths* have exactly the opposite effect; the blood vessels in the skin enlarge and draw the blood to the surface and away from the vital organs.

Questions

1. What are some advantages of endoskeletons over exoskeletons? Are there any vertebrates that have exoskeletons?
2. Why must the arthropods shed their skins periodically? Are there any vertebrates that do this?
3. What part of bone is living?
4. Give examples of the types of joints, and show their fitness for the particular functions that they perform.
5. Show how the shapes of bones are adapted to their particular uses. Why is a hollow long bone stronger than a solid bone of the same size and shape?
6. Explain why the curves in the spinal column protect the brain from jar. Are these curves present in cat skeletons? What relation have the curves to the fact that man walks erect?
7. What are the general functions of the skeleton?
8. Describe the various types of bones and joints of the human skeleton, giving the functions of each.
9. What are the special functions of the pectoral and pelvic girdles?
10. Which has the greatest number of bones, an adult or a young child? Explain.
11. What types of bone marrow are there? What is the function of the red bone marrow?
12. What is the function of the periosteum? How do bones knit together after a fracture or break?
13. What are sinuses?
14. What are some special features of the human skeleton?
15. Are young bones easily bent? What are some general health rules to follow with regard to posture?
16. What are clubfeet? Can rickets be prevented? What are fallen arches?
17. What are the three types of muscles? What is the work of each?
18. Give three functions of muscles. Explain the antagonistic action of muscles, using the biceps as an example.
19. What part does the nervous system play in the work of muscles? Which part of the nervous system controls the involuntary muscles? The voluntary muscles?
20. About how many muscles are there in the human body? What is the effect of exercise upon the muscles? Why does one become warmer upon exercising? Is bad posture the result of weak muscles? Explain.
21. Distinguish between contraction and tonus.
22. Why will a dead body not stand erect?
23. How does a muscle use glycogen?
24. What are the protective functions of the skin? Why will a splinter stuck in the body often "fester"? (See page 445.)

25. How does hair grow? What does the statement "his hair stood on end" mean?
26. Name the glands of the skin, and give an account of their functions.
27. What is fever? A chill? What is the normal body temperature of man?
28. What are four ways in which the body may lose heat?
29. What are the advantages and disadvantages of warm baths? Of cold baths?
30. Define: lacunae, condyle, aponeuroses, extensor, flexor, adductor, abductor, tonus, shivering.

CHAPTER XLII

REPRODUCTION

Each seed includes a plant; that plant again,
Has other seeds, which other plants contain;
These other plants have all their seeds; and those
More plants again, successively inclose.

. . . . .

So Adam's loins contain'd his large posterity,
All people that have been, and all that e'er shall be.

—BAKER.[1]

I. The Span of Life

Everything that lives dies sooner or later. This is a universal law. The span of life may vary from a few minutes, as in certain bacteria, or a day, as with May flies, to thousands of years, as with the big trees of California (Fig. 546). A dog is old at eight years, though he may live longer; elephants live a hundred or more years; and some turtles are said to live more than three hundred and fifty years, though most of them live much less than that. "Three score years and ten" is the allotted span of life for man. Many people live beyond that age, but anyone a hundred years of age is considered very old indeed. Some of the big trees of California existed before the beginning of the Christian era. But to all living things, with the exception of lower forms, death must come in due time. The question arises as to how life can go on. Pasteur is credited with the saying, *Omne vivum e vivo*, all life from life. Virchow's *Omnis cellula e cellula*, all cells from cells, expresses the same idea. The old belief that life can originate from nonliving matter persisted long after scientific tests proved this to be untrue. The conclusion is that if life is not to perish from the earth, the species now in existence must produce others of their kind.

II. Reproduction

Reproduction (L. *re*, back; *pro*, before; *duco*, lead) is one of the most fundamental properties of protoplasm. The enormous power of reproduction possessed by all living things is best shown by a few examples. The egg mass of a single tick that lives on the dog contains thousands of eggs. It is said that if all the eggs from a single female codfish should live, the

[1] From Woodruff, "Baker on the Microscope and the Polype," *Scientific Monthly*, Vol. 7.

sea would be packed solid with codfish within 10 years. But the numbers of codfish and dog ticks remain about the same, since they must compete with other organisms for living space. Usually, only a small fraction of the organisms produced are necessary to maintain the species; the rest die off. However, fossils found in rocks reveal that many creatures ceased to live on earth thousands of years ago, and even now certain species will soon become extinct unless they are protected.

Fig. 446.—The homunculus. Human sperm cell containing a miniature organism, according to Hartsoeker, 1694. See text.

A. Early History.—It was inevitable that fantastic theories about reproduction should develop before exact knowledge about the process was available. Many germ cells could not be seen until microscopes were invented; further, the understanding of the development of embryological structures had to await the perfecting of the microscope. Even after the discovery of the germ cells, there were two schools of thought: (1) the ovists believed that the embryo was *preformed* in the *egg;* (2) the spermists believed that it was *preformed* in the *sperm* and that the female simply nourished it until it was developed. This tiny individual was called a *homunculus* (L. dim. of *homo*, man), or little man (Fig. 446). From this it will be seen that the theory of preformation grew out of the belief that organisms were encased in either the egg or the sperm. It was not until 1875 that Herman Fol and Oscar Hertwig observed independently the sperm penetrate the egg of a sea urchin and the nuclei of the sperm and egg unite after this penetration.

B. Types of Reproduction. 1. General Account.—The principal types of reproduction are illustrated in Figs. 447 and 448. There are two main types of reproduction, *asexual* and *sexual*, the difference between the two being the presence or absence of special *sex cells* or *gametes*.

There are many types of asexual reproduction, the most important being listed below. The main feature of sexual reproduction is gamete formation in special sex organs or gonads, though there are some exceptions. The gametes may be alike, *isogametes* (Gr. *isos*, alike), or they may be different, *heterogametes* (Gr. *heteros*, other). Heterogametes occur in the higher plants and animals as eggs and sperm. Usually a fusion of two gametes must take place before a new individual can develop.

2. Asexual Reproduction. *a. Fission.*—No type of reproduction is simple, but the least complicated type, that of *binary fission*, occurs among one-celled plants and animals (pages 182 and 268). When these organisms reach a certain size, they divide into two or more daughter cells as in *Protococcus* (page 183) and *Amoeba* (page 272).

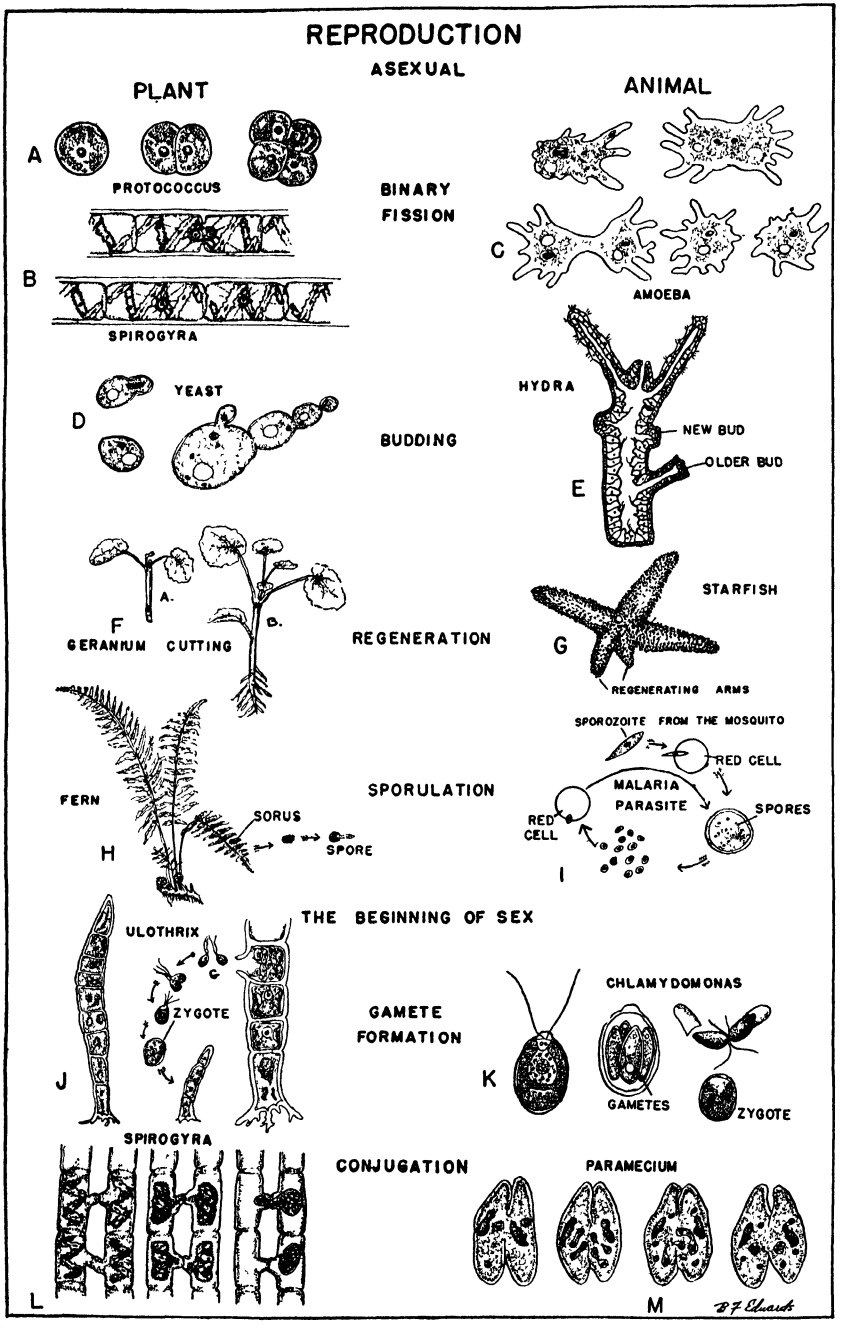

Fig. 447.—Types of reproduction in plants and animals. Asexual reproduction, the beginnings of sex. (B. F. Edwards.)

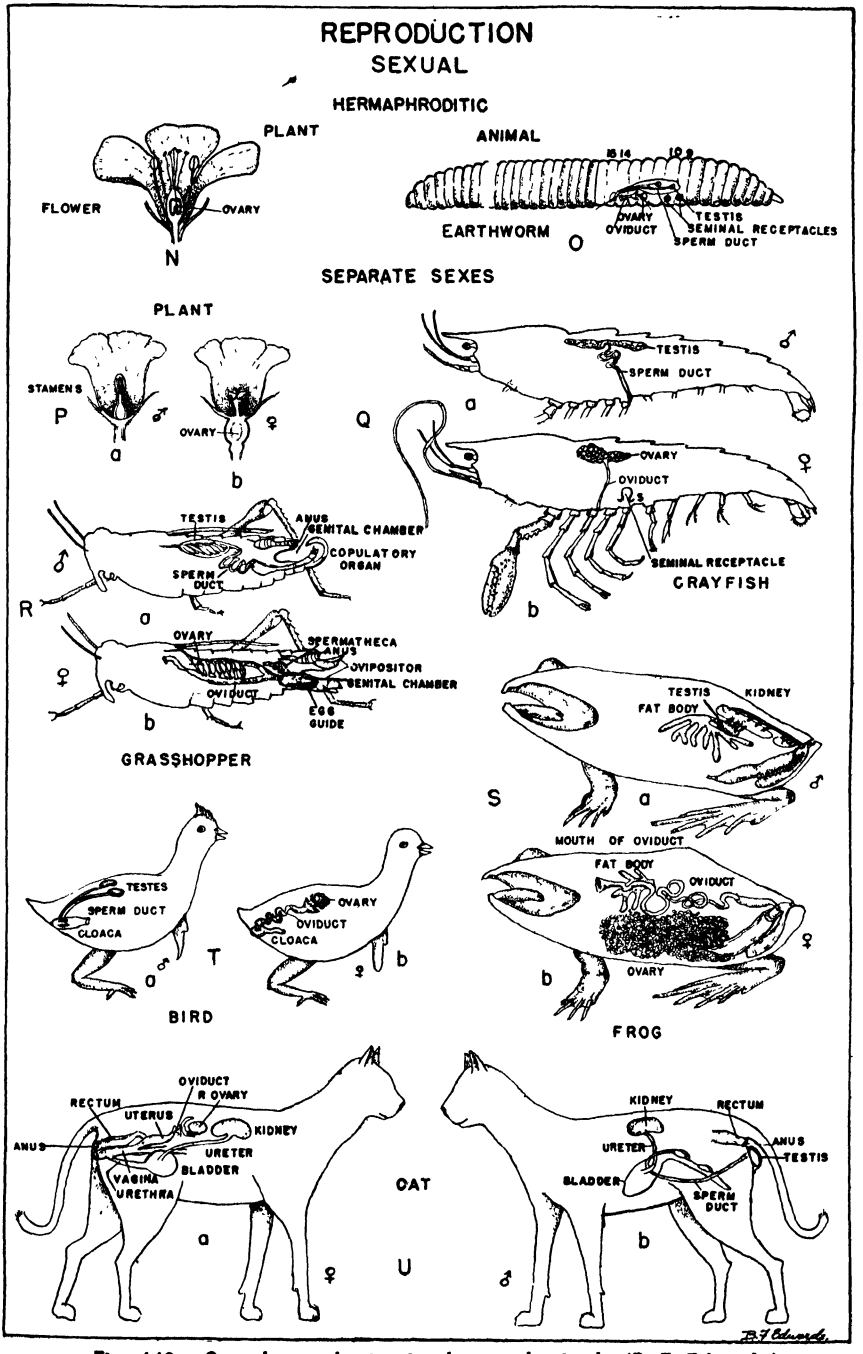

Fig. 448.—Sexual reproduction in plants and animals. (B. F. Edwards.)

b. Budding.—Reproduction by budding occurs in both plants and animals. One of the simplest types is that of *yeasts* (page 193). A bud appears at the side of the cell; this increases in size and finally may separate from the mother cell; or the cells formed by budding may remain together, forming a sort of branching chain. An interesting variation is the *internal budding* that occurs in certain sponges. The resulting body, a *gemmule* (L. *gemma*, a precious stone; bud), forms a wall around itself and drops to the bottom of the pond. In this condition, it can withstand drying, cold, or heat (page 293).

Budding also occurs in *Hydra* (page 298) and in other coelenterates; it also takes place occasionally in the higher forms such as the fresh-water worm, *Nais*, and even among the primitive chordates, such as the colonial tunicates.

c. Regeneration.—The word *regeneration* (L. *re*, again; *generare*, to beget) means literally to grow again. Reproduction by regeneration is the growth of a complete organism from one of its parts, as by cuttings of geraniums and other plants or from leaves of certain plants, as the *Begonia* and *Bryophyllum* (Fig. 55). In *Begonia*, roots develop at the ends of veins, whereas a new plant develops at every notch in the leaf of *Bryophyllum*. The growth of plants from cuttings, runners, bulbs, root-stocks, tubers, and the like (Chaps. IX and X) is asexual reproduction, often called *vegetative reproduction*.

Animals also possess remarkable powers of regeneration; a starfish will grow from a part of the central disk and often regenerates lost arms (Figs. 248 and 447*G*). *Planaria*, *Hydra*, even the earthworm may be cut in pieces and a whole animal will grow from a piece.

A certain amount of regeneration takes place in all living things. The lower in the scale of life the organism is, in general, the greater its ability to regenerate lost parts. Even in man, wounds heal over by the regeneration of cells. But lost parts, such as an arm or a leg, do not regenerate as a whole.

d. Grafting. (1) In plants.—Grafts may be made in several ways, but the fundamental principle is the same. A twig, or *cion*, is cut from a tree and inserted in a cleft made in the stem of another plant, the *stock*, in such a way that the *cambium* of the cion and stock will grow together (Fig. 449). The stock is usually a less desirable variety of plant but more hardy. For example, many choice roses are grown on the hardy wild-rose stock. Since the cion takes only water and minerals from the stock, its character does not change.

(2) Grafting in animals.—One earthworm may be made of several grafted together, or several pieces of Hydra may be grafted together and grow as one. This type of grafting is of no practical importance, but in modern surgery, marvels of skin and bone grafting are performed every

day. When an individual is badly burned, the skin from one part of the body is grafted over the burned area. It will grow and furnish protection while the area from which it was removed regenerates new skin. To some extent, bone may be grafted so as to replace that lost by accident or disease.

e. Spore Formation. (1) IN PLANTS.—Many of the lower organisms produce spores from which new organisms are produced. Spores may be formed from parts of plants, or even whole bodies. The simplest type of spore formation occurs when a cell secretes a wall around itself and the protoplasm breaks up into a number of cells (page 184). After a time, the cyst wall breaks down, and the spores are liberated. If they fall in a favorable place, each spore will produce a new plant. Special spore cases, sporangia, are formed in bread mold (page 192), mosses (page 204), and ferns (page 207).

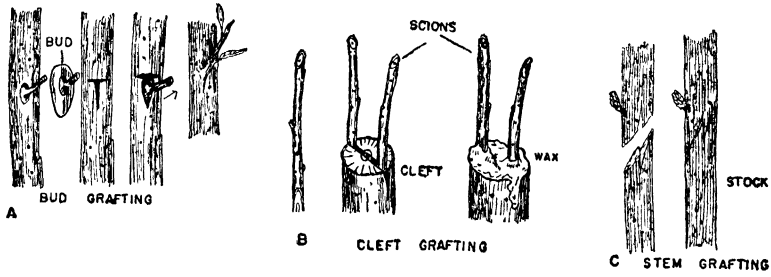

Fig. 449.—Three types of grafting—bud, cleft, and stem. (B. F. Edwards.)

(2) IN ANIMALS.—*Sporulation* in animals is best observed among the Protozoa. The class Sporozoa is so named because the animals making up this class form spores (Fig. 447*I*). Perhaps the easiest way to obtain animal spores for observation is to look for *Monocystis* (a gregarine) spores in the seminal vesicles of the earthworm. If these seminal vesicles are crushed and some of the material examined under the microscope, usually some spores of *Monocystis* will be found.

f. Resting Cells.—Resting cells are often called *spores* but are not to be confused with them. A good example of a resting cell is that of *Vaucheria* (green alga). A cell is cut off from the end of a filament. This secretes a wall around itself and passes into a resting state, in which it is able to resist unfavorable conditions, such as drying, cold, and heat.

g. Parthenogenesis. (1) NATURAL PARTHENOGENESIS.—The eggs of certain plants and animals develop normally without uniting with sperm. This is known as *natural parthenogenesis.* It occurs in certain Fungi, in rotifers (page 328), and in plant lice (aphids). In the water flea, *Daphnia*, the females lay parthenogenetic eggs during the warm weather. These all develop into females. After several generations of females

have been produced in this way, both males and females appear. The eggs of this generation of females must be fertilized by sperm from the males. These become the winter eggs. They have thick shells and are able to withstand unfavorable conditions, such as drying, cold, etc. When conditions become favorable in the spring, females develop from winter eggs, and these, in turn, produce parthenogenetic eggs, thus repeating the cycle.

(2) ARTIFICIAL PARTHENOGENESIS.—Certain eggs that ordinarily develop only after having united with sperm can be stimulated to develop without fertilization by subjecting them to such agents as heat, electricity, X rays, and certain chemicals, particularly the salts of potassium and sodium. In some cases, pricking or shaking is all that is necessary. Not all eggs will develop in this way. Among plants, the eggs of some Algae and a fern, *Marsilia*, can be stimulated to development by artificial means.

Among animals, frog eggs will develop after being pricked with a needle; sea urchin and starfish eggs (page 355) require only a good shaking. In 1900, Jacques Loeb, by changing the content of sea water (page 355), obtained free swimming larvae of the sea urchin. Before that time, Meade had been successful in causing the development of annelid eggs by artificial means. Since then many methods have been successfully employed in stimulating parthenogenesis. The exact cause of the development of eggs is not known. However, since in normally fertilized eggs *oxidation* increases greatly, it may be that this is a factor in the parthenogenetic development of eggs.

3. REPRODUCTION WITH SEX. *a. Conjugation.—Paramecia* may form a temporary union during which micronuclei are exchanged (p. 281). This is conjugation. In the conjugation of *Spirogyra*, certain cells of one filament fuse with cells of another filament (page 183). New individuals arise from these zygotes. Conjugation is especially common among the ciliated Protozoa. Sonneborn and others have found that the conjugating *Paramecia* are of different mating types (page 280).

b. Gamete Formation.—Gametes are sex cells that may be alike so far as the eye can see; or they may be so different that the two types are easily recognized. In the case of sexual reproduction, one gamete cannot form a new organism except under special conditions; it must fuse with another gamete.

(1) ISOGAMETES.—Examples of gametes that are alike, isogametes, are to be found among the lower organisms (page 182). In *Chlamydomonas*, in addition to asexual reproduction, the contents of the body of a single individual may divide to form a number of small bodies, which are *isogametes* (Fig. 447*K*). Two isogametes must fuse to form a zygote before a new individual is reproduced.

(2) HETEROGAMETES.—Even among the simple Algae, gametes of different sizes, or *heterogametes*, may be found (page 184). They are often called *anisogametes* (gr. *an*, not; *isogamete*).

c. Hermaphrodites.—Among many plants and some animals, both male and female sex organs are normally in the same individual organism. Examples of this kind are *Hydra viridis* (page 203), in which the testes are located near the anterior and the ovaries near the posterior part of the animal. The sperm are shed in the water, find their way to the egg, and fertilization occurs. The earthworm also contains a complete set of male

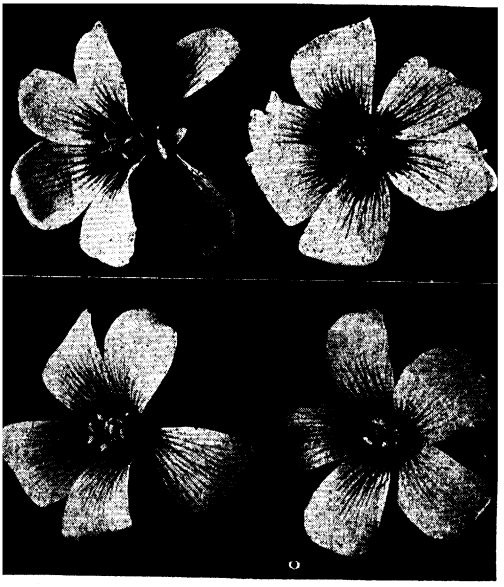

Fig. 450 I.—Flowers of the tung oil tree, Aleurites fordi. Pistillate, or female, flowers above; staminate, or male, flowers below. (Courtesy of Florida Agricultural Station.)

and female reproductive organs, although copulation takes place and cross-fertilization is the rule (page 341). A few cases of hermaphroditism occur among the vertebrates, such as the hagfish. Since the spermatozoa and the ova are ripe at different times, cross-fertilization occurs here, also.

d. Plants with Separate Sexes.—In some plants and most animals, individuals are either male or female (*dioecious*). In many plants, the male, or staminate, flowers and the female, or pistillate, flowers are borne on the same plant (*monoecious*). This is true of the corn (Fig. 109) and tung-oil plants (Fig. 450) and many others. Cross-pollination often takes place in this type of plant (page 164). When staminate and pistillate flowers are on different plants, obviously self-pollination cannot take place (page 164).

Examples of this type of plant are the willow and the holly. In the corn, the staminate flowers are borne on the tassel, whereas it is from the pistillate flowers that the ear develops. The styles in this case are the long silks (Fig. 109). If some of the corn grains are not filled out, the flower has not been fertilized, and hence the endosperm, or reserve food supply for the embryo, has not developed. (For details of double fertilization in plants, see pages 167 and 705.)

e. Animals with Separate Sexes. (1) THE INVERTEBRATES.—In an earlier chapter (page 299), *Hydra* was said to be hermaphroditic, and most of them are. However, in one species, *H. oligactis*, the sexes are separate; *i.e.*, the individuals are either male or female. In the crayfish and the grasshopper, as well as other animals with separate sexes, the male contains a pair of testes for the production of sperm; the females have a pair of ovaries for the production of eggs. In the females of the crayfish and grasshoppers, there is present a seminal receptacle for the reception of the sperm. They are stored here until the eggs pass out of the body, at which time fertilization takes place (pages 385 and 402).

Starfish (echinoderms) are either male or female, two gonads being present at the base of each arm. The animals shed their eggs and sperm into the water, where fertilization takes place.

Mollusks are usually either male or female, although a few are hermaphroditic. When the eggs of the fresh-water mussel are shed (page 364), they become attached to her gills. The sperm shed in the water by the male are carried into the mantle cavity of the female in water through siphons. Fertilization occurs in the mantle cavity. The development of the larvae (glochidia) and the later development of the mussels are described on page 365.

(2) VERTEBRATES. (*a*) General Account.—In the vertebrates, the reproductive processes become more complex in passing from the lower to the higher forms. Yet the essentials of reproduction are the same. In the males, the sex organs are a pair of testes, in which sperm are produced, a pair of sperm ducts, vasa deferentia, and certain accessory glands. The testes may be inside the body cavity or outside. In the females, except in birds, two ovaries, in which eggs are produced, and two oviducts carry the eggs to the outside (or to uteri).

Fertilization usually takes place within the body of the female in the higher vertebrates. In most animals, a sexual cycle is present. The mating time for birds and many other wild animals is in the spring. Among animals that breed during the entire year, sperm may be present at all times in the male, but the egg cells of the female mature and are discharged periodically.

(*b*) Fish.—Many fish lay their eggs in the water, the males fertilizing them by spreading sperm over them. The parents then swim away, and

the fertilized eggs develop without further care. Certain fish, however, build nests that are guarded, usually by the male. In some cases, the nest is simply a depression in the ground, but the common stickleback builds a real nest (Fig. 308). The salmon migrate to the sea to spawn (Fig. 508), and the eels migrate from the fresh water to the sea (page 775). The word *spawn* (L. *expandere*, to spread out) has several meanings. It is used here to mean the shedding of eggs and sperm.

If the eggs are hatched outside the body of the mother, the animals are said to be *oviparous* (page 464); if they are held in the body of the mother until hatching, yet have no direct union with the mother, they are said to be *ovoviviparous* (page 464); if there is a direct connection with the mother, as in the case of mammals, the young are brought forth alive, and the animals are said to be *viviparous* (page 504).

(*c*) Amphibia.—Practically all the Amphibia lay their eggs in water. In the spring, masses of frog eggs are present in fresh-water pools or ponds. Toad eggs are laid in strings (Fig. 313). When the breeding season arrives, toads migrate to the water to lay. During the breeding season, the male frogs can be distinguished from the females by the thickened thumb (Fig. 162*B*). Although fertilization is external, frogs as well as toads mate in pairs. As the female lays her eggs, the male spreads sperm over them. In the water, the jelly around the eggs swells and forms a protective covering; it is also said to protect the eggs from the cold. Eggs of the frog and toad are easily collected, and the whole process of development may be observed in a jar or an aquarium. A detailed diagram of the male and female reproductive systems of the frog will be found on pages 257 *et seq.*

(*d*) Reptiles.—Reptiles breed on land. Fertilization occurs in the body of the female. Turtles and alligators lay their eggs in nests and pay no further attention to them. These eggs have a large yolk and a leathery shell. Some snakes are oviparous and some ovoviparous (pages 464 and 465). The green snake hatches from an egg outside the body of the mother (Fig. 319), and the young of the garter snake and the water snake are born alive (Fig. 318).

(*e*) Birds.—All birds are oviparous (page 490). The male birds have the usual vertebrate sex organs, *i.e.*, testes, sperm ducts, and accessory glands. The female is peculiar in one respect. During development, the right ovary disappears, and only the left ovary and the left oviduct remain. The eggs break out of the ovary and enter the oviduct. As they pass down the oviduct, they receive the "white" of the eggs, an albuminous substance secreted by the walls of the oviduct. Further down in the duct, they receive a double, parchment-like membrane. This is easily peeled off in a hard-boiled egg. Finally, just before it is laid, the shell, secreted by a shell gland in the lower part of the oviduct, is added (Fig. 335).

The sperm are transferred from the cloaca of the male to the cloaca of the female. These then make their way to the top of the oviduct and the eggs are fertilized just before they receive the jelly-like coat or "white." Fertilization takes place in such a bird as the pigeon about 41 hours before the egg is laid.

(*f*) Mammals.—The lowest group of mammals are the egg-laying monotremes. Although these animals lay eggs, they nourish their young with a sort of milk. In all other mammals, the young develop inside of the body and are brought forth alive. The mammal egg is very small, almost microscopic, in some cases. It contains little yolk, and so the young developing embryo is nourished by the mother.

Figure 448 shows the reproductive organs of the cat, and Fig. 450*A* those of man. The testes, formed in the abdominal cavity, migrate to a sac, the scrotum, either before or just after birth. Seminiferous tubules in the testis unite to form an epididymis, which leads into a duct, a vas deferens, and this joins the duct of a seminal vesicle. The ducts from the seminal vesicles unite to form the ejaculatory duct. Sperm from the testes and secretions from the seminal vesicles, Cowper's glands, and the prostate make up the semen or seminal fluid. The relations of all these parts are shown in Fig. 450*A*.

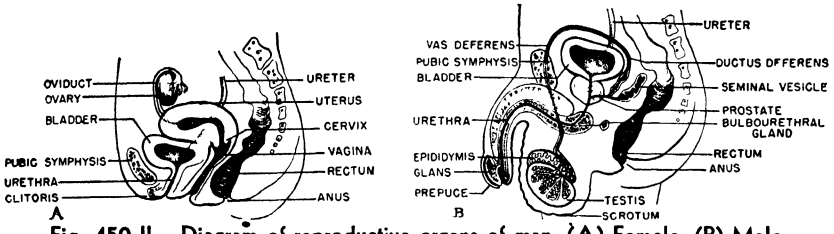

Fig. 450 II.—Diagram of reproductive organs of man. (A) Female. (B) Male.

In the female cat, the eggs cells mature periodically in the two ovaries. When fully grown, the eggs are discharged from the ovary into the body cavity. From here they find their way into the oviducts, where fertilization takes place. The fertilized eggs pass from the oviducts into the two uteri and become implanted in the uterine walls. The placenta is an organ developed by mammals for taking care of the exchange of materials between the mother and the developing offspring (page 694). The two uteri in the cat unite to form a single vagina, a canal that leads from the uterus to the exterior.

In the primates, including man, ova ripen at intervals of about 4 weeks, one, rarely two, being matured at the same time. They find their way into the oviduct (Fallopian tube) after breaking out of the ovary into the body cavity. If fertilization occurs, it takes place in the tube, and

development begins at once. It now moves on into the single uterus and, after several days, being of a size seen with difficulty, it embeds itself in the walls of the uterus. The uterus opens through the cervix into the vagina.

In man, as well as in the other mammals, there is great difference in the size of the male and female germ cells (Fig. 459). (For development of the embryo, see Chap. XLIII.)

f. Paedogenesis.—Paedogenesis is the reproduction by immature or larval stages of animals. It is characteristic of some insects (gall midges of the genus *Miastor*). A classic case is that of the Mexican axolotl (page 459), which reproduces its kind without undergoing metamorphosis or losing its gills. It will be recalled that this form, under suitable conditions, metamorphoses and becomes an *Ambystoma*.

4. Alternation of Generations.—Alternation of asexual and sexual generations is almost universal in plants. It is very common among the mosses (page 202), the ferns (page 206), as well as in certain animals such as *Obelia* (page 302). In certain parasites, there may be one or more hosts involved in the life cycle. For example, the asexual cycle of the human malaria parasite lives in man, and the sexual cycle develops in the Anopheles mosquito. For a comparison of the differences in the life cycles of plants and animals, see Fig. 463, page 709. Note that in plants the sexual generation (gametophyte) is usually haploid, whereas in most animals both generations are diploid.

Questions

1. Discuss some early theories of reproduction.
2. How may grafting be useful to a fruit grower?
3. Discuss regeneration in plants; in animals.
4. Name some organisms that reproduce by budding; by binary fission; by spores.
5. Discuss hermaphroditism in plants and animals, giving the method of reproduction and examples of each type.
6. Distinguish between the types of gametes. Why is a spore not a gamete?
7. If eggs have some protection when laid, is it necessary for a great number to be produced in order to ensure the continuance of the race?
8. Distinguish between oviparous, ovoviparous, and viviparous, giving examples of each.
9. Compare reproduction in fish and Amphibia; reptiles and birds.
10. What types of mammals lay eggs?
11. Give a general account of reproduction in mammals.
12. Define: paedogenesis, hermaphroditism, natural parthenogenesis, artificial parthenogenesis, placenta, marsupial.

CHAPTER XLIII

DEVELOPMENT OF THE INDIVIDUAL

All that happens is as usual and familiar as the rose in spring and the crop in summer.

—MARCUS AURELIUS.

The development of the egg is not a haphazard growth but consists of an orderly series of changes. As development proceeds, definite structural features make their appearance, each typical of the kind of organisms that produced the egg. When the lower plants and animals reproduce themselves by binary fission, no such development of the individual occurs as in the higher plants and animals; each daughter cell resembles its parents except in size.

I. Development in Plants

A. The Fertilized Egg. 1. DEVELOPMENT OF THE ENDOSPERM AND EMBRYO.—The double fertilization that occurs in higher plants has been referred to several times (page 167). The fruit and seed come from the flower. Before these can develop, however, the egg must go through a series of stages leading to this development. As soon as the endosperm nucleus is fertilized, it begins to divide and so forms the endosperm; at the same time, the fertilized egg, now the zygote, begins to divide. The cells derived from the egg organize themselves into three distinct regions: (1) the region from which the seed leaves or cotyledons develop; (2) a region from which the plumule, which grows between the seed leaves, develops; (3) a region of the hypocotyl, which gives rise to the primary root (Fig. 122). The cotyledons disappear shortly after the seed germinates, whereas the plumule gives rise to stem and leaves. (For details of these events, as well as description of further development in plants, see Chap. XIII.)

2. FATE OF THE ENDOSPERM.—Sometimes, as in the bean, the embryo absorbs most of the endosperm and stores it in the cotyledons (page 178); in other cases, the endosperm is crowded around the embryo, as is the case in the castor bean (page 176), and the embryo remains thin.

3. CHANGES IN THE OVULE.—While all these events are taking place, the ovule enlarges, and a hard coat is formed from the coverings of the ovule. Thus the fertilized ovule becomes a seed. In most cases, no further growth takes place at this time, and the seed remains dormant until conditions are right for germination.

4. FRUITS.—The fruit is formed from the ovary and accessory parts (page 167). In the apple, for example, the receptacle grows up around the ovary and forms the edible part of the apple.

B. Germination of the Seed.—The embryo is already formed in the dormant seed, and enough food is stored up there to enable it to begin to grow again. The two essentials for germination are water and proper temperature. (For the events of germination for several types of seeds, see pages 173–178.)

After germination, the plant establishes root, stem, and leaves. It grows until it reaches maturity and then produces flowers, seeds, and fruits, thus completing the cycle.

This generalized account is what usually happens in the higher plants. In general the egg will not develop until the egg is fertilized. There are a few exceptions to this.

II. The Early Development of Animals

One of the most interesting facts in all biology is that certain stages of development may be traced from the lowly creatures to the lordly rulers of the earth. These stages can best be shown by a comparison of the early development of several types.

A. Cleavage of the Egg.—The way in which an egg divides is associated with the distribution of yolk in that egg.

1. HOLOBLASTIC CLEAVAGE.—When the yolk is distributed evenly through the egg, as in *Amphioxus*, it is said to be *homolecithal* (Gr. *homos*, same; *likithos*, yolk), and the type of cleavage is *holoblastic*, that is, total cleavage. Here the planes of cleavage cut all the way through the egg. This may be of two types, equal (Fig. 451) and unequal.

2. MEROBLASTIC.—Eggs like the hen's egg have a large amount of yolk concentrated at the vegetal pole. This type of egg is *telolecithal* (Gr. *telos*, end; *likithos*, yolk). The planes of cleavage do not cut all the way through the egg, and this results in a disk of cells at the animal pole. The cleavage is termed *discoidal*, or *meroblastic* (Fig. 452*A*).

3. SUPERFICIAL.—In insect eggs, the yolk is concentrated in the center of the egg. The type egg is *centrolecithal* (Gr. *kentron*, center; *likithos*, yolk). The egg nucleus divides and moves to the periphery. Here cell walls form around the nuclei, and there is a superficial layer of cells; hence the name for the type, *superficial cleavage* (Fig. 453*B*).

4. SPIRAL.—In mollusk eggs, the cleavage planes alternate with each other in such a way that a spiral of cells is formed. For this reason, the type cleavage is called *spiral cleavage*.

Each cell resulting from cleavage is a blastomere (page 259). The blastomeres do not separate but remain together. Since a group of blastomeres often resembles a mulberry, the name *morula* (L. *morum*, a mul-

berry) is often used to describe the state of the egg during the early cleavage stages.

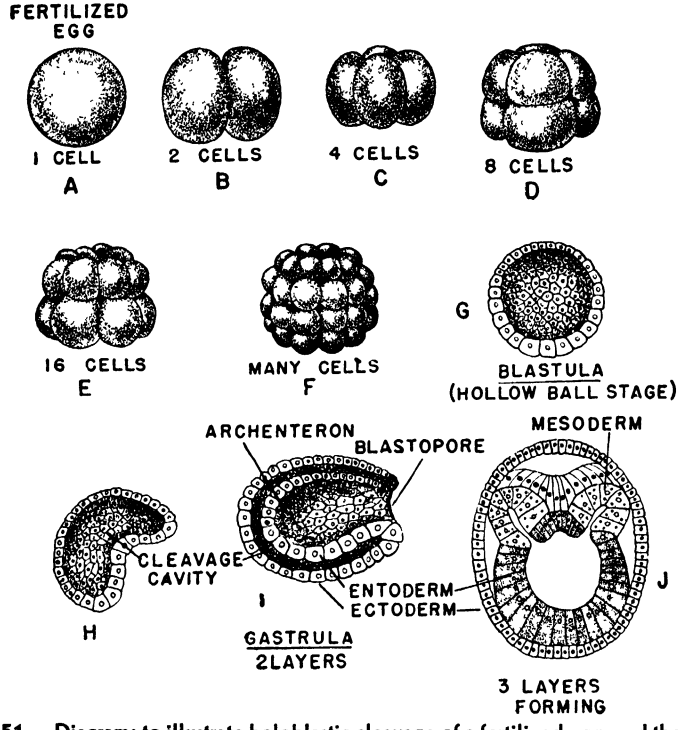

Fig. 451.—Diagrams to illustrate holoblastic cleavage of a fertilized egg, and the formation of the three germ layers, ectoderm, entoderm, mesoderm. From these three layers all tissues and organs develop. For other types of cleavage, see Fig. 452. (Adapted from models of the development of Amphioxus by L. Runyon.)

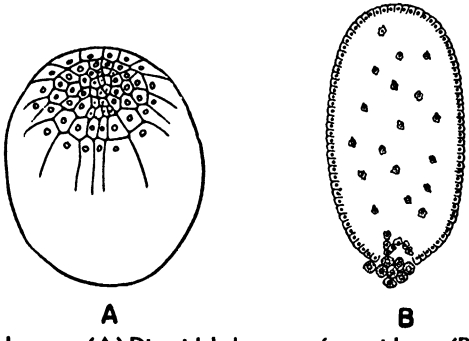

Fig. 452.—Types of cleavage. (A) Discoidal cleavage of a squid egg. (B) Superficial cleavage of an insect egg. For holoblastic cleavage, see Fig. 451. (After Hegner.)

B. The Blastula (page 259).—As development proceeds, a cavity appears in the center, of the egg. The egg now resembles a hollow ball and

is the *blastula* (page 259). The layer of cells on the outside is called the *blastoderm* (Gr. *blastos*, sprout; *derma*, skin), and the cavity within is called the *cleavage cavity*, the *blastocoel* (Gr. *blastos*, sprout; *koilos*, a cavity), or *segmentation cavity* (Fig. 461*G*).

C. The Gastrula (page 260).—When a typical blastula has reached its full size, in some cases it becomes invaginated, much as one might push in the side of a rubber ball with a finger (Fig. 451*H*). This is the beginning of the formation of the gastrula. As this process proceeds (gastrulation), the cleavage cavity becomes obliterated (Fig. 451*I*), and a new cavity is formed, the primitive digestive cavity or *archenteron* (see page 260 and Fig. 451*I*).

Gastrulation does not always proceed according to this plan. Many modifications appear in various animal groups. But at the end of gastrulation there are two layers of cells present, the ectoderm and the endoderm.

D. The Germ Layers and Their Derivatives.—The gastrula is two-layered, ectoderm on the outside and endoderm on the inside. This stage is suggestive of those organisms like *Hydra* and other coelenterates, which possess two layers, the *diploblastic* animals (page 294). The higher animals are *triploblastic*, the third layer being the mesoderm (page 312).

1. Formation of the Mesoderm.—The method of the formation of the mesoderm varies considerably with different organisms, but in all vertebrates two sheets of mesoderm tissue are formed, an outer layer, next to the ectoderm, the *somatopleure* (Gr. *soma*, body; *pleura*, side), or somatic mesoderm, and an inner layer associated with the developing gut from the endoderm, the *splanchnopleure* (Gr. *splanchnon*, gut; *pleura*, side), or splanchnic mesoderm (Fig. 453). Between the outer layer and the ectoderm loose cells (mesenchyme) fill in the space, and between the inner layer and the gut the same sort of cells fill that space. The space between the two layers of mesoderm is the future body cavity or *coelom*.

2. Formation of Tissues from the Three Primary Germ Layers. In summarized form, the tissues are derived as follows:

a. Ectoderm.—Nervous tissues, the skin and its appendages (hair, nails, enamel of the teeth, etc.), and certain parts of the lining of the mouth, nose, and anus are formed from the ectoderm.

b. Endoderm.—The lining of the alimentary canal, except the extremities that are ectoderm, the lungs, trachea, liver, thymus, thyroid (page 261). All these organs have much mesodermal tissue in them, also. In some of the lower chordates, the notochord is from the endoderm.

c. Mesoderm.—From the mesoderm come all the connective tissues, the blood, the vascular system, the skeleton, the muscles, the excretory and reproductive systems, the derma of the skin and, frequently, the notochord (page 689).

E. The Embryonic Membranes. 1. FUNCTIONS.—The function of the embryonic membranes are protection of the embryo from mechanical injury and the taking care of physiological processes of respiration, *excretion*, and *nutrition*, during development or until the organs that later take over these functions are developed.

A knowledge of how these membranes develop sheds some light on the evolutionary history of animals. Embryos that develop in water do not have, nor do they need, membranes other than egg membranes. In these forms, exchange of gases and the elimination of wastes take

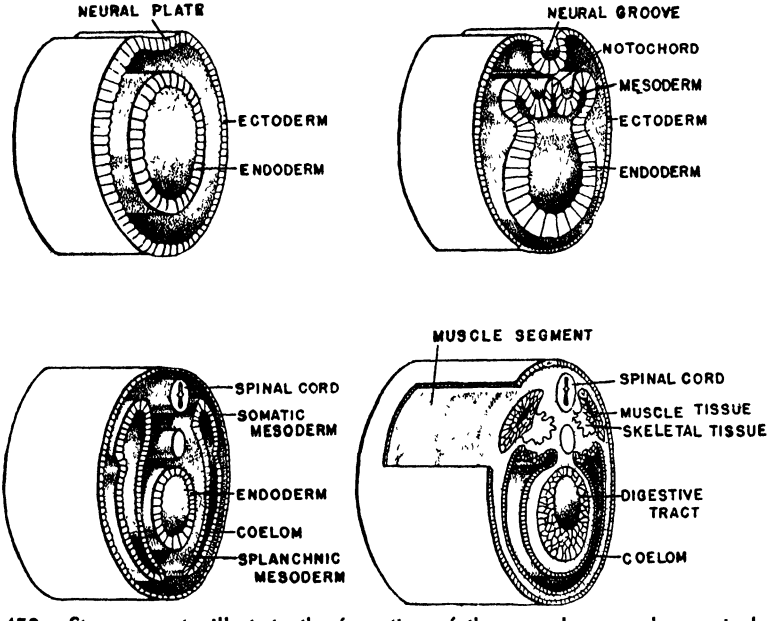

Fig. 453.—Stereogram to illustrate the formation of the mesoderm, coelom, spinal cord, digestive tract, etc. (F. A. Baker.)

place *directly;* the oxygen they need is dissolved in the water and the water takes away the wastes eliminated through the egg membranes. As an adaptation for living on land, however, a new "setup" was elaborated; *i.e.*, an elaborate set of membranes was developed for protection and for taking care of the metabolism of the developing organism.

2. AMNION AND CHORION.—These are not found in the Amphibia. Beginning with the reptiles, they are found also in birds and mammals (Figs. 337 and 455). Their method of origin is easily understood from the study of a hen's egg. Folds of somatopleure grow up over the embryo; they are the head fold, the tail fold, and the lateral folds. These meet and fuse and so form an inner membrane enclosing the embryo, which is the *amnion*, and an outer membrane, the *chorion*. The cavity between the

embryo and the amnion is the *amniotic cavity;* that between the chorion and the amnion is the *chorionic cavity.* From the way it was formed (Fig. 455), it will be seen that the inner tissue of the amnion is ectoderm and the outer tissue, mesoderm, whereas in the chorion, the inner tissue is mesoderm and the outer tissue, ectoderm. In the higher animals, the amniotic cavity fills with fluid. This has a shock-absorbing function, besides keeping the embryo moist.

3. The Yolk Sac.—In forms having eggs with a large amount of yolk, the blastoderm grows down over the yolk, enclosing it. The inner layer of this yolk sac is endoderm, and the outer layer is mesoderm. The yolk sac soon becomes well supplied with blood vessels, and the blood in these vessels absorbs and transports the food from the yolk to all parts of the developing embryo. In the higher animals, a yolk sac is formed but because of the formation of a *placenta,* it does not play as important a role as it does in the birds.

4. The Allantois.—Reptiles, birds, and mammals develop a fourth membrane, the *allantois.* It develops as an outgrowth of the hind-gut; its tissues are therefore the same as those of the gut, endoderm inside and mesoderm outside. It grows out into the extraembryonic cavity and between the amnion and the chorion. In reptiles and birds, it is well supplied with blood vessels and serves as a respiratory membrane. The allantoic cavity serves as a reservoir for wastes from the kidneys, and its walls assist in the absorption of albumen. Because of the development of a placenta in mammals, the allantois, though present in the very early stages, is not the important organ it is in reptiles and birds (page 466).

F. Formation of the Embryo. 1. General Account.—In the formation of the gastrula, the old cavity of the blastula is obliterated, and a new cavity, the primitive archenteron, is formed. This opens to the outside through the *blastopore* (Gr. *blastos*, bud; *poros*, passage). As the embryo elongates, there is a fusion by a backward growth of the blastopore, forming a primitive streak (Figs. 403 and 453). This is a sort of landmark in embryonic development. Anterior to this, the ectoderm in the dorsal region begins to thicken to form the neural plate. This sinks a little in the middle, and the edges begin to roll up to form the neural folds. These grow and finally meet, the edges fusing to form the neural tube (Fig. 403). In later development, the neural tube differentiates into the brain and spinal cord. While this is happening, a long, rod-like notochord has formed under the neural plate (Fig. 453). In the lower chordates, sometimes this is from the endoderm; in the higher animals, it appears to be from the mesoderm.

In the meantime, the lateral folds appear in the endoderm; these meet and fuse a part of the way to form the gut (Fig. 453). The amount of closure of the gut depends upon the amount of yolk in the egg. Meso-

derm grows around the endoderm of the gut. In forms like *Amphioxus*, there is little yolk, and the ventral body wall is completed early, the yolk being carried in the body. On the other hand, the bird's egg has much yolk, and the yolk sac is drawn in shortly before hatching. After the parts of the embryo are established, development proceeds according to the pattern of the animal.

Practically all animals pass through the stages here outlined, though many modifications occur in different species. When one thinks of the varieties of eggs and the varieties of animals that develop from them, it seems quite remarkable that early development is so similar in them all.

2. INVERTEBRATES. *a. Hydra.*—The egg of the *Hydra* undergoes the early stage of development while attached to the body of the parent (see page 329, and Fig. 207) cleavage is holoblastic and the blastula is a hollow sphere. Formation of the gastrula is somewhat different from that of *Amphioxus*. The cells of the blastula divide and drop into the cavity of the blastula, forming a more or less irregular mass of cells within, which becomes the endoderm. The outer layer of cells is the ectoderm. The gastrula now elongates, a mouth appears at one end, and around this a circle of tentacles develops. The endoderm cells arrange themselves so as to line the cavity of the *Hydra*, and between the ectoderm and the endoderm the mesoglea, a noncellular layer, is formed (page 291). The young *Hydra* soon grows to adult condition.

b. Earthworm.—The eggs of the earthworm are fertilized in the cocoon (page 343). Development of the blastula and gastrula differs somewhat from the general plan shown in Fig. 451. Cleavage is *holoblastic* but unequal and continues until a hollow sphere, the blastula, is formed. This invaginates to form the gastrula, the ectoderm being on the outside and the endoderm on the inside. In the earthworm, the third layer, the mesoderm, a cellular layer, develops from two cells called *mesoblasts* (Fig. 238). From these three layers of cells, the young worm develops.

c. Crayfish.—Early development of the crayfish is more specialized than in *Hydra* and the earthworm. The eggs, when laid, are attached to the swimmerets of the mother (page 384); cleavage is superficial; the eggs are filled with yolk, and the cells form a single layer, which surrounds the yolk. The formation of the germ layers in the *crayfish* is very complicated and the process very specialized.

3. THE VERTEBRATES. *a. The Frog.*—A short account of the development of the frog will be found on pages 257–263.

(1) CLEAVAGE.—When the sperm enters the frog egg, streaming movements are set up that result in the distribution of materials. Three regions can now be seen, an upper animal hemisphere, which is pigmented, a yellowish-white vegetal hemisphere, and a gray crescent, with little or no pigment. The gray crescent lies approximately opposite the entrance

point of the sperm. The first cleavage plane (holoblastic) usually bisects the gray crescent so that bilateral symmetry is established at this time. The second cleavage plane is at right angles to the first, and four equal cells are formed. After the third cleavage, however, the cells in the animal hemisphere are smaller. They have less yolk and divide more rapidly than the cells in the vegetal hemisphere.

(2) BLASTULA AND GASTRULA.—The large amount of yolk in the frog egg influences the formation of the blastula and the gastrula. From the eight-celled stage on, there is a cavity in the dividing egg. As development proceeds, a hollow ball, the blastula, is formed with the cavity in the animal hemisphere. The roof of the cavity is of small cells and the floor is of large cells (Fig. 177).

Gastrulation is modified by the large amount of yolk in the cells of the vegetal region. The *germ ring* is an equatorial belt of pigmented cells having a high division rate. This leads to an overgrowth of cells over the vegetal hemisphere by the process of *epiboly* (Gr. *epibole*, a throwing upon). A *crescentric depression*, caused by the inturning of cells at the pigmented border of the gray crescent appears. This invagination, or ingrowing of cells, is conditioned upon the fact that the cells at the dorsal margin of the depression have a high division rate. This dorsal margin is the dorsal lip of the blastopore. The process of inturning spreads rapidly from the dorsal margin or lip until it eventually involves all of the margin of the germ ring. The vegetal cells are gradually enclosed until only a small light area is visible, the *yolk plug*. The lips of the germ ring are now the lips of the blastopore. As invagination and shifting of cells continues, the *blastula cavity* decreases, and the *archenteron* is established (Fig. 177). With the formation of the blastopore, gastrulation is completed.

(3) FORMATION OF THE MESODERM AND THE NOTOCHORD.—Before gastrulation is completed, the formation of the mesoderm and the notochord begins. Where the ectoderm and the endoderm meet, at the rim of the blastopore, cells arise and grow in between the ectoderm and the endoderm. The *notochord* is formed from cells that grow inward from the dorsal part of the rim of the blastopore; *mesoderm* is formed from cells that grow inward from the sides of the blastopore. The mesoderm encloses the entire mass of endoderm. Later, a cavity (Fig. 177) separates the mesoderm into two sheets (see below); this cavity is the *coelom*. With the establishment of three germ layers, the formation of the archenteron, the notochord, and the coelom, the period of early development of the embryo is accomplished.

(4) LATER DEVELOPMENT OF THE EMBRYO.—All organs and tissues are formed from the three germ layers. (For a list of the derivatives of the three germ layers, see page 261.) During late gastrulation, a plate of

ectoderm cells, the *medullary plate*, is differentiated upon the dorsal surface of the embryo. The middle of this sinks a little (medullary groove) while the edges roll up, meet, and fuse to form the *neural tube* (Fig. 403). Later, the brain and spinal cord develop from this. During the closure of the neural tube (fusion of the neural folds), some cells are left under the superficial ectoderm. They form the *neural crest*, and from it other parts of the nervous system develop. In the meantime, the endodermal *enteron* is developing further. At its anterior end, a slight depression, the *stomodeum*, the future mouth region, appears and at the posterior end a slight depression, the future anal region, the *proctodeum*, develops. Both of these are lined with ectoderm. The respiratory system develops in the pharyngeal region; the liver and pancreas are outgrowths of the archenteron and are lined with endoderm. From the *dorsal mesoderm*, the muscles and the skeleton take their origin; from the *intermediate mesoderm*, the excretory and reproductive systems are developed; as mentioned, the *lateral mesoderm* splits into an outer layer, lying next to the ectoderm, and an inner layer next to the endoderm. Between these two layers is the body cavity or *coelom* (page 344).

The *sense organs* develop either as ingrowths from the ectoderm which connect with the central nervous system, or as outgrowths from that system, or in both ways.

Formation of the *eye* occurs when the divisions of the brain have been established. A pair of hollow outgrowths from the forebrain expand into the *optic vesicles* (Fig. 403). These remain attached to the brain by the narrow, hollow *optic stalks*. The optic vesicles grow out toward the ectoderm on each side of the head. When they reach the ectoderm, they flatten and the outer cells fold in, forming the *optic cups*, the inner layer of cells becoming the *retina*. The external ectoderm over these cups now thickens and invaginates to form the *crystalline lens* (Fig. 454). The lens will not form if the optic vesicles do not come in contact with the external ectoderm and stimulate it in some way.

The *ear* begins as two thickenings, the *auditory placodes*, in the superficial ectoderm, one on either side of the hindbrain (Fig. 454). These patches invaginate and form pear-shaped vesicles which open on the surface of the body. In the frog a part of this canal persists as the *endolymphatic duct*. The vesicles undergo changes and the characteristic parts of the ear develop. The middle ear is developed mainly from the first gill pouch.

Olfactory organs appear as two patches of thickened ectoderm just in front of the neural tube. These invaginate to form the *olfactory pits*, and then enlarge to form the nasal cavities. Certain cells of the ectoderm lining become sensory.

(5) The larval stage and metamorphosis.—At the close of embryonic development, the larval stage begins. Little tadpoles now appear that have some fish-like features. They breathe by external gills, but these are partly replaced by internal gills. Water taken into the

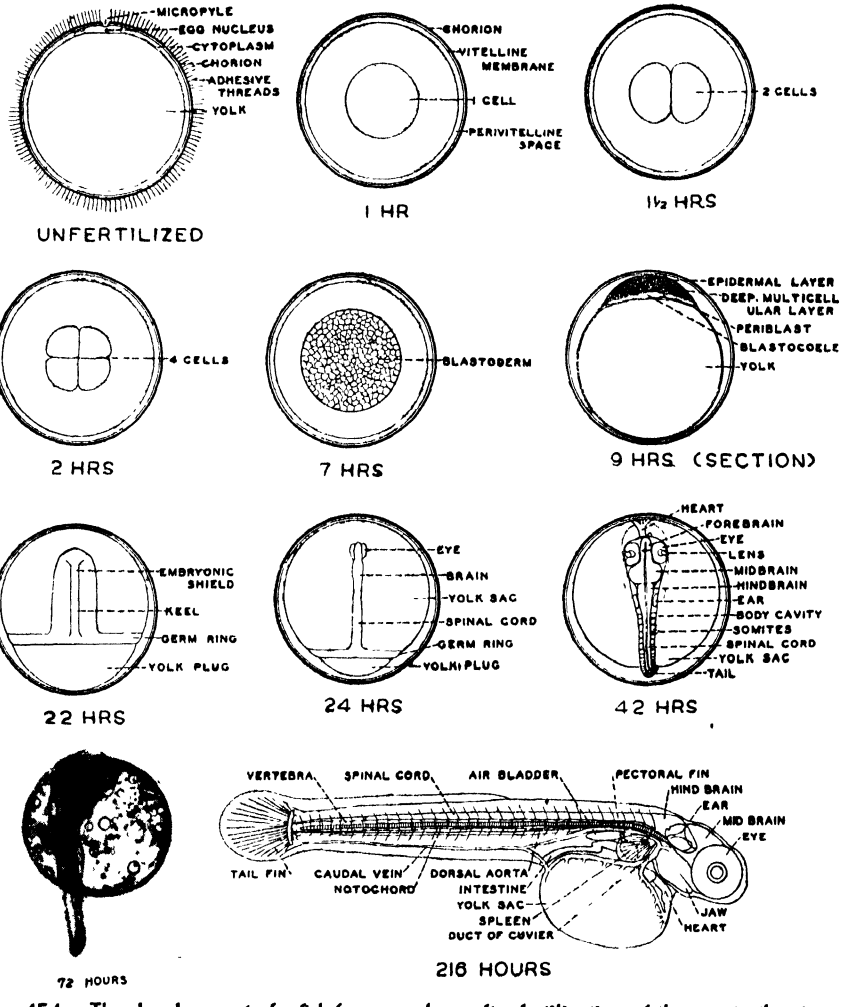

Fig. 454.—The development of a fish from one hour after fertilization of the egg to the stage of late embryo (yolk sac is still present). (Courtesy of Prof. A. N. Solberg.)

mouth bathes these gills and then passes out through the *operculum* (page 261). Later, lungs are developed, and the tadpole must now come to the surface to breathe. The hind legs appear before the front legs do; the tail is resorbed; the long intestine becomes shorter; finally, all the tadpole features are lost, and the adult frog results.

Although the frog develops according to its own pattern, it resembles other vertebrate animals in its early development. There is great similarity in development of all vertebrate embryos (Fig. 513), especially in the early stages. Some remain alike longer than others, but each follows its own definite pattern of development.

b. Fish.—Most fish eggs are laid in the water and fertilized there. In a few cases, however, the eggs are held in the body of the mother until they hatch (*ovoviviparous*), but they have no connection with the tissues of the mother's body, and they are merely protected for a time. Development is the same as for fish eggs laid in the water. Fish eggs contain a large amount of yolk, which is used for nourishment of developing embryos. Cleavage takes place in a restricted area, the *germinal disk* (Fig. 454), and the large yolk remains undivided. It is later enclosed by cell layers from the embryo which form the so-called *yolk sac.* The formation of the blastula and the gastrula is modified on account of the large amount of yolk. As the embryo develops, it becomes more separate from the yolk but remains attached to it by a narrow stalk (Fig. 454). The yolk decreases as it is used up by the fish, and by the time the yolk disappears, the fish is able to ingest its own food.

c. Birds and Reptiles.—The eggs of birds and reptiles are fertilized internally. As they pass down the oviduct, they acquire certain envelopes; first the "white," or albumen, then a double shell membrane, and finally a shell. Further development does not take place until the eggs are incubated. Figure 337 shows a hen's egg after 1 day of incubation.

Many reptile eggs hatch after being laid, but some are *ovoviparous,* as are the fish. All birds are *oviparous; i.e.,* the eggs hatch after being laid. Certain reptiles, such as the alligator, lay their eggs in decaying vegetation. Decaying vegetation generates a certain amount of heat and so facilitates the hatching of the egg. Some snakes protect their eggs by winding their bodies around them. Birds incubate their eggs by sitting on them and keeping them warm.

As is the case with the fish, the method of cleavage and development is modified in birds and reptiles by the presence of a large amount of yolk. A protoplasmic disk on top of the yolk undergoes cleavage, and from this the embryo develops. The yolk does not divide. As in the case of the fish, a yolk sac grows around it. As the yolk is used up by the young chick, the yolk sac is drawn up, being drawn inside the body the day before hatching.

Even though the formation of the blastula and the gastrula is somewhat obscured, these stages do occur. Figure 455*A* is a diagram of the early stages in the development of the bird. This shows in a diagrammatic way how the protecting membranes, the amnion and the chorion, develop. These are entirely different from anything that occurs in the development

of the frog. The embryo is a *flat plate* of cells, lying on the yolk. Soon the edges of this plate begin to fold at each end of the body, and this folding continues until the two ends meet over the embryo and fuse. The embryo is thus enclosed in a sac. The amniotic sac of the higher

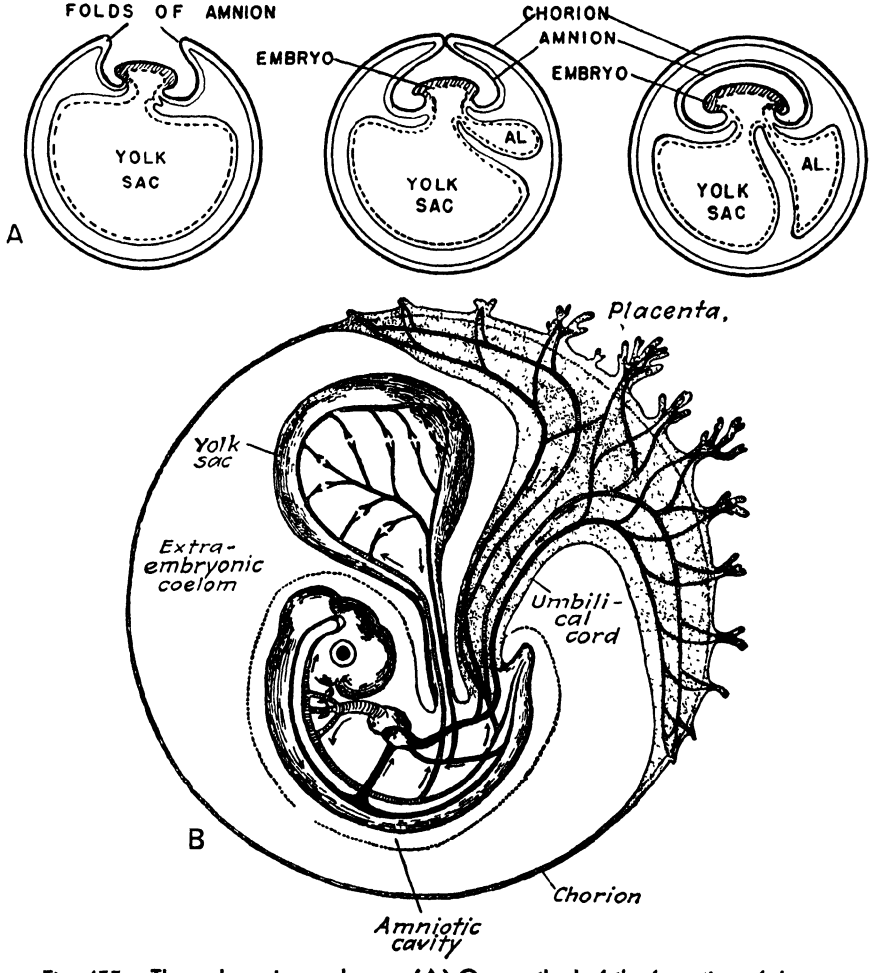

Fig. 455.—The embryonic membranes. (A) One method of the formation of the membranes. (B. Shamos.) (B) The early development of a mammal. Note embryonic membranes, umbilical cord, and placenta. (From Wilder, History of the Human Body, Henry Holt and Company, Inc.)

animals is filled with fluid that protects the young embryo from pressure, blows, etc., and keeps it moist.

Everything that lives, whether embryo or adult, must obtain oxygen and get rid of wastes. The birds solve this problem by developing the

allantois (Gr. *allas*, sausage), a temporary organ of respiration and excretion. It is a sac-like outgrowth from the intestine, just back of the place where the embryo is attached to the yolk. This outgrowth pushes between the amnion and chorion. The eggshell is porous, allowing an exchange of gases in the blood in the blood vessels of the allantois. The membranes remain in the shell when the chick hatches, 21 days from the beginning of incubation.

d. Mammals.—The duckbill and the spiny anteater lay eggs, and these develop much as do the eggs of birds and reptiles. They differ from those of other mammals whose eggs develop within the body of the mother.

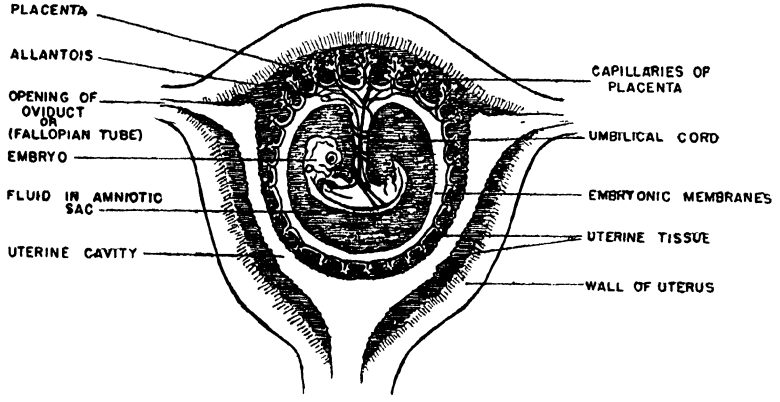

Fig. 456.—Diagram to illustrate the relation of the placenta to the uterus, the embryonic membranes, umbilical cord, and embryo of a mammal (man). (B. F. Edwards.)

The mammalian egg usually contains little yolk. Development begins when the fertilized egg passes down the oviduct to the uterus. When it reaches the uterus, it imbeds itself in uterine walls. At this time, it is so small as to be barely visible.

By a process slightly different from that described above for birds, the mammalian embryo now forms two protective membranes, the *amnion* and the *chorion*. The embryo is enclosed in the *amniotic sac*, which is filled with *fluid*. The outer membrane is the chorion (sometimes called the serosa). The chorion in the mammal develops fingerlike processes that fit into pits in the tissues of the uterus. These are the branching *villi*. They are important connections between the mother and the embryo (Figs 455 and 456) and contain many blood vessels, through which an exchange of gases takes place. The blood in these vessels also brings the food that the embryo needs and takes away the wastes. The villi and the surrounding tissues, partly maternal, partly belonging to the embryo (fetal), form the *placenta* (Gr. *plakous*, a flat cake) (Fig. 455).

The allantois is rudimentary; it is not needed by the mammal, because the placenta takes over its functions of respiration and excretion.

There is *no mixing of fetal*[1] *and maternal* blood; the two systems are separate. However, an *exchange of lymph* occurs.

The cord that connects the embryo with the placenta elongates and becomes the *umbilical cord.* There are no nerves in the umbilical cord; hence the mental states of the mother are not transmitted to the embryo.

The period of embryonic development, or *gestation* (L. *gestatio,* a bearing, carrying), varies greatly among mammals. Below is a time table of embryonic development for some familiar mammals:

Name of the Animal	Time
Opossum	13 days
Mouse	20 days
Rat	22 days
Rabbit	32 days
Cat, dog, guinea pig	9 weeks
Pig	17 weeks
Sheep	21 weeks
Macaque monkey	24 weeks
Man	36 weeks
Cow	40 weeks
Horse	48 weeks
Rhinoceros	18 months
Elephant	20 months

The young mammals are born in various stages of development. Horses, cattle, and sheep are able to walk shortly after they are born. They are, however, dependent upon their mothers for food, as are all mammals, regardless of the state in which they are born. They nourish their young with milk from their mammary glands. Opossums and kangaroos (Marsupials) are born in an undeveloped state and carried in a pouch until development proceeds further. Inside the pouch are *mammary glands* (Fig. 350), to which the young opossums and kangaroos become attached and from which they get their milk (page 508). Many mammals are born with little or no hair, with their eyes closed, in a generally helpless state. Young rats and rabbits are red, squirming, helpless things. The human infant has its eyes open when it is born but is one of the most helpless of young animals and requires parental care longer than any other animal.

TWINS.—Multiple births are common among lower animals (Fig. 457) but fairly uncommon among the higher mammals, including man. In man, it is said that twins are born in 1:88 births; triplets, in $1:(88)^2$ births; quadruplets, in $1:(88)^3$; the ratio varying somewhat in different races.

[1] After the sixth to eighth week, the developing human embryo is known as a fetus.

Twins may arise in two ways. They may develop from separate egg cells, in which case they are no more alike than any other brothers and sisters. These are *fraternal twins* and they may be of the same sex or of different sexes. Twins that develop from one fertilized egg are *identical twins* (Fig. 458). After a fertilized egg has divided, the two halves may separate, and each half may now develop into an individual. Identical twins are always of the same sex, and they may be mirror images of each other.

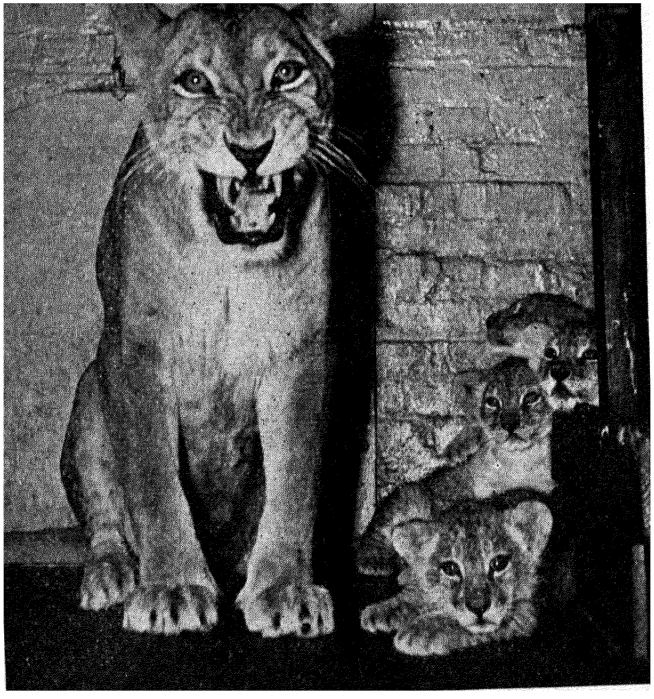

Fig. 457.—Multiple births. Martha, a lioness in the Atlanta Zoo to whom four cubs were born. (Courtesy of The Atlanta Constitution.)

In the armadillo, four young develop normally from each fertilized egg. These are always of the same sex.

G. Parental Care.—Many animals never see their young. The only provision for their future is the storage of yolk in the eggs, which serves as nourishment until the young can obtain food for themselves. Examples of this type are earthworms, starfish, insects, frogs, some reptiles, and most fish. Large numbers of eggs must be laid if the species is to survive, because many of the eggs are lost or eaten. Even among these animals, however, certain species protect their eggs and young by placing them

in favorable places or by carrying the eggs around until they hatch. For example, bee larvae are fed by workers, and crayfish carry their eggs attached to their swimmerets (page 374) until they hatch and the young have molted once or twice. Several species of toads carry their eggs around with them (page 459). Certain fish build nests and guard the eggs in them (page 450), though the majority do not. Other types of animals care for their young with great solicitude. Many birds feed and protect their offspring even after they leave the nest. Mammals vary considerably with respect to the length of time they care for their young. All mammals, being nourished with milk from mammary glands, are dependent upon their mothers for food. The young of man are among the most helpless of animals when born; they must be cared for for many

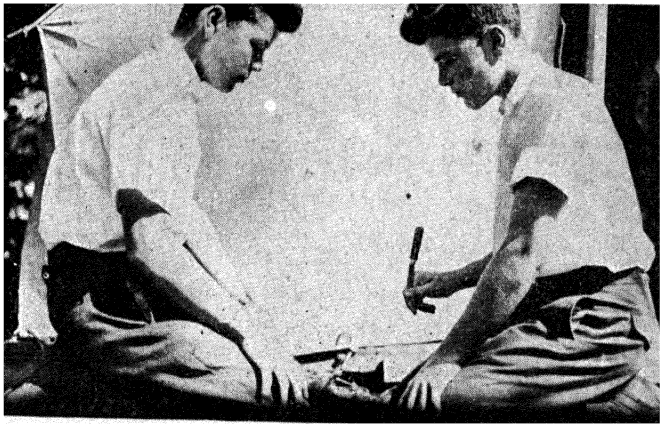

Fig. 458.—Identical twins. Identical twins develop from one fertilized egg and are much alike; fraternal twins develop from two fertilized eggs and are as different as any other brothers and sisters. (Courtesy of Dr. H. F. Perkins.)

years before they are able to take their place in our complex society (see also page 695).

Questions

1. Discuss development in plants. What is meant by germination? What is a seed?
2. Compare the four types of cleavage, and give examples of each. In what way does the amount of yolk in an egg affect its development?
3. Distinguish between mesoglea and mesoderm.
4. Is a blastula always formed in the same way? A gastrula?
5. Describe the formation of mesoderm in the frog embryo.
6. In a summarized account, state the derivatives of the ectoderm; the endoderm; the mesoderm.
7. Discuss the embryonic membranes, their origin, function, and fate. Why are they not needed by fish?
8. Give a general account of the early development of an animal embryo of the *Amphioxus* type.

9. Compare the early development of fish and amphibians.
10. What advanced features over amphibians are shown in the development of birds and reptiles?
11. Do mammals vary greatly in development? Explain fully.
12. Give some examples of parental care not mentioned in the text.
13. Define: allantois, yolk sac, blastopore, archenteron, coelom, telolecithal, centrolecithal, homolecithal, primitive streak, notochord, mesoglea.
14. What is your opinion as to the value of studying embryonic features and development?

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Part V

SOME BIOLOGICAL PRINCIPLES AND THEORIES

CHAPTER XLIV

THE GERM CELLS AND FERTILIZATION

The creation of a thousand forests is in one acorn, and Egypt, Rome, Gaul, Britain, America lie folded already in the first man.

—EMERSON.

I. Germ Cells and Body Cells

A. Germinal Continuity.—The cells in the body of a plant or an animal are separated into two divisions, the *somatic*, or body cells, and the *germ* cells (Fig. 459). The somatic cells form the distinct body of an organism; the germ cells separate from the parent body when mature, giving rise to the new generation. They provide for germinal continuity

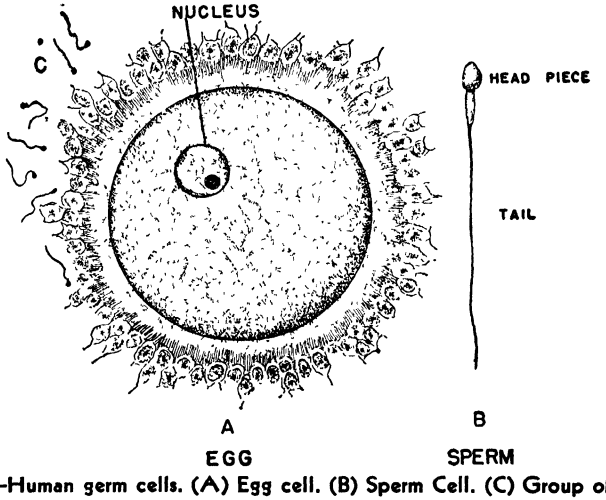

Fig. 459.—Human germ cells. (A) Egg cell. (B) Sperm Cell. (C) Group of sperm cells to show relative sizes of sperm and egg. All cells greatly enlarged and diagrammatic. (Adapted from various sources by B. F. Edwards.)

or the stream of life, whereas in time all somatic cells die. While the body cells are forming the tissues and organs of the organism, the germ cells, except in special cases, are quiescent until the organism is mature. The primordial germ cells in vertebrates may often be formed before the gonad in which they later reside is formed. Later they shift to that portion of the dorsal epithelial lining of the coelom which becomes a part of the gonad.

B. Spermatogenesis and Oögenesis.—The maturing, or development, of the male reproductive cell is *spermatogenesis;* the maturing or development of the female cell is *oögenesis.* The term *gametogenesis* may be applied to both types of development.

C. Meiosis and Mitosis.—Another term for the nuclear changes involved in the maturing of the germ cells, as distinguished from mitosis (page 37), is *meiosis* (page 42).

II. Meiosis in Animal Germ Cells

A. Maturation or Meiosis.—These two terms are used interchangeably. Before a sperm cell and an egg cell fuse to form a zygote from which a new individual develops, a complicated process, *maturation* (L. *maturus,* ripe) occurs in germ cells. As the word implies, maturation is a maturing or ripening of the germ cells in preparation for the formation of a new organism. A definition that mentions only the events of the process and not the way in which they take place is: Maturation is the final stages in the development of sex cells, characterized by two divisions, in one of which the number of chromosomes is reduced to one-half (Figs. 461 and 462).

1. Haploid and Diploid.—When an egg and sperm fuse, one set of chromosomes is contributed by each gamete, and the zygote then contains two sets, or a *diploid number* (page 42). Each germ cell contained a *haploid* (page 42) set or half the diploid number. An example will make this clear. If a garden pea has a diploid number of 14-chromosomes, then each of its mature egg cells and each of its mature pollen cells will contain 7 chromosomes, or a haploid number, the number having been reduced during the reduction division of the maturation process. The following table gives the *diploid* number of chromosomes contained in certain plants and animals:[1]

Garden pea	14	*Hydra fusca* and *viridis*	12
Evening primrose	14	Chicken	18
Onion	16	Bullfrog	26
Corn	20	Monkey (*Rhesus*)	48
Fruit fly	8	Man	48

Chromosome numbers have been determined for many plants and animals and new work along this line is being done at all times. From the foregoing, it will be seen that the only way to keep the numbers of chromosomes constant in any plant or animal is by the reduction of one-half the number in the germ cells before they meet and fuse. This

[1] For an extended list of organisms whose chromosome numbers have been determined, see E. B. Wilson, "The Cell in Development and Heredity," pp. 855*ff*, The Macmillan Company, 1937.

is accomplished during the maturation or maturing of the germ cells in the *reduction division.*

2. Preparation for Meiosis.—The process of ripening of germ cells is essentially the same in both plants and animals, but the changes are a little easier to follow in the animal germ cells; hence they are described first.

a. Period of Multiplication.—The number of germ cells in the ovary or testis of an animal increases by ordinary cell division (mitosis); this increase in number is designated as the *period of multiplication* (Fig. 460I).

b. Period of Growth and Synapsis.—Before the maturation process can take place, each germ cell increases greatly in size. For the sake of emphasis, it is repeated here that each cell contains *two complete sets of chromosomes,* one set contributed by the male parent and one set contributed by the female parent. These two sets now line up and pair, like, or *homologous* (Gr. *homos,* the same; *logos,* proportion), chromosomes fusing together. This is *synapsis* (Gr. *syn,* together; *hapto,* to unite) (Fig. 460I).

3. The Maturation Divisions.—There are two maturation divisions, and the reduction in the number of chromosomes may take place during either the first or the second divisions. It takes place usually during the first division in the higher animals, but among the Protozoa, *Chilodonella,* and others, it takes place at the second maturation division.

a. The First Maturation Division, or *Reduction Division* (first meiotic division).—After synapsis has taken place and the chromosomes have separated, the cells divide, one-half the number of chromosomes going into each of the two daughter cells. By reference to Figs. 460 and 461, it will be seen that the two new male cells are the same size but that the two new female cells are very unequal in size, even though the small one called the *polar body* receives the same number of chromosomes as the larger one, which will finally develop into the egg cell. The polar body may divide, but it eventually degenerates.

The assortment of the chromosomes.—When half of the chromosomes go into each of the daughter cells, the question naturally arises as to which chromosomes go into each cell. If it is borne in mind that there are two complete sets in the germ cell before the number is reduced to half, one set received from the female and one set from the male parent, and that each of the new daughter cells must have a *complete* set, it will be seen that there are four possibilities or combinations that will produce a complete set. It is a matter of chance which member of a pair goes into a cell, but *one member of each pair, i.e.,* either the paternal or the maternal chromosome that united to form the pair of chromosomes during synapsis, will go into each of the new cells, but both members of a pair will not go into the same cell. A simple experiment will make this clear. If two strips of blue paper, one long and one short, are allowed to represent the

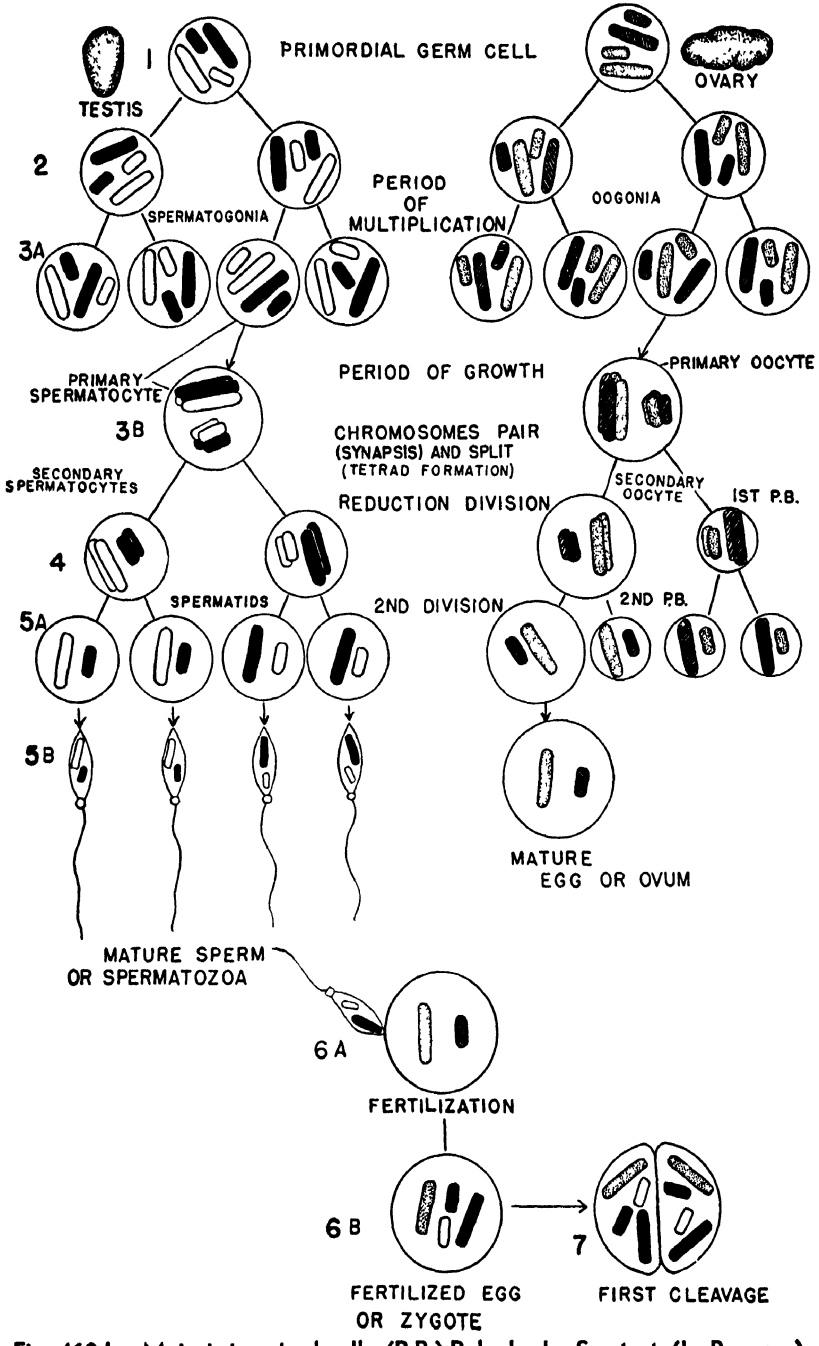

Fig. 460 I.—Meiosis in animal cells. (P.B.) Polar body. See text. (L. Runyon.)

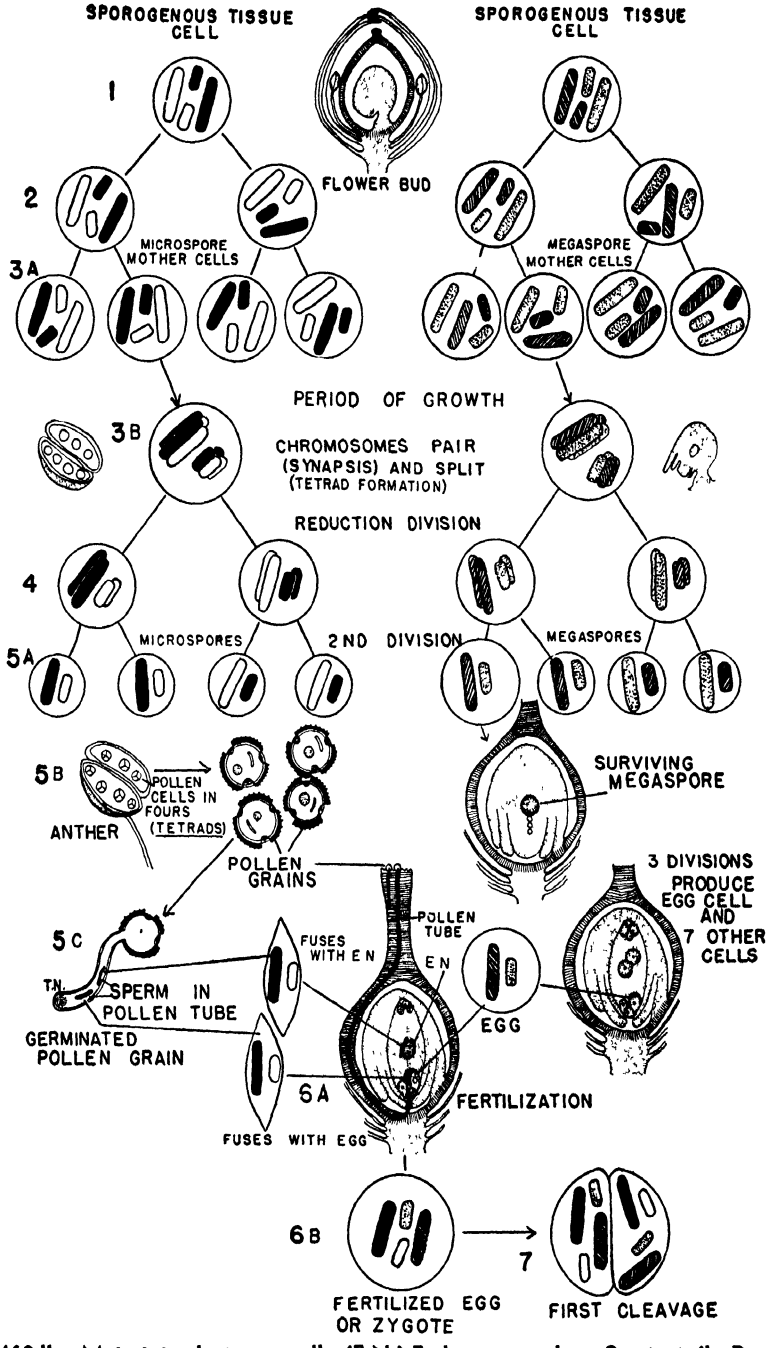

Fig. 460 II.—Meiosis in plant germ cells. (E.N.) Endosperm nucleus. See text. (L. Runyon.)

chromosomes contributed by the male parent and two strips of pink paper, one long and one short, represent the chromosomes contributed by the female parent, at synapsis the long blue and the long pink would

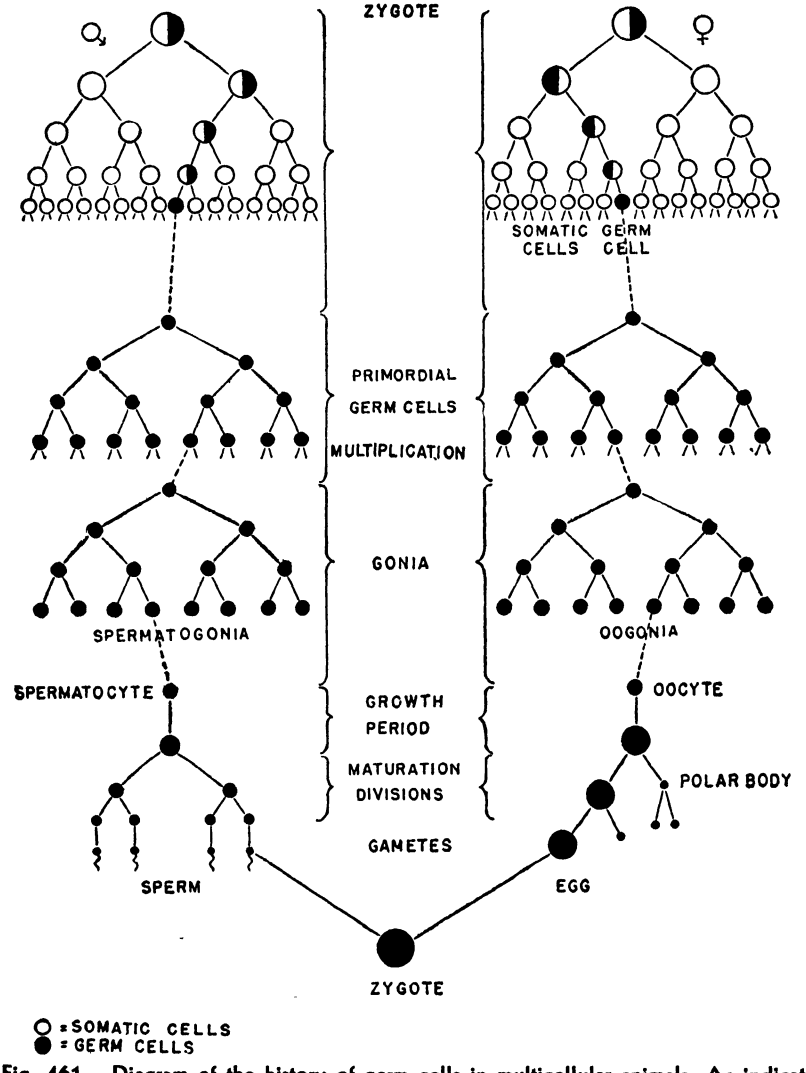

Fig. 461.—Diagram of the history of germ cells in multicellular animals. As indicated in the drawing, the number of divisions is much greater than shown except during the maturation period. (Adapted by F. Baker from Wilson, The Cell, The Macmillan Company.)

pair, and the short pink and the short blue would unite to form the other pair. At the reduction division, there would be four possibilities: If one long blue and one short pink form one combination, then the other

combination must be one long pink and one short blue; or if one long pink and one short pink, then the other combination must be one long blue and one short blue.

The first two combinations represent mixtures, one chromosome from the female parent and one chromosome from the male parent. The other two combinations are not mixtures but represent either the two chromosomes from the female or the two from the male parent. According to the laws of chance, there would be twice as many mixtures as there would be of the nonmixture classes.

To repeat, after the reduction division, each of the daughter cells contains one-half the diploid number of chromosomes, or a haploid number. Although it is a matter of chance which chromosomes pass into each cell, there must be *one member of each pair* in each of the new cells, and it may be either one, to make up a complete set.

b. The Second Maturation Division, the Equation Division (second meiotic division).—In this division, the chromosomes split longitudinally, as in ordinary mitosis, and the cells then divide. The splitting of the chromosomes in preparation for this division may take place long before the first maturation division, so that during synapsis, each of the pairs appears as four strands, there being one pair of chromosomes but each chromosome being split. For this reason, they are called *tetrads* (Fig. 460I), and when the pairs separate, each chromosome has a split and appears as two. For this reason, they are called *dyads.*

As before, the egg cell divides into a large cell, which will become the egg, and a small cell, the second polar body, which later degenerates. The sperm cells divide into two equal cells, both of which will develop into functional sperm cells. The female egg cell is relatively large and the sperm cell very small (Fig. 459).

B. Fertilization.—At fertilization, the sperm cell enters the egg cell, thus restoring the diploid number of chromosomes. Shortly after this, the fertilized egg begins to divide and thus initiates the development of a new individual. Reference to Fig. 460 will give a clear idea of the event of maturation, and Fig. 462 illustrates some of the details of fertilization.

III. Meiosis in Plants

As noted above, the development of germ cells in plants is a little more obscure than it is in animals, although the essential processes are the same. A comparison of Figs. 460I and II shows that the two follow the same pattern of development down to the second maturation division. On account of the way the pollen cell (page 167), or *microspore,* and the ovule (page 167), or *megaspore,* develop, several divisions occur before the egg and sperm cells are actually formed, but the end result is the same; *i.e.,* when the sperm cell fertilizes the egg cell in the flower, the

diploid number of chromosomes is restored. In order to keep the essential process clear, several divisions have been omitted, but where they occur has been indicated on the diagram. (For an account of double fertilization in plants, see page 166.)

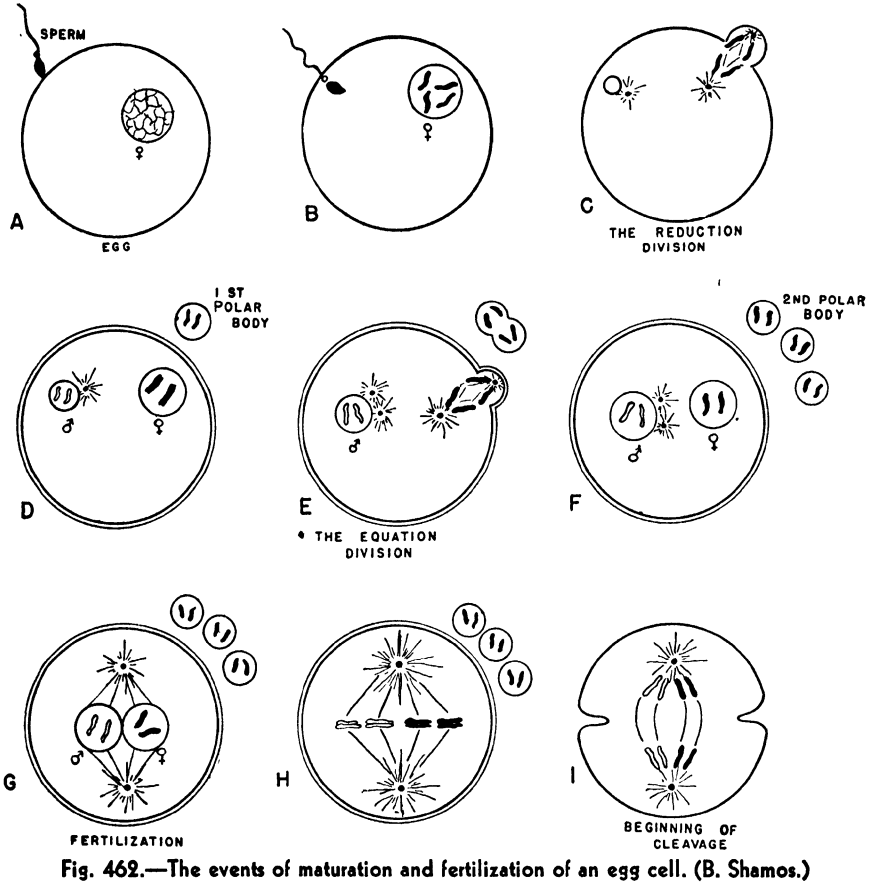

Fig. 462.—The events of maturation and fertilization of an egg cell. (B. Shamos.)

IV. Haploid and Diploid Generations

Figure 463 brings out, in a diagrammatic way, the differences between the haploid and diploid generations of animals and plants.

V. Summary

To sum up, the stages in the development of the germ cells are as follows:

1. Period of *multiplication*. In this stage, the number of germ cells is increased by cell division (mitosis).

2. The first maturation division, usually the *reduction division*. The sperm cell divides into two equal cells and the egg cell into a large cell and a small cell or polar body, one-half the number of chromosomes going into each cell, thus reducing the number of chromosomes by half, the haploid number. It is a matter of chance which member of each pair of chromosomes goes into a cell, but each cell must have a complete set, even though it be the haploid number.

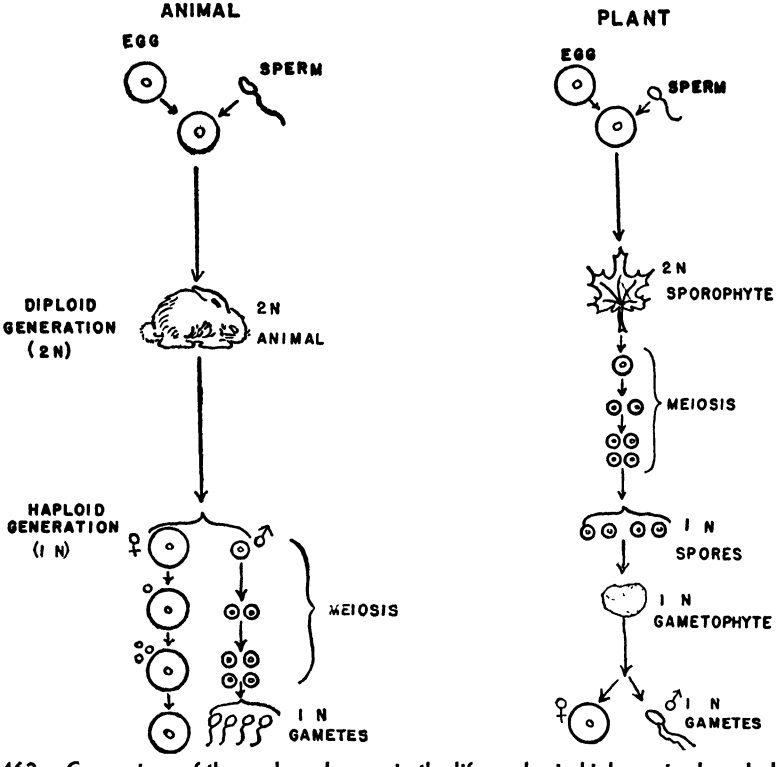

Fig. 463.—Comparison of the nuclear changes in the life cycles in higher animals and plants. N = normal number. (B. Shamos, after Wilson.)

3. The second maturation division, usually the *equation division*. In this division, the chromosomes divide longitudinally; then the cells divide as in ordinary cell division. But the egg cell divides into a large cell, which is to become the egg, and a small cell or polar body. This may divide but eventually degenerates. The splitting of the chromosomes for this division may take place even before synapsis, so that when the chromosomes are paired, it may appear that there are four chromosomes instead of two. These are called *tetrads*, and when pairs separate, each chromosome having a split appears as two and is called a *dyad*.

4. Time of reduction division. The reduction division may take place at either the first or second maturation division. The number of chromosomes appears to be reduced at the first maturation division in most organisms, but in some Protozoa it occurs at the second maturation division.

5. Effect of fertilization. If fertilization takes place, the sperm fuses with the egg, thus restoring the diploid number of chromosomes. Shortly after fertilization, the egg begins to divide, and the future organism is on its way to development.

Questions

1. What is meant by the maturation or meiosis of the germ cells? At what stage in the life of organisms do these processes begin?
2. How does the process of egg formation differ from that of sperm formation? Why must the reduction division precede fertilization? When does it take place?
3. Give an account of the equation division.
4. Construct a diagram to show the possibilities of assortment of chromosomes in the formation of gametes if the germ cell contains three pairs of chromosomes (*Aa*, *Bb*, *Cc*). Explain the statement that each gamete must have in it one member of each pair of chromosomes.
5. During synapsis, which types of chromosomes pair? What are the main differences between the maturation of the germ cells of plants and animals?
6. Refer to Figs. 460I–II and 463, and explain fully the differences in the nuclear changes in a seed plant (angiosperm) and a mammal. Discuss, in this connection, the haploid and diploid generations in these life cycles.
7. Define: gametogenesis, haploid, diploid, synapsis, equation division, tetrad, dyad, microspore, megaspore.

Suggested References

SHARP, L. W.: "An Introduction to Cytology," McGraw-Hill Book Company, 1934.
WILSON, E. B.: "The Cell in Development and Heredity," The Macmillan Company, 1937.

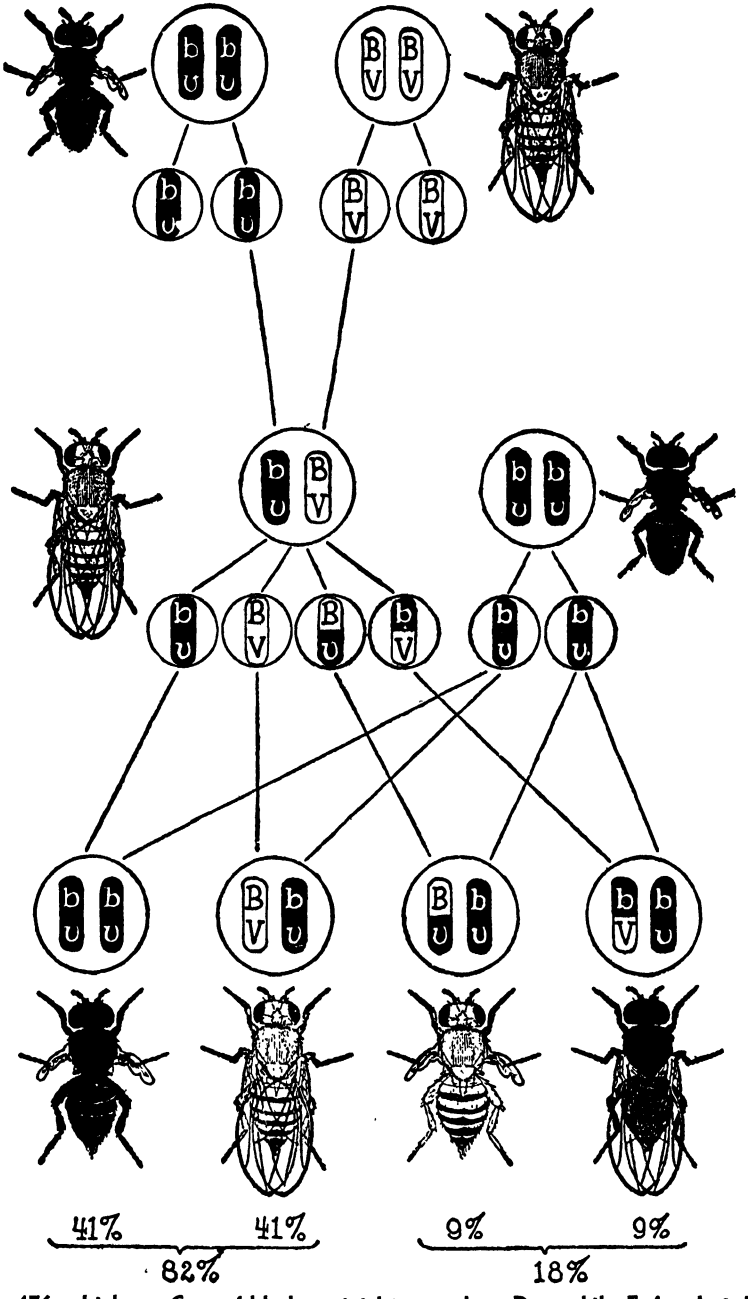

Fig. 476.—Linkage. Cross of black-vestigial to gray-long Drosophila. F_1 female is back-crossed to black-vestigial male. (From Plunkett, Outlines of Modern Biology, Henry Holt and Company, Inc., adapted from Morgan.)

5. The Inheritance of Linked Characters in Fruit Flies.—In *Drosophila*, the genes for black body and for vestigial wings are located in the same chromosome. The normal alleleles of these two characters are *gray body* and *long wings*, and these are dominant over *black-vestigial.*

a. Gray-long by Black-vestigial—If a gray-long fly is crossed with a black-vestigial fly, all the offspring in the first generation will be gray-long (Fig. 476). Since the characters for black and vestigial are in the same chromosome and the characters for gray-long are in the other chromosome of the pair, there can be no independent assortment among the four genes. The only way a gray-vestigial or a black-long fly can be obtained from this particular combination is for the chromosomes to break during synapsis, and this is what happens in a small number of cases in the female germ cells. There is *no crossover in the male germ cells* of *Drosophila*, though it does occur in other animals. Apparently the exception to this rule in *Drosophila* is due to the peculiarities of synapsis in its germ cells; the homologous chromosomes are not so intimately associated during synapsis as is the case in the female *Drosophila.*

Figure 476 shows the four types of gametes formed in the female germ cells for these two pairs of characters; one like each parent and a small number of two crossover types would be formed. The male would have only two types of gametes, since there is no crossover in this case, there being one like each parent. It would simplify matters to backcross the F_1 female with a black-vestigial male, since both his gametes would then be alike and since both black and vestigial are recessive characters.

The F_1 female, backcrossed to a black-vestigial male, would give 41 per cent gray-long flies, 41 per cent black-vestigial, 9 per cent gray-vestigial, and 9 per cent black-long (Fig. 476).

b. Gray-vestigial by Black-long.—To show that linked characters that go into a cross tend to stay together, it is interesting to follow the results of a cross between *gray-vestigial* and *black-long flies.* In this case, the F_1 flies would be gray-long, as before, since these two characters are dominant. The F_1 female would produce four types of gametes, one like each parent, and a small number of two crossover types. Here the large classes would be, as before, the two parental types. Backcrossing the F_1 female to a black-vestigial male would give 41 per cent gray-vestigial; 41 per cent black-long; 9 per cent gray-long, and 9 per cent black-vestigial (Fig. 477). In each of the two cases, the large classes are the original combinations of the parents, and there are comparatively few new combinations.

The amount of crossing over differs in each linkage group, some genes being close together, some far apart. Naturally, then, the situation must be worked out for each case. But percentages of crossovers in any particu-

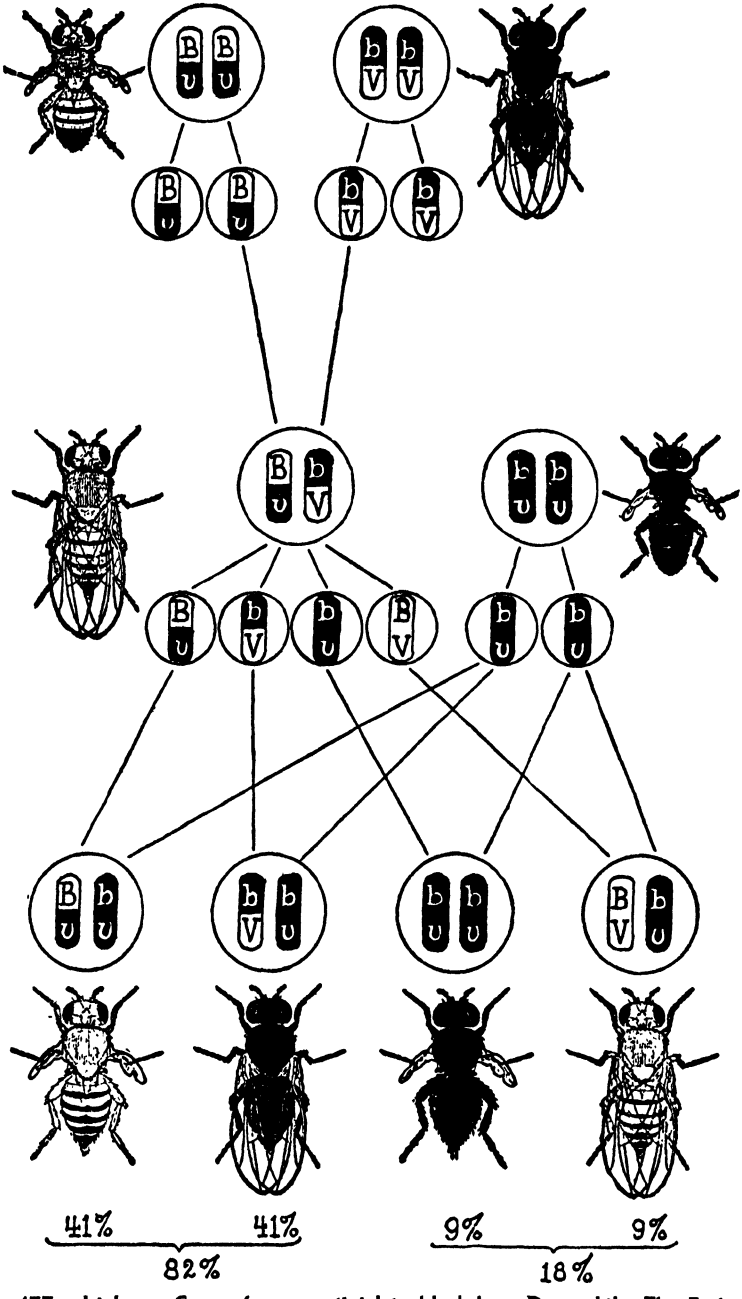

Fig. 477.—Linkage. Cross of gray-vestigial to black-long Drosophila. The F_1 female is backcrossed to black-vestigial male. (From Plunkett, Outlines of Modern Biology, Henry Holt and Company, Inc., adapted from Morgan.)

lar case are fairly constant; *i.e.*, the crossovers between gray-long and black-vestigial will always give about the same percentages.

6. Sex-linked Characters.—In *Drosophila*, the female has two X chromosomes that influence the determination of sex, and the male has one X and one Y chromosome. Recently the Y chromosome, thought to be empty, has come into prominence as a gene bearer. It appears to have few genes, however. Crossovers have been reported between X and Y in fish and in some other animals. Besides the genes that influence sex, many

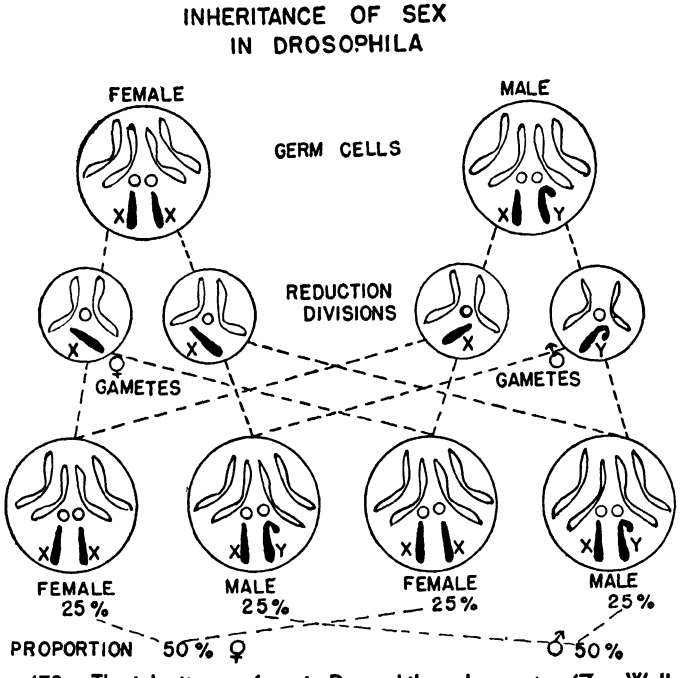

Fig. 478.—The inheritance of sex in Drosophila melanogaster. (Zoe Wells.)

other genes are present in the X chromosomes. These are very naturally linked together, and this is what is meant by *sex-linked* characters.

a. Red Eyes and White Eyes in Drosophila.—The behavior of the XX and the XY chromosomes at the reduction division is shown in Fig. 478. In *Drosophila*, the gene for white eye is in the X chromosome; its normal allelomorph is red eye, and red eye is dominant over white eye.

(1) Red-eyed female by white-eyed male.—If a red-eyed female fly is crossed with a male white-eyed fly, the F_1 flies will all be red-eyed. The female will have two X chromosomes, one with a red gene from the mother and one with a white gene from the father. The male will have one X chromosome, and it will have a gene for red eyes inherited from the

mother and a Y chromosome inherited from the father, which will carry no factor for eye color. In general, the Y chromosome carries no normal

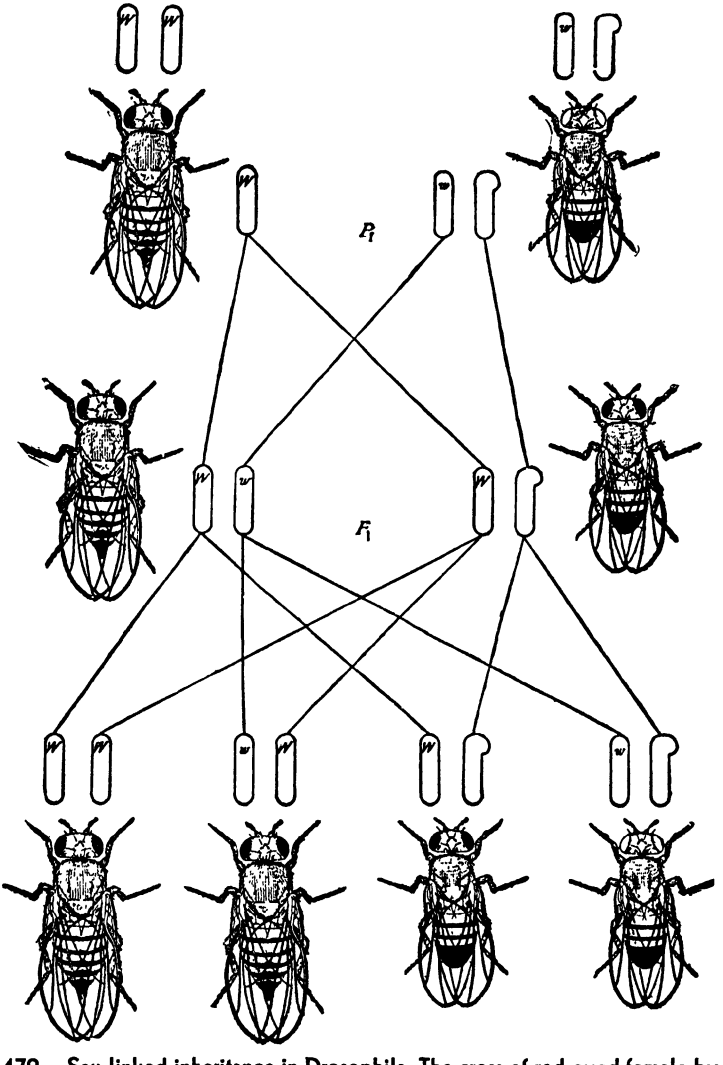

Fig. 479.—Sex-linked inheritance in Drosophila. The cross of red-eyed female by white-eyed male. The course of the sex-linked gene W — w is traced from parents to F_2. Females at left, males at right. (From Morgan, Bridges, and Sturtevant, Mechanism of Mendelian Heredity, Henry Holt and Company, Inc.)

allele for a sex-linked character but in a few cases mutant genes have been discovered in the Y chromosome (*Drosophila*, man, certain fish). These follow the course of the Y chromosome in inheritance.

The F_1 females will have two types of gametes. One type will carry the X with the gene for red eyes, and the other type will carry the X with the gene for white eyes. The male will also have two types of gametes,

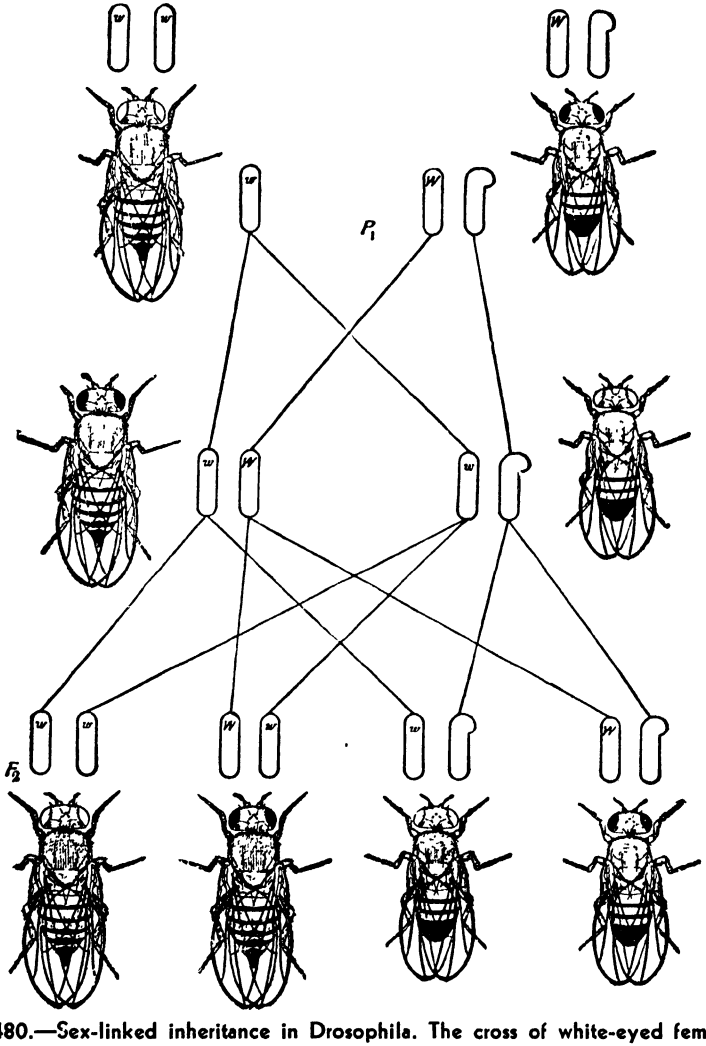

Fig. 480.—Sex-linked inheritance in Drosophila. The cross of white-eyed female by red-eyed male, the reciprocal of cross shown in Fig. 479. Females at left, males at right. (From Morgan, Sturtevant, and Bridges, Mechanism of Mendelian Heredity, Henry Holt and Company, Inc.)

one with an X chromosome carrying the gene for red eyes and the other with the Y. Crossing the hybrids would give the results shown in Fig. 479: one homozygous red-eyed female, one heterozygous red-eyed female, a

homozygous red-eyed male, and a homozygous white-eyed male in the proportions of 1:1:1:1. Obviously, the phenotypes would be three-fourths red-eyed and one-fourth white-eyed, or all the females red-eyed and half the males red-eyed and the other half white-eyed.

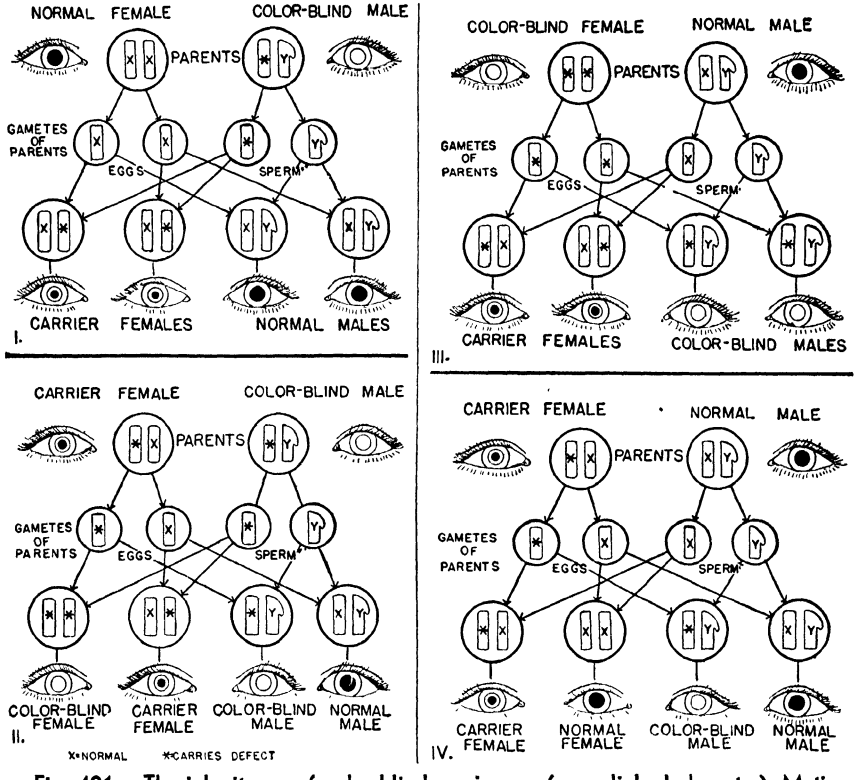

Fig. 481.—The inheritance of color-blindness in man (a sex-linked character). Matings as follows:

I. Normal female and color-blind male
II. Carrier female and color-blind male
III. Color-blind female and normal male
IV. Carrier female and normal male

(2) WHITE-EYED FEMALE AND RED-EYED MALE.—The reciprocal cross works out in a little different manner. In crossing a white-eyed female with a red-eyed male, the F_1 females will be heterozygous, red-eyed females with one X chromosome carrying the gene for red eyes and one X chromosome carrying the gene for white eyes; the males will be homozygous white-eyed males with one X chromosome carrying the gene for white eyes and the Y chromosome. If the hybrids are mated, F_2 will be one homozygous white-eyed female, one heterozygous red-eyed female, one red-eyed male, and one white-eyed male, or proportions of 1:1:1:1;

but the phenotype percentages will be 50 per cent white-eyed flies and 50 per cent red-eyed flies, or 25 per cent red-eyed females, 25 per cent white-eyed females, 25 per cent red-eyed males, and 25 per cent white-eyed males (Fig. 480).

b. Sex-linked Characters in Man. (1) COLOR BLINDNESS.—Color blindness is a sex-linked character in man. It is inherited exactly as are the sex-linked characters in *Drosophila*. The possibilities of the inheritance of this defect are shown in Fig. 481. Normal eyes are dominant over color-blind eyes. It will, therefore, take two doses of the defect to produce color-blindness in the female, because the character is recessive. If the gene for normal eyes is present in one of the *X* chromosomes, she will appear normal even though the other *X* chromosome carries the defect, whereas in the male, only one dose will produce color-blindness, the *Y* chromosome having no normal allele to obscure the defect.

(2) HEMOPHILIA.—Hemophilia is also a sex-linked character. The individuals with this defect have blood that clots very slowly. They are in danger of bleeding to death, even from a small wound. It is also a case of "crisscross" inheritance, the manner of inheritance being the same as for color-blindness.

7. THE DETERMINATION OF SEX.—How sex is determined has been a favorite subject of speculation since the dawn of time. In 1902, McClung suggested that the *X* chromosome was related to the determination of sex. However, he did not examine the chromosomes of the female insect and did not learn that she had two *XX* chromosomes. He supposed that she had none. Later, Miss N. M. Stevens (1905) and, shortly after that, E. B. Wilson worked out the relations of chromosomes to sex as we know them today. Many other workers, especially Bridges, have added to these early studies.

a. In Drosophila. (1) NORMAL MECHANISM OF SEX DETERMINATION. As Fig. 478 shows, the female *Drosophila* has two *X* chromosomes, and the male has an *X* and a *Y*. When the gametes are formed, all the eggs will contain an *X*, whereas the sperm will be of two kinds, one type containing an *X* and one type containing a *Y*. It is evident that the egg fertilized by the sperm containing a *Y* will produce a male and that the egg fertilized by the sperm containing an *X* will produce a female. Males and females, then, will be produced in equal numbers. It must be borne in mind that it is the genes inside the chromosomes that are responsible for appearance of characteristics and not the chromosomes themselves. No character or gene has been discovered for maleness or femaleness.

(2) NONDISJUNCTION.—Occasionally it has been found that during the reduction division of the egg, some of the chromosomes fail to go into the cells in the normal way, one or more being left behind. Figure 482 shows what may happen when one of the *X* chromosomes is left

behind. The egg may have XX and the polar body, no X; or the egg may have no X and the polar body, XX. If now the egg with one set of autosomes and XX were fertilized, the result would be a female with the normal two sets of autosomes and XXX (superfemale). As we shall see this would upset the relationship between the number of autosomes and the X chromosomes. The other conditions that would arise are shown in the Figure 482.

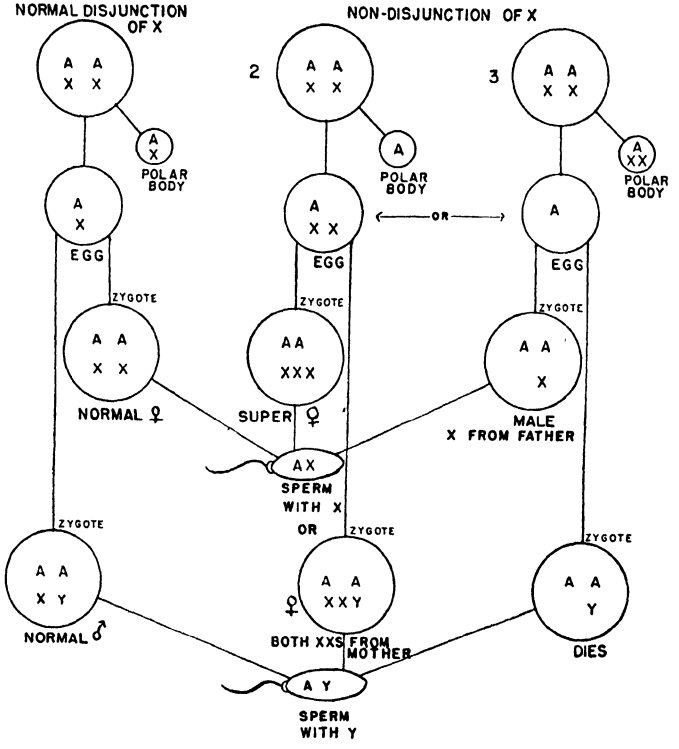

Fig. 482.—Nondisjunction of the X chromosome. (1) Normal disjunction and fertilization; (2) and (3) results of nondisjunction of the X chromosome and later fertilization of the eggs containing the normal haploid set of autosomes (A) and two X chromosomes, or egg with a haploid set of autosomes (A) only. (Based on Bridges.)

(3) GENIC BALANCE.—From his work with triploid flies, Bridges concluded that there are more female characters in the X chromosomes and more determiners for maleness in the autosomes; in other words, the determination of sex is a matter of *genic balance*. In triploid flies, there are three sets of autosomes and three X chromosomes (Fig. 482*B*). This condition could come about in several ways through nondisjunction. If there were a failure of reduction division and the egg contained two sets of autosomes and two X's and this were fertilized by a sperm with

the usual one set of autosomes and either X or Y, the results would be triploid flies with $3A:3X$ or $3A:XXY$.

(4) INTERSEXES IN DROSOPHILA.—The genic balance may be upset when triploid *Drosophila* are bred. As has been said, there are more determiners for maleness in the autosomes of *Drosophila* than there are determiners for femaleness. Therefore, if an egg cell containing two sets of autosomes (instead of one normal set) and one X chromosome were fertilized by a normal sperm cell containing one set of autosomes and one X, the result would be $3A:2X$, and an *intersex* would result (Fig. 383*E*). The determiners for maleness in the extra set of autosomes would overbalance the determiners for femaleness in the $2X$ chromosomes.

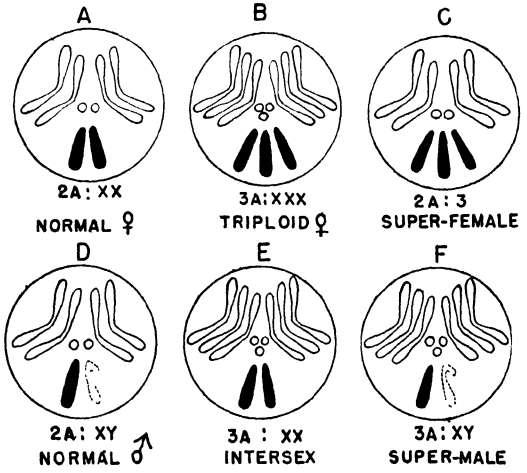

Fig. 483.—Effect on sex of the balance between X chromosomes (solid) and autosomes in Drosophila melanogaster. (Adapted from Sinnott and Dunn, Principles of Genetics, by B. Shamos.)

In the superfemale, the extra X chromosome gives a preponderance of female characters, and the animal has the female characters exaggerated. In the same way, the characters for maleness in the extra set of autosomes in the $3A:XY$ males (Fig. 483*F*) produces a supermale with the male characters exaggerated. Both superfemales and supermales are sterile.

b. In Man.—In man, sex is of the XX type for the female and XY for the male. It has been determined that there are 24 pairs, including two XX, in the female germ cells before reduction division and that there are 24 pairs, including an X and a Y, for the male cells (Fig. 484).

c. Birds and Moths.—In these animals, as well as in some others, the individuals heterozygous for sex chromosomes are the females (XY), and the males are homozygous for X chromosomes (XX). These are sometimes designated at WZ (or XY), female, and ZZ (or XX), male. Sex-linked

characters would follow the *Z* chromosome and be inherited in exactly the *opposite* manner from the *Drosophila* type. The mechanism is, however, obviously the same.

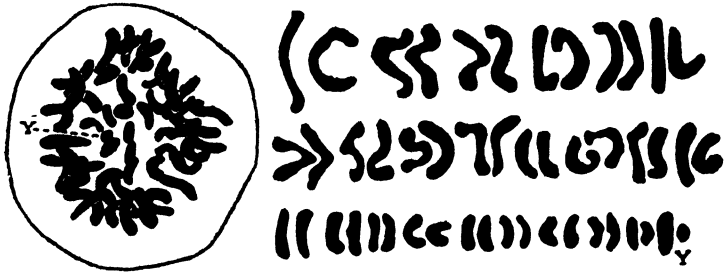

Fig. 484.—Chromosomes of man (male). At left, equatorial plate of a spermatogonium, showing typical arrangement of the 48 chromosomes. Y chromosome is near center. At right, chromosomes from a somatic cell sorted out and arranged in pairs. (After Evans and Sweezy.)

d. Special Cases of Sex Determination.—There are some special cases of sex inheritance, as in certain insects, bees, wasps, etc., and also in some rotifers and plants. In the bees, for example, the male bee comes from an unfertilized egg (page 410) and has, therefore, only the haploid number of chromosomes that he received from his mother. For this reason, he is said to have had "no father and no sons but a grandfather and grandsons." A little reflection will show how this comes about.

In some other cases, the matter of the life cycle is complicated by the fact that there are *parthenogenetic generations*, as in the rotifers (page 329) or in plants, by the fact that there are sporophyte and gametophyte generations.

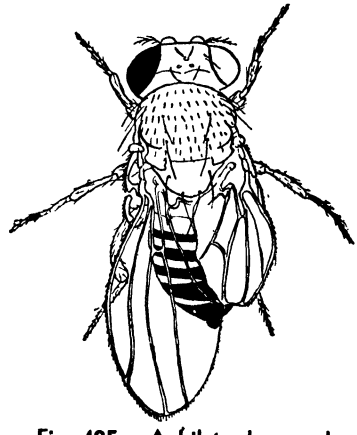

Fig. 485.—A bilateral gynandromorph of Drosophila. Left side is female, left eye red and wing long; right side, except abdomen, is male with eosin eye and miniature wing. Sex comb is on right foreleg only. (After Morgan.)

e. Gynandromorphs and Mosaics.—Sometimes *Drosophila* as well as other animals appear that have part male and part female characteristics. These animals start as females. It may be supposed that when the fertilized egg divides, one of the *X* chromosomes gets caught and lost. This gives one of the new cells the normal diploid number XX or $2A + XX$ and the other with one X or $2A + X$. The XX cell develops the female side of the animal and the cell with one X

develops the male side (Fig. 485). This type of animal is a *gynandromorph.* If the *X* were lost in a later division, only a small area with male characteristics would appear in the female fly, and this would be called a *mosaic.*

8. MUTATIONS (L. *muto,* change).—A mutant is a variant or sport that arises suddenly or abruptly and breeds true. Another way of saying the same thing is that the term *mutation* is applied to changes or variations in plants and animals that are inherited. The old name for these mutations was "sports." Formerly, it was supposed that the differences between mutants and their parents were great ones; now it is realized that it is not so much the magnitude of the change as it is the heritability of the change that is important.

Hugo de Vries, a Dutch botanist, working with the evening primrose, found certain types of plants appearing that bred true. On the basis of a long series of experiments with these plants, he formulated the *mutation theory.* Further work upon the cytology of the evening primrose revealed that certain of the types that he worked with are the result of peculiarities in the behavior of the chromosomes at the reduction division. Nevertheless, the theory still stands.

Some well known mutations that have taken place in plants are single flowers changed to double flowers, as in petunias, roses, primroses, daisies, etc.; a certain type of tobacco changed so as to produce, on an average, 70 leaves instead of the usual 20; a plant that bore yellow sunflowers that gave rise to a plant that bore red sunflowers; and the purple-leaved beech arising as a mutation from a beech with green leaves. In all these cases, the offspring that exhibited these differences from their parents gave rise to offspring like themselves; *i.e.,* the change was inherited, and they "bred true."

Hundreds of mutations are known to have occurred among animals. For example, a male lamb with short, bent legs appeared in a flock of sheep in 1791 in Massachusetts. Seth Wright, the owner, realized that a sheep with short legs couldn't jump over fences; so he raised it and with it established the famous Ancon breed of sheep. *Albinism* is a type of mutation that is very common. In albino animals, the customary pigment is lacking, and the eyes are defective. The result is a pure-white, pink-eyed animal. Largely because of their conspicuousness in their environment, except in polar regions, albinos do not succeed well in the struggle for existence, because they are easily seen by their enemies. Hence, although albinism is inherited, albino animals usually do not live long enough to pass on their character to their offspring. The race of polled Hereford cattle arose from a hornless animal that appeared in 1889 at Atchison, Kans.

The most famous of all mutations are those that have appeared among fruit flies of the species *Drosophila melanogaster.* Millions of flies have been

studied by geneticists within the past 30 years, and it is estimated that about 1 fly in 50,000 exhibits a new visible mutation. It is estimated that *Drosophila* contains from 2,000 to 3,000 different genes; hence mutations in only a comparatively few of them have been noted in spite of the millions that have been examined.

Causes of Mutations.—We are somewhat in the dark as to the causes of changes of genes in nature. Some mutations have been brought about by the use of X rays, radium, and heat, and further work along this line may shed some light upon the cause of mutations in nature. Mutations are rare, and genes are stable substances; otherwise species would change often.

9. Some Special Conditions and Factors Affecting Heredity. *a. Ploidy.*—Sometimes mutations are due to a doubling of the chromosome numbers. One pair may be doubled, or the whole set may be doubled, tripled, quadrupled, etc. This is known as polyploidy, and many cases are known, especially in plants.

b. Inversion, Deletion, Etc.—When chromosomes break during synapsis, they may be lost, they may become attached to other chromosomes, or they may be joined on upside down from their original position. Recalling that in synapsis, like genes lie opposite each other, this displacement results in peculiarities in *synapsis*. Sometimes parts of chromosomes are lost, and synapsis is again of a peculiar type. These *deletions* naturally affect the organisms.

c. Interaction of Factors.—In some cases, factors that are inherited independently *act together* to produce a given character. In this case, the expression of the character depends not on one factor but on the interaction of two or more factors. Bateson and Punnett discovered the first case of this kind while studying the inheritance of combs in fowls. Some breeds of chickens have a low oblong rosette-like comb, a "rose" comb; others have a narrow-ridged comb, a "pea" comb; still others have "single" combs, as the white Leghorns. In breeding experiments, it was found that these three types breed true, that rose and pea are both dominant over single, but that when rose and pea are bred together a new type, walnut, appears (Fig. 486). When fowls bearing walnut combs are bred together, a characteristic 9:3:3:1 ratio for two pairs of characters appear. Figure 486 shows the genotypes and the phenotypes of the cross. The explanation appears to be that a single dominant factor R will produce the rose comb, a single dominant factor P will produce the pea comb, but the walnut comb depends upon the presence of two dominant factors R and P. The combination of the recessive alleles of these factors (r and p) will produce the single comb (Fig. 486).

Another case of interaction of factors, somewhat different from the foregoing, is shown by Bateson's cross of two white-flowered sweet peas

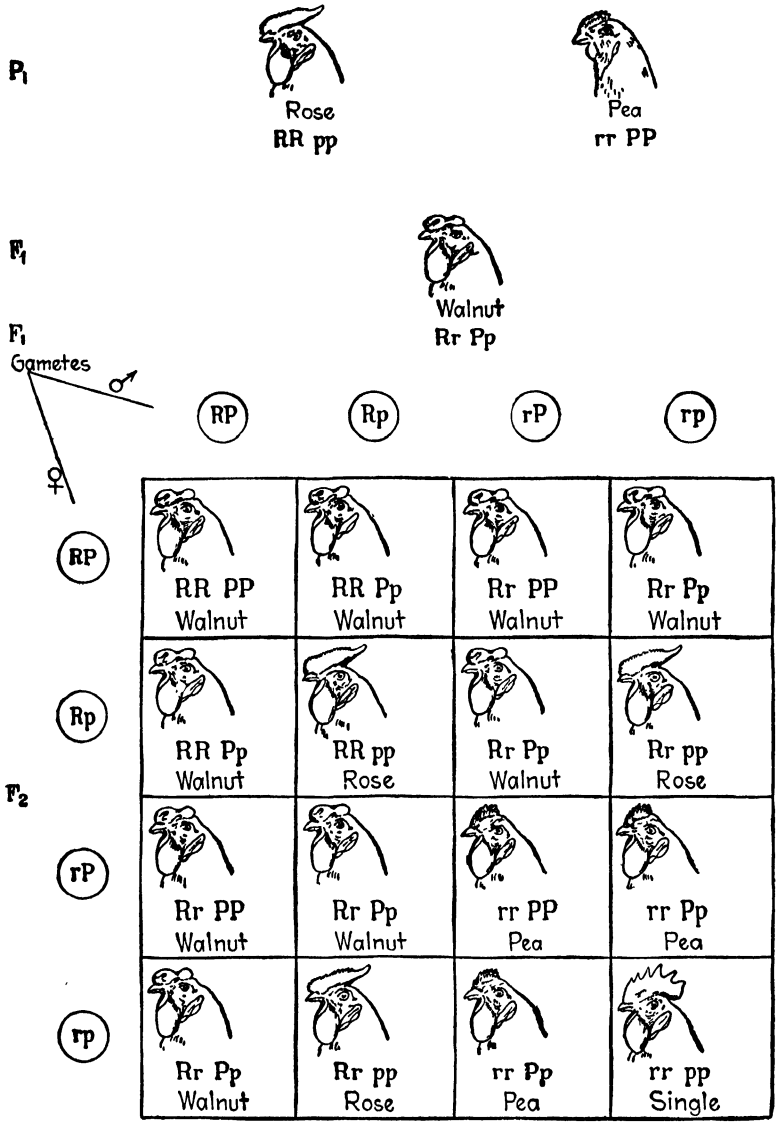

Fig. 486.—Diagram showing interaction of factors for comb form in fowls. The cross of a pure rose-comb bird with a pure pea-comb gives all walnut-combed offspring. The sixteen possible combinations of the F_1 gametes, with their genotypes and the phenotypes resulting from factor interaction, are shown in the F_2 checkerboard. (From Sinnott and Dunn, Principles

that produced only purple-flowered sweet peas in the F_1. These resemble somewhat the wild Sicilian ancestor of the cultivated sweet peas. When these were bred together, there were nine-sixteenths purple and seven-sixteenths white-flowered peas (Fig. 487). As shown by the chart, the purple color appears only when two dominant factors are present. There is evidently some sort of interaction between them. White color is evidently due to the absence of either or both of these factors.

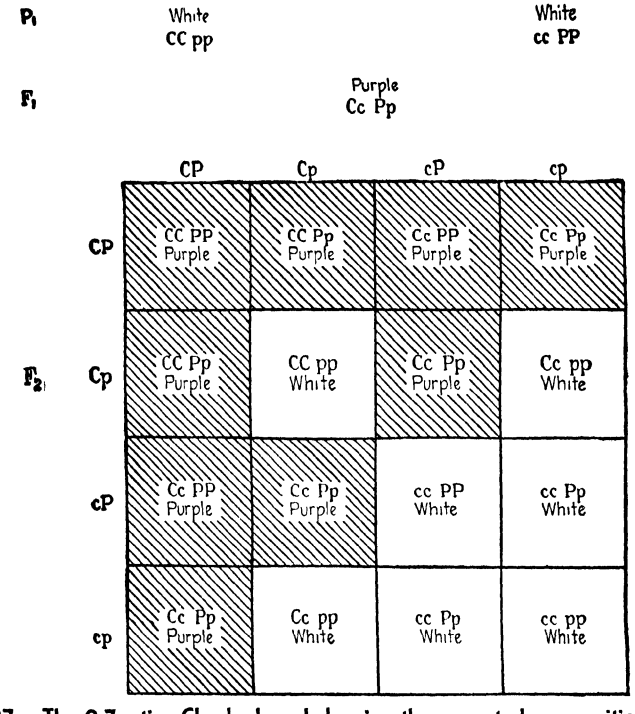

Fig. 487.—The 9:7 ratio. Checkerboard showing the expected composition of F_2 from a cross of two white-flowered sweet peas which produce all purple-flowered plants in F_1. (From Sinnott and Dunn, Principles of Genetics.)

The ratio is evidently the 9:3:3:1 ratio expected in F_2. The three types of white-flowered peas, however, added together, equal seven, and the ratio is 9 colored, 7 white.

d. Lethal Factors.—Genes exist that will cause the death of an organism if they are present in double dose, *i.e.*, in homozygous condition. When present in the heterozygous condition, however, the lethal is balanced by its normal allelomorph and the animal survives. Only two of many lethal factors discovered will be mentioned.

1. Yellow and Black Mice.—In a cross between yellow and black mice, it was found that the ratio in the F_1 generation was 1:1 instead

of all yellow, as was expected, since yellow was known to be dominant over black. Also, when yellow animals were mated with yellow, the ratio was 2:1 instead of the expected 3:1. The explanation of this is that the animal homozygous for yellow dies (Fig. 488). The yellow mice that survive are, therefore, heterozygous for yellow and black.

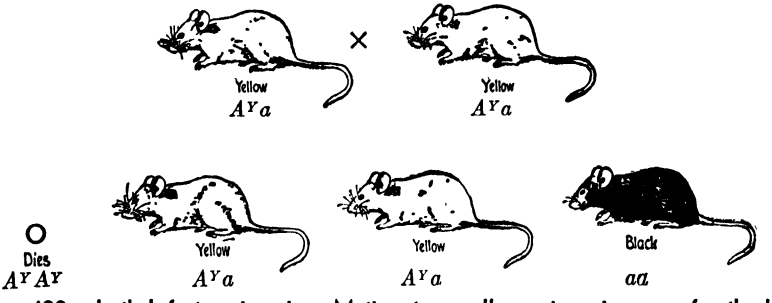

Fig. 488.—Lethal factors in mice. Mating two yellow mice gives one-fourth dead embryos, one-half yellow, and one-fourth black mice. The homozygous yellow mouse does not survive. (From Sinnott and Dunn, Principles of Genetics.)

(2) TUMORS IN DROSOPHILA.—Many lethal genes have been discovered for *Drosophilia*. One of these, discovered by Bridges and worked out by Miss Stark, is a lethal that causes tumor in the larvae. It is a recessive sex-linked character and is inherited according to all the rules for this type of inheritance. If a female carrying the factor for tumor is mated to a normal male, in their offspring one-half of the males receive the factor and die; the other half are normal. Also, there are two kinds of females, those that are normal and those that carry the defect. Since the lethal is balanced by its normal allelomorph in the heterozygous flies, all the females survive.

e. Multiple Factors.—It is possible for two or more independent genes for the same character to exist; either of them is able to produce the character independently but when combined in the same individual, the character is more pronounced. According to Davenport, for example, the skin of a full-blooded Negro is due to two factors lacking in the white race. In a Negro-white cross, $BB,B'B' + bb,b'b'$, the F_1 individuals would be $Bb,B'b'$ and be of medium lightness. If now mulattoes of this formula should marry, the possibilities would be 15 mulattoes of varying degrees of lightness to 1 white. There would be only 1 full black, on an average, out of the 16 combinations. There would be varying degrees of lightness and darkness according to the number of genes of a kind in an individual. For example, $Bb,b'b'$ would be very light, and $BB,B'b'$ would be quite dark. Some authorities believe that more than two pairs of factors are involved in the Negro-white cross.

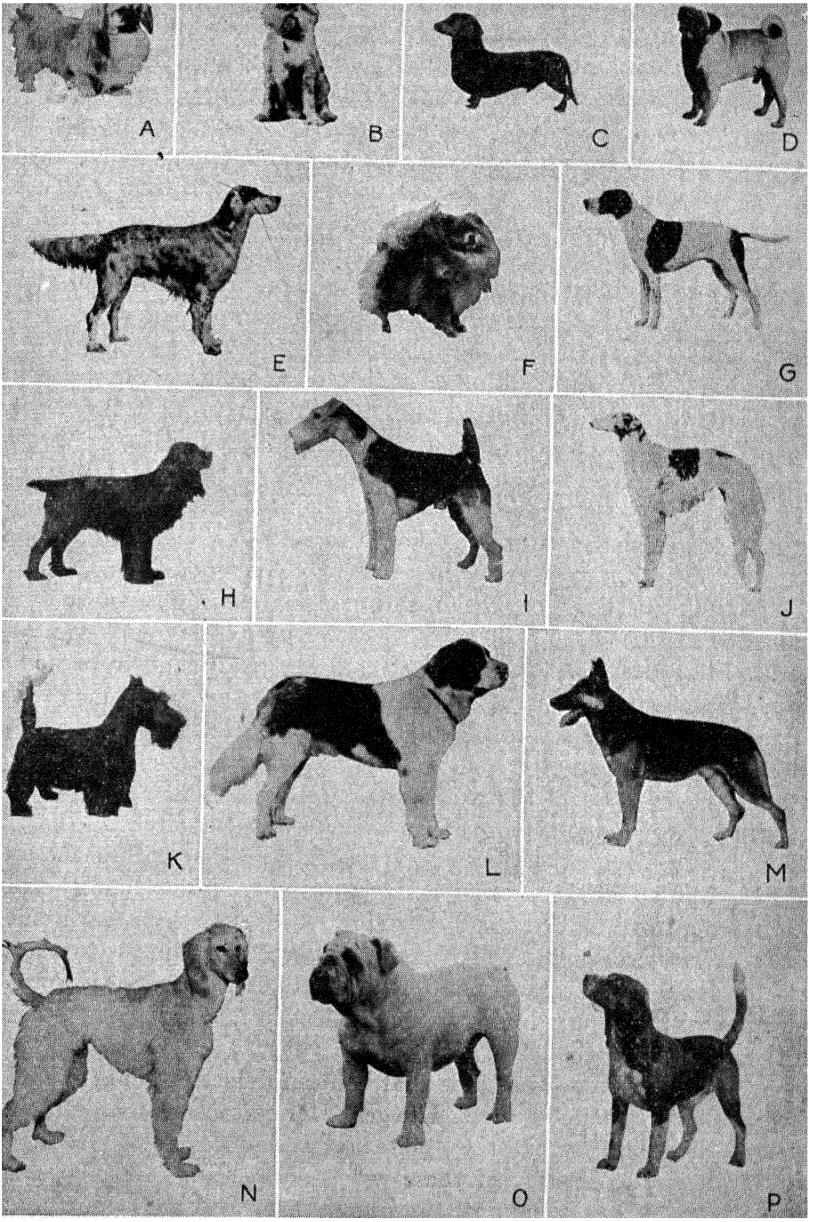

Fig. 489.—Effect of selection. Although the ancestry of dogs is somewhat in doubt, these breeds show what can be done by selection for various features. (A) Pekingese, (B) Brussels griffon, (C) dachshund, (D) pug, (E) English setter, (F) Pomeranian, (G) pointer, (H) cocker spaniel, (I) wire-haired fox terrier, (J) Russian wolf hound, (K) Scottish terrier, (L) Saint Bernard, (M) German shepherd, (N) Afghan hound, (O) English bull, (P) beagle hound. (G, courtesy of the Waldeck Kennels; others, by courtesy of Dog News.)

When multiple factors are present, as in certain coat colors of rodents, selection of only the lightest, or the darkest, for breeding purposes for many generations will produce a light, or a dark, race. The influence of selection is shown in our domestic animals (Fig. 489).

f. Dominance Modified by Sex.—There are some cases of inheritance that are modified by sex hormones. These characters are not sex-linked and are dominant in one sex and not in the other. Horns in sheep are examples of this type of inheritance. In the Dorset breed of sheep, both sexes are horned, and in the Suffolk, both sexes are hornless. If these breeds are crossed, the males in the first generation are horned, and the females are hornless; yet their genetic formula, as far as horns are concerned, is the same (*Hh*). If now these hybrids are bred together, there will be an average of three horned males to one hornless male and three hornless females to one horned female. Obviously, all males that are *HH* or *Hh* will be horned, and only *hh* males will be hornless, whereas all females will be hornless that are either *Hh* or *hh*; only the *HH* females will be horned.

Baldness in man is supposed to behave in some such manner, but if this were true there would be more bald-headed women than there are. It is possible that the hormone in this case is more inhibitive than in the case cited above.

10. Pure Lines.—Plants that are self-fertilizing tend to be homozygous. Johanssen, a Danish botanist, worked with garden beans (*Phaseolus vulgaris*), which are self-fertilizing, in his experiments on the effects of selection. His apparently homozygous "nineteen beans" have become famous. Starting with a mixed population of 19 beans, he kept the progeny of each one separated, or isolated, and secured 19 lines that differed from each other in some respects. Selection within these lines produced no effect. If he selected large seeds from one line, the plants grown from them tended to produce large seeds, but there was a fluctuation within the original extremes of that line. The same was true if he selected small seeds from any of the original lines. His conclusion was that selection within a pure line is without effect in modifying any character in the offspring of that line.

11. Inbreeding.—If strains that contain defective genes are inbred, they are likely to show defects. The genes for certain human defects have been studied, such as cataract, goiter, albinism, deafness, insanity, and feeble-mindedness. Many of these genes are recessive. If only a single gene for the defect is present, the normal gene will balance it, and the person will appear normal. If two genes are present, however, the defect will appear. When one has a knowledge of how genes for defects are transmitted, it is easy to understand why inbreeding is sometimes harmful. Closely related plants and animals tend to carry the same genes for

defects, and when these are bred together some of the offspring receive two genes for the same defect, which will then appear in them.

Inbreeding is not always harmful, however. The Jersey cow is a very much inbred race, and so are certain good varieties of cotton and corn. In these cases, instead of defects, many favorable characters are present.

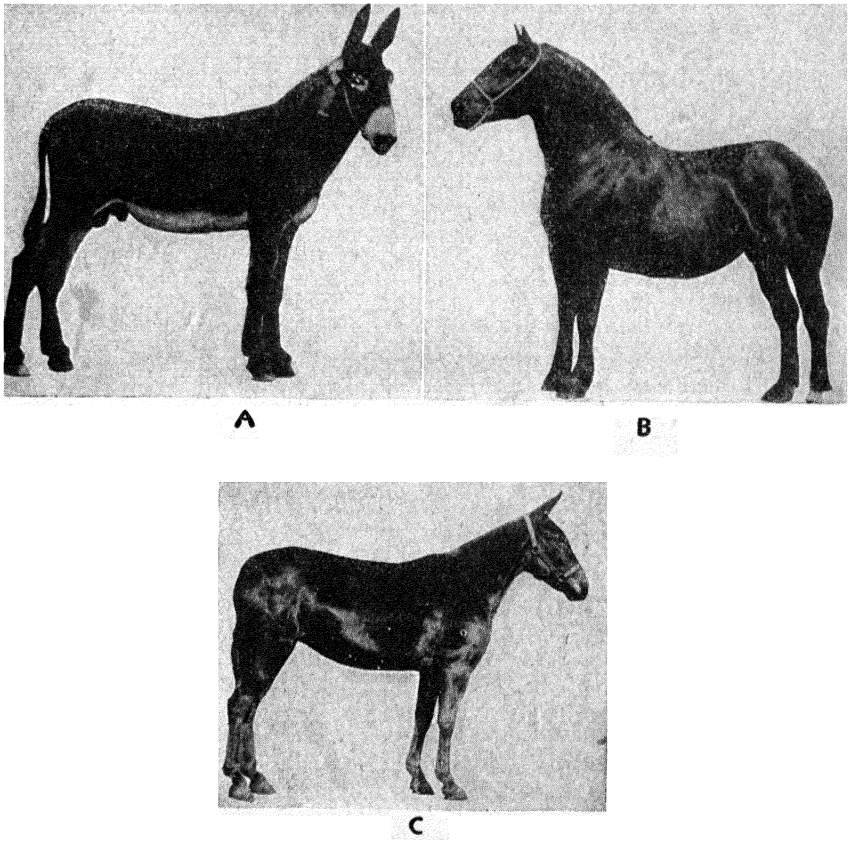

Fig. 490.—The cross between a male ass, or jack (A) and a female horse, or mare (B), results in a hybrid, a mule (C). (A, courtesy Wm. E. Morton; B and C, courtesy of U.S. Biological Survey.)

12. Heterosis or Hybrid Vigor.—It is well known that cross-breeding in plants and animals is beneficial, leading to increased vigor for a time. This hybrid vigor, or *heterosis* (Gr. *heterosis*, alteration) is due to the fact that races or lines within a species will have various desirable characteristics. Some may excel in size, some in resistance to disease; some may be more productive. When crosses are made, several of these characteristics are brought together. They cannot be fixed, for at the reduction division during the maturation periods they will again

sort out, and continued inbreeding will lead to loss of vigor. This is the exact opposite of inbreeding, where only the best traits are selected and all weaklings eliminated.

13. TELEGONY.—Many animal breeders believe that if a female is bred to a male, this male will not only influence the character of the offspring resulting from the mating but will influence offspring that are

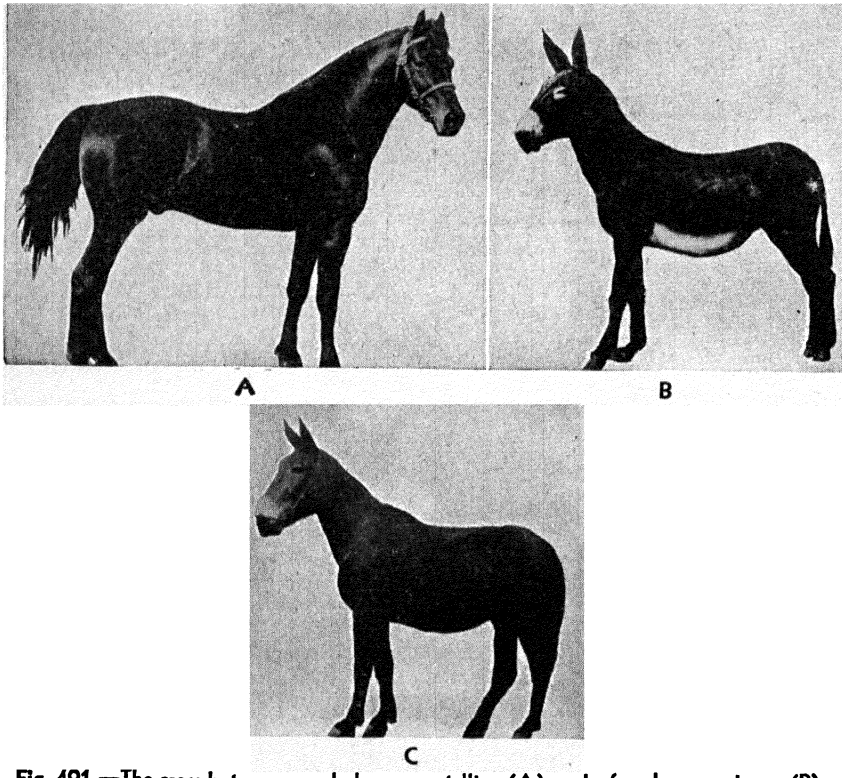

Fig. 491.—The cross between a male horse, or stallion (A), and a female ass, or jenny (B), results in a hybrid called a hinny (C). This animal is smaller than a mule but more horse-like. (A, courtesy of U.S. Biological Survey; B, courtesy of W. E. Morton; C, courtesy of L. M. Monsees and Sons.)

the result of subsequent matings. There is no real evidence to support this theory of *telegony*, as the belief is called.

14. CROSSING DIFFERENT SPECIES.—In plants, wide crosses are sometimes made. For example, the radish (nine chromosomes) can be crossed with a cabbage (nine chromosomes); the hybrid, however, is sterile except under favorable circumstances.

One of the reasons why hybrids that are the result of crossing different species are sterile is that the chromosome mechanism is upset. If the

chromosomes are unlike, there can be *no pairing* of *homologous* chromosomes in synapsis because none is present. This upsets the whole mecha-

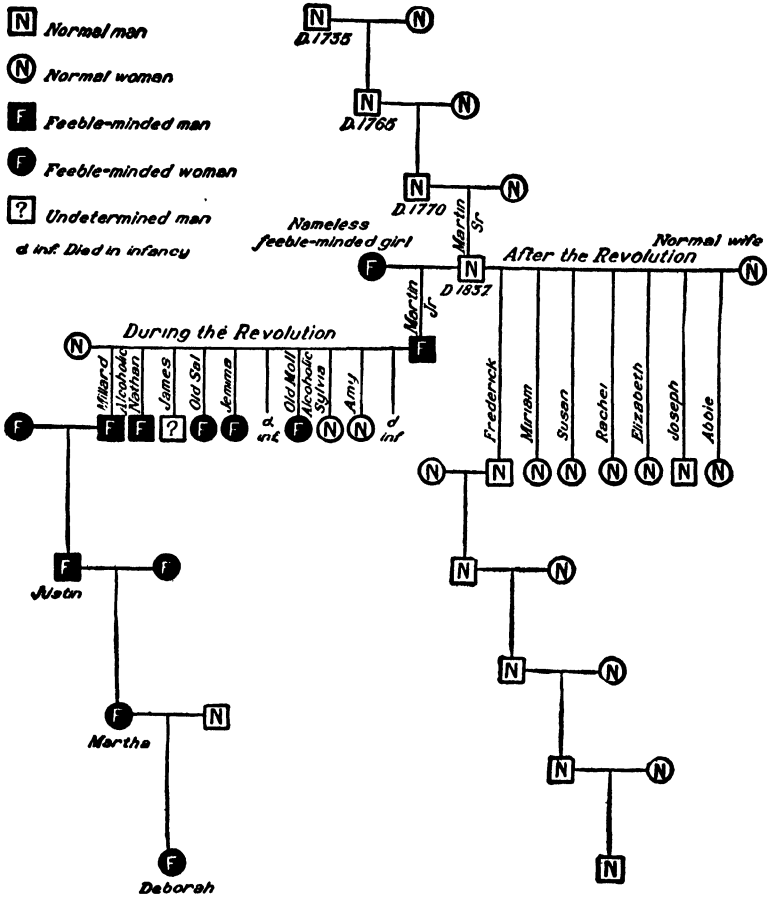

Fig. 492.—The Kallikak family. (From Woodruff, Foundations of Zoology, The Macmillan Company.)

Of the 480 descendants, in five generations, of this branch, 143 are known to have been feeble-minded, 36 illegitimate, 33 sexually immoral—mostly prostitutes, 24 alcoholic, 3 epileptic, and 3 criminal. 82 died in infancy.

Of the 496 descendants, in five generations, of this branch, none were feeble-minded, and all but 2 were normal mentally. 2 were alcoholic and 15 died in infancy. Thus nearly all were good citizens. Among them were educators, physicians, lawyers, judges, traders, landowners—men and women prominent in every phase of social life. (After Goddard.)

nism of reduction division, etc. Sometimes a complete set of chromosomes from one of the parents is segregated in a germ cell, and this cell is capable

of being fertilized. Although this is a rare occurrence, it explains why certain hybrids, usually sterile, are occasionally fertile.

Among mammals, the mule is an example of a cross between different species, the ass and the horse. The common mule (Fig. 490) is an offspring of a male ass and a female horse; the hinny (Fig. 491) is the offspring of a female ass and a male horse. In both cases, the superficial characters and the voice are inherited from the father, and the strength, stature, and symmetry are inherited from the mother. The mule has the voice of the

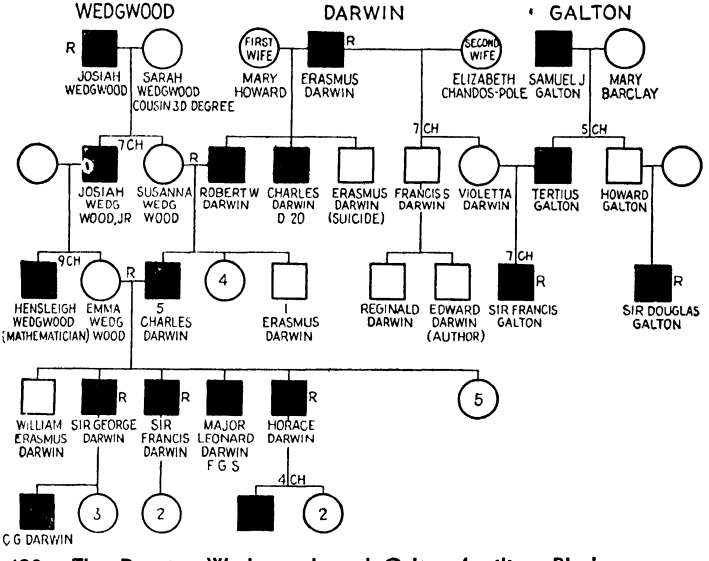

Fig. 493.—The Darwin, Wedgwood, and Galton families. Black squares represent unusual ability; R = Fellow in Royal Society. The chart probably does not tell the whole story as the women had little opportunity to show their mental gifts. (Courtesy of Dr. S. J. Holmes.)

ass, small hoofs, scanty mane and tail; the hinny is more horse-like, is smaller, and has the voice of the horse. Only rarely is the mule able to breed: it has been said that it is an "animal without pride of ancestry or hope of posterity!" It is, however, a desirable animal, because it combines some of the best qualities of both the horse and the ass. It is less excitable than the horse, is sure-footed and able to thrive on poor food. This is the inheritance from the ass. From the horse are inherited size, speed, strength, and spirit. Mules are good work animals.

Many phases of inheritance are not discussed here on account of the technical aspects of the subject. Some of these are *modifying factors*, the *effect of genes upon each other*, the *manifold effects of a single gene*, and others. For a discussion of these, the interested student is referred to any of the excellent supplementary texts listed at the end of this chapter.

15. INHERITANCE IN MAN.—Inheritance in man follows the same laws as inheritance in other organisms. Sex-linked characters for color blindness and hemophilia have been described. There are many more cases, as shown by the table that follows, in which the mechanism or type of inheritance has been determined; there are many other cases, mainly defects, known to be inherited, but their type of inheritance is obscure.

Good and bad human stocks are well known. Perhaps the best worked out case is that of the Kallikak family (Fig. 492). Study of this chart

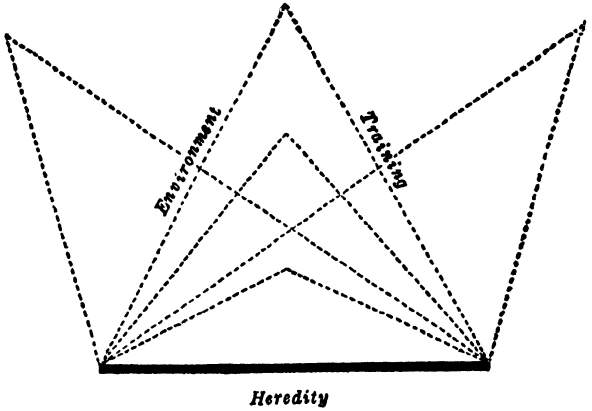

Fig. 494.—Diagram to illustrate the influence of heredity, environment, and training in the development of an individual. The heredity is assumed to be a constant in the particular individual, but heredity is expressed in different ways according to the environment and training. Thus various types of individuals, as represented by the several triangles, may be produced from zygotes having the same hereditary potentialities. (From Conklin, Heredity and Environment, Princeton University Press.)

shows two distinct lines, the same man being the progenitor of the two lines. The defective line begins with a feeble-minded girl, and the good line begins with a normal woman.

The famous Edwards family presents a very different picture, but the principle is the same. The descendants of Jonathan Edwards and Elizabeth Tuttle have many famous people among them. This combination was one of the best, producing a superior human strain. Later Jonathan Edwards married Maria Talbott. Their descendants have not distinguished themselves. They are good citizens but are not to be compared with the Edwards-Tuttle descendants.

It should be noted that the defective line of the Kallikak family lived in a poor environment, while the normal line had the advantage of a good environment. Environment alone, however, cannot explain the differences in the two lines of this family.

Both lines of the Edwards family enjoyed superior environment, and this doubtless contributed to the development of this family. Yet only

INHERITED CHARACTERS IN MAN*

1. *Blending*

General body size, stature, weight, skin color, hair form (in cross section, correlated with straightness, curliness, etc.), shape of head, and proportions of its parts (features).

2. *Mendelian*

	Dominant	Recessive
Skin and hair	Dark	Blond or albino (probably multiple allelomorphs)
	Spotted with white	Uniformly colored
	Tylosis and ichthyosis (thickened or scaly skin)	Normal skin
	Epidermolysis (excessive formation of blisters)	Normal skin
	Hair beaded (diameter not uniform)	Normal hair
Eyes	Front of iris pigmented (eye black, brown, etc.)	Only back of iris pigmented (eye blue)
	Hereditary cataract	Normal
	Night blindness (when not sex-limited)	Normal
	Normal	Pigmentary degeneration of retina
Skeleton	Brachydactyly (short digits and limbs)	Normal
	Polydactyly (extra digits)	Normal
	Syndactyly (fused, webbed, or reduced number of digits)	Normal
	Symphalangy (fused joints of digits, stiff digits)	Normal
	Exostoses (abnormal outgrowths of long bones)	
	Hereditary fragility of bones	Normal
Kidneys	Diabetes insipidus (excessive production of urine)	Normal
	Normal	Alkaptonuria (urine black on oxidation)
Nervous system	Huntington's chorea	Normal
	Normal	Hereditary feeble-mindedness

3. *Mendelian and Sex-linked*

(Appearing in males when simplex but in females only when duplex)

Dominant	Recessive
Normal	Gower's muscular atrophy
Normal	Hemophilia (bleeding)
Normal	Color blindness (inability to distinguish red from green)
Normal	Night blindness (inability to see in faint light)

* From Castle, "Genetics and Eugenics," Harvard University Press.

4. Probably Mendelian but Dominance Uncertain or Imperfect

Defective hair and teeth or teeth alone, extra teeth, a double set of permanent teeth, harelip, cryptorchism and hypospadias (imperfectly developed male organs), tendency to produce twins (in some families determined by the father; in others, by the mother), left-handedness, otosclerosis (hardness of hearing owing to thickened tympanum).

5. Subject to Heredity But to What Extent or How Inherited Uncertain

General mental ability, memory, temperament, musical ability, literary ability, artistic ability, mathematical ability, mechanical ability, congenital deafness, liability to abdominal hernia, cretinism (due to defective or diseased thyroids), defective heart, some forms of epilepsy and insanity, longevity.

one line has shown numbers of superior individuals, indicating that the Edwards-Tuttle combination was an excellent biological combination.

The pedigree of the Darwin, Wedgwood, Galton families (Fig. 493) clearly demonstrates the inheritance of mental ability. It can be no accident that so many distinguished people have come from these families.

Talent is likewise inherited as the history of the famous Bach family shows. Many cases might be cited to show that talent, or mental ability, or both, "runs in families," but enough has been said to show that many human traits are definitely inherited (see table, page 752).

Nature vs. Nurture.—Experiments seem to prove that equal training does not change inborn differences, good or bad. Certainly some traits are more modified by environment than others, and a good environment will bring out latent ability (see above). Figure 494 shows that heredity is expressed in different ways according to environment and training.

The table on page 752 gives a list of some human characters and their mode of inheritance.

Questions

1. What are some of the earliest known cases of hybridization?
2. Distinguish between the following types of variations: structural, physiological, heritable, and nonheritable. Could you prove that some apparently heritable characters are really not inherited?
3. Explain fully the relation between the reduction division in the germ cells and the possibilities of inheritance.
4. Give a short account of the life of Mendel.
5. What two "laws" of heredity result from Mendel's work? What four "laws" of heredity have been added by Morgan and his associates? Who established the theory of linear order of the genes? Is there any other spatial relationship of the genes that would account for the genetic results obtained from crosses? Explain fully. Explain crossing over. How are new genes located?
6. If you wish to have a bed of pink four-o'clocks, how would you plan for it?
7. Why do not the blue Andalusian fowls breed true? How could you plan to keep a flock of these blue Andalusian fowls?

8. Describe the types of linkage. Why is a sex-linked character somewhat easier to follow than the other type? What are some sex-linked characters in man? How is the number of linkage groups limited in organisms?
9. Give a full account of sex determination in *Drosophila;* man; moths; birds. What is meant by genic balance? Show how normal sex conditions are sometimes upset. Explain the differences between gynondromorphs, intersexes, and mosaics.
10. Explain De Vries's mutation theory. With what plants did he work at first? Was this good material? How do mutations arise? Are they common?
11. How would you explain the fact that a cross between pea and rose-comb chickens give walnut-comb fowls? What result is obtained from crossing two walnut-combed chickens with the genetic formula $RpP'r$?
12. Show how the presence of multiple factors affects the results of selection.
13. Is inbreeding always harmful? Explain. In determining differences between individuals, which is more important, inborn genetic traits or training? Give reasons for your answer.
14. Explain the occurrence of families in which there are many brilliant people. Would environment alone explain the Kallikak family? Give reasons for your answer. Can you explain (1) why exceptional children are sometimes born of parents with average mental ability; (2) why brilliant parents sometimes have mediocre children?
15. In studying the differences between the effect of heredity and environment, in what ways might the study of identical twins be valuable?
16. Define, as related to genetics: ploidy, inversion, deletion, factor, gene, allelomorph, homozygous, heterozygous, interference, heterosis, telegony, mule, hinny.

Problems

1. In summer squashes, white fruit (W) is dominant over yellow (w). Cross a white summer squash with a yellow, and work out the possibilities for F_1 and F_2.
2. In summer squashes, white summer squashes (W) are dominant over yellow (w), and diskshaped squashes (D) are dominant over sphere (d). Cross a white, disk-shaped squash with a yellow sphere-shaped squash, and work out the possibilities for F_1 and F_2.
3. In man, brown eyes (B) are dominant over blue (b). A blue-eyed man marries a brown-eyed woman. What would be the color of the eyes of their children? Suppose one of these children grew up and married a woman with the same inheritance that he has as to eye color (Bb). What are the possibilities for eye color for their children? Make a diagram showing inheritance of eye color in these cases.
4. If one of the blue-eyed children in the preceding cross should grow up and marry another blue-eyed individual, what type eyes would their children have? Explain fully.
5. Right-handedness (R) and brown eyes (B) are both dominant characters; blue eyes (b) and left-handedness (r) are both recessive characters. If a right-handed brown-eyed man marries a left-handed, blue-eyed woman, what type of handedness and what eye colors would their children have? Suppose one of these children grew up and married a brown-eyed, right-handed man whose mother was blue-eyed and left-handed and whose father was brown-eyed and right-handed; what would be the possibilities for inheritance of handedness and eye color in their children? Work out the possibilities for inheritance in this case.
6. In cases of disputed paternity, would it be possible to use what we know of the inheritance of eye color to help in settling the dispute?
7. Color blindness is a sex-linked character in man. Construct a diagram to show how a man must inherit color blindness. Construct another diagram showing how a woman may inherit color blindness. Explain why there are not many color-blind women.
8. Tumor is a sex-linked character in fruit flies that kills the male larvae. Construct a diagram showing the only way it can be inherited.

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CHAPTER XLVI

ADAPTATIONS

Marvel how a bat discerns,
Some pitch black cavern's fifty turns,
Led by a finer tact, a gift
He boasts which other birds must shift
Without, and grope as best they can.
—BROWNING.

I. The Struggle for Existence

Adaptations of organisms to the environment may be of great importance in enabling them to survive in the struggle for existence. When conditions become unfavorable for life, organisms must do one of three things; adapt themselves to new conditions, migrate, or become extinct. In addition to remaining alive, organisms must leave offspring, or there will be no survival of the race.

A. The Wealth of Life.—In another section (page 670), attention has been called to the wealth of life. If all the descendants of even one pair of flies survived, they would soon take the earth. Linnaeus once said that "three flies would destroy a dead horse as quickly as a lion." But millions of flies are destroyed by birds; millions more die from starvation, etc. And so the number remains constant; *i.e.*, nature establishes a balance (page 58).

The struggle for existence is threefold: (1) with the conditions of life, (2) for competition for food among individuals of one species, as among flies, and (3) for competition for food among different species, as between flies and other insects.

No plant or animal is entirely isolated from other plants and animals. Organisms must be able, therefore, to live together without destroying one another and to adapt themselves to the activities of their neighbors. In some cases, one type of organism depends upon another species for food; or two species may live together and be of mutual benefit (*symbiosis*[1]); or one species may live as a *parasite* upon another.

B. The Environment.—A large part of the life of an organism is concerned with the struggle with the environment itself (Fig. 495). Both plants and animals have certain fundamental requirements, and these are related to the environment in which they live. Whether the

[1] For a description of symbiosis, types of communities, etc., refer to Chap. VI.

organism is a plant or an animal, *food*, *moisture*, and *air* are usually needed For most living things, a definite range of temperature is essential, and *light* is an important factor Naturally, there are special requirements for special cases. For example, plants and animals that thrive in the desert would not do well in the Arctic Circle And this is what is meant by one type of adaptation—the methods by which plants and animals have adapted themselves to every sort of environment Other types of

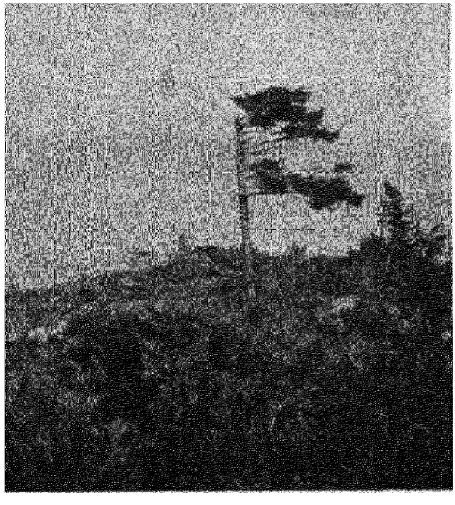


Fig 495 —Response to environment. "Wind-blown' tree in Maine (Courtesy of Edith Mortensen)

adaptations are modifications for food getting, breeding habits, and the like Man has learned to control his environment and may live anywhere he pleases, provided there is food supply and air

It is of practical value to know the relations of living things to the environment For example, knowing that the malaria parasite has become adapted to live a part of its life cycle in an *Anopheles* mosquito, man is able to take steps to protect himself against this type of mosquito (page 274) The whole science of agriculture is based upon the fitness of plants to grow in certain environments (see Chap VI)

II. Origin of Adaptive and Nonadaptive Characters

The question of explaining how adaptations arose that enable organisms to fit so perfectly into their environments naturally arises In general, weaker organisms are soon weeded out in the struggle for existence by

the process of *natural selection.* But it must be borne in mind that variations brought about purely through the influence of the environment do not survive; there must be a change in the germ plasm if the character is to be inherited. The environment, however, may determine how the character is to be developed. For example, among *Drosophila* is a character known as *abnormal abdomen.* If flies having this character in their germ plasm are reared in damp bottles, the defect appears; if they are reared in dry bottles, it does not appear. Yet normal flies do not develop abnormal abdomens if they are reared in damp bottles, showing that the defect is definitely inherited and that only a damp environment will cause it to develop. Certainly natural selection (page 797) plays a part in the selection of the fit, but this principle alone is not sufficient to explain the origin of adaptations. It must be borne in mind also that all structures that appear are not useful; that all organisms are not perfectly adapted to their environments; that it is difficult to explain the very beautiful colors, patterns, and shapes of some animals that lie buried in the mud or that live in the deep sea. In spite of all this, however, the biological picture will not be complete without some mention of adaptations, useful and nonuseful.

III. Some Adaptations of Plants

Plants live in every type of environment, and they have developed many types of structures that enable them to adapt themselves to various factors in their surroundings. Two important sets of factors affect the plant: those included in the general term *climate* and those connected with the character of the soil. For adaptive responses to light, gravity, etc., see Chap. VI.

A. Adaptations to Moisture.—Although one of the "must haves" of plants is a sufficient *water* supply, they are adapted to live and thrive in situations of all degrees of dryness and wetness. The average living plant body is about 90 per cent water, all the materials necessary for life activities, nutrition and the like, are dissolved in water, and the processes of diffusion and osmosis are dependent upon its presence. Furthermore, if the cells are not kept filled with water, the plant wilts and soon dies (page 145).

1. Desert Plants, or Xerophytes (Fig. 25).—The xerophytes thrive in dry situations. Some of their adaptations to dryness are great development of root in proportion to that of the shoot, as shown by the mesquite tree of the Southwest, which sends its roots down 50 to 70 ft., though the tree itself does not reach a height of more than 20 to 40 ft.; development of horizontal roots to absorb chance rainfall; reduced leaves, which may disappear altogether and whose functions may be taken over by the modified stem; development of hairs and spines. In

some cases, the stem becomes succulent and fleshy, as in the case of the cacti.

2. Water Plants, or Hydrophytes (page 57).—Water plants have very different structures from those of the xerophytes. They do not exhibit the great root systems of the drought-loving plants; their root systems may be much reduced or absent altogether; the stems are weak since the water buoys them up to some extent; leaves that are submerged are often small or dissected into small parts; floating leaves may be quite large (Fig. 91), such as those of the water lily; large air passages, as well as air bladders, are often developed that aid in keeping the plant afloat. In addition to all these adaptations to living in the water, bog and swamp plants have a typically spongy structure. In cypress swamps, "knees" are developed (Fig. 64); the reason is not well understood. It has been suggested that they are for aeration of the trees, but this has been disputed.

3. Plants Needing Moderate Water Supply, Mesophytes (page 57).—These include the familiar plants. Their root, stem, and leaf systems are well developed and the cuticle rather thin.

B. Special Adaptations of Seed Plants.—The seed plants exhibit special adaptations for securing and preventing pollination; they develop hooks, barbs, hairs, and the like to aid in seed dispersal (Chap. XIII).

IV. Adaptations of Animals

The adaptations of animals to their environment involve all the organs and all the physiological processes that make up the activities of the animal. Different animals are adapted to different conditions in different ways. Thus, aquatic insects and fish are able to move and obtain oxygen under water, but the methods by which these activities are accomplished are very different. A review of the morphology and behavior of any animal will show how wonderfully it is adapted to life in its particular environment. Each species of animal, however, is not adapted to a certain habitat to the exclusion of other species, but many species of animals and plants may live in one habitat, in communities (page 871).

A. Adaptive Radiation.—It was pointed out by Osborne that diversified mammalian fauna arises in large isolated regions where there is a variety of environments, *i.e.*, variations in soil, climate, vegetation. The need for food and safety is given as the primary cause of adaptive radiation and, for this reason, the teeth and limbs are the main structures that show modifications. It is further pointed out that the modifications of the teeth and the limbs do not necessarily parallel.

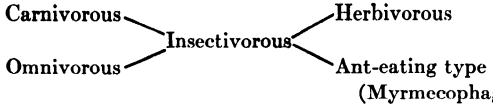
Organisms of different groups may develop, or possess, similar characters not due to kinship, but usually to similarity in habits or environment. This is what is meant by ***convergence*** or ***parallelism.*** ***Divergence*** is the oppo-

site phenomenon, *i.e.*, the tendency of animals to radiate into various types of environments and become adapted to them (adaptive radiation).

1. THE MAMMALIAN TEETH.—The type of dentition of mammals is *heterodont* (Gr. *heteros*, other; *odon*, tooth); *i.e.*, there are several types of teeth, each with a different function. A typical set includes *incisors*, mainly grasping, in front; *canines*, which may be used for offense and defense as well as for grasping and tearing; *premolars*, which may be used for shearing or grinding; and *molars*, for grinding (Fig. 367).

Using the teeth of mammals to illustrate radiation, the stem or focal form is thought of as the *insectivorous type* with teeth suitable for crushing feeble prey. The table that follows[1] shows radiation in four directions:

ILLUSTRATION OF DIVERGENCE IN FOUR DIRECTIONS FROM A PRIMITIVE INSECTIVOROUS STEM



a. Insectivores.—These have low-crowned, sharp-pointed teeth, having few cusps; an example is the armadillo.

b. Carnivores.—The teeth of lions, cats, etc., are suited for seizing and cutting up flesh. The attachment of the jaw to the skull is of the hinge type, allowing little lateral movement of the teeth, which shut past each other somewhat in the manner of a pair of shears, and hence are called *shearing teeth.* Cats have almost no true grinding teeth; dogs, with a less specialized diet, have both shearing and grinding teeth. Flesh-eating, carnivorous animals like seals have simplified teeth.

c. Herbivores.—The incisors of herbivorous animals are fitted for seizing and cutting vegetation. In the ruminants the *upper incisors are lacking;* the lower ones bite against a horny pad (cow). Canine teeth of the herbivores may be used in fighting (musk deer); otherwise they are of little importance. The grinding teeth, however, are broad and have some intricate patterns (Fig. 522). Folds of hard enamel are imbedded in the softer dentine. The dentine wears, keeping the surface rough, which aids in the mastication of the grain or vegetable foods.

There are various types of teeth fitted for various types of vegetation. Succulent twigs, tender vegetables, leaves, etc. do not require as efficient teeth as do the harsh grasses. Horses have teeth especially fitted for handling the latter type of vegetation.

d. Omnivores.—Some animals, primarily carnivores, as the bears, become adapted to the *omnivorous* diet. In man, an omnivorous type, there are few cusps on the molar teeth and little distinction in the incisors and canine teeth (Fig. 367).

[1] Adapted from various sources; mainly from Lull.

In rats, beavers, and other rodents, the front teeth are prominent and chisel-like, and the back teeth have the enamel ridges parallel to each other. This is an adaptation to the "fore-and-aft" movement of the jaws, which is a different type of motion from that of either the carnivores or the herbivores.

e. Mammals without Teeth, Myrmecophagidae (Gr. *myrmex*, ant; *phagein*, to eat).—In some mammals, as the anteaters, the teeth have entirely disappeared, the mouth is tubular, and there is a highly specialized tongue; it is both extensile and prehensile. When the tongue is thrust into an anthill, because of the adhesive substance on the tongue, great numbers of ants will stick on the tongue. These are brought to the mouth and swallowed without mastication. An interesting adaptation to use of this type of food is that the interior nostrils are in direct communication with the windpipe; otherwise the ants might wander into the "wrong pew" and disturb the breathing of the anteater.

2. The Mammalian Limbs.—As with the teeth, the mammalian limbs show adaptive radiations in four directions, according to the table below.

Types of Modification[1]

Cursorial-unguligrade Runners on tips of toes	Flying or volant Aerial
Cursorial-digitigrade Runners on finger and toe pads	Climbing or scansorial Arboreal
Ambulatory (short-limbed) Terrestrial (plantigrade)	
Amphibious. Good swimmers but living partly on land	Fossorial. With digging organ but living above ground
Aquatic	Subterranean. Living entirely underground

[1] Modified from Lull.

The table shows possible modification of limb structure in four different directions in adaptation to various types of environment.

a. Types of Limb Adaptation.—On the earth's surface, speed is desirable if animals are to get out of the way of their enemies; hence adaptations for speed (*cursorial*); subterranean life calls for a different set of adaptations (*fossorial*); tree dwellers must be *climbers* or *fliers* if they come to earth (*scansorial and volant*); and finally, the denizens of the water must be fitted to live in that medium (*aquatic*).

b. Adaptations for Speed.—Adaptations for moving with speed over a firm surface involve a change in foot posture. The primitive posture is *plantigrade*, as is that of the bear. Some speedy animals have a *digitigrade* gait having developed special sole pads to absorb the shock of

impact with the ground (Fig. 435). The hoofed animals (*unguligrade*) walk on the modified nail or hoof. Between the extreme specialization of the horse type of gait and the plantigrade, there are all gradations. For example, the foot of the African antelope shows a semiplantigrade condition (Fig. 435). In the speedier types, the fibula and the ulna are reduced; there is a loss of universal movement, and movement is restricted to one plane, except at the shoulder and the hip. Adaptations for speed naturally include adapting the contour of the body so as to offer the least resistance to the medium through which they pass, whether water, air, or earth. The streamlined body that passes through water or air is spindle-shaped.

B. Adaptations for Special Habitats.—Permanent residents of any special habitat, such as swamp or plain, will show different structural adaptations that fit them for their special environment. In the following description of adaptations to habitats, only the main types are mentioned. Some adaptations other than type of limbs will be included.

1. DESERT ANIMALS. *a. General Features.*—No desert animals are green but are mostly gray, brown, or red, harmonizing with the rocky background of the desert. Although a few desert animals are brightly or warningly colored, the majority are difficult to see, even at a short distance, so long as they *keep still.* When frightened, many of them remain motionless until danger is past. Since shelter is not always at hand, this is an important adaptation.

Many desert animals are *poisonous.* These include scorpions, spiders, and reptiles.

The *feet* are modified for speed and for traveling on sand. The limbs incline to be long and slender, for the animal must have speed to escape its enemies and must also travel far for food.

The *organs of special sense* show marked adaptations. The *eyes* may be shifted high in the head; long *eyelashes* may be present, or other types of eye shields may be developed. In one lizard, the lower eyelid is enlarged and has a *transparent window* in it; in another, the whole lower lid is transparent and is fused to the reduced upper lid.

The *ears* are protected by hairs and other devices, and the *nostrils* are often provided with valves that may be closed and so keep out the sand.

b. The Camels.—Camels show very well many desert adaptations. In addition, two species show differences in adaptation to environment.

(1) THE ONE-HUMPED OR ARABIAN CAMEL.—This species is often called the *ship of the desert* and shows many adaptations for survival in the harsh conditions of the desert. As in all animals traveling in the desert, water must be conserved. The stomach of the camel has many flask-like *pouches,* each closed with a sphincter muscle. When the camel

drinks water, the muscles relax, and the cavities are filled. The water in the stomach is absorbed in due course, but that in the cavities is doled out as needed. *The hump* is a reservoir of food, being composed largely of gelatinous fat. When the camel goes without food, or is exhausted from overwork, the hump becomes shrunken and may fall to one side. Shifting of the sense organs gives the camel its proud carriage. The *eyes* are shifted high in the head and are protected by eyelashes; the *nostrils*, shifted upward somewhat, have valves that may be closed against blowing sand; the *ears* have hairs in them to keep out sand. The *limbs* are long and adapted for speed, and the *foot* has retrogressed from the unguligrade foot to the digitigrade type; well-developed *pads* give the camel a noiseless tread and adapt him for moving on yielding sand.

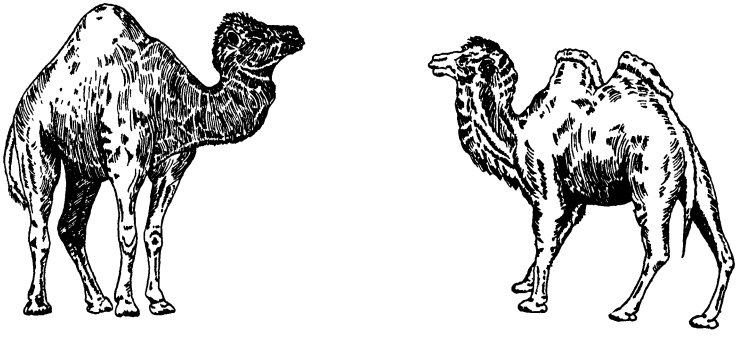


Fig. 496.—(A) Arabian camel. (B) Bactrian camel. The Arabian camel is fitted for life on the desert; the Bactrian camel has special adaptations for life in northern as well as southern climates. (L. Runyon.)

(2) The two-humped or Bactrian camel.—This camel lives in a more northerly region than its one-humped relative. It has long, shaggy hair and is adjusted to the extremes of heat and cold. Much of the country in which it lives is rocky and broken; the feet are adapted to this, being harder and more cloven than those of the Arabian camel (Fig. 496).

2. Adaptations for Subterranean Life.—Many animals that live above ground have digging organs, as elephants, swine, etc., but many others spend their lives underground, and these are profoundly modified to fit into this environment. Representatives from all the vertebrate groups live underground; many insects, either as adults or larvae, lead a subterranean life. The mole (*Talpa*) exhibits modifications for its life underground to a remarkable degree. Like an animated plow, the *head* is wedge shaped for penetrating the soft earth. The enormously *enlarged forelegs* are armed with long, broad nails and with an extra sickle-shaped bone on the outside of the thumb, forming, all together, an effective living chisel for gouging out the earth. The *fur* consists of short

hairs, so closely packed as to resemble velvet; it does not become wet easily or allow penetration of earth to the skin.

The *sense of sight* is reduced; the *ears* are small but are sensitive to sound waves passing through the soil; the sense of *touch* is remarkable; the *snout* is abundantly supplied with nerves and is wonderfully sensitive; the tail is naked, is also sensitive, and guides the mole as it moves backward through its tunnel.

The rate at which a mole can dig a tunnel (Fig. 32*A*) is almost unbelievable. If placed on the surface, it will dig out of sight in 10 seconds and will tunnel at the rate of 1 ft. in 3 minutes. One mole is reported to

Fig. 497.—The two-toed sloth (Choloepus didactylius). (Courtesy of The National Zoological Park.)

have dug a tunnel 100 yd. long in a single night. To do a proportionate amount of digging, a man would have to make a tunnel about 50 miles long, large enough for him to crawl through.

3. ADAPTATIONS FOR AERIAL LIFE.—Animals that are adapted to fly rest either on the earth or in the trees.

a. Adaptations for Climbing.—Adaptations for climbing may apply to animals that climb walls and trees for temporary safety or to arboreal forms that spend most of their time in trees or to forms like the sloth that never leave their tree homes.

(1) GENERAL FEATURES.—Climbing animals have especially long shoulder girdles, long arms, and feet of two types; these may be prehensile or grasping, as in the monkeys, or they may be nonprehensile, with well-developed claws, as in squirrels and cats. Special devices may be present, as the sticky adhesive pads on the feet of tree frogs or the vacuum "cups" on the feet of the geckos.

(2) THE SLOTH.—The sloth is specialized in many ways for the life it leads in trees. Sloths have long, strong, curved *claws* with which they

hook onto limbs (Fig 497) and hang with the back downward In this position, they move from limb to limb by slow motion The hair is arranged so that during torrential tropical rainstorms the water runs off as the sloth is hanging upside down.

The head of the sloth is round, the ears are small; the tail is only a vestige, sloths feed on leaves from which they obtain sufficient moisture so that they need not descend to the ground to drink

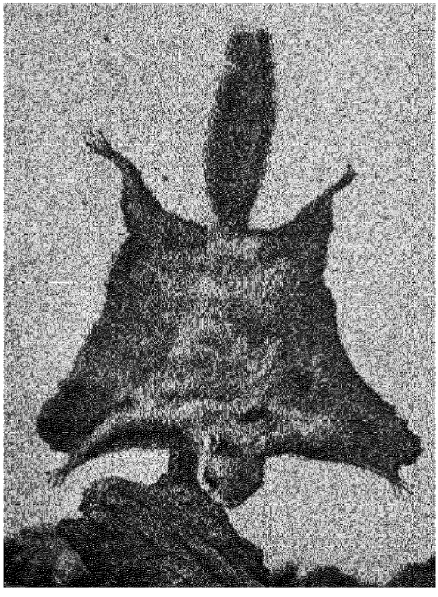


Fig 498 —The Eastern flying squirrel (Glaucomys volans) Large eyes enable the animal to see at night. (From S H Williams, The Living World, The Macmillan Company)

b. Adaptations for Flying —Adaptations for flying involve two types of flight, passive flight, which includes two types of gliding, and true flight

(1) PASSIVE FLYING —The flying fish and the squirrel both glide but in a different manner There is some dispute as to how the flying fish leaves the water, the wing-like fins are not vibrated after leaving the water but are simply extended like the wings of a glider In shape, the flying fish resembles an airplane more than any other animal

The flying squirrel, on the other hand, has a fold of skin, the *patagium* (L *patagium*, an edge or border) supported between the fore- and hind limbs (Fig. 498).

(2) TRUE FLIGHT.—True flight implies sustained movement in the air, or power. If the flying invertebrates are left out, true flight has evolved three times among the vertebrates. Among the extinct reptiles, the pterodactyls could fly (Fig. 499); the bird is a very familiar flying animal; and the bat is the third type. Bird wings have been mentioned (page 479). Figure 342 shows various positions of the wing of the white ibis in flight. Bird wings vary greatly in the manner of vibration. The humming bird wing moves with extreme speed; many birds, especially some birds of prey, sail or soar for hours at a time. They are apparently motionless, but there may be some small movements of the wings that

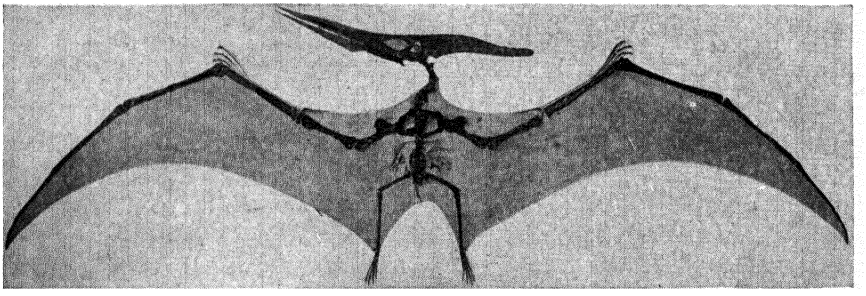


Fig. 499.—Winged lizard, Pteranodon. Probably the largest flying animal that ever lived, measuring 20 feet across its wings. (Courtesy of The American Museum of Natural History.)

keep them aloft, or they may be descending in great spirals. The bird wing is the most specialized of all wings.

The bat wing is a true wing, though not so highly adapted as the bird wing. The forelimbs are provided with four very long fingers (Fig. 352), between which is stretched the wing membrane. This membrane also extends along the sides of the body between the fore- and the hind limbs and the tail. The thumb is free, ends in a claw, and is used for climbing purposes. The hind toes are also free; they terminate in sharp, strong claws, which are used to suspend the body head downward from a support when the bat is at rest. The bat's flight is noiseless, fluttering, and rather erratic. It captures its insect food during the twilight hours while it is "on the wing" or in flight.

4. AQUATIC ADAPTATIONS.—Animals that have never lived on land but only in water are primarily aquatic animals; they may become secondarily adapted to water after their forebears have lived on land.

a. Primarily Aquatic Animals.—These include the fish, with their spindle-shaped bodies adapted to move through the water with the least resistance. They move by means of fins and by the undulations of their bodies. For maintaining themselves at various depths, fish have evolved a swim bladder, a sac filled with gas (page 448).

b. Secondarily Aquatic Animals. (1) AMPHIBIOUS ANIMALS.—These present an array of adaptations that fit them to live either on land or in the water. The adaptations of the frog (page 245) for leading an amphibian life have been mentioned. Many of the higher animals show amphibian habits. The feet of the wading and swimming birds are webbed. Most higher animals with amphibian habits have special breathing arrangements; valves in the nostrils, etc.; the eyes tend to shift higher, as in the hippopotamus and polar bear. Either of these

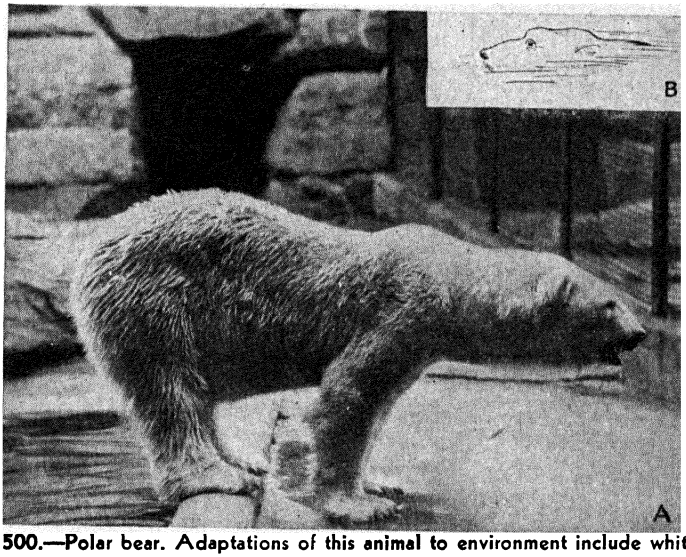


Fig. 500.—Polar bear. Adaptations of this animal to environment include white color, which makes it inconspicuous in polar regions, long neck, shape of head, and position of eyes, which facilitates swimming.

animals can keep nostrils, eyes, and the top of the head out of water and the rest of the body submerged. *Polar bears* are excellent swimmers (Fig. 500) and actually capture fish in the water.

(2) AQUATIC ANIMALS (LUNG BREATHERS).—In the sea are whales, seals, sea lions, and sea walruses among the mammals, as well as countless other types of animals. The bodies of these mammals are streamlined so that they offer the least possible resistance to the water. The feet are completely webbed, forming flippers; those in front are used as oars and those behind as a rudder.

The largest mammal alive today is the whale. The body is fish-like in shape; the forelimbs have become modified as *paddles;* the hind limbs have disappeared entirely; *hair* is present but is scanty, appearing only as bristles on the snout; there are no external *ears;* the *nostrils* of the whalebone whale are paired and called *blowholes.* When the whale rises to the surface, it expels warm air or "steam" through its nostrils, *i.e.*, it

"spouts." The *fat*, or blubber, of the whale lies beneath the skin, is about a foot thick, and keeps the body heat from escaping. The *tail* is flattened horizontally, and the two lobes are called *flukes* (Fig. 355).

5. ADAPTATIONS FOR DEEP-SEA LIFE.—In the dark depths of ocean, no green plants survive. In addition to being dark, the sea bottom is cold, and there is no seasonal variation. Currents do not disturb the quiet waters at great depths. Pressure here is enormous since 1 ton per square inch is added for every 1,000 fathoms. In spite of this, frail, delicate animals are to be found here, chiefly fish.

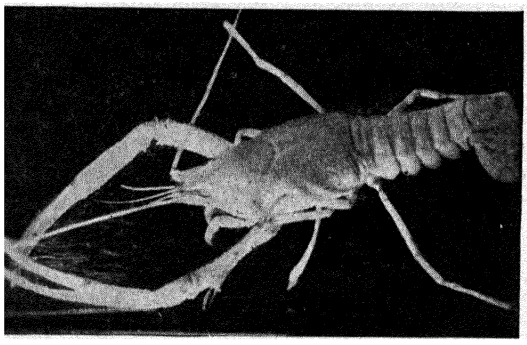


Fig. 501.—Adaptations to environment. Crayfish from a cave. Note reduced eyes (no pigment), and length of legs and antennae. (Photograph of a live specimen by H. H. Hobbs, Jr.)

The *eyes* of these animals are modified in two directions; they may tend to disappear as in cave animals; or they may be developed so as to use every bit of light, as eyes formed like concave mirrors and telescopic eyes. To make up for lack of vision, *tactile* organs may be developed, such as long feelers, modified fins, etc. Almost all deep-sea animals are luminescent (Fig. 310).

The adaptations for food getting are varied; some animals live on the ooze at the bottom; others have powerful *jaws* and are able to swallow animals larger than themselves.

6. ADAPTATIONS FOR CAVE LIFE.—Cave animals may live in water or on land. Most of them are blind or nearly so. Their bodies are inclined to be long and slender, and in many forms there is a reduction of pigmentation (Fig. 501). On account of the scarcity of food, the digestive organs are so specialized as to allow long fasts and also to utilize to the utmost such food as may be found.

C. Coloration and "Mimicry."—In the tropics, brilliant colors in the world of life are the rule. Many insects, birds, and other animals and most flowers are brilliantly colored. Not all coloring is protective. Sometimes it plays an important part in the survival of an organism, but

there are cases in which no utilitarian purpose can be discovered, the brilliant colors of some deep sea animals, for example.

In other parts of the world, colors are more subdued. There are distinct types of coloration.

1. PRODUCTION OF COLOR.—Color in the biological world is universal. It may be either chemical or physical. *Chemical* coloration may be due to pigments, or it may be due entirely to the nature of the food consumed, to waste products, or to reserve products. *Physical* colors may be caused by the light falling on finely incised parallel lines, often running in more than one direction. This is characteristic of the brilliant, metallic colors seen on the neck of a hummingbird and the scales of some butterflies and moths. The scales of the butterfly, *Morpho*, for example, have two sets of striae, one perpendicular to the other.

2. CONCEALING COLORATION.—In the following description of protective coloration and mimicry, it must be borne in mind that authorities who have given the matter much thought question whether animals are protected by their coloration as much as it would seem. Without going into all reasons for this point of view, it may be said that it is not known in most cases how well animals are able to distinguish colors or color patterns. In the matter of "mimicry," there are certain cases in which the mimic and the model are not found in the same areas; also, two poisonous forms may mimic each other. Just what the explanation of this is is far from certain.

Protective coloration is characteristic of animals that are so colored as to blend in with the environment and are, therefore, not readily seen. This may be a protective adaptation in two ways: the animal may escape its enemies, or it may lie in wait for food. Many insects show protective coloration (page 772). Both grasshoppers and *Catocala* moths show brilliantly colored hind wings when the animals are in flight; when they are at rest and their wings folded, the hind wings are hidden, and the insects blend in with the environment.

The flounder is a flat fish capable of changing its color pattern to a remarkable degree. It lives on sandy or muddy bottoms, where it lies buried, except for the eyes (Fig. 303). The young are shaped like other fish when they hatch, but as they grow, the left eye moves around toward the right, the entire head becomes twisted to the right, and the body becomes as "flat as a flounder," with both eyes on the same side of the head!

Certain types of coloration are typical of particular habitats, though there are always exceptions. In the arctic regions, the animals are white, except aquatic forms like the seals; even the seals are white when they are young. Among mammals, the desert animals are duns or grays; the plains animals, somewhat the color of dried grass; the forest forms are

dappled. Many animals are spotted when young, as the lion and the Virginia deer (Fig. 507). The tigers live in the jungle, and it is suggested that the stripes characteristic of these animals simulate bars of sunlight and shadows.

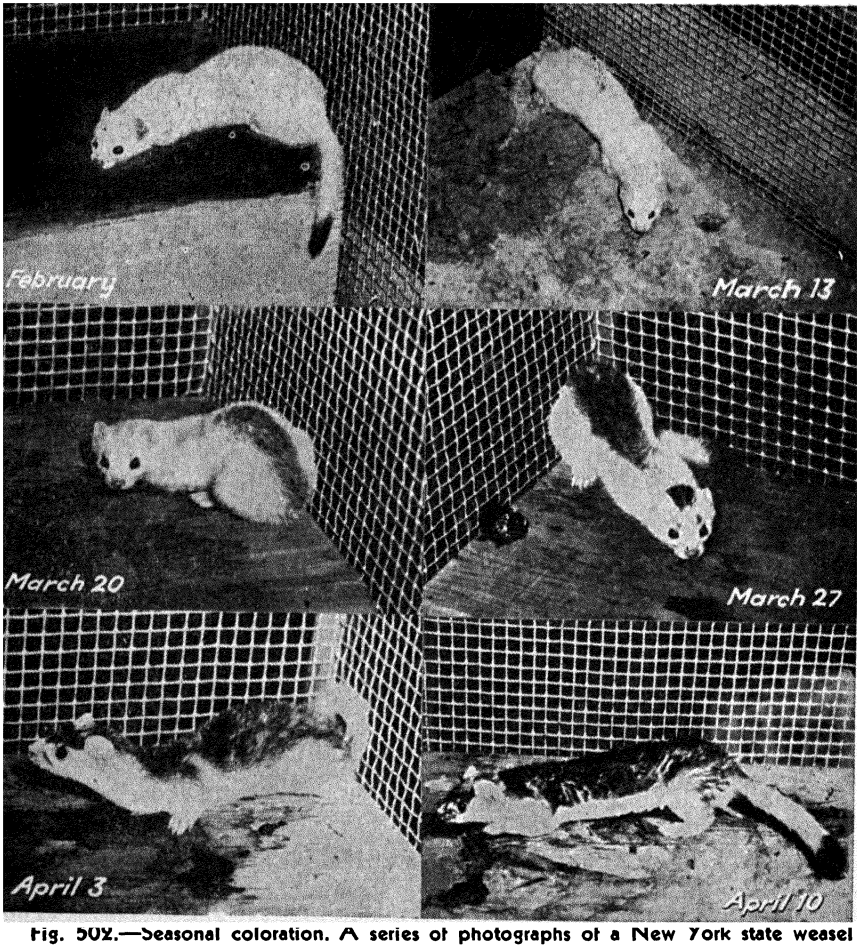


Fig. 502.—Seasonal coloration. A series of photographs of a New York state weasel (Mustela noveboracensis) taken at intervals of one week as he molted from winter to summer pelage. (Photographs by Joseph Lyons, Courtesy of The New York Zoological Society.)

Some animals are able to change color and so blend in with the environment more perfectly. This color change may be temporary or seasonal. The chameleon, many frogs, as well as other animals, are able to change their colors temporarily. The tree frog (Fig. 314) changes from green to gray and shades of brown as he finds himself in different situations.

Many animals, especially those in the arctic regions, show a seasonal coloration. They are white in winter, but when the vegetation appears in summer, they change their coats to brown, spotted, etc., and so are enabled to fit in with the surroundings. Examples are the ptarmigan, the ermine (Fig. 502), the lemming, etc.

3. Warning Coloration.—Vividly colored animals are conspicuous and are easily seen by other animals. Often such animals possess some

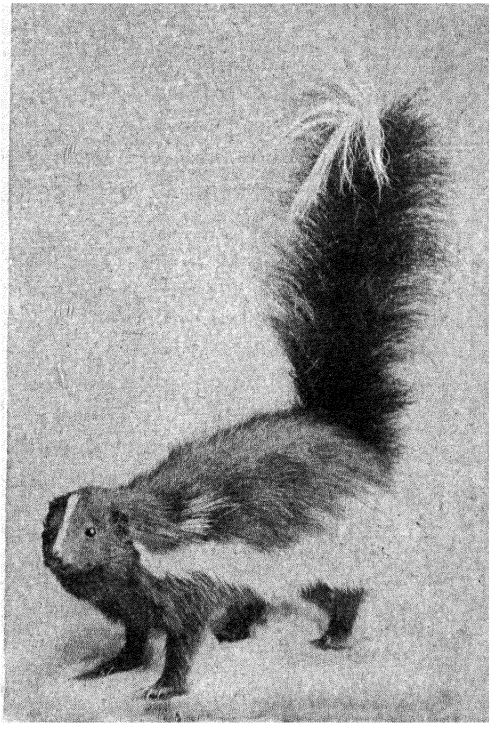


Fig. 503.—Conspicuous coloration. The skunk does not need to hide; it is protected by its scent, produced in special glands. (Courtesy of U.S. Biological Survey.)

quality that renders them unpalatable as food. They may be poisonous, as the coral snakes, or they may be offensive on account of their scent, as the skunk (Fig. 503).

4. Alluring Coloration.—This is a term used to describe such a situation as that presented by an Indian mantid, which is colored like a flower, and thus lures other insects within the reach of its grasping legs.

5. "Mimicry."—Animals may "mimic" each other, or they may look like plants or sticks or stones. When animals resemble each other closely, usually an inedible species with warning coloration is "mimicked" by

an edible species. The viceroy butterfly, for example, differs in its coloration from other species of its genus (*Basilarchia*) but resembles the disagreeable monarch butterfly (Fig. 504*A*) so closely that it is said to secure thereby immunity from attack. The monarch is the model and

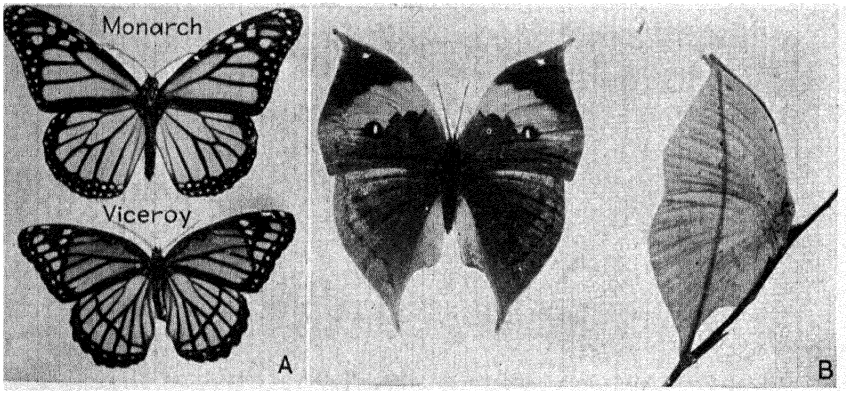


Fig. 504.—Mimicry. (A) The mimicking of the inedible monarch butterfly (Anosia plexippus) by the edible viceroy butterfly (Basilarchia archippus). (B) The "dead leaf" butterfly, Kallima (E. H. Runyon). (Courtesy of The American Museum of Natural History.)

the viceroy the mimic. Many such cases have been reported, but whether they are cases of real protective mimicry is not always certain.

The Kallima butterfly, *Kallima inachis*, of India (Fig. 504*B*), has the upper side of its wings brilliantly colored and is conspicuous when in flight and difficult to catch; the lower sides of its wings are colored like

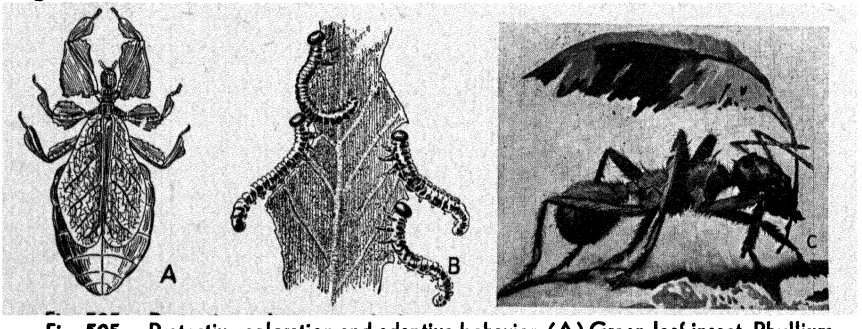


Fig. 505.—Protective coloration and adaptive behavior. (A) Green leaf insect, Phyllium, illustrates both protective coloration (green) and "mimicry" (resembles leaf). (B) Saw fly larvae hold posterior ends of bodies stiffly to resemble twigs. (C) Umbrella ant, carrying leaf over its body (Bolivia). (A and B, drawn by B. Shamos; C, courtesy of The American Museum of Natural History.)

a dead leaf. When at rest, the wings are held together over the back, thus hiding the brilliantly colored upper surface. The tails of the wings are held together against the twig on which the butterfly rests. When the butterfly is in this position, the resemblance to a dead leaf is remarkable.

Many insects resemble in color twigs, foliage, or bark on which they rest. Walking sticks (Phasmatidae) resemble twigs, and the green-leaf insect (*Phyllium*) looks like an animated leaf (Fig. 505*A*).

6. Signal and Recognition Marks.—Among gregarious animals, there are adaptations that aid in warning the group of danger: for example, the white tail of the "Molly cottontail" is of aid in leading her young to safety. The Virginia deer has a white patch under its tail; when frightened, it raises its tail as a signal to the herd. The antelope (Fig. 506)

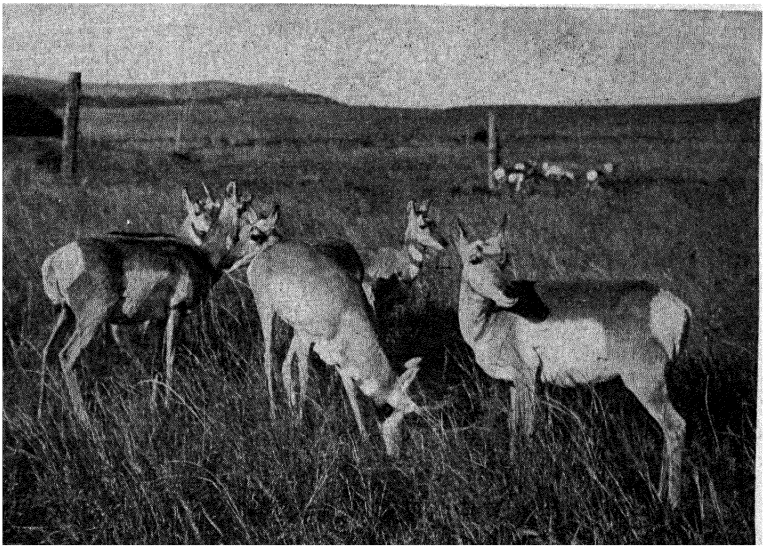


Fig. 506.—Signal and warning coloration. Antelope in Wichita National Forest, Okla. When these animals are frightened, the hairs on the white rump patches stand erect and so become more prominent. This serves as a danger signal to other antelopes. Unfortunately the signal which may have aided the animals formerly now aids man in hunting them and they are becoming scarce. (Courtesy of U.S. Forest Service.)

has a more conspicuous signal. On each rump is a patch of white. The hairs can be spread and become more conspicuous by reflecting light. The rest of the herd is thus warned of approaching danger.

7. Sexual Coloration.—Males of many animals are more conspicuously colored than the female. Why this is so has not been satisfactorily explained. It is interesting to note, however, that the young males are protectively colored. For example, the red breast of the robin and the brilliant plumage of the male cardinal require several years for its perfection; and the young fawn of the Virginia deer is spotted (Fig. 507). Nesting birds and the less conspicuous females of other animals may escape detection more easily than their conspicuous mates.

D. Beaks and Feet of Birds.—Some of the best examples of adaptations among animals are the beaks and feet of birds (Figs. 330 and 331).

E. Adaptive Behavior.—Without any preliminary training at all, many animals perform the most amazing tasks. Only a few may be mentioned:

1. FOR THE CONTINUANCE OF THE RACE. *a. Courtship.*—Authorities differ as to the value in the final mating of the antics of some animals during the mating season. Some common examples of antics are the

Fig. 307.—Protective coloration. Young fawn of the Virginia deer "hidden" in the woods. (Courtesy of U.S. Forest Service.)

strutting of the rooster, the spreading of the tail of the peacock, the fighting of penguins, the waving of brightly colored claws by male fiddler crabs when females are in view, and the display of wing colors by orthopterans during courtship.

b. Oviparity and Nest Building.—Nests of fish and birds protect the eggs and the young. Each animal builds its own kind of nest without previous teaching; an oriole builds an oriole nest, a robin a robin's nest, and the very beautiful hummingbird nest of lichens and moss is an object of perfection. With the assistance of the male, the Surinam toad deposits her eggs in the concavities on her back, where they remain until hatched (Fig. 316). The male sea horse has a brood pouch into which eggs are placed after they are laid by the female; they remain in the pouch until hatched.

c. Viviparity.—The young are protected in the body of the mother in viviparous animals. Sometimes this involves only holding the eggs in the body until they are hatched, as is the case with some snakes (Fig. 319); sometimes they are born in an undeveloped condition and carried in a pouch, as in the case of the opossum (Fig. 350) and the

kangaroo. The higher animals are the most specialized of all, the embryo being attached to the mother by a placenta and nourished through it until they are born. The instinct of the mother to care for the young, even at the sacrifice of her own life, is well known. These are adaptations quite as important as the structural adaptations mentioned above.

d. Special Breeding Habits.—Aside from the mating instincts and behavior, there are innumerable breeding habits that are adaptations to ensure the life of the race. The student will think of many that are matters of common everyday life. Spiders and some other insects are so stung as to be paralyzed and then are shut up in the compartments in which the insect has laid its eggs. When the eggs hatch, the food is ready for the young larvae. Sometimes the eggs are laid in living caterpillars, as is the case with ichneumon flies and some wasps. When the eggs hatch, the larvae feed on the tissues of their host and then pupate.

The need of the young to shift for themselves is met in the case of the opossum by the precocious development of the forelimbs to enable them to make the trip from the birth pore to the *marsupial* pouch. The young animals are less than ½ in. in length at this time, but their forelimbs have a flipper, and they make their way through the dense hair of the mother in a hand-over-hand manner. Reaching the pouch, they attach themselves to mammary glands in the pouch by swallowing them deep in the throat (Fig. 350). They have special *holdfast* mouths. Here they remain, obtaining milk from the glands until they are able to creep upon the back of the mother. She carries them for a short time longer, and then they shift for themselves. Sometimes there are not enough glands in the pouch for the number of young that are born; the strongest push the weakest away, and they perish.

2. Migrations.—Some migrations are merely moving on to better feeding grounds. Many, however, are migrations of parents to situations in which their young will be able to get plenty of food. Most bird migrations are of this type (page 494). However, most migrating birds return to their former homes with the change of the seasons.

The migrations of the salmon and eels, however, are of a different variety. After spending several years in salt water, the salmon ascend the Columbia and Yukon rivers, a distance of from 1,000 to 2,000 miles. On the way, they pass barriers (Fig. 508), and when they reach the spawning grounds they are bruised and worn out. As soon as spawning is accomplished, they all perish; there is no return of the adults to the salt water. The young fish make their way from the fresh-water rivers in which they are born to the salt water and remain there until they are mature. They then return to the rivers to spawn.

The eels have a different history. They are born in the sea and as larvae (*elvers*) make their way to the fresh-water rivers, sometimes

journeying over 3,000 miles. After several years, they return to the salt water for breeding. Apparently all these die afterwards, for the adults never return to the fresh water.

3. Protective Behavior.—Many animals depend upon their legs for escape from their enemies. They may run, fly, jump, swim, or dive. Another type of protective behavior is the feigning of death. Desert animals remain immovable when frightened, but the opossum "plays

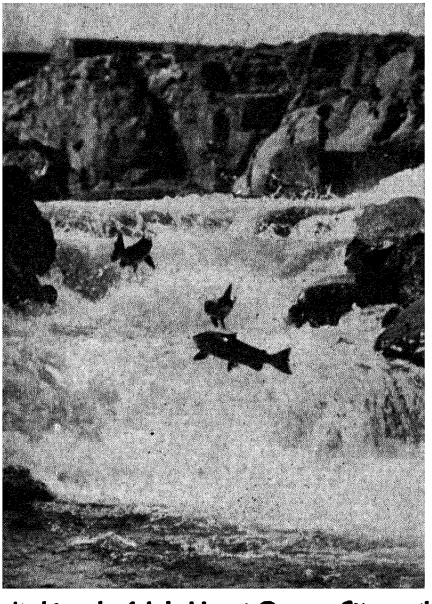


Fig. 508.—Salmon climbing the fish ladder at Oregon City on their way to the headwaters of the Willamette River. (Courtesy of Oregon State Highway Department.)

dead" (Fig. 509). Leaf beetles, click beetles, sphinx larvae, cuckoo wasps are a few of the many animals that behave in this manner.

4. Adaptations for Communal Life.—Social life among bees (page 410) has been mentioned and shows well some types of adaptations necessary for the communal life that bees lead. There are all gradations in the types of adaptations for communal life, ranging from herding habits to very complex ant colonies (Fig. 510).

a. Ants.—Among the ants, there is a wide range in the degree of adaptation to communal life, as well as other types of adaptations.

(1) Members of a Colony.—Among some ant communities there are four types of castes: (1) true males and females; (2) workers, which, unlike the bees, may be either male or female; (3) soldiers, blind, wingless, and sterile individuals with great development of scissors-like jaws; (4) complemental males and females, also blind and wingless, but having limited powers of procreation.

The true or chief males and females are the only ones concerned with the outside world. They come forth in the spring on their mating flight.

Fig. 509.—"Playing 'possum." This is perhaps a protective adaptation, the animal feigning death and hoping to be left alone. (Courtesy of U.S. Biological Survey.)

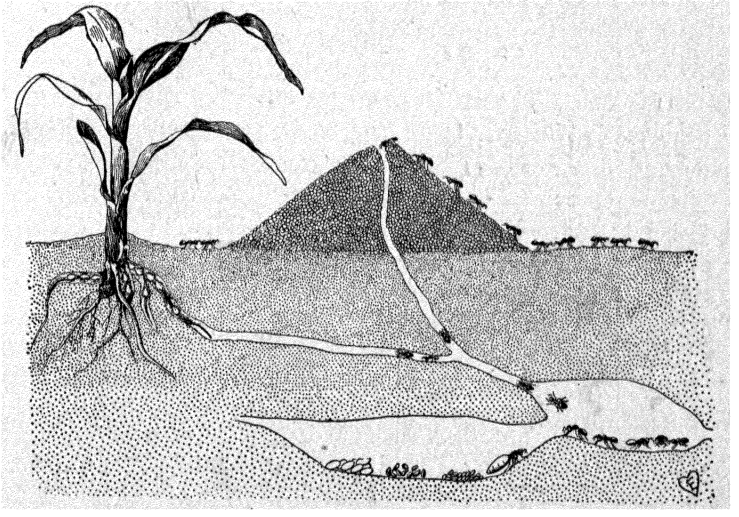


Fig. 510.—Corn root aphids are cared for by ants in their underground nests during the winter and carried through tunnels to roots of corn in the spring. These aphids are called "ant cows" because the ants feed on a sweet substance given off from the bodies of these corn lice or aphids. (Courtesy of U.S. Bureau of Entomology and Plant Quarantine.)

Many are eaten by birds; those that survive settle down, tear off their wings, and found new colonies.

(2) SLAVES.—Ants are war-like insects, and the soldiers, in addition to protecting their own colonies from predacious insects, sally forth and

attack other communities, take possession of food stores, and make slaves of the conquered ants. They take the eggs and pupae of the conquered ants, and when these hatch in the new nests, they care for the young of their conquerors, extend the nest, etc.

There are two kinds of soldiers, large and small. When on the march, the small soldiers march in a long narrow column, the larger ones marching on the outside.

(3) ANT "COWS."—Ants often care for certain of the plant lice (Aphidae) and scale insects (Coccidae), because they like the "honeydew" that they secrete. The aphids feed on the juices of plants and, when stroked by ants, allow small drops of "honeydew" to issue from the body. One type of aphid lives on the roots of corn (Fig. 510). When the plant lice hatch in spring, the corn has not yet been planted and the ants are said to place the aphids at the roots of another plant, a certain knotweed, until the corn roots appear; they then transfer them to corn roots.

(4) CULTIVATION OF FUNGI BY ANTS.—A peculiar adaptation of leaf-cutting ants is their habit of cutting leaves, carrying them to their underground chambers, where they are chewed up to furnish a culture medium for certain kinds of fungi. The spores of this fungus are carried in the head fold or pouch of the queen, or founder of the colonies. Different species of leaf-cutting ants cultivate different species of fungi.

(5) THE HONEY ANT.—In Mexico and the Southwest United States is a species of ant community in which some of the workers become storage vessels for honey. They feed upon it until they become little swollen sacs of honey. They then attach themselves and serve as a source of honey for the rest of the colony.

(6) ROBBER ANTS.—One of the most specialized types of ants is the robber ants of South America, which do no work for themselves, all the work of the nest being done by slaves.

(7) UMBRELLA ANTS.—These ants carry on a sort of camouflage by carrying leaves over their bodies (Fig. 505*C*).

b. Beavers.—Beavers work together to build dams, thus creating the marsh or pool necessary for their houses (Fig. 349). They furnish an example of truly communal life.

c. Prairie Dogs.—The villages or communities of prairie dogs may cover several acres.

The animals that have developed community life are among the most successful in the struggle for existence. The bees, working together, can put to rout bears and others animals; alone they would not survive long.

Questions

1. Discuss some adaptations of plants to their environment with regard to moisture.
2. How do mammalian teeth show adaptive radiation in four directions? Explain fully.

3. From a central type, the mammalian limbs may show modifications in four directions; explain.
4. Discuss the special features of animals that are adapted to the desert; to subterranean life; to climbing; to flying; to aquatic life. Distinguish between primary and secondary adaptations for living in water; give examples of each, and state reasons for your answer.
5. Why is a camel a good example of several types of adaptations?
6. Discuss some types of concealing coloration; seasonal coloration; signal and recognition marks; warning coloration; mimicry; sexual coloration. What are some objections to the value of these types of coloration?
7. What are some examples of adaptive behavior? In what ways are they useful?
8. Discuss migrations in general.
9. How are ants adapted for communal life? Include in this discussion a description of the various types of ants and their special adaptations.
10. Are all adaptations useful?
11. How do you think adaptations arose?

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CHAPTER XLVII

DESCENT WITH CHANGE; EVOLUTION

Observe always that everything is the result of change, and get used to thinking that there is nothing Nature loves so well as to change existing forms and to make new ones like them.

—MARCUS AURELIUS.

I. The Theory of Evolution

The word *evolution* means an unrolling or unfolding. The formation of the universe is designated as *inorganic evolution*, and the gradual transformation from simpler to more complex living organisms is *organic evolution*. In other words, the plants and animals of today are the modified descendants of those that lived in earlier times. The word *evolution* is much abused; there are very many popular misconceptions as to what it means.

The book that has had the greatest influence on human thought within the past century is "The Origin of Species by Means of Natural Selection," which was written by Charles Darwin and published in 1859. The idea that one species of plant or animal evolved from another species was not new, but Darwin assembled such a large number of facts in favor of this hypothesis and presented them in such convincing fashion that a bitter controversy immediately arose as to whether species are specially created or are derived from other species by the process of organic evolution.

II. Evidences of Evolution

There is evidence from several fields that there has been descent with change.

A. Classification.—If either plants or animals that are living today are arranged according to the way in which they seem to be related to each other, they form a series from the simpler to the more complex, much as the fossil plants and animals form regular series from the simplest types to the most advanced. Linnaeus (1707–1778), who gave us our present system of classification (page 69) believed in *special creation* of each species, yet his system of classification is arranged to show kinship. In order to classify any organism, its structure, often its development, must be known. In work of this kind, it is often difficult to distinguish species

from each other; there are intergrades. This gives some evidence for the idea of evolution of organisms, *i.e., descent with change.*

B. Comparative Anatomy.—A comparison of the anatomy of animals brings out many similarities and many dissimilarities. There is a remarkable correspondence among the structures of the vertebrates. The wing of a bird, the wing of a bat, the flipper of a whale, the forelimbs of man are built according to the same plan, even though their outward appearance is very different (Fig. 434). The same is true of the hind limbs (Fig. 511). The skeletons of the primates also exhibit remarkable similarities.

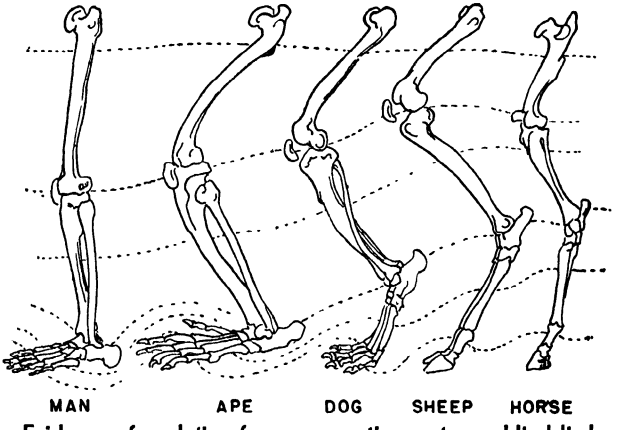


Fig. 511.—Evidence of evolution from comparative anatomy. Hind limbs of five vertebrates. Homologous parts are indicated by dotted lines. (Redrawn by B. Shamos from Leconte, Comparative Morphology and Physiology of Animals, D. Appleton-Century Company, Inc.)

A study of the appendages of the crayfish will reveal that all 19 pairs are built upon the fundamental plan of the more simple abdominal appendages, the swimmerets (Fig. 265), even though some of them have become very much specialized.

A vestigial structure may be defined as a remnant of an organ that once existed in more developed condition. The human body has so many of these structures as to be spoken of by one authority as a "museum of antiquities." Most of these vestigial structures are muscles. The most familiar vestigial structure of man is the *vermiform appendix.* This structure is greatly enlarged and is useful in some animals. Another vestigial structure is the remnant of the third, or nictitating, eyelid (Fig. 512*B*), which, in man, is a fold in the corner of the eye next to the nose. This eyelid is functional in birds, turtles, and frogs. Porpoises have useless vestigial legs enclosed within the body; some snakes show remnants of once useful legs (Fig. 512*A*). Many other vestigial structures have

been found in animals that have adapted themselves to different modes of living.

C. Embryology.—That there is a remarkable resemblance of vertebrate embryos to each other in their early stages was first noted by von Baer (1792–1876), known as the *father of embryology*. This suggested to Haeckel the recapitulation theory, or the biogenetic law already men-

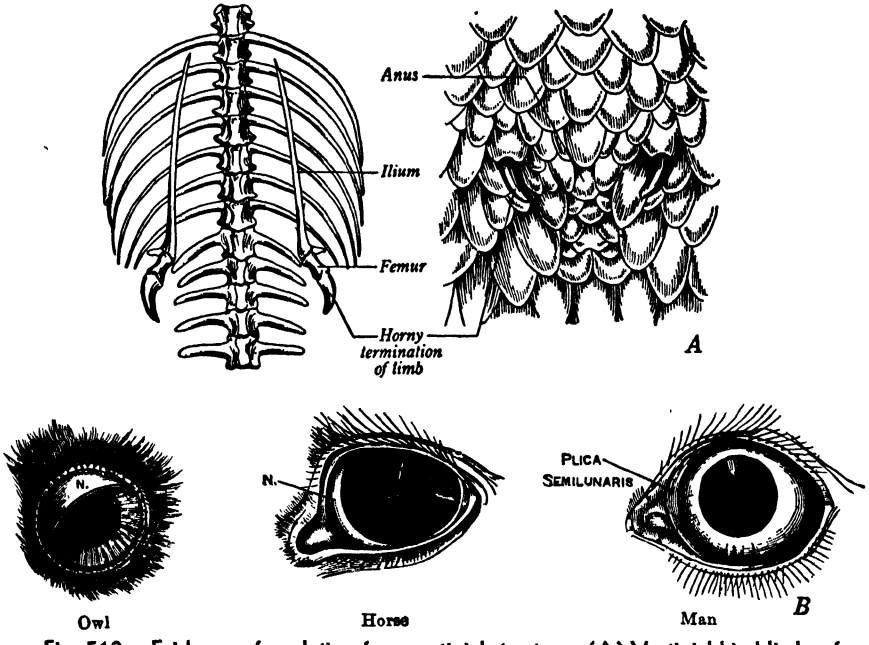


Fig. 512.—Evidence of evolution from vestigial structures. (A) Vestigial hind limbs of a python as seen in the skeleton. (B) Nictating membrane (N) in the owl and the horse compared with the rudiment in man. (From Romanes, Darwin and after Darwin, The Open Court Publishing Company.)

tioned (page 391). According to the latter, *ontogeny recapitulates phylogeny*, or the development of the individual recapitulates the development of the race (Fig. 513). Von Baer did not subscribe to this theory, and there are objections in making too extensive an application of this law. New features (*coenogenic*) have been added to the ancestral features (*palingenic*) in some cases.

It is interesting to note, however, a few of the many features that develop and disappear in the complex forms. In the lower forms, gill slits develop that are functional; in the higher forms, the gill slits develop, but they vanish. Connected with the development of the *gill arches* are the *aortic arches*. With the disappearance of the arches, there is a transformation of the aortic arches, as shown in Fig. 514. In the lower forms,

functional primitive kidneys (*pronephroi*) develop that are functional; in the higher forms, these develop but are replaced by other types (*mesonephroi* and *metanephroi*). There are many other structures that appear in embryos and then disappear during development.

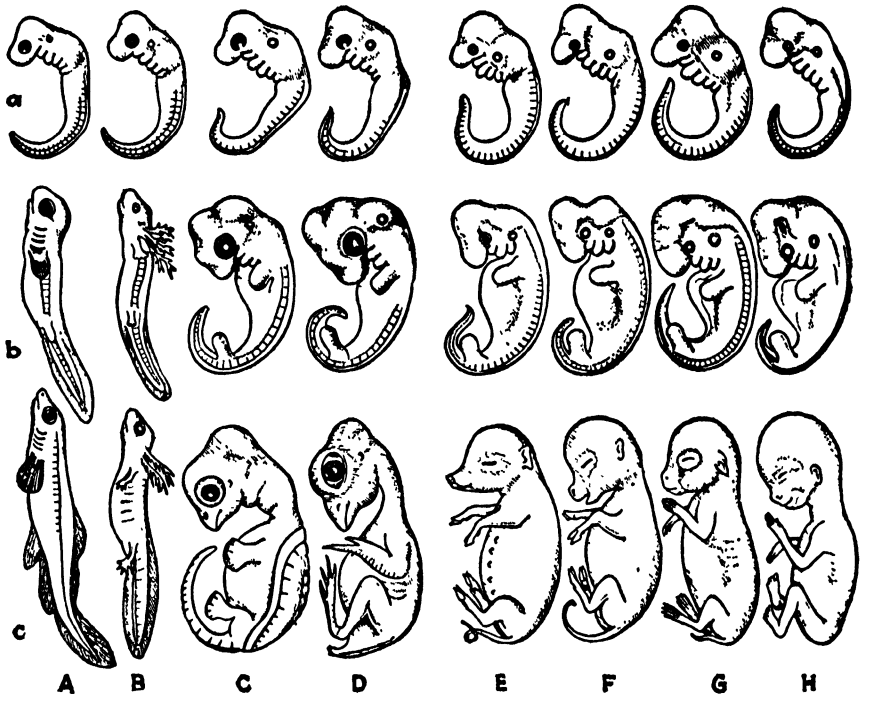


Fig. 513.—Evidence of evolution from embryology. A series of vertebrate embryos at three comparable and progressive stages of development. Widely different animals look much alike at early stages. Animals closely akin resemble each other in the embryonic stages for a longer time. (A) Fish. (B) Salamander. (C) Turtle. (D) Chick. (E) Pig. (F) Calf. (G) Rabbit. (H) Man. (From Romanes, Darwin and after Darwin, the Open Court Publishing Company.)

Knowing early embryonic stages is often an aid in classification. For example, *Sacculina* (Fig. 273) is a parasite on crabs. In its adult stage, it is little more than a sac with root-like processes that penetrate the body of a crab. Yet its embryonic development shows that it is a crustacean. Likewise, the goose barnacle (*Lepas*) has a mollusk-like shell, yet its development establishes it as crustacean (Fig. 272). The larva (nauplius) of the Crustacea has a short unsegmented body with three pairs of appendages and a median eye. The larvae of the two animals mentioned both have features of the *nauplius larva* (Fig. 273), though they differ in some details. Without a knowledge of the embryology of these two forms, they would receive a different classification.

D. Geographical Distribution.—No species of plants or animals lives all over the world. All species are restricted to certain definite habitats. Plants and animals live in fresh water or in salt water, on the land or under the surface, and each major habitat may be subdivided into a great number of habitats (page 871). It has been noted several times that plants and animals produce more offspring than can live in their immediate environment. This law of overproduction was emphasized

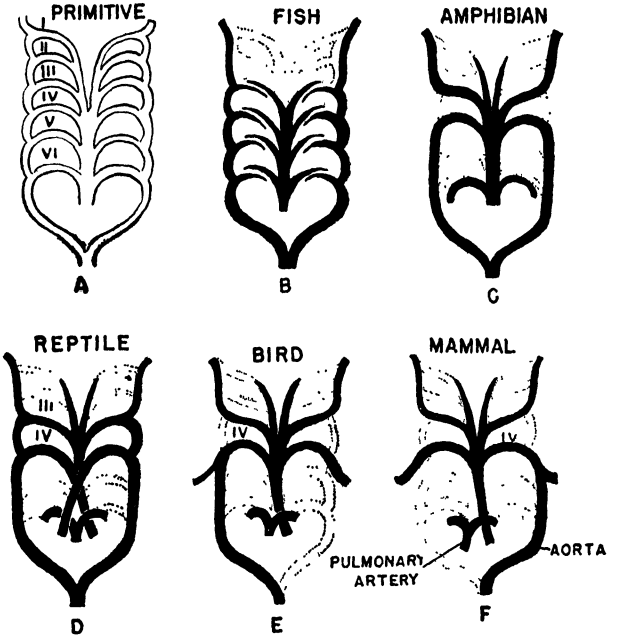


Fig. 514.—Transformation of the six pairs of aortic arches accompanying the development of lung breathing. (A) is the primitive or embryonic condition.

by Malthus (1766–1834) in his "Essay on Population," an essay that stimulated both Darwin and Wallace to formulate their theories of origin of species by means of natural selection.

Organisms may meet the emergency of overpopulation in one of two ways: (1) they may *remain in the habitat* of their parents; or (2) they may *migrate* to other habitats. In the first case, many individuals perish; only the most vigorous, or the most cunning, or those having characteristics that better adapt them to their environment survive in the *struggle for existence.* In the second case, a suitable environment may be found by migration, but there are peculiar instances of large groups of certain species setting forth at the same time on a journey, the end of which they cannot possibly foresee, many of which perish by the way.

Any feature in an environment that prevents an organism from escaping from its habitat is known as a *barrier*. For example, salt water is a barrier for fresh-water animals and vice versa; large bodies of water, mountain ranges, forests that stand in the way of animals used to the

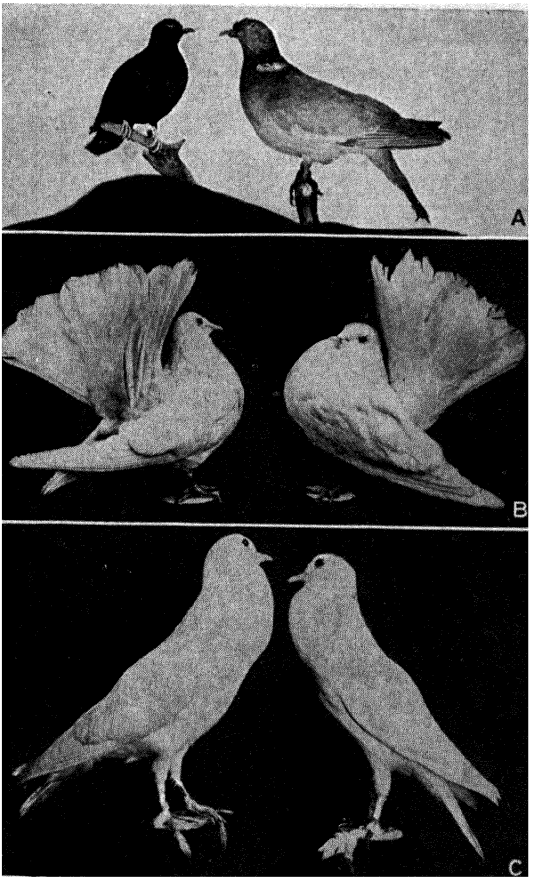


Fig. 515.—Evidence of evolution from domesticated animals. (A) A pair of Rock pigeons (Columbia livia) regarded as the ancestral types of many pigeons. (B) Fantail pigeons. (C) Pouter pigeons. (E. H. Runyon.)

prairies, climate, moisture or the lack of it, jungles that large animals cannot go through are some examples of barriers.

Animals that fly are the most successful in finding highways and in distributing their species over the earth. These animals include birds, bats, and insects. The Atlantic and Pacific oceans, however, appear to be too large even for flying animals to cross, since very few species ever migrate from America to Europe or to the West coast of America. In America,

birds migrate mostly from north to south in the autumn and from south to north in the spring.

E. Domesticated Plants and Animals.—Man has by selection taken wild forms useful to him and by cultivation and selection developed the plants and animals useful to him today. Various types of poultry, which have developed under domestication, trace their ancestry to the jungle fowl; the many varieties of pigeons (Fig. 515) are descendants of the rock pigeon (*Columbia livia*); the remarkable varieties of dogs are descendants of wolf-like ancestors (Fig. 489), and the modern hog is quite different from the wild hog, and, if the truth must be told, less fitted to survive in nature.

Plants have been so much improved that they yield more of the materials desired by man. *Corn*, for example, has many more rows of grains on the ear, as well as ears of larger size, than formerly; the cotton plant has been bred to produce more fiber. A long list of plants might be mentioned that would show the work of man in improving varieties that are useful to him. If man can do this by selection and breeding, then changes of this kind can also occur in nature. Plants and animals under domestication show how modifications may have occurred in organisms.

F. Parasitology.—The types of parasites that live on or within the bodies of animals differ according to the type of animal they parasitize. Specialists in this subject have found that the more nearly related the hosts are the more clearly their parasites resemble each other. Therefore, when the parasites of two species of animals are similar, the animals are likely to be closely related. This gives further evidence of how some types of modifications occur.

G. Physiology.—In general, all protoplasm possesses the same characteristics: irritability, metabolism, etc. This would appear to indicate some relationship, since all living organisms are made up of protoplasm that follows the same set of laws.

1. Enzymes and Hormones.—It is an interesting fact, also, that if man lacks a substance like pepsin, which is an enzyme, this can be supplied by an extract from the cow, sheep, or other animal.

2. Blood Tests.—Relationship of animal phyla can be determined to some extent by the so-called *precipitin* tests with blood. If human blood is injected into a rabbit at intervals, it will cause the rabbit blood to become *sensitized* to human blood. It has formed antibodies. Nuttal found that if serum from this rabbit is mixed with moderately diluted serum of man, apes, and monkeys, it reacts with them, although in varying degrees. If the serums from these animals is more highly diluted, it forms a precipitate only with man and man-like apes. Application of the precipitin test to reptiles indicates close relationship between lizards and snakes, between turtles and crocodiles, between birds and reptiles.

3. Blood Crystals.—The hemoglobin of the blood forms crystals. These are the same in one species of animal but differ in different species;

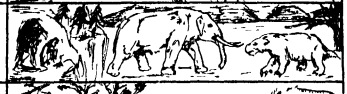
ERAS	PERIODS	EPOCHS	DOMINANT FORMS OF LIFE		AGE	Age in Millions of Years: Duration	From Present
PSYCHOZOIC		Recent	Rise of Civilized Man (Mental Dominance) Age of Modern Insects, Birds and Mammals		AGE of MAN	.03	03
CENOZOIC	Quarternary	Pleistocene (Glacial Period)	Periodic Glaciation Dawn of Civilization and Rise of Primitive Man Extinction of Great Mammals		AGE of MAMMALS and MODERN FLORA	.97	1
	Tertiary	Pliocene	Appearance of Primitive Man Decline of Great Mammals			6	7
		Miocene	Maximum Mammalian Life Anthropoid Apes Culmination of Land Flora			12	19
		Oligocene	Rise of Higher Mammals Extinction of Archaic Mammals Rise of Anthropoids			16	35
		Eocene	Decline of Archaic Mammals and Rise of Placental Mammals Rise of Grasses, Fruits and Cereals			20	55
MESOZOIC	Late MESOZOIC	Cretaceous	Extinction of Dinosaurs and Pterodactyls, Specialization of Birds and Reptiles Toothed Birds and Ammonites		AGE of Reptiles and EARLY SEED FLORA	65	120
	Early MESOZOIC	Jurassic	Rise of Toothed Birds and Giant Reptiles Spread of Pterodactyls, Ganoid Fishes and Ammonites			35	155
		Triassic	Rise of Dinosaurs Origin of bony Fish Spread of Cycads and Conifers			35	190

Fig. 516.—Table of geologic eras, showing the main types of plants and animals characteristic of the various ages. (B. F. Edwards.)

the more closely the animals are related the more the crystals of hemoglobin resemble each other.

H. Paleontology.—Paleontology (Gr. *palaios*, old; *logos*, discourse) presents some of the best evidence we have of the gradual development of the living world from simple to complex organisms.

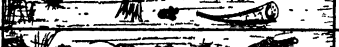
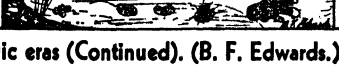
ERAS	PERIODS	EPOCHS	DOMINANT FORMS OF LIFE		AGE	Age in Millions of Years: Duration	Age in Millions of Years: From Present
PALEOZOIC	LATE PALEOZOIC	Permian (Glacial)	Rise of Land Vertebrata Rise of Ammonites and Modern Insects Rise of Seed Flora Periods of Glaciation		AGE of AMPHIBIA and SPORE-BEARING FLORA	25	215
		Carboniferous: Pennsylvanian	Spread of Primitive Insects and Amphibia Dominance of Spore Flora			85	300
		Carboniferous: Mississippian	Spread of Ancient Sharks Culmination of Crinoid Earliest Reptiles Extinction of Trilobites Decline of Nautiloids				
	MIDDLE PALEOZOIC	Devonian	Rise of Amphibia and Fish First Crabs and Land Shells First Spiders and May-flies First Forests and Land Flora		AGE of FISHES	50	350
		Silurian	First Air-breathing Animals, (Scorpion and Insects) First Known Land Plants Dominance of Cephalopods Rise of Lungfish Abundance of Coral			40	390
	EARLY PALEOZOIC	Ordovician	Rise of Fishes and Cephalopods Rise of Corals and Calcareous Algae Culmination of Trilobites		AGE of MARINE FLORA and INVERTEBRATES	90	480
		Cambrian	Rise of Shell-bearing Mollusks Dominance of Trilobites First Well Known Marine Flora Algae			70	550
PROTEROZOIC			No Fossils Age of Simpler Marine Invertebrates and Algae		Shell-less Invertebrates	950	1500
ARCHEOZOIC			No Fossils Evolution of Unicellular Life. Deposition of Ores		Dawn of Life		

Fig. 517.—Table of geologic eras (Continued). (B. F. Edwards.)

1. The Fossil Record.—The earliest rocks are uniformly without evidence of life on earth during the time they were laid down. Further study of the rock strata shows simple forms in the ancient rocks and more and more complex forms in the rocks laid down later. Figures 516 and 517 show the forms of life that were characteristic during the various periods of time that make up the record of the history of the earth. One fact stands out clearly; various types of plants and animals change from one epoch to the next. Another striking fact is that plants and animals in each epoch are found to be more advanced in the scale of life than those of the preceding epoch (Figs. 516–517).

Fig. 518.—Evidences of descent with change from the fossil record. Imprint of ferns in a coal bed, Olyphant, Pa. (Courtesy of U.S. Geologic Survey.)

Fossils appear first in the Cambrian epoch; these are all types of aquatic invertebrates. In the Ordivician epoch, all the animals were still aquatic, but a few vertebrates (fish) appear. The Silurian and Devonian epochs are together called the Age of Fish, because during these epochs fish were the predominating type of living things. Air-breathing insects and other air-breathing land animals appeared at this time; also, primitive amphibians. The next two epochs, the Carboniferous and the Permian, constitute what is called the *Age of Amphibia*, because of the large number of Amphibia that lived at that time. Primitive reptiles put in an appearance in the Carboniferous epoch; some of these reptiles left the water and lived on land.

The next four epochs are combined into the Age of Reptiles. This must have been an exciting period in the world's history, when the earth was populated with enormous dinosaurs and other ponderous reptiles

and when the first flying bird, the *Archeopteryx* (Fig. 328), and other birds *with teeth* were abundant.

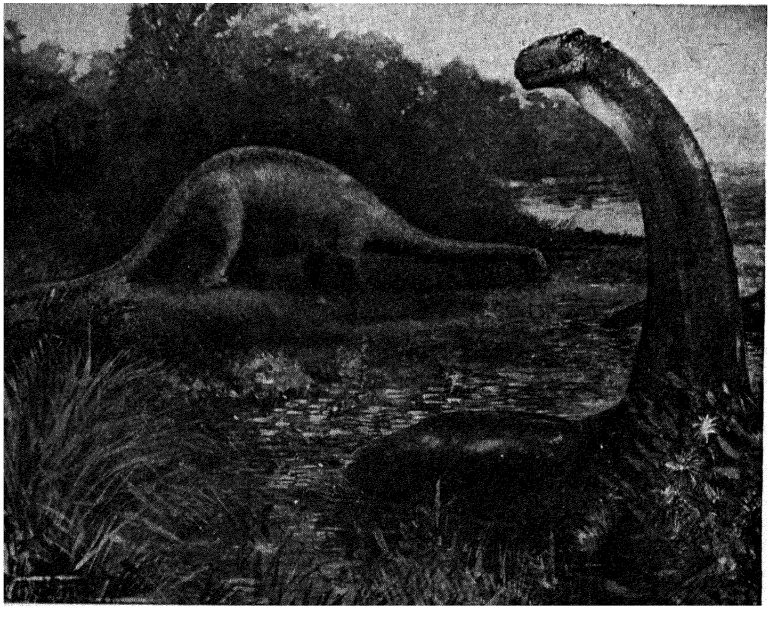


Fig. 519.—The thunder lizard, Brontosaurus. These huge animals were over 60 ft. long and weighed about 30 tons. (Courtesy of The American Museum of Natural History.)

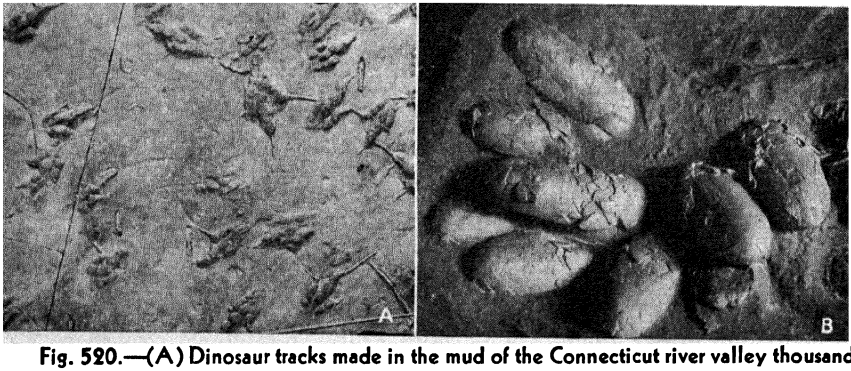


Fig. 520.—(A) Dinosaur tracks made in the mud of the Connecticut river valley thousands of years ago. The mud afterward hardened into brown stone, thus preserving the tracks. (B) Dinosaur nest, found in Mongolia. Each egg is about 8 in. long. (Courtesy of The American Museum of Natural History.)

Special mention should be made of the dinosaurs, whose remains are among the most interesting of the exhibits of extinct animals in museums today. They developed heavy armor and great size (Fig. 519). Many were vegetarians; a few were carnivorous. Their eggs were only

of fair size for such large beasts (Fig. 520*B*). In addition to the small brain, there was an enlargement of the spinal cord in the lumbar region, one of the "two sets of brains" mentioned in the poem that follows.

Dinosaurs lived for hundreds of thousands of years and then became extinct rather suddenly. The cause of this extinction can only be guessed at, but some of the reasons advanced are changes of climate, elevation of the land, and draining of inland seas where the dinosaurs had their home; the theory even exists that some small mammal destroyed the dinosaur eggs.

B. L. Taylor, in the *Chicago Tribune*, describes the dinosaurs in a humorous manner as follows:

Behold the mighty dinosaur
Famous in prehistoric lore,
Not only for his weight and strength
But for his intellectual length.

You will observe by these remains
The creature had two sets of brains
One in his head (the usual place)
The other at his spinal base.

Thus he could reason a priori
As well as a posteriori.
No problem bothered him a bit;
He made both head and tail of it.

So wise he was, so wise and solemn,
Each thought just filled his spinal column.
If one brain found the pressure strong
It passed a few ideas along.

If something slipped his forward mind,
'Twas rescued by the one behind.
And if in error he was caught,
He had a saving afterthought.

As he thought twice before he spoke,
He had no judgement to revoke;
For he could think, without congestion,
Upon both sides of every question.

O gaze upon this model beast,
Defunct ten million years at least.

The *Archeopteryx* was reptile-like, yet its feathers place it in the bird group. Like the reptiles, it had teeth, free, clawed fingers in the hand, a

feeble breastbone, abdominal ribs, an elongated tail, and scales on the head During the Age of Mammals, more birds appeared, but these were without teeth, primitive mammals developed and passed out of the picture, to be replaced by higher types, monkeys came into existence, and the first examples of the human race entered the scene Finally the world came under the control of the human race, and the Age of Man was ushered in

The rocks give evidence of the most convincing kind of descent with change The ancestry of several species has been worked out from fossils Among these the most complete are the camels, the elephants, and the horses

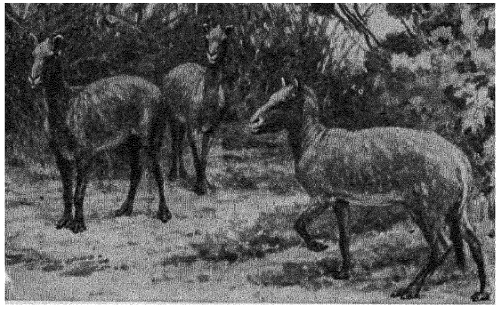


Fig 521 —Eohippus, a horse that lived in prehistoric times His front feet have four complete toes and a vestige of a fifth, while the hind feet have three complete toes and a vestige of a fourth (Courtesy of The American Museum of Natural History)

2 The Ancestry of the Horse – The horse has been used as an example of the importance of the fossil record so often that it has been called the *Stalking Horse* Nevertheless, it is one of the best examples of tracing ancestry by means of fossil remains

a History of the Horse —The history of the horse covers a period of 40 million years The fossil record shows that the ancestors of the horse lived in North America Some of the finest fossil horses have been found here These primitive horses all died out, however, there were no horses in America when this country was discovered and settled by Europeans Our horses are descendants of domesticated animals that were brought over from Europe by the early settlers

(1) *Hyracotherium* and *Eohippus* lived during the Lower Eocene epoch Only the skull of *Hyracotherium* has been found, and this shows primitive characters The fossil remains of *Eohippus* have been found in

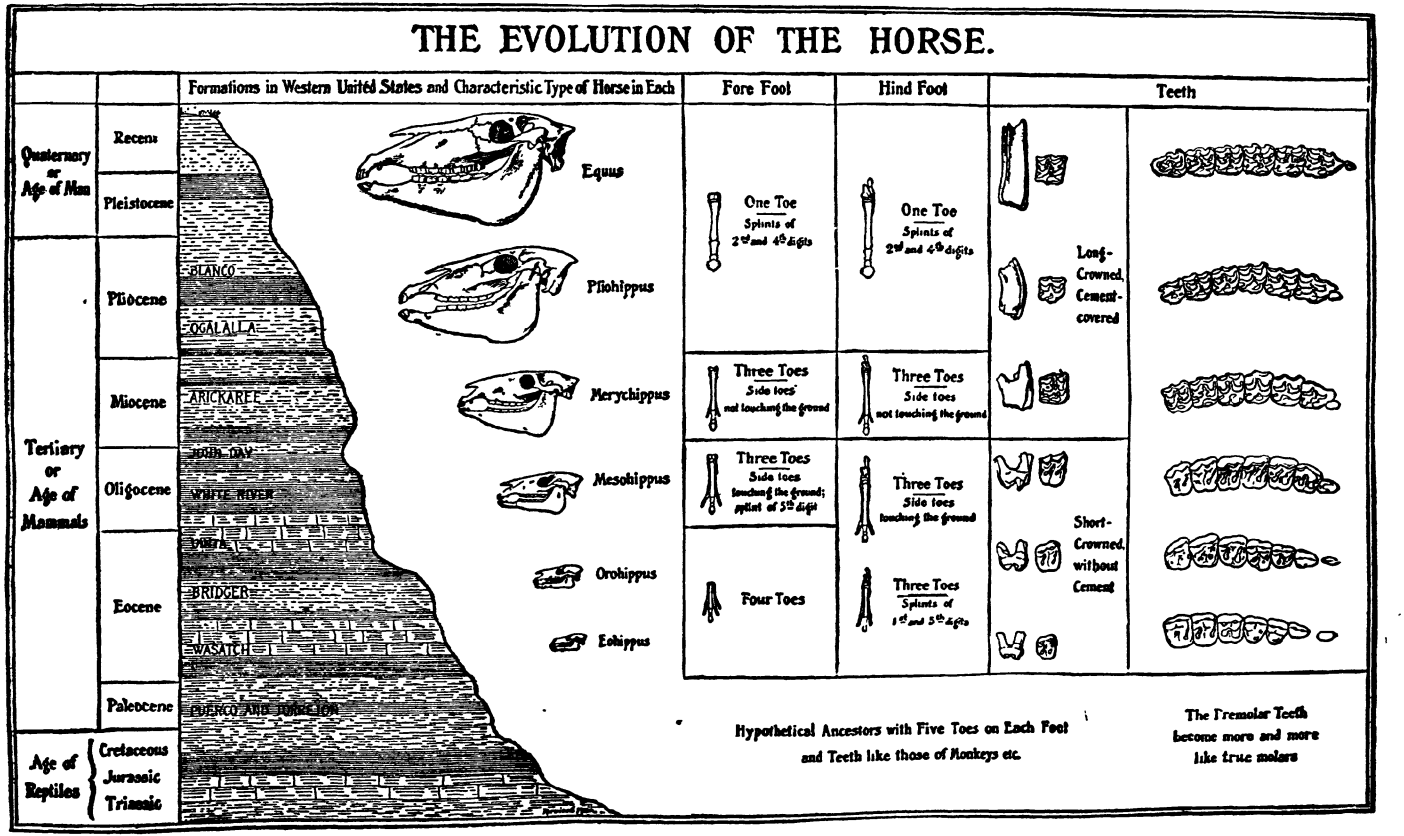


Fig. 522.—Diagrams showing the evolution of the horse. (From Matthew, 1926.)

Eocene rocks of Wyoming and New Mexico. It was about 12 inches in height (Fig. 521). On the forefeet of the animal, there were four toes and the splint of the fifth; on the hind feet were three complete toes and a splint of the fifth, the functional toes being the second, third, and fourth and the first having disappeared. Its teeth were short, without cement.

(2) *Protorohippus* and *Orohippus*, of the Middle Eocene times, were about the size of a small dog, a little larger than *Eohippus*. The feet had lost the splint of the fifth digit, and the teeth were larger.

(3) *Mesohippus* lived during the Oligocene epoch and was about the size of a sheep. It was slightly larger than *Eohippus*. The forefeet had three toes and a splint of the fifth, the first having disappeared; the hind feet also had three complete toes but no splint. The middle toe was larger, but all three toes touched the ground.

(4) *Merychippus*, which lived during the Miocene epoch, was larger than *Mesohippus*. The side toes were small and did not touch the ground; the middle toe was larger and bore the entire weight of the body. The teeth were larger (Fig. 522) and had ridges of cement on the ends that provided an excellent surface for the grinding of coarse grass.

Other forms in the Miocene epoch were *Anchitherium*, larger than *Mesohippus*, and two forms from the Middle Miocene epoch, which reached the size of a Shetland pony, *Parahippus* and *Hyohippus*.

(5) *Protohippus* and *Pliohippus*, of the Pliocene epoch, were one-toed horses with two lateral vestigial toes that did not touch the ground. They were about the size of donkeys. The teeth were moderately long crowned and were fitted for grinding.

(6) *Equus* is the horse of today. Our horses have only one large toe and two useless splints on each foot. Their teeth are very long and are fitted for grinding. It is probable that to take care of these large teeth, the front part of the skull was enlarged. The teeth grow continuously during early and middle life, the growth being approximately equal to the wear. In late life, the teeth cease to grow and become short.

True wild horses occur today only in Asia and Africa. These include the wild asses and the zebras. The wild horses of our Western plains and of South America are descended from domesticated horses that were brought from Europe.

b. Summary of the Evolution of the Horse.—A number of other stages in the evolution of the horse have been discovered, so that we have a complete series covering a period of 40 million years, during which time a creature about the size of a dog developed into one of our largest animals. The feet, which originally bore five toes, became modified so that one toe supports all the weight; two toes were lost entirely; and the other two toes degenerated into useless splints. The legs became longer, thus enabling the animal to move about more rapidly. These long limbs made an elongated head and neck necessary so that the mouth could reach the

ground. The teeth became modified for biting off and grinding up dry grass. The front teeth are now effective chisel-shaped cropping organs, and the back teeth are admirably adapted for grinding by the presence of complicated ridges. In every case, the changes described fitted the animal better for the kind of life it led. Longer legs and a single toe enable a horse to run faster and thus escape its enemies if it lives in the wild state. The modification of the teeth into better grinding organs made it possible for horses to eat dry grass as well as softer vegetation and greatly increased the usable food supply.

3. Some Animals Recently Extinct.—Although a knowledge of why certain animals became extinct in recent times will not give evidence of descent with change, it does show why they were unable to survive,

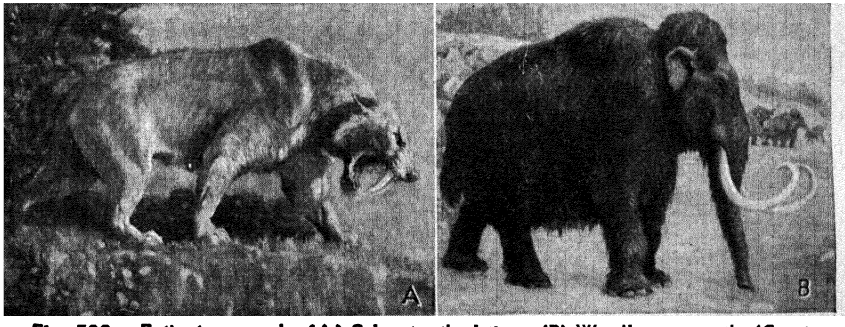


Fig. 523.—Extinct mammals. (A) Saber-toothed tiger. (B) Woolly mammoth. (Courtesy of The American Museum of Natural History.)

some of them on account of man's interference (page 839). Most of the plants and animals that have left their remains as fossils in rocks have no living representatives. They were unable to live in their environment. But other species descended from them were better adapted to their environment and make up the flora and fauna living on earth today. There are more than 840,000 species of animals, to say nothing of plants, on earth today.

The passenger pigeon (page 843), the dodo (page 499), and the auk (page 500) are all birds recently extinct. Species belonging to many other groups have also become extinct during recent times. For example, the mammoth (Fig. 523*B*) must have lived with the men of the Old Stone Age from 10,000 to 50,000 years ago, since primitive man made sketches of mammoths on the walls of the caves in which he lived. Entire mammoths are even now from time to time discovered in Siberia, frozen solid in the soil.

III. Theories as to the Method of Evolution

The *fact* of evolution is now accepted by competent biologists, but the *method* by which it has come about is far from a settled question.

A. From 695 B. C. to 1900. 1. BEFORE THE CHRISTIAN ERA.—Contrary to the generally accepted view, the idea of evolution is nothing new. Many of the ancient Greek philosophers had a concept of organic evolution. Empedocles (495–435 B. C.) is often called the *father of evolution.* He believed in the gradual development of organisms and suggested the survival of the fit. Aristotle believed in the development of the perfect from the imperfect. He also believed the operation of natural law by *intelligent design.*

2. IN THE DARK AGES.—Even during the Dark Ages, there were some theologians who believed in evolution of the organic world. Among these were St. Augustine (A. D. 354–430) and Thomas Aquinas (A. D. 1225–1264).

3. IN THE EIGHTEENTH CENTURY.—Buffon (1707–1788) had the evolutionary conception. He believed in direct modification of organisms by the environment but gave no proof for his beliefs. Erasmus Darwin (1731–1802), grandfather of Charles, was a physician, who believed, among other things, in the inheritance of acquired characters and in the survival of the fittest. Linnaeus (1707–1778) believed in special creation and the *fixity* of species.

B. Since the Nineteenth Century.—Some of the following theories are presented for historical reasons. Even though they are not sufficient to account for the facts, they were important in stimulating thought as to a reasonable explanation of observable phenomena.

1. THE THEORY OF LAMARCK.—In the year Charles Darwin was born (1809), Lamarck's book "La Philosophie zoologique" appeared. His idea was that the environment played an important role in the transformation of species. He also believed that the characters acquired by an individual during its lifetime were handed on to the following generations; in other words, he believed in the inheritance of acquired characters. He had an idea that use and disuse of parts brought about changes that were inherited. For example, if a browsing animal wished to reach higher and higher limbs of a tree, he kept on stretching his neck, and after a time something like the neck of a giraffe was the result!

The importance of the contribution made by Jean Baptiste Lamarck (1744–1829) was that he stimulated thought about the transformation of species, overthrowing the idea of the fixity of species.

The chief criticism of the theory is that it is difficult to see how the characters *acquired* during the life of an individual can be impressed upon the germ plasm in such a way as to be handed on to subsequent generations (pages 706, 798).

2. DARWIN'S PANGENE THEORY.—This theory is mentioned for historical reasons only. Darwin himself set no great store by it. The theory states that every part of the body forms determiners or *pangenes,*

which finally find their way into the germ cells, and that these germ cells then form new individuals. At the time this theory was formulated. nothing was known of chromosomes and heredity as we know them today,

3. Darwin's Theory of Natural Selection.—Charles Darwin (page 867) attempted to explain the workings of evolution by his theory of natural selection. As a youth, he entered a school of medicine but did not find studies of this kind suited to his taste. Later he studied for the church. In 1831, however, he had a chance to go on a 5-year journey around the world, making navigation surveys. It was on this voyage of the *Beagle* that he collected the material for his famous book. He required 20 years for assembling and studying this material. When the manuscript was ready for publication, he received a manuscript from Alfred Russel Wallace (1822–1913), who had arrived independently at essentially the same conclusions. At first Darwin was inclined to withhold his own paper, but the counsel of friends prevailed, and so a joint statement of the views of both authors was read before the Linnaean Society of London in 1858. Wallace had not amassed the wealth of material to back up his arguments that Darwin had. The epoch-making book, "The Origin of Species by Natural Selection" was published in 1859. Darwin was of a retiring disposition, and so it remained for Thomas Henry Huxley (1825–1895), a forceful man of remarkable learning, to champion Darwin's theory (page 864).

a. Facts in Favor of Natural Selection.—Some of the facts considered by Darwin in arriving at his theory of natural selection as a factor in evolution are: (1) the universal occurrence of variation; (2) the prodigality of reproduction in nature leading to a struggle for existence and the survival of the fittest; (3) the inheritance of favorable useful variations enabling those organisms to have a better chance of survival. There would thus be a modification toward firmness, a continual selection that, in time, would produce new species.

b. Some Objections to the Theory of Natural Selection.—There are several objections to Darwin's theory of natural selection as a universal factor in evolution: (1) there are many variations *so slight* that they could have no value to the animal in the struggle for existence; (2) not all structures that are developed are *useful* in the struggle for existence, and some of these continue to develop (see Orthogenesis, page 798).

In spite of the real objections to the theory of natural selection, the fact of natural selection, or Darwin's central thesis, still stands. Some modifications of it are necessary in the light of what has been learned since Mendel's time about variations and the mechanism of heredity. In Darwin's time, nothing was known about chromosomes as bearers of heredity. His work stimulated thought and research and had very great influence upon the development of zoology.

4. Isolation as a Factor in the Origin of Species.—There are some cases of modification through isolation that are well authenticated. During the fifteenth century, a litter of rabbits was placed on the island of Porto Santo. After several hundred years, the descendants of these rabbits were so different as to be described as a new species.

The effects of isolation were noticed by Darwin during his famous voyage of the *Beagle.* At that time he visited the Galapagos Islands, a group of islands about 600 miles off the west coast of South America, and noticed that although the species of animals, particularly birds, resembled those on the mainland, they were different enough to be classed as different species. The fauna on the islands that were far apart were more different than those on the islands close together. He drew the conclusion that these had arisen by descent with change.

Some type of isolation seems necessary for when new heritable variations arise, they may soon be "swamped" by breeding with the original stock.

Isolation may occur in various ways, but geographical distribution of species suggests that barriers and highways have played an important part in the survival of "selected" plants and animals.

If, in their migrations, a group of organisms becomes isolated from the rest of the species and if, in their new environment, heritable changes (mutations) occur, a chance is provided for these changes to persist and spread throughout the entire group. Continued isolation and change, in the course of time, result in a group of organisms so different from the original species that they may be recognized as a distinct species. Thus a new species may be said to originate.

5. Orthogenesis (Gr. *ortho,* straight; *genesis,* origin).—Many characters that appear in organisms tend to continue to develop even though this development may lead to extinction. An example of this kind is the very large antlers developed by Irish elk. The antlers became so large and heavy that the animal could not get out of the way of its enemies, and finally the race became extinct. The theory of orthogenesis is that the variations of plants and animals are not random or according to chance but follow definite lines or directions. Orthogenesis might offer an explanation for some things if there were any experimental evidence to back it up.

6. The Germ-plasm Theory of Weismann.—August Weismann (1834–1914) set out to prove that acquired characters are not inherited and formulated his famous germ-plasm theory in 1892.

Weismann's idea was that since, in many cases, the germ cells are set aside at an early stage of development of the embryo, the body cells or somatoplasm could have no influence on the germ cells. According to his theory, various lines of germ plasm are united at the time of fertiliza-

tion of the egg, and these, by combination, were sufficient to account for variation. Characters that appeared then were already present in the germ plasm.

It is fortunate that acquired characters, such as the mutilations of parents, are not passed on to the offspring. The feet of the Chinese women have been multilated for centuries, but their children are still born with normal feet. The tails of certain types of dogs have been cut off for many generations, yet the young puppies are still born with tails.

7. THE MUTATION THEORY OF DE VRIES.—De Vries, a Dutchman, published his famous book "Species and Varieties, Their Origin by Mutation" in 1905. A *mutation* is a variation that is inherited (page 740), and the change is due to a change in the genes. At least 4,000 such characters have been described in plants and animals; undoubtedly they occur in nature.

It was unfortunate that De Vries worked with the evening primrose (*Oenothera*), since there are some peculiarities in the behavior of the chromosomes during the reduction division that have since been worked out. Some of his "mutations" were not mutations at all but the reappearance of combinations of characters already present in the germ plasm. However, mutations, as we understand them today, suggest a mechanism for the origin of species.

C. Summary.—After examination of the various lines of evidence, it would seem that evidence of descent with change (evolution) is to be found in the several fields of comparative anatomy, embryology, paleontology, etc. As to the *method* of evolution, the most reasonable view seems to be that new species arise by mutation and that natural selection plays a role in determining which species shall survive. Other factors in the environment, such as isolation, etc., determine, at least partially, the extent to which natural selection shall be effective.

IV. The Ancestry of Man

Ancient man seems to have left very few fossil remains in the earth's crust. For this reason, we have very little evidence of his ancestry.

A. Primitive Man. 1. THE JAVA MAN, *Pithecanthropus erectus*.—The earliest remains, which appear to be human are those of *Pithecanthropus*, who lived about 500,000 years ago. These remains, the top of a skull, some teeth, and a femur were found by Dr. Eugene Dubois in 1891 in the Tertiary rocks of Java. The cranial capacity, so far as can be determined, was about 840 cc. This is quite small in comparison with that of modern man, which is about 1,450 cc. Reconstruction by experts make the *Pithecanthropus* appear as shown in Fig. 524*A*. The teeth found are intermediate between those of an ape and man.

2. The Peking Man, *Sinanthropus pekinensis.*—The Peking man is probably closer to the *Pithecanpthropus* than any of the prehuman remains discovered to date. Though the skull shows a larger brain capacity, it has massive brow ridges and a low, receding forehead. Rudely chipped stones have been found which suggest the use of tools; also charred materials indicate use of fire. Broken and split bones give evidence that the Peking man practiced cannibalism. The remains were found near Peking, China, in 1928.

3. The Heidelberg Man, *Homo heidelbergensis* (Palaeanthropus). This prehistoric man probably lived about 300,000 years ago. Only a

Fig. 524.—Prehistoric men. (From restorations by Dr. J. H. McGregor.) (A) Ape-man of Java (Pithecanthropus erectus). (B) Piltdown man (Eoanthropus dawsoni). (C) Neanderthal man (Homo neanderthalensis). (D) Cro-Magnon man, type of Homo sapiens.

lower jaw was discovered by Mauer, in 1907, near Heidelberg, Germany. The teeth are very similar to those of the savage races of man alive today, though the jaw is very ape-like.

4. The Piltdown Man, *Eoanthropus dawsoni.*—An English lawyer named Dawson found these remains in a gravel pit near Piltdown, England, in 1911. The Dawn man is supposed to be taller than *Pithecanthropus;* the skull shows a larger cranial capacity (about 1,260 cc.); the chin is absent and the canine teeth large (Fig. 524*B*).

Associated with the remains of the Piltdown man were found crude, chipped flints, which suggest that he possessed a primitive sort of culture. He probably lived during the Pleistocene age.

5. The Neanderthal Man, *Homo neanderthalensis.*—Skeletons of this type have been found in various parts of Europe. The Neanderthals were about 5 ft., 3 or 4 in. tall and lived in caves. Since their thighbones were somewhat curved, they did not stand erect. Their brain capacity was fairly large. They lived about 60,000 to 100,000 years ago, built

fires, made and used flints, and buried their dead ceremonially. The race lived a long time, geologically (Fig. 524*C*).

6. The Cro-Magnon Races.—One of the Cro-Magnon races, the Aurignacians, appeared in western Europe 30,000 to 40,000 years ago. They spread over a large area and amalgamated with the Neanderthals. They had better brains than the Neanderthals, knew how to make fires, also how to hunt the reindeer and the horse. They made implements and used ornaments. They also knew something of sculpture and made paintings on the walls of caves, which are preserved in France and Spain today. The later Cro-Magnons (Fig. 524*D*), Mousterians and Magdalenians, lived from 20,000 to 30,000 years ago. They are said to have begun to plant certain plants for food and to have herded cattle, sheep, and goats.

B. Modern Man, *Homo sapiens.*—All authorities agree that none of the primitive men named above is the direct ancestor of modern man, *Homo sapiens.* Anthropologists regard Asia as a place of probable origin of the one living species of man alive today, though no fossils have as yet been discovered. Although there is only one species of man alive today, there are several races and many subraces of men. These present wide differences of stature, color, habits, etc.

The human race may be divided into three primary groups (Sedgwick): (1) the Negroid races, (2) the Mongolian races, and (3) the Caucasian races.

The *Negroid races* possess frizzly hair, dark skin, broad, flat noses, thick lips, prominent eyes, and large teeth. There are the African Negroes, the South African Bushmen, the Central African and Philippine Pygmies, the Melanesians, Tasmanians, and Australians.

The *Mongolian* races possess black, straight hair, yellowish skin, broad faces with prominent cheekbones, small noses, sunken, narrow eyes, and teeth of moderate size. They are the inhabitants of northern and central Asia; the Lapps, Finns, Magyars, Turks, Eskimos, Malayans, brown Polynesians, and American Indians.

The *Caucasian,* or white races, possess soft, straight hair, well-developed beards, retreating cheekbones, narrow, prominent noses, and small teeth. There are two main varieties: (1) the Xanthochroi, with fair, white skin, ranging from northern Europe into North Africa and western Asia; and (2) the Melanochroi, with black hair and white to black skin, inhabiting southern Europe, northern Africa and southwestern Asia.

Questions

1. Do you think that there is any significance to the remarkable similarities in structures of the vertebrates? Explain.
2. Compare the forelimbs and hind limbs of several vertebrates. Name some interesting vestigial structures of animals. Is there any significance attached to these structures?

3. Why does the study of the embryology of an organism often give a key to the relationship of that organism to special groups?
4. What are barriers? Highways? How do these affect the establishment of species?
5. What evidence of descent with change do we get from domesticated animals?
6. What are some physiological characteristics that show relationships of organisms?
7. What is a fossil? Why is the fossil record important in any study of descent with change? Name the great epochs of the earth's history, and state what plants and animals were characteristic of each.
8. Give some interesting facts about dinosaurs.
9. What are the reptilian features of the *Archaeopteryx*? The avian features?
10. Give an account of the history of the horse. Why is it so often quoted as an example of descent with change?
11. What are some animals recently extinct?
12. Discuss the theories as to the method of evolution (*a*) before the Christian era, (*b*) in the Dark Ages.
13. What are the arguments for and against Darwin's theory of natural selection as a method of evolution?
14. Discuss the work of Lamarck and Weismann.
15. Do you think the mutation theory might explain some of the facts of descent with change? Give reasons for your answer.
16. Describe the various types of primitive men. About when did each type live?
17. Why do we say that *Homo sapiens* is the only species of man alive today? Are the races fundamentally different?

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Part VI

APPLIED BIOLOGY: BIOLOGY AND HUMAN WELFARE; CONSERVATION

CHAPTER XLVIII

BIOLOGY AND HUMAN WELFARE

Learn from the birds what food the thickets yield.
Learn from the beasts the physic of the field,
The art of building from the bee receive,
Learn of the mole to plow, the worm to weave.
—POPE.

I. Applied Biology

Many people who do not think of themselves as biologists spend their lives applying biological facts and principles. For example, the farmer must plant the kind of crops that will grow in the type of soil contained on his farm, must raise food, and must see that the animals are properly fed. Yet agriculture is only one phase of biology that serves man. Medicine and public health are to a considerable extent dependent upon biology. All drugs, whether obtained from plants or other sources, must be tested on animals before being given to man. In each of the groups of plants and animals, there are many species that are beneficial to man and others that may be classed as enemies. The special relation of organisms to man with regard to health are discussed in the next chapter under the heading Conservation of Man (page 846).

II. The Relations of Plants to Man

A. Thallophytes.—Although the majority of useful and ornamental plants are included in the higher groups, many of the most lowly are useful, and some are the most harmful of all living organisms. The thallophytes include the Algae and Fungi. In the latter group are the important bacteria, often placed in a class by themselves (Schizomycetes).

1. ALGAE.—From the Algae, especially the brown Algae, we obtain *iodine;* from the red seaweeds, agar-agar, a substance used in medicine and in biology laboratories for the cultivation of bacteria. Perhaps the greatest importance of Algae is due to their use as food for fish.

On the debit side, Algae may be a pest in reservoirs and give drinking water a disagreeable odor and taste. They are very easily killed by adding a small amount of copper sulphate to the water.

2. FUNGI.—Fungi are both beneficial and harmful.

a. Beneficial Fungi.—The role of yeasts in breadmaking (page 174) and their use in making liquors and industrial alcohol (page 193) have

been described. Also, yeasts are at present much advertised as a source of vitamins, particularly of vitamin B.

The mold fungi give flavors to cheese, for example, the green mold of Roquefort cheese.

b. Harmful Fungi.—Some important plant diseases are caused by rusts, mildews, blights. The wheat rust (page 196) does great damage each year to the wheat crop; the chestnut blight has destroyed whole forests of chestnut trees; several varieties of smut infect small grains; certain human diseases are caused by Fungi, such as ringworm, athlete's foot, and some scalp infections.

c. Bacteria.—Bacteria are so important that they are usually considered by themselves. For a more detailed account of bacteria, see page 185.

(1) BENEFICIAL BACTERIA.—Without the bacteria of decay, the world would soon be filled with dead organisms (page 63), and so they have an important role in the nitrogen cycle. Without them cheese making and butter making would be impossible (page 190). They are responsible, also, for the "curing" of tobacco and for the separation of flax fibers from the other parts of the stem (retting). These fibers are used in making *linen.*

(2) HARMFUL BACTERIA.—Bacteria cause many diseases of both plants and animals. They may be carried by the air, as in the case of the tuberculosis germ, or in food and water, as in the case of the typhoid bacilli; or they may be carried by insects and other animals. For example, the bacteria of the bubonic plague is carried by rats and transmitted to man by fleas; typhus fever is transmitted to man by body lice. For a discussion of human diseases caused by pathogenic bacteria, see the next chapter.

Control of bacterial diseases is possible through sanitation or cleanliness, sterilizing articles known to be contaminated, quarantine of infected plants and animals, use of vaccination, antitoxin (page 569), and other specific measures. It is particularly important that the water and milk supply be kept pure.

B. Bryophytes; Liverworts and Mosses.—Peat moss, or *Sphagnum,* is used by florists in packing and shipping flowers and in gardening to keep the ground moist. This moss is able to absorb from sixteen to twenty times as much moisture as the same weight of cotton. It had a limited use in hospitals during the First World War as surgical dressings. The most important use, however, is in the form of peat (page 204). In some countries (as in Ireland), it is dried and used as a fuel. *Sphagnum* forms bogs; then other plants come in, and gradually the land is reclaimed from water.

C. Pteridophytes (Lycopsida, Sphenopsida, and Pteropsida) (p. 206).

1. CLUB MOSSES.—Club mosses are extensively used as Christmas greens.

From them we obtain *Lycopodium* powder, used by druggists. This powder was formerly used in the manufacture of fireworks.

2. HORSETAILS.—These are often called *scouring rushes* because of the silica in their walls, which make them good scouring agents. They also had a share in the formation of coal beds (page 208).

3. FERNS.—These are extensively used as ornamental plants. They furnish a few unimportant drugs. However, they have played an important part in the formation of coal (page 208; Fig. 518).

D. Seed Plants (Gymnosperms and Angiosperms).—The seed plants furnish man with so many types of supplies that it is difficult to mention even the important contributions from the various families. Products like sugar come from several families; for this reason, some important products of this kind are mentioned separately.

1. A FEW IMPORTANT PLANT FAMILIES AND THEIR PRODUCTS. *a. The Grass Family (Gramineae).* (1) FOOD PLANTS.—Here belong the cereals that include the great crop plants wheat, corn, barley, rice, and oats; also, sugar canes and sorghums, from which we obtain sugar and syrups.

(2) INDUSTRIAL USES OF THE GRAINS.—Corn is used in making industrial alcohol; pith of the cornstalks is of value in packing and making explosives; a coarse paper is made from corn stalks; the husks are used in making a poor grade of mattress; corncobs make a fine quality of charcoal. Rye is also a source of commercial alcohol and liquor; the straw is used in making strawboard and hats.

b. The Pea Family (Leguminosae).—Members of this family furnish food for both man and beast.

(1) FOOD PLANTS.—Peas and beans are important starchy foods; peanuts are used as food, and the oil expressed from the seed is used as salad oil and in soap making; important leguminous crops are alfalfa, clover, and vetch, all of which are used as hay.

(2) PRODUCTS USED IN INDUSTRY.—The soybean is becoming more and more important as a food and for the oil contained in the seed, which is used in the paint industry; the cake left behind after the oil is expressed from the seeds is used as stock food and as a fertilizer.

(3) SOIL BUILDING.—Nodules on the roots of leguminous plants contain nitrogen-fixing bacteria (page 63), bacteria that are able to fix nitrogen from the air; these plants, therefore, play a role in soil building.

c. The Mallow Family (Malvaceae). (1) ORNAMENTAL AND FOOD PLANTS.—Hollyhocks, poppies, mallows, etc., are ornamental plants of this family. Okra is a common food plant belonging here.

(2) COTTON.—Cotton is cultivated for its fiber. This fiber was employed in India in making cloth as long ago as 3000 B. C.

(*a*) Cotton Fiber (Fig. 525).—Cotton fiber is an extension of a hair from the seed coat; its length varies with the type of cotton, being longest in sea-island cotton; it is almost pure cellulose but contains a little fat and some protein. Products from the fiber are cotton thread and textiles; rayon, often used in place of silk;[1] guncotton, used in the manufacture of explosives; celluloid, collodion, and many other products.

(*b*) Cotton Seeds.—From cotton seeds, the important products are cottonseed oil and cottonseed meal; the cake left after expressing the

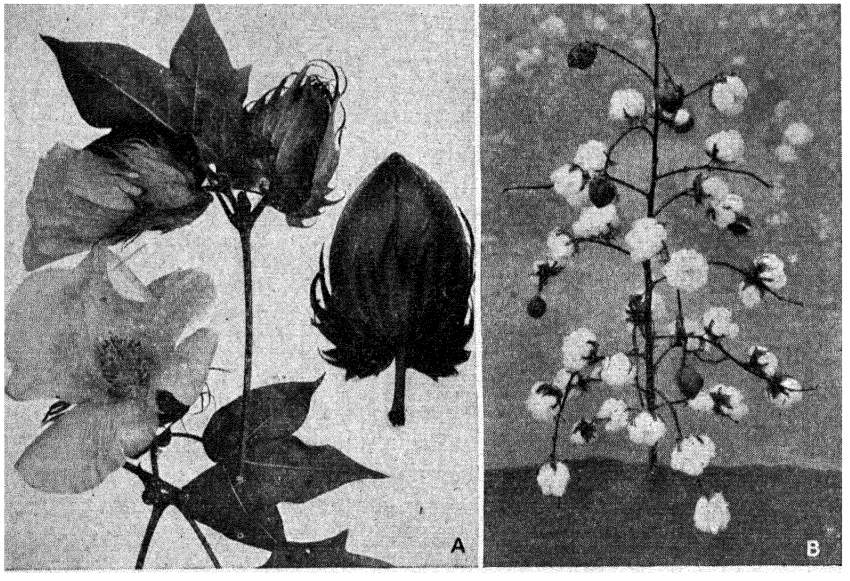

Fig. 525.—Cotton. (A) Cotton flowers, leaves, and green boll. (B) Cotton fiber in mature bolls, ready for picking. Leaves have been removed from this plant. (Courtesy of the Extension Division, U.S. Department of Agriculture.)

oil from the seeds, may be ground into meal and used as stock food or may be used as a fertilizer; the oil is used in cooking, as a salad oil, in soap making, and in butter and lard substitutes; cottonseed hulls are also used as a stock food.

d. The Flax Family (*Linaceae*).—Linen thread, twine, and other articles are made from the fiber of the flax plant. Linseed oil is expressed from the seed and is used in the paint industry; flaxseeds are of value in medicine, being used especially in making poultices.

e. The Mulberry Family (*Moraceae*).—Rubber is made from the milky juice (latex) of many members of this family. The best crude rubber is obtained from the para rubber tree (*Hevea braziliensis*) (Fig. 526*A*); gutta-percha, made from the milky juice of a plant (*Palanquium oblongi-*

[1] Another source of cellulose for making rayon and other products is wood pulp.

folia) somewhat like the rubber plant, is a hard, firm material used in covering submarine cables and in other ways; figs are used as food by man; hops, from the hop plants, are used in making beer; hemp plants produce valuable fibers used in making twine, sacking, bagging, etc.; the leaves of the mulberry furnish food for the larvae of silkworms and so are important in a successful silk industry.

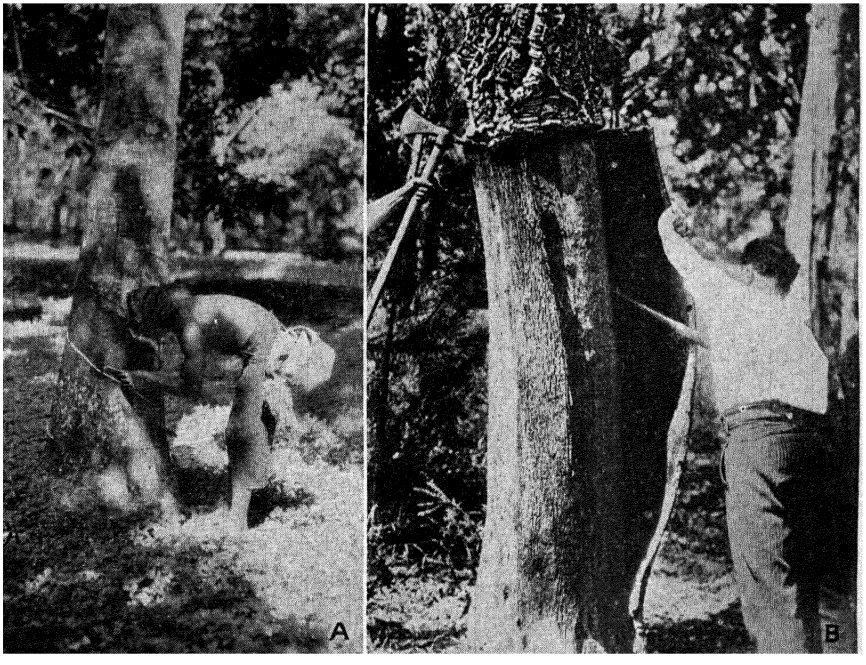

Fig. 526.—Products from trees useful to man. (A) Tapping a rubber tree (Hevea braziliensis). (Courtesy of U.S. Rubber Company.) (B) Stripping corkwood from a cork tree (Quercus suber). (Courtesy of Armstrong Cork Company.)

2. Some Important Plant Products. *a. Sugar.*—Sugar is obtained from sugar cane, the sugar beet, and from several trees, especially the sugar maple.

b. Familiar Beverages.—Tea, coffee, and chocolate are familiar beverages of the household. Tea was made from the plant *Thea sinensis* in China as long ago as 2700 B.C. The leaves of the plant are plucked and dried, and the type of tea depends upon preparation; green tea is from leaves that have been dried quickly; black tea is prepared by allowing the leaves to dry slowly, some fermentation taking place. The stimulating effect of tea is from a drug known as *theine;* tannin is also present, as well as a volatile oil that gives the tea its pleasant odor.

Coffee comes from two shrubs, *Coffea arabica* and *C. liberica*. Th coffee is made from berries (Fig. 527), and these berries contain a volatil oil. The aroma is derived from substances produced in the roasting of th berries. A drug, *caffein*, gives coffee a stimulating effect.

Chocolate and cocoa come from the seeds of the cacao tree (*Theobrom cacao*). If chocolate is to be made, the seeds are cleaned, roasted, an ground; if cocoa is to be made, the fat (cocoa butter) is taken out of th beans by a hydraulic press. The stimulating effect comes from a drug *theobromine*, present in the cocoa beans.

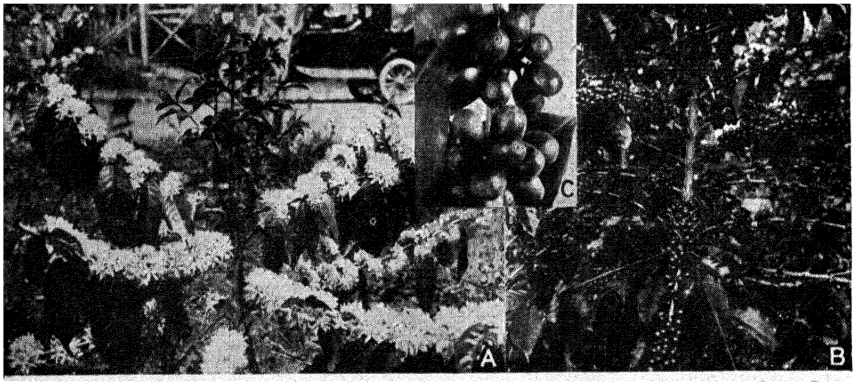

Fig. 527.—(A) Flowers of the coffee tree. (B) and (C) Berries of coffee trees from Costa Ri and Brazil. (Courtesy of Pan American Union.)

c. Drugs.—Every country has its own medicinal plants, and the are thousands of these. Only a few of the more important will be mer tioned. (1) *Opium*, an important drug for relief of pain, is made from th dried, milky juice of a poppy capsule (*Papaver somniferum*) (Fig. 528*A*) it contains *morphine*, *codeine*, and about a dozen other alkaloid drug it may be habit-forming (page 852). (2) *Quinine* is an important dru used in the treatment of malaria. It is obtained from the bark of th Cinchona tree (Fig. 528*B*) and was named for the Countess of Chincho wife of a viceroy to Peru, who was cured of a fever by the use of the bar in 1628. She caused some of the powdered bark to be carried to Spai (3) *Digitalis* is of value in the treatment of heart diseases and is obtaine from the ornamental foxglove (*Digitalis*) (Fig. 174*C*). (4) *Belladonna* a member of the nightshade family (Fig. 528*C*, *Atropa belladonna*). *Atr pine* is obtained from it and is used by oculists. It paralyzes the eye mu cles of accommodation so that the oculist is able to see the eye structur more clearly; its effects soon wear off. (6) *Chaulmoogra oil*, obtained fro the seeds of the chaulmoogra tree, or, as the natives call it, the *kalew*, important in the treatment of leprosy. (7) *Cascara* is a mild cathartic pr

pared from the bark of the California buckthorn (*Rhamnus purshiana*). (8) *Strychnine* is a stimulant and is obtained from an East Indian tree

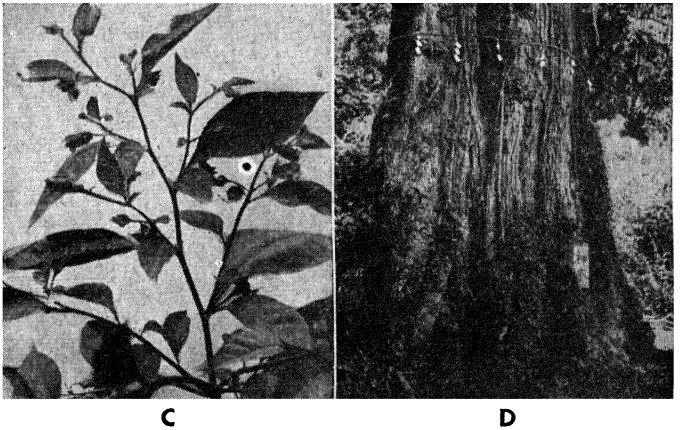

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Fig. 528.—Some important drug plants. (A) Opium is obtained from a species of poppy, Papaver somniferum. (B) Quinine is obtained from the bark of Cinchona trees. (C) Beladonna, a drug used by oculist, is prepared from the plant Atropa belladona. (D) A camphor tree about 2,000 years old. Natives in Formosa worship these old trees. [(A) (B) (C), Courtesy of Merck and Company, (D) Courtesy of University of Minnesota, College of Pharmacy.]

(*Strychnos nuxvomica*) and other plants. (9) *Camphor* is used in medicine and in the manufacture of celluloid; it is obtained from the camphor tree, *Cinnemomum camphora* (Fig. 528*D*), and is now made synthetically.

d. Spices and Volatile Oils.—Certain oils, such as bergamot, sassafras, clove, cedar, nutmeg, thyme, wintergreen, peppermint, and lemon are of value for flavoring and for making perfumery.

Cinnamon is obtained from the bark of several trees of the laurel family. Black pepper is made from the berry of a climbing plant (*Piper nigrum*). White pepper is obtained from the same source, the outer coat of the berry being removed. Cayenne pepper is the fruit of a plant belonging to the *nightshade family* (*Capsicum*). Cloves are the dried buds of the clove tree (*Eugenia aromatica*); oil obtained from cloves is used by dentists as a local anesthetic. Nutmeg is the seed and mace the outer coat of the

Fig. 529.—Turpentining near Ocilla, Ga. (A) Cutting a gash for holding gutter. (B) Emptying the carrying bucket.

seed of a tree (*Myristica*) that grows wild in New Guinea and the Molucca Islands. Ginger is the rhizome of the ginger plant (*Zingiber officinale*). Allspice is the dried fruit of a West Indian tree of the myrtle family (*Pimenta offinalis*). Vanilla is the extract of vanilla beans from a climbing orchid plant (*Vanilla planifolia*), which grows in Mexico and Central America; a cheap substitute is prepared from coal tar.

e. Turpentine, Resin, Tar.—Turpentine is used in making paints and varnishes and as an antiseptic. Methods of collection are shown in Fig. 529. After collection, the turpentine is taken to a still, where the turpentine is distilled off. The material left behind is a solid substance called *rosin*. Turpentine is derived from various conifers, especially pine trees (*Pinus*). *Pine tar* is obtained by the slow burning of pine wood in making charcoal; it is used in road building, roofing, etc.

f. Cork.—Cork is the bark of the cork tree (*Quercus suber*); it is stripped from the trees when they are about 20 years old (Fig. 526*B*).

Later crops, gathered at intervals of about 10 years, produce finer cork than the first crop.

III. The Relations of Animals to Man

A. Protozoa.—Although Protozoa are mostly microscopic in size and are the most primitive of all animals, they exert a profound influence on human welfare. The majority are harmless and may even be considered beneficial, since they make up a large part of the food supply of the higher animals. A few, however, are responsible for some of the most important of all human and animal diseases; others are of interest in relation to the fertility of the soil, to the purity of our drinking water, and to the building up of the earth's crust.

1. Some Protozoa That Affect Drinking Water.—*Dinobryon* (Fig. 188*C*), *Synura* (Fig. 188*F*), and *Uroglena*, all flagellates, may get into the water supply and give the water a fishy odor and a bitter taste. While alive, these Protozoa are harmless, but when they die they liberate into the water minute droplets of aromatic oil. It is said that the odor produced by *Synura* can be detected when only one part of the oil is present in 25 million parts of water. Copper sulphate in very small quantities will destroy these organisms.

2. Soil Protozoa.—Moist soil is teeming with Protozoa to a depth of 1 ft. to 18 in. About 250 different species have been described in this environment. Many soil Protozoa feed on bacteria, and, since bacteria are known to influence the soil fertility, the soil Protozoa influence soil fertility indirectly.

3. Protozoa in the Earth's Crust.—The radiolarians and the foraminiferans have played an important role in building some types of the earth's crust (page 287).

4. Parasitic Protozoa.—A parasite may be described as an organism that lives on or within the body of another species of organism, the *host*.

a. Harmless Parasites.—In many cases the parasite is harmless to the host and, in some cases, may be even beneficial. The flagellates that live in the intestine of the "white ant" (page 287) digest the wood that these termites eat; if these flagellates were not present, the termites would die.

b. Some Animal Diseases Caused by Protozoa. (1) Texas cattle fever was found by Smith and Kilbourne, in 1893, to be caused by a minute protozoan *Babesia*, or *Piroplasma bigemina;* it is transmitted by a certain species of tick. The red blood corpuscles of the host are destroyed by the parasite.

(2) Pebrine, or silkworm disease.—In 1867, Pasteur saved the silk industry of France by discovering this parasite, *Nosema bombycis*.

The larvae of the silkworm get the spores by eating infected mulberry leaves. Inside the body of the larvae, the spores hatch, multiply very rapidly, invade all the tissues, and eventually kill the host. As is the case in Texas cattle fever, spores penetrate the eggs of the moth, and the larvae that hatch from these eggs are infected.

(3) COCCIDIOSIS.—*Coccidia* are spore-bearing Protozoa that invade the tissues of the alimentary canal or the liver of various kinds of animals, especially rabbits and chickens. They affect man rarely. When the oöcysts, or reproductive bodies, are swallowed by the animal, the spores escape from them and penetrate into the walls of the intestine. Large numbers of rabbits and chickens are destroyed in this way.

(4) CILIATE DISEASE OF FISH.—A ciliated protozoan, *Ichthyopthirius multifiliis,* attacks fish by embedding itself in the skin or gills. Here it forms pustules in which growth to maturity takes place. The full-grown ciliates break out and sink to the bottom of the pool or aquarium and divide rapidly; each ciliate will produce about 1,000 minute young ciliates; these attack other fish and so repeat the cycle.

(5) TRYPANOSOME DISEASES OF ANIMALS.—In Africa and South and Central America, it is difficult in some localities to keep horses and cattle alive because of the attacks of trypanosomes. These protozoans live in the blood plasma and probably secrete a substance that poisons the infected animal. Transmission of trypanosomes from one animal to another are by blood-sucking tsetse flies in Africa, kissing bugs in South America, and vampire bats in Central America.

c. Human Diseases Due to Protozoa.—Twenty-five or more species of Protozoa live inside of the bodies of human beings: 2 species in the mouth, 2 in the small intestine, 10 in the large intestine, 1 in the urinary tract, 9 in the blood, and 1 in the muscles. One individual may harbor as many as half a dozen species; some are harmless; many are harmful.

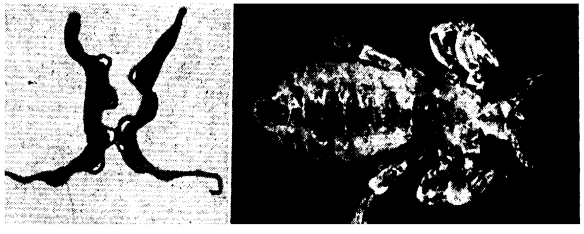
(1) DYSENTERY IN MAN is caused by a species of *Amoeba* (*Endamoeba histolytica*), a ciliate (*Balantidium coli*), as well as certain other organisms (bacteria). *Endamoeba histolytica* produces spherical cysts with protective coverings. These may contaminate food and drink. If swallowed while they are still alive, they hatch in the small intestine and pass to the large intestine, where they attack the intestinal wall, causing abscesses and ulcers. Amoebic dysentery (amoebiasis) may cause death.

On Aug. 15th, 1933, a number of cases of amoebic dysentery occurred in two Chicago hotels. Examination revealed a leak in a sewer pipe that contaminated a tank of ice water that was being circulated throughout the hotels. After the plumbing was repaired, no further cases appeared. Cysts probably live longer in iced water than under any other conditions. The data indicate that about a thousand cases of amoebic dysentery were contracted in these hotels, resulting in about 58 deaths.

Ciliate dysentery is somewhat rare. Human infection is probably from pigs, most of whom are parasitized by *B. coli*. The pigs appear to suffer no ill effects from the parasite. Cysts are passed with the excreta of the host; infection resulting from swallowing food or drink contaminated with these cysts.

(2) TRYPANOSOME DISEASES.—Trypanosomiasis occurs in certain parts of Africa, Central and South America. None of the blood-sucking insects that transmit the trypanosomes occur in the United States.

(*a*) African Sleeping Sickness.—The trypanosome, *Trypanosoma gambiensi* (Fig. 530), is transmitted by tsetse flies belonging to the



A B

Fig. 530.—(A) Trypanosomes, organisms which cause African sleeping sickness. These organisms are transmitted by the tsetse fly. (Courtesy of The Army Medical Museum.) (B) The "cootie," or human body louse (Pediculus humanis corporis), the insect which transmits trench fever. (Courtesy of U.S. Bureau of Entomology.)

genus *Glossina*. When infected blood is drawn into the fly's stomach, the trypanosomes begin to multiply; in about 10 days, they migrate to the salivary glands through the salivary ducts in the mouth and pass through developmental stages here. When such an infected fly bites man, trypanosomes are inoculated into the victim. The trypanosomes live in the blood plasma, multiply rapidly by binary fission, and are soon distributed to all parts of the body by the blood and lymph. These animals appear to be attracted especially to the lymph glands and the central nervous system. Sometimes the patient recovers; often the disease proceeds to the sleeping-sickness stage, characterized by a slow, shuffling gait, a vacant expression, a tendency to fall asleep at any time, and, finally, a coma, from which there is no awakening, death following in due time.

(*b*) American Trypanosomiasis, or Chagas' Disease.—This is transmitted by the kissing bug (*Triatoma*), which lives in the Southern states, as far north as southern Illinois and Ohio, and also in the Southwestern states. The bug is infected by sucking blood containing the trypanosomes. They multiply in the stomach of the bug, then pass to the rectum. When biting a human being, the bug may evacuate a drop of excrement containing the trypanosomes; scratching or rubbing may force some of the

trypanosomes into the wound made by the bug, and so infection results The effects of infection depend upon the organs invaded: when the heart is parasitized, myocarditis results; when the nerve cells are invaded nervous symptoms arise; general symptoms are irregular fever, enlarged glands, and anemia. No satisfactory treatment has been discovered.

Reservoir hosts in Africa are the antelopes; in America, opossums and armadillos may be infected and may furnish an infective dose to bugs that bite them.

(3) ORIENTAL SORE AND KALA AZAR.—These two diseases are due to flagellated protozoans belonging to the genus *Leishmania*, named

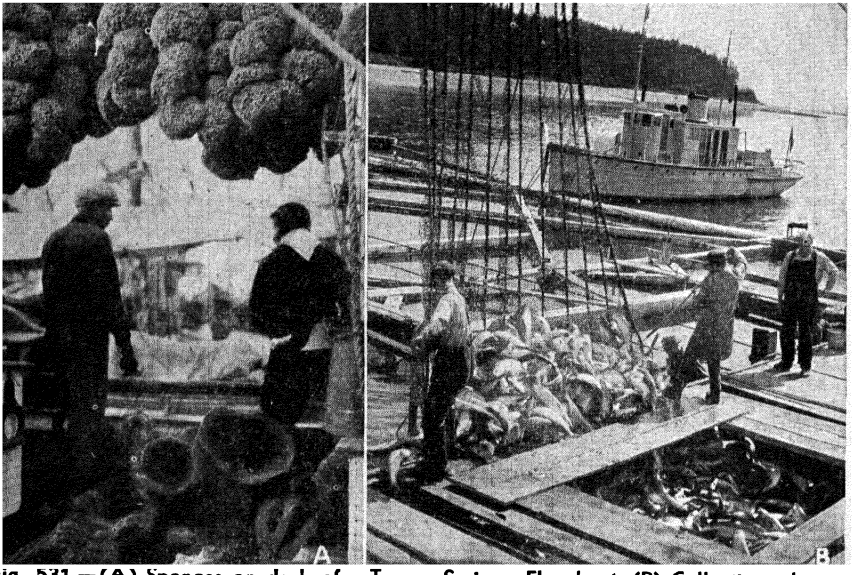


Fig. 531.—(A) Sponges on deck of a Tarpon Springs, Fla., boat. (B) Collecting salmon from a floating trap, Alaska. (Courtesy of U.S. Bureau of Fisheries.)

after Leishman, a British army surgeon. Oriental sore is limited to the Near and Far East; a type of disease similar to it occurs in Central and South America. Kala azar is a disease of Oriental countries, usually fatal and characterized by emaciation, enlargement of the spleen, and anemia.

(4) MALARIA.—This is by far the most important disease due to a protozoan. Vast regions in tropical and semitropical countries are practically uninhabited because of malaria. People who do live there are made miserable and ineffective by attacks of this disease. (See pages 274 to 277 for the life cycle of the malaria parasite *Plasmodium*.)

B. Sponges. 1. INFLUENCE ON THE FOOD SUPPLY OF MAN.—Sponges indirectly affect the food supply of man by covering oysters and other bivalves and so cutting off their food supply.

2. Sponges of Commerce.—Sponges used by man are skeletons of *spongin* secreted by the Demospongiae. This substance contains some of the same materials as those in silk. Commercial sponges are of various types (Fig. 531).

C. Coelenterates.—Only the corals among the coelenterates are of any great value to man, although *Hydra*, *Obelia*, *Aurelia*, and some other types are favorite animals for biological study (Chap. XIX). Precious, or red, coral is composed of carbonate of lime secreted by coral polyps. It is used in jewelry and is found off the coast of Algeria, Tunesia, Sicily, and Japan.

D. Platyhelminthes. 1. Parasitic Flatworms.—Two types of flatworms live in man and domestic animals, the flukes and tapeworms.

a. The Liver Fluke of the Sheep.—This parasite causes great loss among the sheep flocks when it makes its appearance. It lives in the liver of the sheep (Fig. 220), and one fluke may produce as many as 500,000 eggs. For the life cycle of this parasite, see page 315.

This is only one of many species of flukes that are parasitic in animals that serve as food for man. Domestic and food animals are also frequently parasitized by tapeworms, whose life cycles are similar to that of the pork tapeworm of man.

b. Flatworms That Parasitize Man.—Few flukes occur in human beings in this country. In China, Japan, and Egypt, however, thousands become sick, and many die because of infestation with these flukes. The flukes may live in the intestine, the liver, the lungs, or the blood.

Tapeworms, *Taenia solium* and *T. saginata*, parasitize man. Infection occurs by eating undercooked pork containing the parasites in the case of *T. solium* and from eating infected rare steak in the case of *T. saginata*. (For the life cycle of tapeworms, see page 317.)

E. Nemathelminthes. 1. Roundworms That Parasitize Domestic Animals.—Every type of domesticated animal contains parasitic roundworms that do more or less serious injury. Among these are the little worms that cause the gapes in poultry, the stomach worm of sheep and goats, which is a serious pest, and the roundworms of dogs, which cause the death of many valuable animals.

2. Parasites of Man. *a. Hookworms.*—Within the human body, hookworms attach themselves to the wall of the small intestine and suck blood. When many worms are present, a great deal of blood is lost, and the infected person becomes anemic, dull, and lazy; his skin becomes dry, his breath short, and his development retarded, both physically and mentally. (For the life cycle of the hookworm, see pages 322–324.)

b. Trichina.—Besides pigs, rats are involved in the transmission of trichina worms (Fig. 532). Rats are frequently infected with these

worms. Pigs become infected by eating offal or infected rats and the worms become embedded in their muscles. If muscle that is not cooked enough to kill the worms is eaten by human beings the worms escape from the digested muscle, burrow into the intestinal wall, and

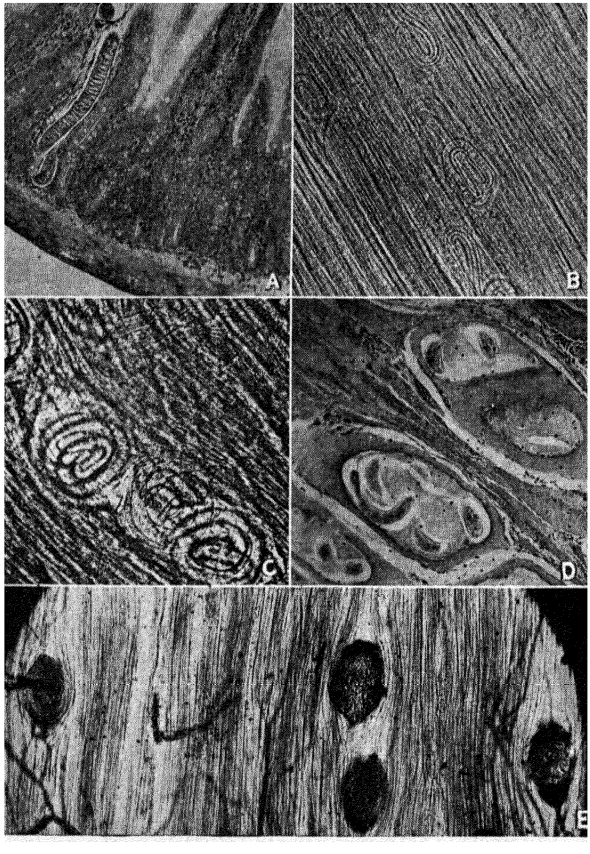


Fig. 532.—Trichinella spiralis, the organism causing trichinosis. Man gets the disease by eating uncooked infected pork. (A) Adult in the mucosa of a rat intestine 3 days after infection. (B) Migratory larvae, 16 days after infection. (C) Encapsulated worms in the muscle tissue of the rat, 30 days after infection. (D) Massive infection; note degeneration of muscle. (E) Calcified cysts of Trichinella spiralis from human (cadaver) muscle. Last stage. (Courtesy of Prof. R. O. Christiansen, Alabama Polytechnic Institute.)

become mature there. The mature females may deposit as many as 10,000 young larvae directly in the lymphatics; or the larvae may burrow through the intestinal wall and get into the blood stream. They are carried to all parts of the body and become imbedded in muscles.

c. Other Roundworms Parasitic in Man.—Human beings are parasitized by at least 45 species of roundworms, some of which are wide-

spread and cause great suffering and thousands of deaths annually. *Ascaris lumbricoides* is an important parasite that lives in the intestine of man. The eggs of *Ascaris* are laid in the human intestine and pass out of the body with the excrement. They are very resistant and if deposited on the soil may remain alive for many months. Embryos are formed under favorable conditions in about two weeks. Infection with *Ascaris* results from ingesting embryonated eggs. The eggs are usually carried to the mouth, either with food or water or by accidental transfer of soil containing such ova. They do not regularly hatch in the stomach but pass into the small intestine, where they begin to hatch within a few hours after ingestion. The larvae leave the intestine immediately and follow a definite path of migration through the tissues of the host, afterward returning to the intestine to grow into mature worms.

When large numbers of larvae pass through the lungs, inflammation is set up, and generalized pneumonia may result. The adults may be present in the intestine in such large numbers as to produce intestinal obstruction. Nervous symptoms, due to the presence of toxins from the worms, may appear. Fortunately, several drugs will easily remove the worms. Ascariasis is essentially a children's disease.

d. Filaria.—The filarias cause several diseases, one of the most important of which is *elephantiasis*. The larvae of the parasites causing this disease (*Wuchereria bancrofti*) live in the blood of man. During the day, they live in the blood of the deeper blood vessels, migrating at night to the superficial capillaries. When a mosquito bites the victim, blood containing the parasites is sucked up. The larvae develop in the body of the mosquito, get into its mouth parts, and are injected into the next victim, very much as malaria is transmitted. Persons infected have lymph glands obstructed by the parasites; this causes the enormous swelling of the limbs and other parts of the body and so gives the disease its name *elephantiasis*.

e. Guinea Worm.—The worm, *Dracunculus mediensis*, is a common human parasite in tropical countries. It was probably the "fiery serpent" mentioned by Moses (Numbers 21). Man becomes infected by drinking water containing the fresh-water crustacean *Cyclops* (Fig. 271). The female worm may reach a length of 3 ft. It is located under the skin and is extracted by being rolled on a stick a few turns a day (Fig. 224*d*). The larvae are discharged by the female through an opening in the human skin. If they reach water and find the *Cyclops*, they burrow into its body cavity and metamorphose.

F. Annelids. 1. EARTHWORMS.—Earthworms are continually honeycombing the soil, making it more porous and ensuring better penetration of air and moisture and, like miniature plowmen, are working over the

surface layers of the earth. The castings of the earthworms furnish fertilizer for the land thus making it more fertile.

2. LEECHES.—The medicinal leech can swallow three times its own weight of blood at one meal, but since it takes about 9 months to digest this amount, meals are few and far between. Formerly leeches were used for "blood letting," and for this reason physicians were referred to as *leeches*.

G. Mollusks. 1. MOLLUSKS USED AS FOOD FOR MAN.—Among the mollusks that furnish food for man are oysters (the most important), clams, mussels, scallops, snails, abalones, and squids. Snails are eaten in some countries.

a. Oysters.—Oysters occur close to the seashore throughout the world (Fig. 259). The adults are fastened on one side and incapable of locomotion. No muscular foot, such as is found in the clam, is developed; hence the body is soft and edible.

Oyster farming is a successful industry. The beds are prepared by strewing empty shells on the proposed site. These settle to the bottom and furnish a place of attachment for the young oysters, or *spat*, as they are called. The larvae are free-swimming for a time, often several days, before they attach themselves and begin to grow. At the end of a year, they are about 1½ in. long; they are now taken up, thinned out, and replanted. In from 3 to 5 years, they are ready for the market. About 30 million bu. of oysters are sold in the United States every year.

b. Squids, Cuttlefish, Octopi.—Squids are used as food for man in Oriental countries. They are eaten in enormous quantities by fish, and especially by whales. They are also very valuable as bait; about one-half of the bait used in fishing for cod on the Newfoundland banks consists of squids (page 368). Cuttlefish are close relatives to squids. They furnish the cuttlebone given to caged birds (page 369).

Octopi live in dark caves in the rocks and in crevices in coral reefs in the warm waters of the tropics. Most of them are not large enough to harm a human being, but the giant octopus (devilfish) of the Pacific reaches a diameter of 28 ft. and is really dangerous (page 369).

2. MOLLUSKS AS SCAVENGERS.—Organic particles that would soon pollute water if not destroyed in some way are used by mollusks as food. In this way the mollusks do real service as scavengers.

3. COMMERCIAL PRODUCTS FROM MOLLUSKS. *a. Pearl buttons* are manufactured largely from the shells of mussels (Fig. 263). Thousands of tons are used in this way.

b. Cameos of some types are carved from mollusk shells (Fig. 263).

c. Pearls are prized as jewelry. They consist of a substance secreted by the mantle of the animal around a foreign particle or parasitic worm that has become lodged in the shell (page 371). The best pearls are obtained

from pearl "oysters," which are really mussels. Ceylon is the site of the most famous pearl fisheries.

4. HARMFUL MOLLUSKS.—The mollusks that do the most damage are slugs, shipworms, and oyster drills.

a. Slugs.—Slugs (page 366) are closely related to land snails (Fig. 258). They come forth at night to feed on vegetation, which they grind up with their rasping tongue, selecting especially tender young lettuce, celery, and potato plants. Those slugs that live in warm greenhouses remain active all winter unless destroyed.

b. Shipworms.—*Teredo navalis* is a bivalve mollusk whose valves are provided with tiny teeth that are capable of rasping away wood when the shell is rotated. Eventually the largest timbers infested with them become so honeycombed that they crumble to bits. The damage these animals do yearly is enormous.

c. Oyster Drills.—These animals look like ordinary snails (Fig. 259). Although some of them are less than an inch long, they do not hesitate to attack oysters and clams many times their size. Selecting a place near the hinge of an oyster's shell, the drill rasps a hole through it and then sucks the soft, living tissue of the oyster through the hole.

H. Echinoderms. 1. TREPANG.—In the Far East, sea cucumbers (page 357) are collected in large numbers, cooked, dried in the sun, and sold under the names *trepang* and *bêche-de-mer* (caterpillar of the sea). It is considered a great delicacy, especially by the Chinese, who use it in making soup.

2. HARMFUL ECHINODERMS.—The starfish is a voracious, carnivorous animal, especially injurious to oysters and clams (page 354).

I. Arthropoda.—The arthropods include many types of animals that are economically important, especially crustaceans and insects.

1. CRUSTACEA. *a. Crustaceans Used as Food.*—Lobsters are the most important Crustacea used as human food. In certain localities, especially Louisiana, Georgia, and California, the blue or edible crabs and shrimps are the basis for important industries.

Probably the Crustacea are most valuable as food for lower animals, since many edible shrimps live almost exclusively on them.

b. Harmful Crustaceans.—In some of the Southern states, crayfish destroy cotton and corn plants (page 386). A small crustacean, *Cyclops*, is responsible for transmission of the Guinea worm (page 819; Fig. 271) to man.

2. INSECTA. *a. Beneficial Insects.*—The two most important beneficial insects are the silkworm and the honeybee. Other insects produce valuable materials such as cochineal, lac, and tannic acid; some serve as scavengers; many are predaceous and feed on insects that are harmful; some are parasitic on injurious species; a number of our important plants depend entirely upon insects for pollination, *e.g.*, red clover.

(1) SILKWORMS.—The silkworm is the larva of the moth, *Bombyx mori*. The silk is produced by a fluid that passes out from the silk glands and hardens as it comes in contact with the air. The thread is first attached to a near-by object; then the larva spins a cocoon around itself by winding around and around a single thread about 1,000 ft. in length. It then pupates, and the mature moth emerges from this cocoon in about 2 weeks, if undisturbed. To get the silk, the larva of the moth must be killed in the cocoon; otherwise the moth destroys one end of the cocoon when it emerges.

(2) HONEYBEES.—Honeybees produce wax and honey and gather pollen. The wax out of which honeycomb is built is secreted by glands on the undersurface of the abdomen of the workers. Honey is not collected

Fig. 533.—(A) A wasp, Lysiphlebus testaceipes, (Hymenopteran) laying egg inside body of plant louse, or aphid. (B) Adult parasite emerging from aphid after it has completed its development inside. (After Webster, Cir. 107, N.J. Experiment Station.)

from flowers but is manufactured from the nectar of flowers. When the bees gather pollen for their own use, they accidentally perform a valuable service of cross-pollination of many flowers. (For further information about bees, see page 403.)

(3) SCAVENGERS.—Many insects feed on decaying matter. For example, flies quickly locate dead animals, upon which they lay eggs. The maggots that hatch from these eggs quickly devour the carcass. Burying beetles have the peculiar habit of digging the soil away from beneath the dead bodies of small animals, thus burying them. These bodies furnish an excellent food supply for the grubs that hatch from the insect's eggs.

(4) BENEFICIAL PREDACEOUS INSECTS.—These are insects that capture and devour other animals for food, principally other insects, many of which are injurious. Perhaps the most remarkable predaceous insect is the Australian ladybird beetle, *Rodalia cardinalis*, which was imported into the United States in 1888. Since the food of ladybird beetles is the fluted-scale insect, which was destroying the orange trees of California, these beetles are credited with saving the orange industry of California.

(5) BENEFICIAL PARASITIC INSECTS.—Many parasitic insects likewise attack other insects that are harmful. They lay one or more eggs in or on the body of their victim, and the larva that emerges from the egg feeds

slowly upon the substance within the victim's body (Fig. 533). Many insect pests such as the Tussock moth, the army worm, and the gypsy moth are partly held in check by such parasites.

(6) INSECTS AND POLLINATION.—Besides the red clover (page 164), many other plants depend upon insects for pollination. One striking example is the case of the Smyrna fig. Prior to 1900, this fig could not be grown in California. The figs did not ripen, because their flowers were not

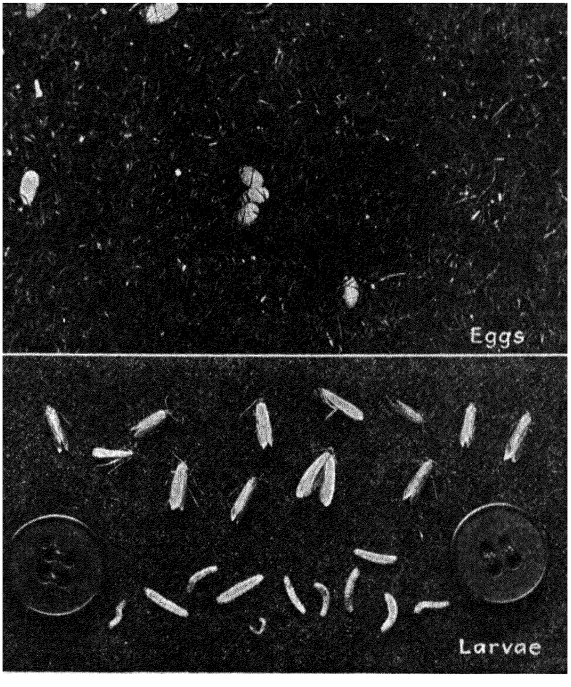


Fig. 534.—The eggs (greatly magnified), larvae, and adults of the clothes moth (Tinea pellionella). The larvae of these moths eat wool, feathers, and furs, doing immense damage each year. (Courtesy of U.S. Bureau of Entomology.)

pollinated. When pollination was found to be accomplished by a small wasp, *Blastophaga psenes*, this insect was introduced into the fig-growing districts of California, and a successful new industry was established.

b. Some Insect Household Pests.—Certain insects are unwelcome household guests. Among these are: (1) houseflies, which distribute germs of various diseases, such as typhoid, cholera, and anthrax. Many of these germs are carried on the hairs of the legs (Fig. 132). (2) Cockroaches, which have an offensive odor and seem able to eat any kind of food. (3) Silverfish, which eat starch in bookbindings, clothing, and even wallpaper. (4) Bedbugs, wingless insects that may attack birds, mice, and man. (5) Clothes moths (Fig. 534), very small insects that lay their

eggs in clothing or fur. The larvae eat this material and destroy annually clothes and furs valued at millions of dollars. These insects were known in ancient times, for they are mentioned in the Book of Job. (6) Carpet beetle larvae that also feed on furs and woolens, especially carpets. (7) Meal worms, larvae of a type of beetle that appear in oatmeal and other cereals. (8) Ants, sometimes serious pests, especially the little red ants which may live in colonies in walls, or under floors. (9) House fleas, which live in dusty crevices and under carpets. (10) Termites, or "white ants," which feed on wood and wood products (page 287).

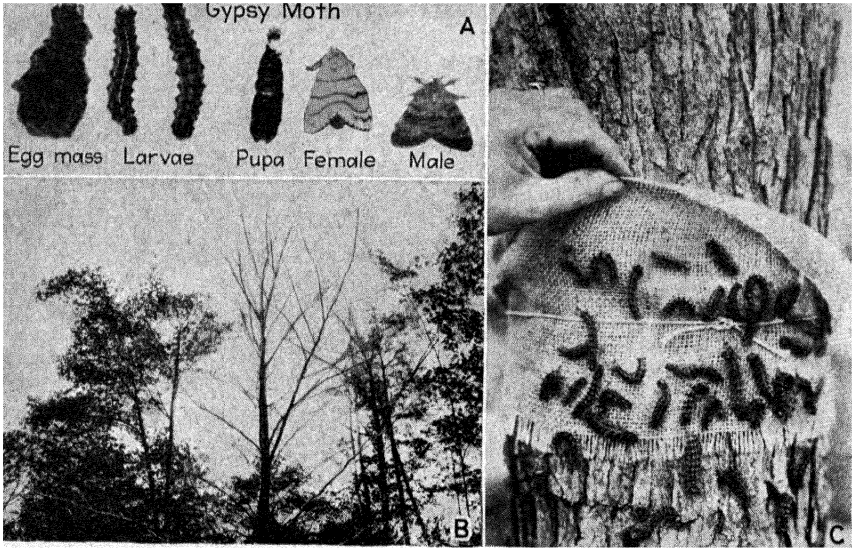


Fig. 535.—The gypsy moth. (A) Life cycle, from eggs to adults. (B) Tree defoliated by these moths. (C) One method of preventing young larvae from climbing trees. (Courtesy of U.S. Bureau of Entomology.)

c. Special Insect Pests That Injure Vegetation.—Most of the 625,000 species of insects that have been identified feed on plants. In addition to attacking weeds and nonuseful plants, they attack flowers and trees, as well as plants from which useful products are derived. Each species of plant is infested with many kinds of insects, but usually only a few of these are destructive. Thus, corn is attacked by about 200 different species of insect enemies; clover, by a like number; apple trees and apples, by about 400; and oak trees, by probably 1,000.

(1) GYPSY MOTHS (Fig. 532).—The caterpillar of the gypsy moth (*Porthetria dispar*) is hairy and about 2-in. long. It feeds on all sorts of leaves. The adults are brownish and inconspicuous with a wingspread of 1½ in. The caterpillars can be prevented from reaching the leaves by surrounding the trunks of trees with a burlap band (Fig. 535) or a ring of

sticky tanglefoot. This moth, which does untold damage each year, was accidentally introduced into this country in 1869.

(2) POTATO BEETLE (*Leptinotarsa decemlineata*).—Before 1850, the potato beetle, or bug, used sandbur plants for food. When the settlers introduced the succulent potato plant, the beetles found it an excellent food plant, and they traveled eastward at an ever-increasing rate until, by 1874, they had reached the Atlantic coast. They acquired a new name, the Colorado potato beetle. Paris green, an arsenic preparation, sprinkled on the plants, kills the beetles, which take this poison into the stomach when they eat the leaves so treated.

(3) THE COTTON BOLL WEEVIL (*Anthonomus grandis*).—Cotton is produced in this country over a region of 600 miles from north to south and

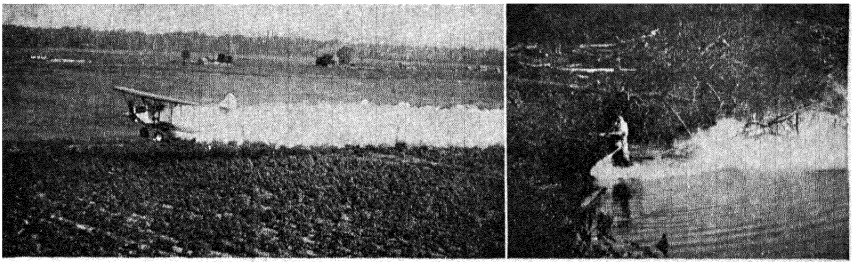


Fig. 536.—Two methods of combating the insect menace. (A) Dusting cotton with calcium arsenate from an airplane to control the boll weevil. (Courtesy of U.S. Bureau of Entomology.) (B) Spraying pool with Paris green to prevent mosquito breeding. (Courtesy of The Army Medical Museum.)

2,000 miles from east to west. It is attacked by the boll weevil, pink bollworm, leaf worm, louse, leaf hopper, and many other insects of less importance. The boll weevil does the greatest damage. It now covers 90 per cent of the cotton area and in recent years has destroyed about 15 per cent of the entire crop. It is indirectly controlled by increasing the productivity of the plants and by hastening the maturity of the plants before the weevils become abundant. Dusting with calcium arsenate has been found effective and profitable as a control measure (Fig. 536).

d. Vegetation Injured by Groups of Insects. (1) FARM CROPS.—Many farm crops are attacked by army worms, which crawl along in vast armies, feeding upon the leaves and stalks of grains and grasses, the heads of which they generally bite off. Chinch bugs suck the juices from plants, injuring particularly small grains and corn. Cutworms are the caterpillars of small moths that eat the leaves of young corn and damage the roots of many kinds of plants. The European corn borer is the larva of a moth that was introduced from Europe; it has the habit of boring into the stalk of a corn plant. Other notorious pests of field crops are grasshoppers; the

Hessian fly, which attacks the stalks of wheat; the green bug, a plant louse that sucks the juices of oats, wheat, barley, and corn, stunting or killing the plants; the corn-ear worm, which eats the ears of corn; and the alfalfa weevil, which attacks alfalfa plants.

(2) GARDEN VEGETABLES.—Garden vegetables are injured or destroyed by insect pests, every vegetable being attacked by one or more. The cabbage worm of the larva of the cabbage butterfly is a species accidentally introduced in this country in 1860. Peas and beans are attacked by weevils, cucumbers by the striped cucumber beetle, squashes by the squash bug, and celery by celery caterpillars.

(3) FRUIT TREES AND FRUIT.—Injurious insects are attracted to fruit as well as to fruit trees. For example, the San Jose scale (*Aspidiotus perniciosus*), which appeared near San Jose, Calif., in 1880, and other scale insects are particularly harmful to young trees. Apple trees and apples are attacked by plant lice and codling moths, the latter being responsible for wormy apples. All sorts of fruit fall prey to the Mediterranean fruit fly. During recent years, Japanese beetles have become a notorious pest. They feed on over 200 species of plants, and strenuous efforts are being made to keep them from spreading.

(4) SHADE TREES.—Many shade trees have specific pests. A few of these are the elm-leaf beetle, the brown-tailed moth, and the tent caterpillar, as well as various types of borers.

e. Insect Parasites of Man.—Fleas and lice may be ectoparasites of man. The jigger flea, or chigoe, is a common pest in tropical and subtropical countries. When ready to lay her eggs, the female burrows into the skin, usually of the feet, causing a swelling that may become a dangerous ulcer.

Three species of sucking lice live on human beings: (1) Head lice are the most numerous above the ears and on the back of the head. They are about $\frac{1}{8}$ in. long, gray in color; the legs are stout and strong, with recurved claws fitted for clasping and holding hairs; the mouth parts form a tube in which are the piercing organs. (2) The body louse, or "cootie" (Fig. 530*B*), famed in the annals of the A.E.F., is somewhat similar to the head louse but is slightly larger and prefers to live in clothing. (3) Crab lice are less common than the other two species. They live in the pubic region, are nearly as broad as long and are grayish white.

f. Some Insects That Transmit Human Diseases. (1) MOSQUITOES transmit the organisms causing malaria (page 274) and, among other organisms, those causing yellow fever, dengue fever, and elephantiasis (page 819).

(2) FLIES, BUGS, AND RAT FLEAS.—African sleeping sickness is transmitted by tsetse flies (page 815); Chagas' disease, by Tritoma bugs (page 815); and bubonic plague, by rat fleas (page 806).

(3) BODY LICE transmit typhus. This discovery enabled the sanitary officers of the First World War to prevent typhus by disinfecting the clothes of the soldiers. It is transmitted to man from rats by fleas and from man to man by lice (page 848).

3. ARACHNIDS. *a. Beneficial Arachnids.*—Spiders, harvestmen, and scorpions benefit man indirectly, since they are carnivorous and feed largely on insects, most of which are injurious.

b. Poisonous Spiders and Scorpions.—Some spiders are provided with poison claws, with which they kill their insect prey, but, with the exception of the black-widow spider (Fig. 297) of the South and the tarantulas of the Southwest, they are not harmful to man.

The black-widow spider is velvety black and has an hourglass-shaped bright red spot on the underabdomen. The bite is painful and may cause death. The spider gets its name from the fact that the female is likely to eat the male shortly after mating.

Tarantulas are the giants of the spider world. One species that lives in South America has a body 2 in. long and legs that spread out over 7 in. Although the regular diet of these spiders is insects, they are known to catch small birds occasionally. Its bite is supposed to be deadly, but experiments indicate that it is ordinarily no more serious than a bee sting.

Scorpions are, in general, larger than spiders (Fig. 294). The tip of the tail is provided with a poison sting used in paralyzing the prey, mainly insects and spiders.

c. Mites and Ticks.—These are directly injurious to man and the lower animals. Included in this group are species that attack poultry, that cause mange and scab in domestic animals, and a few that parasitize man.

Chicken mites are serious pests in certain parts of this country. They attack poultry at night and suck their blood. Fowl ticks are also a serious pest in some localities.

Scab, or mange, on dogs, horses, sheep, and other animals may result from the attack of mites. A close relative of these mites (*Sarcoptes scabei*) is responsible for a type of human itch.

Harvest mites, or chiggers (*Trombicula irritans*) are young mites that are red in color, hence often called *red bugs*. They live on or near the surface of the ground and crawl up on any part of the body that comes near them. They attach themselves to the human skin, insert their piercing mouth parts, and begin to suck. After a few hours, itching begins that may last several days.

Texas fever in cattle is transmitted from a diseased animal to a clean one by a species of tick (page 427).

A number of other diseases are also transmitted by these arachnids,

including Rocky Mountain spotted fever (page 427). This type of fever is primarily a disease of gnawing animals, such as ground squirrels, chipmunks, woodchucks, and rabbits and is transmitted by ticks. As in the Texas fever tick, the disease germs of Rocky Mountain spotted fever are passed on from parent to offspring in the egg.

J. Fish.—Although a few species of fish are harmful because of the valuable food fish and other useful aquatic animals that they destroy, most fish are of value to man (page 452). Some fish are usually called *game fish* and others, *food fish*. From fish are derived a number of different kinds of products that are of importance to man.

1. HARMFUL FISH.—The lamprey eel (Fig. 299) is not a true fish but is included here for convenience. It does great damage to fish used by man as food (page 436). The great white or man-eating shark may reach a length of over 40 ft. It is one of the most voracious of all sharks and occasionally attacks man. Some of the injuries attributed to sharks are due to a much smaller, bony fish, the barracuda.

2. GAME FISH.—Some game fish occur in fresh water and others in the sea. All game fish provide recreation for those who like to fish and, besides, nearly all of them are good to eat.

Among the fresh-water game fish may be mentioned yellow perch, trout of various species, pickerel, and bass. The sea contains such game fish as tarpon, sea bass, tuna, swordfish, and sailfish.

3. FOOD FISH.—In addition to game fish, there are some species that are especially important as a food supply for man. Some of these are herring, the mackerels, flounders, and codfish, all of which live in salt water. In fresh water are the whitefish, lake trout, and wall-eyed pike.

The Pacific salmon is the largest and most valuable of all salmon. An average specimen weighs 20 lb., but 60-pounders are frequently caught; some may be 5 ft. in length and weigh 100 lb. (page 452).

The sturgeons live both in the sea and in fresh water. They resemble sharks in shape. Some of them reach a length of 12 ft. and a weight of 500 lb. The flesh of the sturgeon is rather coarse and beefy when fresh but is improved by smoking. The swim bladder is made into isinglass, which is used as a clarifier of wine, and as high-grade glue and court plaster.

4. SOME FISH PRODUCTS. *a. Caviar* is made from the eggs or roe of sturgeons. That caviar was known in the sixteenth century is proved by Shakespeare, in "Hamlet," when he says, "His play . . . pleased not the million; 'twas caviare to the general."

b. Oils and Fertilizers.—Quantities of fish oil are produced every year from sharks and other fish. Oil from the livers of the cod and some other fish is valuable because it contains vitamin D (page 527).

5. Fish and Malaria Control.—Certain species of fish obtain their food near the surface of the water, and some of these are particularly fond of mosquito larvae. Sanitary officers now regularly use top minnows of the genus *Gambusia* for this purpose.

K. Amphibia.—The members of this group are mostly beneficial. The toad, for example, devours vast quantities of injurious insects, and frog legs are used by some people as food.

L. Reptiles.—Most reptiles are harmless, and some are beneficial.

1. Reptiles Useful to Man.—Some reptiles destroy many worms and insects; a few are used for food, especially turtles. The diamond-back turtle is especially esteemed as an article of food. Among the articles of commerce derived from reptiles are alligator hides, used as leather, and tortoise shell from the hawksbill turtle.

2. Poisonous Reptiles.—The Gila monster of the Southwest is one of the few poisonous reptiles in the United States. Others are rattlesnakes, copperheads, and water moccasins (page 475). These are all known as pit vipers, because a depression, or pit, is present between the eye and the nostril on either side of the head. The pupil of the eye also differs from that of nonpoisonous snakes in that it is vertical instead of round. A recent review of the subject indicates that only about 16 persons per year die in the United States as a result of snakebites. (For snake venoms, see page 476.)

M. Birds. 1. The "Farmer's Friend."—Because of the insects that they devour, birds are often referred to as friends of the farmers. It would not be possible to imagine the number of insects there would be on earth if birds did not keep them in check. Seed-eating birds also eat seeds of weeds, which might otherwise choke out useful plants.

2. Game Birds.—Formerly game birds were of considerable economic importance. They are so greatly reduced in numbers, however, that they must be protected by law. They are hunted more for sport now during the "open" season than for food. Quail and ducks are still present in important numbers. Quail and turkeys are now reared in hatcheries for restocking the forests (page 843).

3. Birds of Prey.—Many birds of prey were formerly thought to be injurious on account of the poultry and game birds that they destroyed. However, some of these birds destroy field mice, rabbits, ground squirrels, and other small mammals, some of which are injurious to crops. Among the really harmful birds are the duck hawk, sharp-shinned hawk, Cooper's hawk (Fig. 343), and goshawk.

4. Birds Used as Food for Man.—In addition to the game birds used as food, the domesticated varieties of birds and their eggs are an important source of food for man. These include the common chicken, turkeys, ducks, geese, pigeons, and guineas.

5. Songbirds.—Although the industry is not great, many thousands of canaries and other songbirds are sold each year. Songbirds contribute indirectly to the health and enjoyment of man.

6. Industrial Products from Birds. *a. Feathers.*—Plumes of the ostrich have important commercial value for millinery purposes (Fig. 340). Ostrich farms are successfully run, especially in California. Many other types of feathers are used in the millinery business. Down feathers of various kinds are used for making pillows and bed comforts. Eiderdown is especially fine.

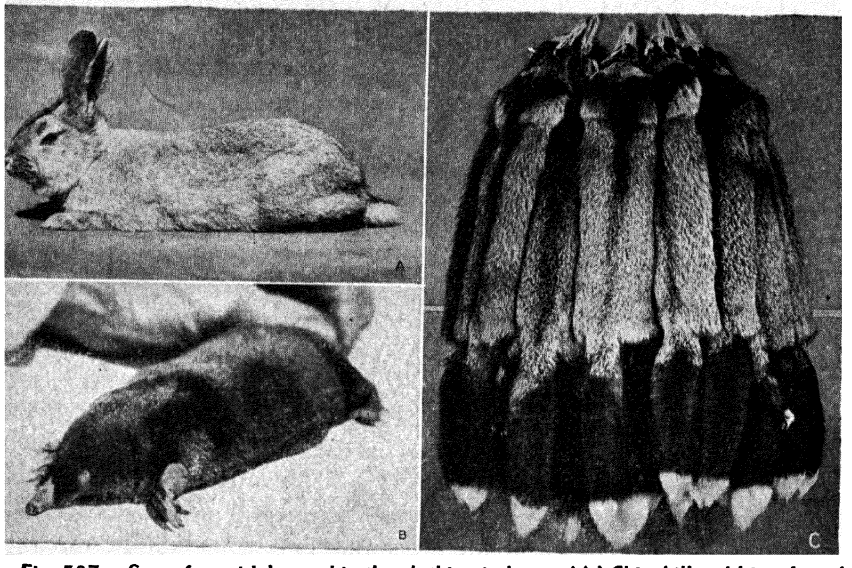


Fig. 537.—Some furs widely used in the clothing industry. (A) Chinchilla rabbit, a breed reared for its beautiful fur. (B) A mole (male). Note spade-like forelimbs for digging. (Courtesy U.S. Biological Survey.) (C) Silver fox furs, ready for the market. There are many fox farms in the United States. (Courtesy of Fromm Brothers.)

b. Guano is present on the coast of Peru and in other parts of the world, having been deposited by birds, mainly cormorants. It is of commercial value, being sold as fertilizer.

N. Mammals. 1. Domesticated Mammals.—Cattle, horses, asses, sheep, goats, pigs, cats, and dogs are the most common domesticated mammals. In the desert regions of the Old World, the camel (Fig. 496) is practically indispensable. Other members of the camel family domesticated in South America are the llamas and alpacas. Asia is the home of the tame elephant and the yak. Llamas, the yak, and the elephant are used as beasts of burden.

2. Game Mammals.—Our game animals include certain species, such as the moose, wapiti or elk, deer, and rabbit, that are shot or cap-

tured for food, and bears, mountain lions, foxes, wolves, coyotes, and wildcats that are hunted for sport. Some of the latter are so injurious to livestock that a bounty is paid for their destruction in certain parts of the country. The food value of game animals has steadily decreased with the cutting down of forests and the cultivation of the land, until now only successful hunters are able to eat "wild" meat.

3. Some Common Predaceous Mammals.—Among the predaceous mammals may be included wolves, mountain lions, coyotes, wildcats, and, unfortunately, house cats. These animals are all carnivorous. The animals they capture may be harmful, such as rats and field mice, but

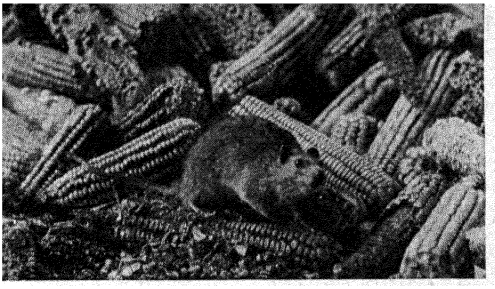


Fig. 538.—Rat, Rattus. Rats destroy corn and other valuable crops. In addition, they carry bubonic plague. The fleas from the sick rats are the transmitting agents.

some of them are domesticated animals and birds. The house cat is one of the worst enemies of birds.

4. Fur Bearers.—The marten family contains the most important fur bearers, namely, the otter, mink, weasel, marten, wolverine, and badger. These species have been hunted so persistently, however, that they are scarce. Other mammal furs are widely used; skunk, muskrat, raccoon, squirrel, seal, rabbit (Fig. 537*A*), and the mole (Fig. 537*B*) furnish a large proportion of the furs of commerce today. Many fur bearers are raised on fur farms, especially silver foxes (Fig. 537*C*).

5. Injurious Gnawing Animals.—Rats, mice, and rabbits are the most injurious of the gnawing animals. They live on vegetation but do not confine themselves to weeds and valueless trees. Field crops, vegetables, and fruit trees are also attacked, and a great deal of damage is done to them. Rabbits and mice gnaw away the bark of trees just above the surface of the ground, especially in the winter, under cover of the snow, thus girdling them. The trees die as a result.

The rat is probably our worst mammalian pest (Fig. 538). It destroys hundreds of millions of dollars' worth of property every year. Grain crops are seriously damaged by rats; they destroy more poultry than any other animal; they are a serious pest of the game preserves; they damage fruit and vegetables both before and after they are gathered; they appear to

eat anything, and the damage done by them to stored merchandise is enormous. They have also been known to start fires by gnawing matches.

O. Introducing Foreign Animals.—Experience has shown that it is a serious thing to introduce animals that are foreign to a country unless its life cycle and feeding habits are known. For example, the brown rat, which appeared in this country about 1775, is one of our worst pests. Australia has been overrun by rabbits, which were introduced there about 1864. In Jamaica, the *mongoose* of India, which was brought to that island for the purpose of killing rats and snakes, changed its habits and began to destroy birds and domesticated animals. Because animals from other countries may become pests, it is now necessary to obtain a permit from the government before bringing foreign species into the United States.

Questions

1. Discuss the economic importance of each of the four groups of plants.
2. Name at least 20 plant products, giving the names of the plants from which they come.
3. Discuss harmful plants.
4. Discuss Protozoa (*a*) with regard to formation of the earth's crust; (*b*) as parasites of animals; (*c*) as parasites of man.
5. Give a full account of the life history of the malaria parasite. How may malaria be prevented?
6. How may sponges affect the food supply of man? What types of sponges are used by man?
7. How are the corals important?
8. Give a complete account of the liver fluke of the sheep. How does man become infected with tapeworm? How may infection be prevented?
9. Discuss the life cycle of the hookworm. What other roundworms are parasitic in man?
10. Which mollusks are valuable as food for man? What are some useful products obtained from the mollusks? What are some harmful mollusks, and what damage do they do?
11. What is trepang? What is one of the great enemies of oyster beds?
12. Discuss the economic importance of crustaceans. What damage is done by some crustaceans?
13. Make a list of beneficial insects; a list of harmful insects. What methods are used to fight the insect menace? Why is a predatory insect sometimes very useful to man? Explain?
14. Make a list of game and food fish. What are some harmful fish, and what damage do they do? What are some valuable fish products?
15. In what ways are reptiles useful to man?
16. Why are birds spoken of as "the farmer's friend"? How do birds of prey benefit man? Make a list of birds used as food for man. What industrial products useful to man come from birds?
17. Make a list of the domesticated animals that you know. How are they useful? What are some valuable game animals? Discuss the harm done by some common mammals. Make a list of valuable fur bearers.
18. Why is it dangerous to introduce foreign animals into new situations?

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CHAPTER XLIX

CONSERVATION

. . . And wilful waste, depend upon 't
Brings almost always woeful want.
—ANN TAYLOR.

I. Conservation of Our Natural Resources

A. Natural Resources.—Natural resources are of two kinds: (1) those which may be replaced if destroyed, such as forests, soil, etc., and those which, once used, are gone forever, such as coal, oil, minerals, and natural gas. A forest that has been burned over may be replaced in time; our deposits of coal, however, when once used, can never be replaced. Biologists are interested in the origin of coal from plants, in the formation of petroleum from the distillation of organic materials, and in the mineral resources that, aside from industrial uses, are necessary to maintain the health of living things on earth. The replaceable resources, however, are the most interesting to us here: the conditions that render the soil unproductive, the destruction of forests, the disappearance of wild life, and the methods by which these natural resources may be conserved and built up.

B. Historical.—To the early pioneers, our natural resources appeared inexhaustible. They found seemingly endless *virgin forests* with an abundance of wild life in them; the streams were stocked with fish; vast deposits of minerals and fuel were soon discovered. It was unthinkable that the day would come when these resources would be exhausted. When land was cleared, logs were piled and burned. Men who hunted game for sport left thousands of dead animals on the ground.

The first attempts at conservation in the United States were made in the late seventeenth century. By 1670, building material was becoming scarce in Massachusetts. In 1681, William Penn, of Pennsylvania, signed an ordinance requiring that 1 acre in 5 be left wooded when forest land was cleared.

One of the first instances of conservation of a national scope was the result of the desire to have plenty of live-oak timber for the construction of battleships. In 1828, President John Quincy Adams established a naval station in the live-oak region of Pensacola, Fla. He set aside 30,000 acres of land on the island of Santa Rosa across the bay from Pensacola for the cultivation of live-oak trees. This project was abandoned by the next

administration but may be cited as an example of conservation that was national in scope and not local.

The American Forestry Association was organized in 1875 and worked for the promotion of conservation. In 1891, Congress passed an act that made possible setting apart areas as national forests and national parks.

All our first national parks were in the Western part of the country. In 1892, the Yellowstone National Park was established, and before President Harrison left office he had set aside 13 million acres as forest reserves. President Cleveland added 21 million acres to the forest-reserve system, and President Theodore Roosevelt increased the forest reservation to more than 100 million acres. Further, during his administration, large areas of public land were studied as possible sources of such necessary materials as coal, oil, natural gas, and minerals.

C. Waste and Conservation of Natural Resources. 1. FORESTS.—Besides their value as timber, trees and shrubs serve as food for browsing animals.

a. Destruction of the Forests. (1) OVERCUTTING.—It is said that we cut twice as much timber as we grow.

(2) DESTRUCTION BY ANIMALS.—Animals browse on the lower limbs of trees, but the real damage they do is to destroy young seedlings, grass, and herbs. It is the practice in some parts of the country to burn over forests used for grazing. The dead leaves and underbrush are burned, and a grass crop appears in spring. Fires of this kind may not kill trees but do injure them, and bacteria and Fungi begin their work; nests of game birds are destroyed, and the rich black mold will in time be destroyed.

(3) FOREST FIRES.—Forest fires destroy timber it may have taken hundreds of years to grow, ruin the land for productive purposes, and destroy the homes of wild life. The destruction of the forests on watersheds, either by fire or logging, starts erosion and all the ills that follow in its train. It takes from 50 to 100 years for a forest to develop; it can be destroyed in a few hours by a carelessly thrown lighted cigarette or by campers who do not put out their fires (Fig. 539*A*).

b. Conservation Measures.—Conservation today includes reforesting by planting burned-over areas (Fig. 540), building fire lanes, and removal of dead timber and other trash from the forest. The Civilian Conservation Corps is doing excellent work in saving the forests; forest rangers watch for fires from lookout posts (Fig. 539*B*) and so bring small fires under control. In addition, some patrol work is done with airplanes. The U.S. Forest Service has charge of this work.

2. GRASSLANDS. *Removing Nature's Cover.*—The great American plains of the Southwest were originally covered with grass, which held

the soil together. The grass was ploughed under, great crops were raised, and the country became prosperous. Removal of the top cover, however, soon led to disaster, as will be seen.

3. Destruction of Vegetation by Chemicals.—Ducktown, Tenn. is a highland area, which, in former times, was covered with vegetation. When copper mining was begun there, no precautions were taken to prevent the fumes from ruining the vegetation. In time, all the plants were killed over an area of about 50 miles. After the protective cover was

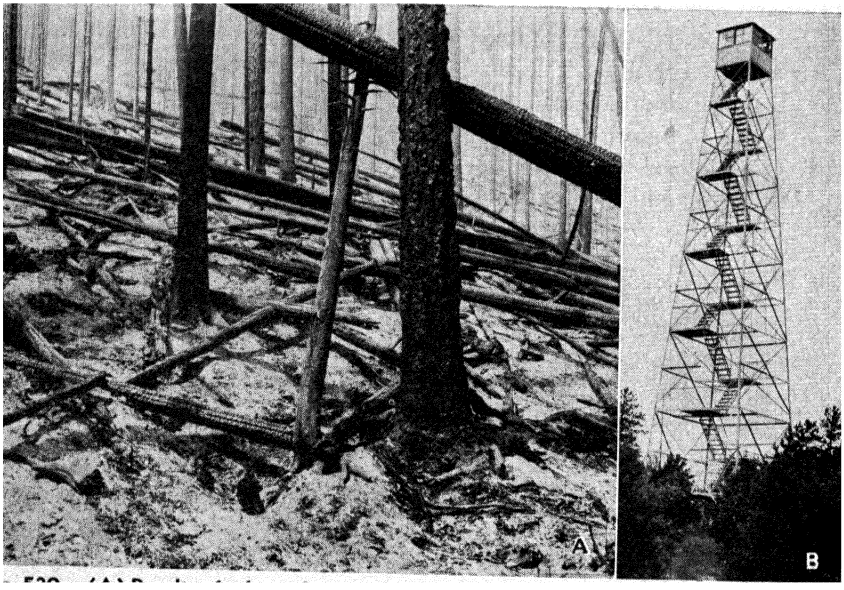


Fig. 539.—(A) Results of a forest fire in Montana. (B) Modern steel lookout tower, used by forest rangers in fire prevention program. (Courtesy of U.S. Forest Service.)

lost, erosion began (Fig. 541). Precautions are now taken and "nature's cover" is slowly returning. It will be a long time, however, before the hillsides are again covered.

4. Soil.—There are two main types of soil erosion, water erosion and wind erosion. In either case, the soil is carried away.

a. Water Erosion.—The amount of soil lost by water erosion, as estimated by experts, is almost unbelievable. For example, on a 2 per cent slope, it is estimated that 40 tons of soil per acre were washed during a single rainy season. After land is denuded of vegetation, the first part of the soil to go is the humus, the sponge-like water-holding layer normally held in place by roots of plants. With nothing to hold the water, *sheet erosion* takes place, especially on rolling land. The field may appear to be good land, but the topsoil is gone, and good crops cannot be produced.

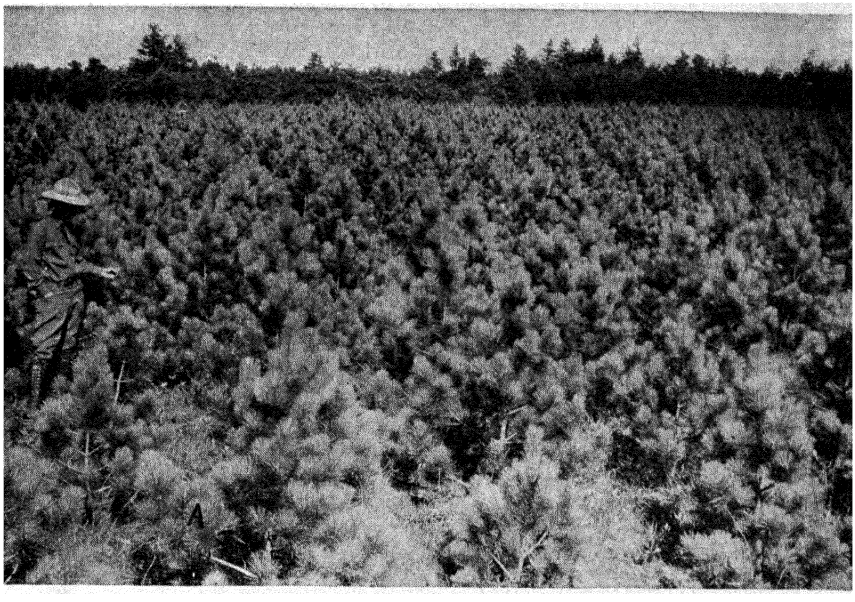


Fig 540.—Reforestation. Many cut-over and burned-over areas are being replanted. (Courtesy of U.S. Forest Service.)

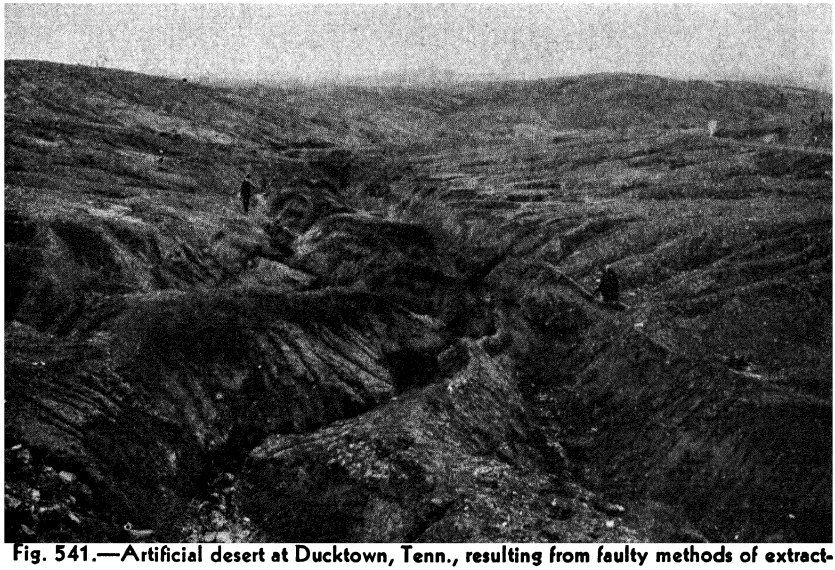


Fig. 541.—Artificial desert at Ducktown, Tenn., resulting from faulty methods of extracting copper from ore. Vegetation was killed over an area of fifty square miles. (Courtesy of Tennessee Valley Authority.)

After sheet erosion, *gully erosion* begins. This leads to the formation of bad lands like the Ducktown area, and the land is unfit for agricultural uses.

b. Wind Erosion.—The vegetation that covered the prairies before the days of intensive farming and overgrazing kept it from erosion. After the vegetative cover of sections of the prairies had been removed, the great drought came. Gone were the grass roots to hold the soil in place, and the topsoil in some sections was literally blown away (Fig. 542). Unless efforts of the U.S. Soil Conservation Service are successful, a large area of the Great Plains section (the "Dust Bowl") will become wasteland, unfit for the great crops once grown there.

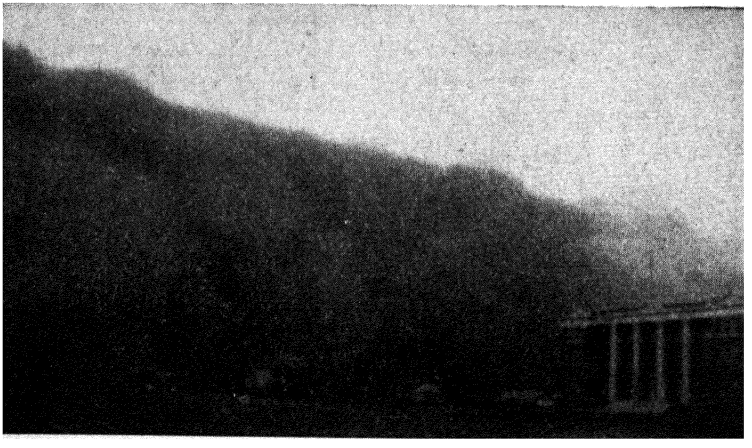


Fig. 542.—A dust storm rolls over Wheeler, Texas. (From Field and Laboratory.)

c. Some Effects of Erosion. POLLUTION OF STREAMS.—Besides rendering the land unfit for crops, the soil that is washed away enters the streams and does damage in many ways. This *silt*, as it is called, settles to the bottom of streams, killing the plants and animals living there, particularly mussels. It shuts out the light that is indispensable to plants, and the organisms that feed on these plants starve to death. Other animals that feed on these organisms are thus cut off from their food supply.

d. Prevention of Erosion. (1) TERRACING.—Terracing is a raised level space, usually supported on one or more faces by a wall or a bank of turf. These are usually arranged one above another.

(2) ESTABLISHMENT OF WOODLANDS.—Woodlands protect against erosion, because the forest carpet is a sponge through which the water filters slowly to the soil below, and this soil is anchored in place by an interlocking meshwork of roots that absorb much water. Trees and

underbrush break the force of falling water, and hence soil is less likely to wash away.

(3) PERMANENT PASTURES.—These may be established if certain minerals used by plants, chiefly phosphates, are added and if clover is added to the grass. The nodules of the clover roots will fix the nitrogen from the air, and so this important substance is added to the soil.

e. Depletion of the Mineral Content of the Soil.—This may come about in two ways. The minerals may be washed out through erosion, or they may be used up by certain crops. Preventive measures are guarding against erosion, rotation of crops, planting of leguminous crops that have nitrogen-fixing nodules on their roots, and the use of proper fertilizers to replace lost minerals.

5. STREAM POLLUTION.—Attention has been called to the silt and its influence on life in the streams. Fish cannot exist if their food supply is cut off. In addition, the water of lakes and streams has been much *polluted* with sewage, industrial wastes, gasoline, and oil from filling stations, etc. Various methods of treating sewage are possible and so render it harmless; the disposal of industrial wastes is a problem that has received much attention in recent years.

6. "FROM ABUNDANCE TO ABUNDANCE."—The series of pictures in Fig. 543 tell the story of waste and rebuilding of natural resources better than it can be described in any other way. Rebuilding takes time and money, and people must be heavily taxed to reclaim land that, if properly cared for, would have remained fertile.

7. WILD FLOWERS.—Many wild flowers are decreasing in numbers because the places where they are able to flourish are disappearing. When a forest is removed, thousands of flowers and animals are destroyed. Another factor that must be mentioned is the ruthlessness of man. The more beautiful the flowers, the more likely are they to be picked, often merely to be thrown away. In gathering the flowers of a trailing arbutus (Fig. 544*A*), it is often pulled up by the roots, because the stem is short. The showy lady's-slipper will not long survive unless it is protected (544*D*).

8. WILD LIFE.—Because of the acquirement of their grazing lands by man and also because of hunting, the great buffalo herds of the plains country have practically disappeared. A small herd, however, was placed in a national park, and here they have actually increased in numbers (Fig. 29).

The *Alaskan fur seal* was on its way to extinction when the Federal government took control of the herds. Hunting is prevented during the breeding season, and the number and type of animals to be killed is limited. The herds are now said to be increasing.

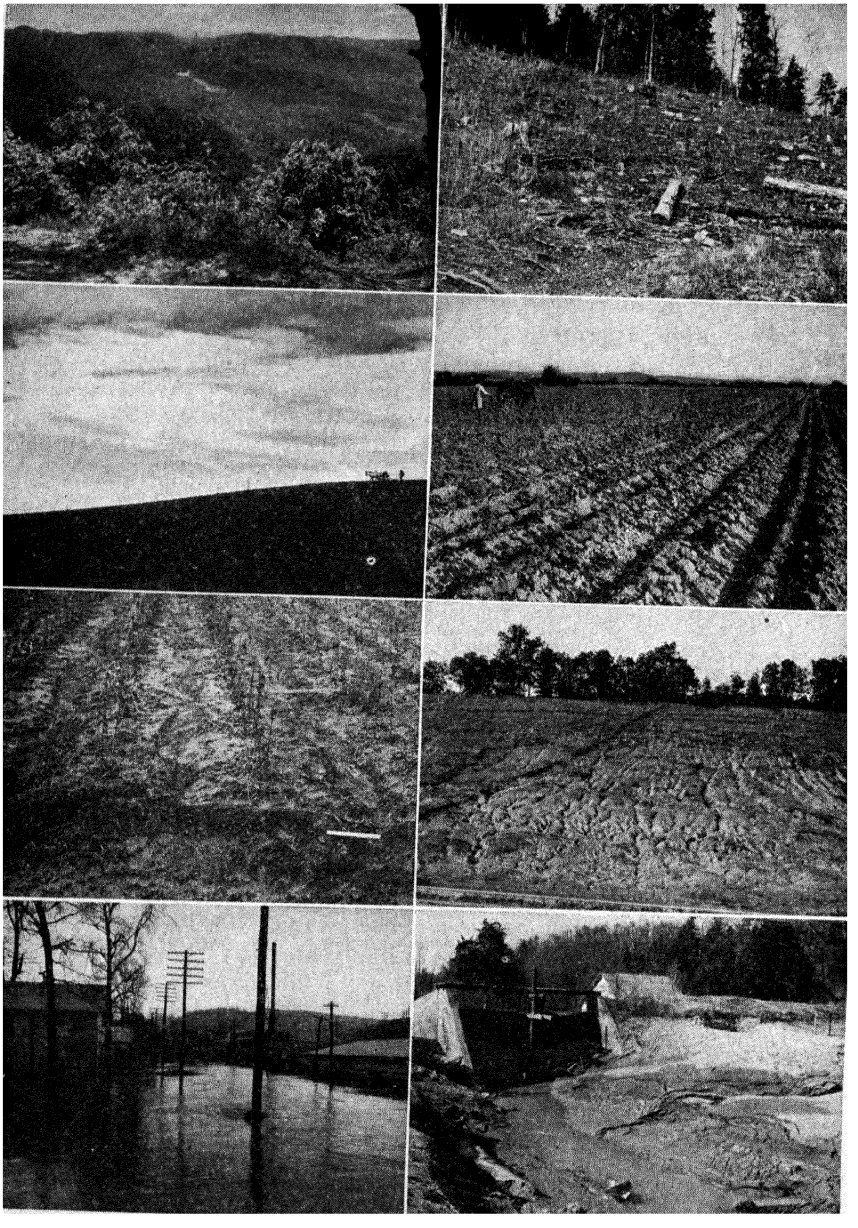
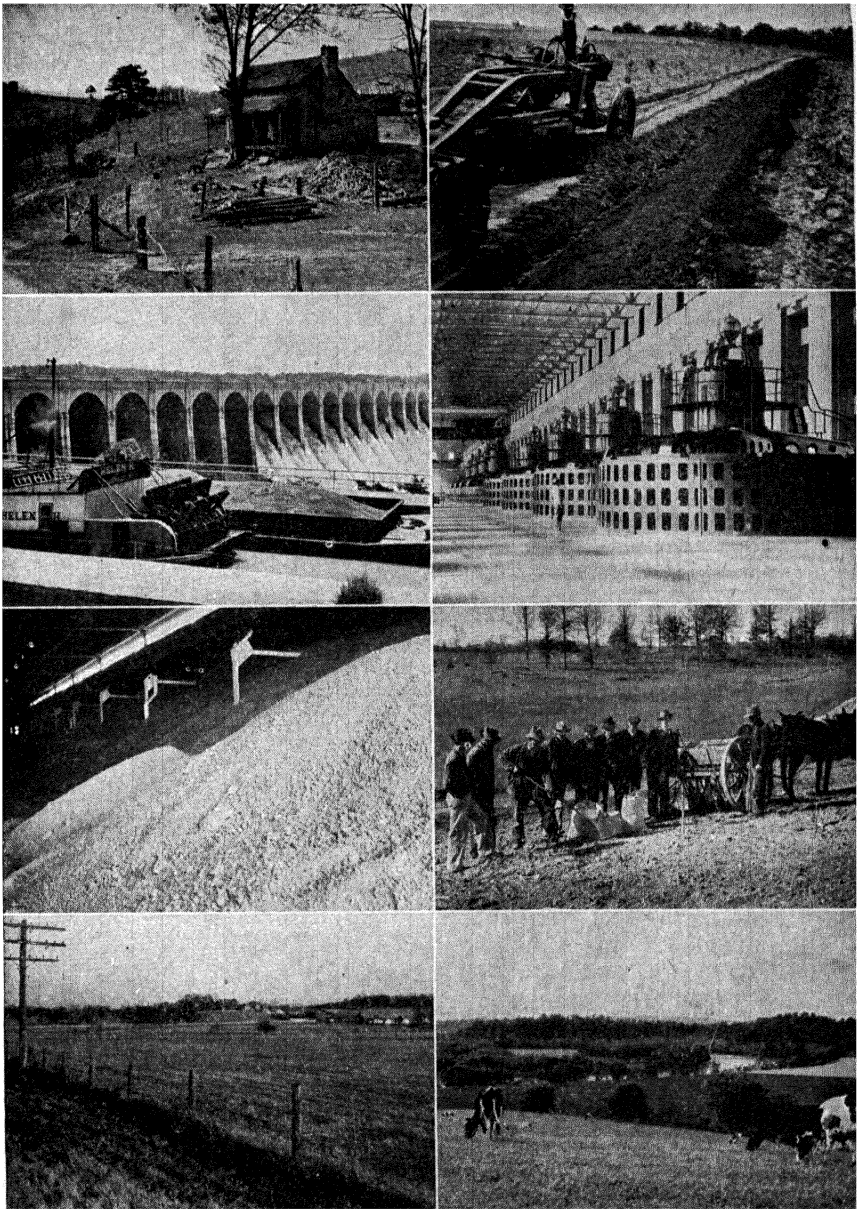


Fig. 543.—From abundance to abundance, the cycle of soil depletion and rebuilding. The pictures reading from left to right show:

Forest and grass protect nature's abundance. Removal of timber that protects the soil. Removal of the sod which protects the soil. Clean cultivation and absence of winter crops encourages erosion. Erosion follows. Land become poorer and poorer and less able to resist erosion. Flood and drought follow severe erosion. Organic and mineral plant foods are carried off to clog the streams and destroy reservoirs.



People on relief. Corrective measures begun. Land terraced, gullies clothed with vegetation, dams built, inland waterways created, and floods controlled. Electric power from controlled water makes possible the manufacture of phosphate plant food, key to land conservation and restoration. Electric power plant. Phosphates. People taught by government agents how to conserve land and increase fertility. Readjusted land use.

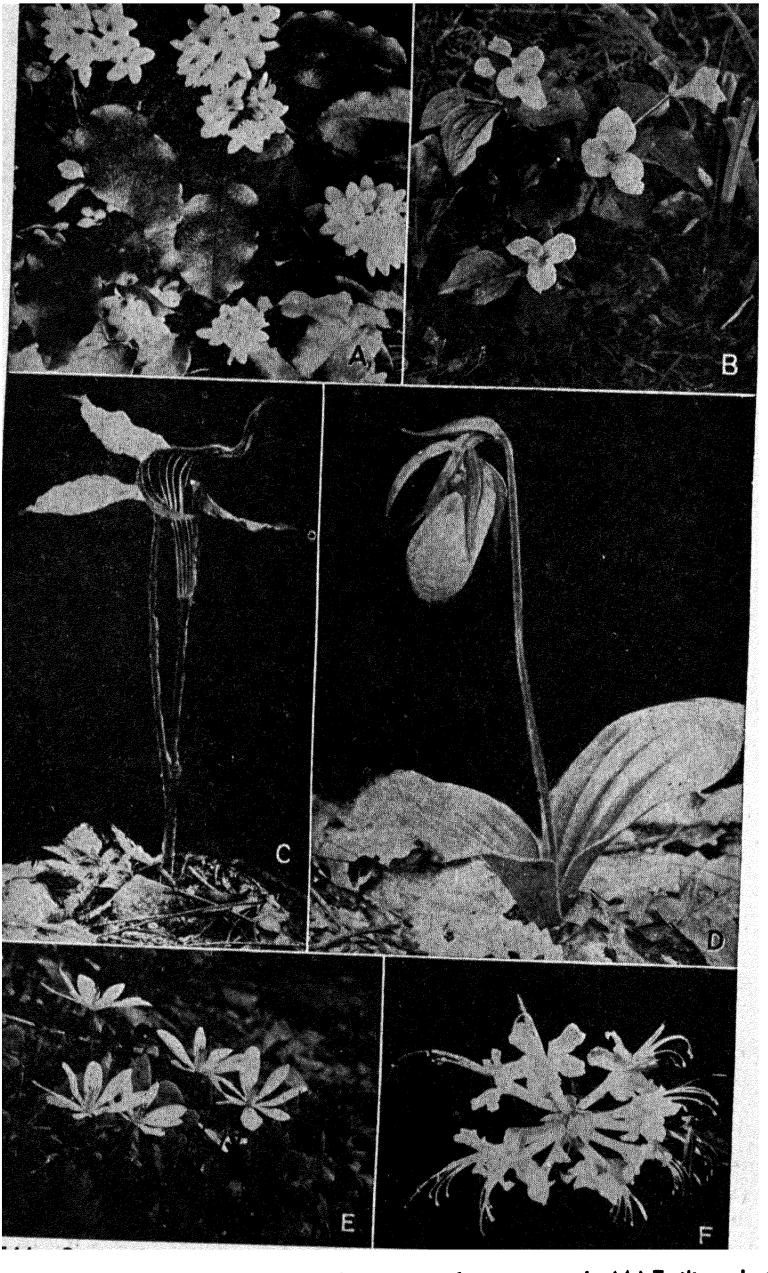


Fig. 544.—Some wild flowers that are disappearing from our woods. (A) Trailing arbutus, Epigaea repens. (B) Trillium. (C) Jack-in-the-pulpit, Arisaema triphyllum. (D) Pink lady-slipper, Cypripedium. (E) Hepatica. (F) Wild "honeysuckle," Azalea. [(A), (B), (D) Courtesy of Wild Flower Preservation Society. (E) Courtesy of Abe Furman.]

Other fur-bearing animals are also disappearing. *Beavers*, hunted for their fur, are becoming scarce. It is now recognized that, in addition to their value as fur bearers, beavers were the first "check-dam" (Fig. 349) builders and that their ponds help prevent floods.

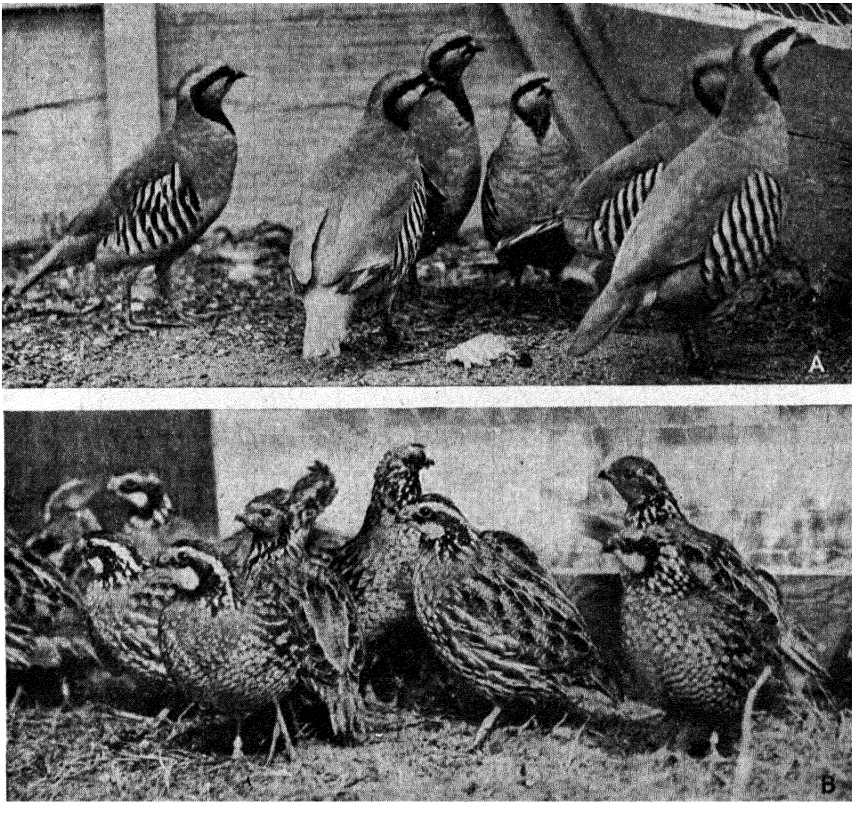


Fig. 545.—Game birds reared in hatcheries and placed in the woods to replace the kill of sportsmen. (A) Chukor partridges, Egyptian game birds now successfully reared in hatcheries. (B) Bob whites (Colinus virginiana), sometimes called quail, or partridges. (Photographs by Kenneth Rogers.)

Birds.—It is said that nearly 12 million passenger pigeons were marketed in one town in Michigan in 1869. They were still plentiful in 1870 but are now extinct. Other birds that have disappeared in recent years are the Labrador duck, in 1875, and the heath hen, in 1931. The latter was plentiful in colonial times, but only one was left in 1931, and it died on Martha's Vineyard Island in the fall of 1931.

Many thousands of birds were formerly destroyed for plumes, especially the egret. The "aigrettes" are nuptial plumes (Fig. 341) grown

only during the nesting season, and the birds must be killed to obtain them. They are now protected by law.

Conservation measures include the establishment of bird sanctuaries. The egret and some other birds that were becoming quite rare are said to be increasing in numbers. Hunting is now regulated so that hunters may kill only limited numbers. In many states, quail (Fig. 545), wild

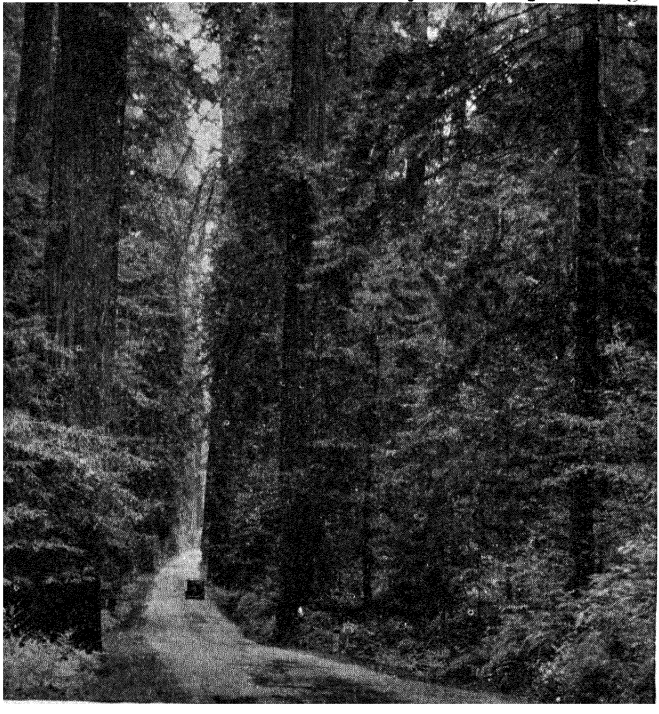


Fig. 546.—The redwood empire of northern California. In this forest are 97 per cent of all the redwood trees (Sequoia sempervirens). They are the oldest and largest living things on earth. (Courtesy of Southern Pacific Railway Company.)

turkeys, and other game birds are reared in preserves and then turned loose to replenish the woods.

Fish are also reared in hatcheries and the young taken to streams to maintain a supply.

9. National Parks.—If the government did not set aside areas containing unusual natural features, these areas would soon disappear. It is important, for example, to protect our "redwood empire" (Fig. 546). The trees are very old, and their destruction now would be little short of a calamity. The national-park areas are being conserved so that all the citizens of the country may have access to them. Thousands of people avail themselves of the privilege of visiting these parks. In addition

to national parks and national forests, 34 states now support state parks. These are of particular importance as centers for recreation and rest. Besides all kinds of accommodations from tourist camping grounds, cabin camps, and hotels, hunting and fishing are provided for.

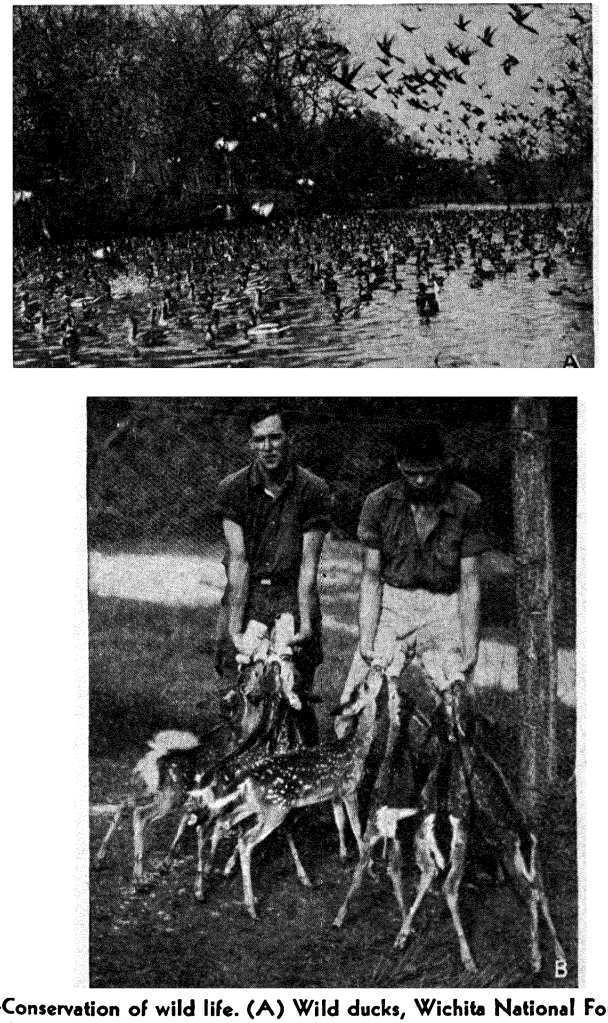


Fig. 547.—Conservation of wild life. (A) Wild ducks, Wichita National Forest. (B) Fawns, "bottle fed," at the Pisgah National Forest. (Courtesy of U.S. Forest Service.)

10. AGENCIES FOR CONSERVATION.—Conservation has many phases, and the Federal government has many agencies for the conservation of our natural resources. The work of the U.S. Forest Service has been mentioned. The U.S. Biological Survey was founded in 1885. The latter agency works with life histories, migrations, distribution, economic

value, etc., of birds, mammals, and other animals. The U.S. Bureau of Fisheries is concerned, among other things, with the conservation, propagation, and replenishing of shellfish, fish, etc. In addition to other Federal agencies, states have their own agencies. Wild-life conferences endeavor to formulate long-range plans for unification of conservation programs. Much has been done, but conservation work is just in its beginning.

D. Summary.—Some of the things man has done to destroy natural resources, either directly or indirectly, are the cutting and burning over of forest land, thus making it unproductive; the pollution of lakes and streams with chemical wastes from industries and from sewage; the plowing of grasslands that should have been left for wild life and for pasturage; the overgrazing of land so that wind erosion has led to desert formation; the draining of marshes that harbored wild life, such as water birds, fur-bearing animals, etc.

Some of the efforts at restoration are the replanting of burned-over and cut-over areas, thus providing for a future supply of forest products as well as wild-life refuges; the rearing of quail, wild turkeys, and other game birds, as well as deer (Fig. 547), to replenish the forests; the establishment of bird sanctuaries, where no hunting is allowed; the establishment of fish hatcheries and the restocking of lakes and streams; the placing of big game in the large national forests; the making of international agreements to protect migrating animals such as the fur seal.

II. The Conservation of Man

> Humanity has but three great enemies: fever, famine and war; of these by far the greatest, by far the most terrible, is fever.
>
> —Sir William Osler.

A. Human Resources.—America's greatest resources are her human resources. Besides the social measures for improving living conditions and the eugenics program for the betterment of the race itself, there remains the necessity for conservation of human life through the prevention of disease. Authorities tell us that of the more than 2 million babies born in the United States each year, approximately 55 per 1,000 die during the first year of their lives. Some interesting figures have been compiled that show that the average cost of being born is about $250. Add to this other costs for maintenance the first year, and the estimate of $607 is the investment to bring the child through its first year. The 1930 census showed 2,190,000 children under one year of age. The investment of the country, then, for this group for that year was well over a billion dollars. It is further estimated that the cost of bringing a child to the age of eighteen years averages approximately $10,485, exclusive of the cost of education furnished by the community.

But money value aside, the well-being of all people is dependent upon *pure food* and *water* supplies, *eradication* and *prevention* of *communicable diseases*, *prevention* of *infant mortality*, and related problems. No attempt is made here to describe all the agencies for the promotion of health, important though they be. From a biological standpoint, however, the cause and prevention of communicable diseases and related subjects and the effects of drugs and alcohol are problems that concern all students. The advance of civilization depends upon a knowledge of how to control disease and promote health. This involves a knowledge (1) of parasites, (2) of the way in which they enter the body, (3) of the diseases they cause, and (4) of methods of control.

About 1½ millions of people die in the United States each year. A small proportion of these deaths are due to old age; a large proportion could be prevented. But about ten times as many people suffer from various types of diseases as die from them. If the agents of these diseases were properly controlled, much misery could be prevented. Federal and state health agencies are doing much to educate the general public with regard to health problems.

B. Communicable Diseases.—The disease in this group are of three principal types: (1) those that are spread largely *through discharges* from the nose and mouth; (2) those spread largely by *contamination* of food and drink; (3) those *transmitted* by animals.

1. Transmission through Discharges of the Nose and Throat.—Belonging to the first type are smallpox, tuberculosis, diphtheria, measles, scarlet fever, whooping cough, mumps, lobar pneumonia, influenza, and the common cold. Prevention is accomplished by isolation of the patient and by sterilization of all articles used by the infected person, such as cups, spoons, etc. The patient can help by taking care of sneezing, coughing, etc.

2. Transmission by Carriers.—People who are apparently well sometimes harbor organisms that cause disease. They are *immune* (page 568) themselves, but they can transmit the organisms causing disease to others.

The story of "typhoid Mary," the first of its kind to be reported in America, has become a classic. Mary Mallon was a cook in a family for 3 years. In 1901 she developed typhoid fever. At about the same time, a visitor of the family had the disease. One month later the laundress in this family was taken ill. Later, in a new place, seven members of the household were taken ill with the disease in a short time. In 1904, 1906, 1907, Mary went to new places, and in each place, typhoid fever made its appearance. After 1907, she was cared for by the New York Health Department for a time. However, in a hospital in which she was engaged as a cook, an outbreak of typhoid occurred in 1915. Other cases appear

to have been traceable to her up to the time of her death. "Carriers" of this kind are not common, but they exist.

3. TRANSMISSION BY ANIMALS. *a. Insects.*—Diseases transmitted by insects include malaria (page 274), yellow fever, dengue, filariasis (page 819), tularemia, plague, typhus, and Rocky Mountain spotted fever.

Typhus fever results from an infection with minute microorganisms, *Rickettsia prowazeki*, transmitted by the body louse, or "cootie." This problem was serious during the First World War. Rocky mountain spotted fever is also a *Rickettsia* disease but is transmitted by ticks.

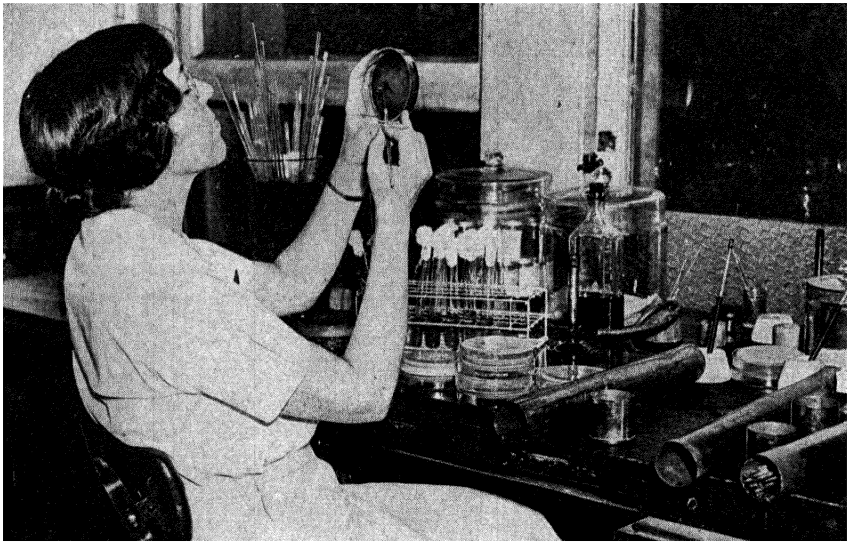


Fig. 548.—A laboratory in a State Board of Health. Federal and state agencies do a great work in safeguarding the health of the public. (Courtesy of The Atlanta Journal.)

All insect-borne diseases can be prevented by destroying the transmitting insects, a well-nigh impossible problem in some cases.

b. Diseases Transmitted by Other Animals.—Tularemia is due to an infection with *Bacterium tularense;* it is a disease especially of rabbits and other rodents but may attack man (from rabbits).

Bubonic plague is due to a bacterium, *Pasteurella pestis*, carried from rat to rat and from rat to man by fleas.

Psittacosis, a virus disease of parrots, is transmitted to man by diseased birds, some of which may be healthy carriers.

Rabies, or hydrophobia, is a filterable virus disease due to a wound infection. Man usually acquires the disease as a result of the bite of a mad dog. Pasteur devised a treatment for preventing the development

of the disease after infection has taken place. If the suspected dog is killed and the brain examined, certain nerve cells will show Negri bodies if the infection is present.

4. Contamination of Food and Drink.—Four important diseases are spread by contamination of food and drink: typhoid fever, cholera, dysentery, and hookworm disease. Much has been accomplished in prevention of these diseases by chlorination of water supplies to destroy typhoid bacilli, the pasteurization of milk, and the inoculation of vaccines. General sanitation and the proper disposal of sewage also play a large part in keeping typhoid and hookworm disease under control.

Health and efficiency depend greatly upon the food we eat. For example, foods may be poisonous (certain mushrooms); may contain parasites (cysts of *Amoebae*, roundworm eggs); may contain harmful bacteria (tubercle bacilli, typhoid bacilli); may contain toxins (botulism); may contain poisons (lead); and may be unbalanced (too few vitamins; too much protein, fat, or carbohydrate) (page 550).

5. Some Common Preventable Diseases.—*Cholera* is due to infection with spiral-shaped bacilli, *Spirillum cholerae*. The disease may be prevented, as in typhoid fever. Dysentery may be due to an amoeba, *Endamoeba histolytica* (page 814), the ciliate *Balantidium coli* (page 815), or to *Bacillus dysenteriae*. All three types are due to the entrance of the causative organisms in the mouth, principally in contaminated food and water. These diseases may be controlled in the same way as typhoid fever.

Infantile paralysis is due to a filterable virus that attacks the nervous system of all classes of human beings indiscriminately. Neither the nature of the virus nor the method of transmission is known.

Tetanus, or lockjaw, is caused by an infection of a wound with spores of a bacterium, *Clostridium tetani*. These spores occur frequently in manure and in cultivated garden soil. Prevention may be effected by injection of tetanus antitoxin.

6. Social Diseases.—The ravages of *venereal diseases*, both physical and mental, can hardly be estimated. *Syphilis* is the most important of the social diseases. Because of the brilliant work of F. Schaudinn and E. Hoffmann, the spiral organism causing syphilis, *Treponema pallida*, was discovered in 1905. This organism is considered by some authorities to be a plant, others consider it a protozoan, still others regard it as being in a class by itself. It may produce widely different symptoms in different parts of the body. For example, there may be external sores, destruction of motor centers, general paralysis, a type of insanity, and other effects.

Syphilis is not inherited, although the children of parents afflicted with syphilis are frequently syphilitic at birth. It is spread in various ways, principally by contact. Tests for the presence of the disease (the Wassermann reaction; the Kahn test) are known. It can be cured, espe-

cially in the earlier stages, by certain arsenic compounds. Paresis is sometimes treated by giving the patient malaria fever (page 276).

Gonorrhea is the second most important social disease transmitted by contact. The causative organisms are bacteria of the gonococcus type. Some effects of the disease are blindness in the newborn, sterility, and various chronic conditions. New methods for the control of this disease have recently been announced.

7. Occupational Diseases.—Workers exposed to air containing silica dust are particularly susceptible to a type of respiratory tuberculosis called *silicosis*. This is now the most important industrial disease in this country, particularly in mining centers. Dust can be controlled, and so the disease may be prevented.

Lead is the chief industrial poison. It is usually absorbed from the respiratory tract or the alimentary canal. To prevent lead poisoning, the air should be kept free from dust where lead is being worked with. Many chemical compounds are also responsible for industrial poisoning.

Pulmonary tuberculosis is more prevalent among industrial workers than it is among professional men. *Anthrax*, which is an infection with *Bacillus anthracis*, is acquired from spores on the hides of infected animals.

8. Deficiency Diseases.—These have been mentioned in other sections of the book and are due principally to lack of certain vitamins (page 527). They are *scurvy*, *rickets*, *pellagra*, *beriberi*, and *goiter*. Proper foods for prevention of these diseases are listed on page 873.

9. Some Eye Defects.[1]—One-eighth of all blindness is due to *glaucoma*. This condition occurs in later life and is due to injury to the optic nerve resulting from pressure within the eyeball. The cause is not known, and prevention is impossible, but early treatment will check the progress of the disease.

Trachoma is a virus disease that thrives where sanitary conditions are poor. It is infectious, and preventive measures involve protection from infected persons and improvement in sanitary conditions.

Cross-eye, or squint (page 639), is due to defects of the eye muscles. Some cases are corrected by proper glasses; other cases require surgery.

Cataract (page 640) is a condition in which the crystalline lens becomes opaque. The cause in many cases is unknown, and hence prevention is impossible.

C. Infant and Maternal Mortality.—Infant mortality is the most sensitive index we possess of social welfare. Healthy parents are likely to produce healthy children. The percentage of deaths among infants has been on the decrease for many years. In the United States, in 1900, 1 out of 10 infants under one year of age died; in 1922, 1 out of 13 and, in 1932, 1 out of 17 died. Human infants are born in a more helpless condition than the young of most mammals and must be cared for. A certain amount of

[1] For *nearsight, farsight,* and *astigmatism,* see page 639.

infant mortality cannot be prevented—for example, that due to birth before the seventh month; but some of it can be prevented. Proper feeding and care and protection against contagious diseases such as measles, whooping cough, diphtheria, etc., are effective.

Maternal mortality due to childbed fever may be prevented by elimination of the infective bacteria that are mainly of the streptococcus type.

D. Relations of Water Supply, Air, and Soil to Public Health.—It is not necessary to emphasize here the desirability of having a good water supply, since every household and community knows how important this is. Water may be clean, polluted, or contaminated. Polluted water contains substances that produce color, odor, or taste. Pollution of drinking water by certain Protozoa has been referred to several times. Streams that flow into reservoirs may bring with them wastes from manufacturing establishments that render the water unfit for human consumption.

Contaminated water contains infective organisms. These reach the water usually as a result of unsanitary conditions. The principal diseases contracted by drinking contaminated water are typhoid fever, cholera, and dysentery. Suspected water is tested for colon bacilli, since the presence of these organisms proves contamination of the water with human wastes.

Water may be *purified* in several ways: *aeration*, or exposing water to air, removes tastes and odors; *sedimentation* removes suspended particles; *filtration* through sand removes bacteria, Protozoa, tastes, odors, and harmful minerals; *chlorination* kills bacteria. The last is one of the most widely used methods of purification, but even this does not kill cysts of the dysentery *Endamoeba* and some types of spores.

An abundant supply of fresh air is now generally recognized as necessary for good health (page 581). Air at high temperatures may lead to exhaustion and is responsible for the death of many infants. Air that is excessively humid is depressing, whereas dry air is stimulating. Moving air is more comfortable than stagnant air. Smoke in the air is irritating to the eyes and mucous membranes and may lead to respiratory diseases. Dust may be irritating and may contain infective bacteria. Pollen grains in the air are responsible for hay fever in susceptible persons. Certain gases in the air, especially carbon monoxide, cause death; illuminating gas escaping in the house is responsible for much discomfort and causes many deaths each year.

Soil Pollution.—Although the upper few inches of soil, especially soil containing organic material, is swarming with bacteria and Protozoa, most of them are harmless. Soil may become polluted, however, with infective organisms, especially where sanitary conditions are bad. Hookworm disease (page 323), infections with the roundworm *Ascaris lum-*

bricoides (page 819) are commonly acquired from polluted soil. Tetanus (page 849) and anthrax bacilli may live in the soil in the spore stage. The typhoid bacilli and cysts of dysentery amoebae may remain alive in the damp soil for days, weeks, or months and may find their way into drinking water or food. Prevention of soil pollution will eliminate many dangers of infection from many diseases.

E. Mental Diseases.—Among mental diseases are classed not only insanity but a great number of other abnormal conditions due to mental difficulties. Some of these are larceny, lying, misconduct of various types, truancy, maladjustment to environment, hallucinations, inferiority complex, insomnia, etc. The causes of most types of mental diseases are unknown. Certain conditions are inherited and cannot be cured, but many others, such as some types of feeble-mindedness, can be treated successfully and the patients returned to society in a normal state.

F. Habit-forming Drugs.—Drugs are special preparations made from plants, animals, and inorganic sources. Some are very useful, even indispensable, in the practice of medicine. Some of these useful drugs may be habit-forming, as shown by the fact that in the United States it is said that there are about 150,000 persons who are slaves to morphine. Large numbers are addicted to other drugs. Morphine, cocaine, and alcohol were in use long before the era of modern civilization.

Some drugs are poisons, as certain salts of mercury; others, such as ether and chloroform, have an *anesthetic* (Gr. *anaisthetos*, insensible) action and, when breathed into the lungs, cause temporary loss of consciousness. Too much inhaled causes death. A third type is *narcotic* (Gr. *narkoun*, to benumb), causing dullness and stupor, and is often used to relieve pain. Some drugs, however, give a pleasurable feeling and lead to habit formation. The commonest narcotics are opium, cocaine, nicotine, laudanum. Opium is made from the dried juice of the opium poppy (*Papaver somniferum*, Fig. 257). Marijuana is a narcotic obtained from a weed belonging to the Indian-hemp family. While under its influence, people may commit acts that they do not remember afterwards. Drug addicts must take larger and larger doses of the drugs to obtain the desired effect. The nervous system is particularly affected; the general health is ruined; sometimes mental disorders result.

G. Alcohol.—The formation of alcohol was discussed on page 193. Wine, cider, and beer are alcoholic drinks. Wine comes mainly from fermented grapes and certain other fruit juices; cider results from fermentation of apple juice; beer is made from fermented grain. Distilled liquors contain a larger percentage of alcohol.

1. KINDS OF ALCOHOL.—Alcohol made from grain is called *grain*, or *ethyl, alcohol;* that from distilled wood is *wood*, or *methyl, alcohol.* The latter is poisonous and unfit for internal use or in medicines. It is useful,

however, in manufacturing processes. All alcohol is of great value as a solvent and is used in the manufacture of paints, varnishes, and many other industrial products. Alcohol is said to be *denatured* when something is added to it that renders it unfit for internal use.

2. Effect on the Body.—Alcohol is absorbed into the blood unchanged but is oxidized in the body as other foods are. It is, however, believed to be injurious to the various organs and is, therefore, not classed as a food. On account of its solvent action, it may cause injury to fat-like materials such as the substance in the nerve sheaths (*lipoid*). It has been found that substances such as chloroform and ether, used in modern surgery to produce unconsciousness, are substances that dissolve lipoids; they also act as poisons.

For a long time, the test of the effects of alcohol was the loss of one's self-control. It has been found, as a result of careful studies, that persons who drink liquids containing 2.7 per cent or more of alcohol are not able to make precise measurements or perform skilled acts with the same degree of accuracy as those who do not. Individuals differ in this respect, some being more affected than others. Heavy drinkers are not considered good insurance risks, and an appalling number of automobile accidents are the result of the fact that drivers either were intoxicated or had lost some of their skill as a result of a drink or two.

It has been observed that the first effect of alcohol is on the higher centers of the brain. "The brake is off," so to speak, and persons who have been drinking behave in a manner that they would condemn when sober.

Statistics show that alcohol reduces the resistance of the body to disease. What happens is that, after taking alcohol, more blood reaches the surface of the skin, and a pleasurable feeling of warmth may ensue. There is danger that too much heat may be lost if a person stimulated in this way is exposed to cold. Also, the feeling of stimulation may be followed by a depressing reaction.

Many "patent" medicines contain a considerable amount of alcohol. Under the Food and Drugs Act of 1907, the presence and amount of alcohol in any medicine must be printed on the label.

H. Tobacco and Health.—According to a famous story, when Sir Walter Raleigh returned to England from America, he had learned to smoke. One day a servant entering a room saw the smoke and threw a bucket of water over him to "put out the fire." Even before this, Columbus had observed a peculiar habit of the Indians, who took hollow sticks in the shape of a Y and placed the horns of the Y in the nose and the stem in the smoke of burning tobacco. They then inhaled the smoke directly into the nostrils. The poison in tobacco is known as *nicotine*. It gets its name from Nicot, who, in 1561, was the French ambassador to Lisbon. Nicot became an early user of tobacco.

Billions of dollars are spent in the United States each year for tobacco. Aside from its effect on the population, millions of dollars of property "go up in smoke" each year from the careless habits of smokers.

A wide difference of opinion exists with respect to the harmfulness of smoking. As in the case of alcohol, not all persons are affected alike. Two types of trouble may result from excess smoking or from moderate smoking if a person has a low tolerance to the effects of smoking. These are (1) an impaired *sense of color vision* and (2) the *inflammation of the optic nerve.* Many experiments have been conducted that seem to show that the *heartbeat* is also affected by the use of tobacco. For this reason, persons in training for athletic events do not smoke.

Tobacco is especially harmful to young persons, particularly when it is inhaled into the lungs. The mucous membrane of the nose and lungs absorbs small quantities of the poisons produced when the tobacco is burned. Curiously enough, nicotine has recently been found to be of use in the treatment of pellagra.

Questions

1. Distinguish between the types of natural resources.
2. Besides those mentioned in the text, suggest methods for preventing forest fires.
3. How does nature protect the soil? Do you know of a man-made desert?
4. Give an account of water erosion; of wind erosion. What is meant by sheet erosion? Gully erosion? How did the "Dust Bowl" come into existence?
5. How may forests be preserved indefinitely and yet be valuable to the owner?
6. What is a permanent pasture? Does it necessarily deteriorate?
7. Why must big game necessarily disappear from most "settled" country? Make suggestions for its preservation.
8. In what ways are national forests valuable to all the people?
9. Can you suggest methods of preserving wild flowers that are becoming rare?
10. Give an account of the way in which erosion and industrial wastes affect the life of plants and animals that live in streams.
11. Make a list of preventable diseases, stating how each one is transmitted.
12. In your opinion, should mental defectives be allowed to have offspring? Give reasons for your answer.
13. What are some effects of alcohol on the health, particularly of young people? Of tobacco?
14. Why is a well-planned conservation program necessary? Should this affect only the replaceable resources? What other resources must be conserved?
15. Why do we speak of man as our greatest resource? Do you think a public-health program the best type of conservation? Give reasons for your answer.

Part VII

THE HISTORY OF BIOLOGY

CHAPTER L

THE DEVELOPMENT OF BIOLOGY

The history of science is science itself. . . .
—GOETHE.

I. Introduction

The history of the development of the science of biology is the history of the men who have worked in this field, leaving a record of their patient research and discoveries. There is evidence that man possessed some biological knowledge even before written history. This is shown in pictures, carvings, and relics of primitive man.

Each of the periods into which the history of biology may be roughly divided is dominated by certain concepts. These have been referred to from time to time in this book. Some of these concepts were strengthened by later research; others have been proved false and have disappeared. An example of the latter was the theory of abiogenesis, or spontaneous generation (page 10).

In one short chapter, it is possible to select only a few men concerned with the high lights of the subject. Often the brilliant accomplishments of these men were built upon obscure work of many workers.

II. From Ancient Times to 400 B.C.

Primitive man must have had a body of biological knowledge that was handed down from generation to generation. Plants and animals useful for food were known to him, as well as some that were to be avoided.

Beginning with the ancient civilizations, an Assyrian bas-relief shows that hand-pollination of the date palm was practiced at least nine centuries before Christ, and there are records that this palm was cultivated in 6000 B.C. These ancients must have known that there were two kinds of date-palm trees and that both were necessary for the production of fruit, though nothing was known of the mechanism of sex at that time.

Sculptures and drawings also show that ancient Egyptians and Assyrians reared horses and cattle. It is to be presumed that they knew something about selection, for "an engraving on bone in an excavation in Mesopotamia, dating from about ?2800 B. C. is interpreted by Amschler (1935) as a pedigree chart of horses of several different types."[1]

[1] Shull, "Heredity," p. 4, McGraw-Hill Book Company, Inc., 1938.

The Chinese were cultivating rice as early as 5,000 years ago, and barley grains have been found in the tombs of mummies who lived about 4000 B.C.

In ancient Babylon, clay models of various parts of the human body and ancient Babylonian writing show that some progress had been made in medicine. The practice of embalming the dead in ancient Egypt reveals that they had a knowledge of human anatomy.

From all these facts, it is clear that the existence of a considerable body of biological knowledge was possessed by the ancient peoples.

III. The Greek and Roman Period

A. The Early Greeks.—The earliest zoological writings of importance were produced by the Greeks. These early writers were philosophers who developed the deductive method of reasoning. They refer to the beliefs of "the ancients." From this it may be assumed that there was a body of philosophical and biological knowledge handed down to them. Five of the more important men may be mentioned in connection with the early period of scientific development of the Greeks.

Thales (640–546 B.C.) was an astronomer who believed that all life originated in the ocean; the belief is not dead even today.

Anaximander (611–547 B.C.) believed in spontaneous generation and in the theory that animals developed in the sea, becoming transformed into terrestrial animals.

Empedocles (495–435 B.C.) also believed in spontaneous generation. He held to the curious belief that parts of organisms were kept separated by hate and were later brought together by love!

Hippocrates (460–370 B.C.) has been called the *father of medicine.* Many of the Hippocratic treatises dealing with anatomy, physiology, etc., are believed to be of a later date, though they are influenced by his views.

Democritus (460–357 B.C.) Finally, the close of the period of Greek development may be represented by Democritus. He had a materialistic idea of the universe. For him, even the soul perished with the body. Some of his teachings concerned the adaptations of single organs; he believed that the brain is an organ of thought and that types of animals might be distinguished by the quality of the blood.

B. Later Greeks and the Romans.—The figure that stands out far above all others of his time in Greek philosophy (Fig. 38) was *Aristotle* (384–322 B.C.). His were the first scientific treatises that had an influence upon modern biological thought, and so careful were his observations and deductions that they were considered authoritative for 20 centuries. Aristotle was the foremost pupil of *Plato* and the tutor of Alexander the Great. His works reveal a remarkable familiarity with the

facts of comparative anatomy, physiology, and embryology. He was a critical compiler and, from the fabric of scattered facts and fancies that existed at his time, produced a compact and fairly accurate account of animals.

Aristotle did not believe in special creation, but he did believe in an "internal perfecting tendency," or *intelligent design.* He was interested mainly in animals, but his pupil Theophrastus (370–287 B.C.) first studied plants scientifically. He is often spoken of as the *founder of the science of botany.*

After the time of Aristotle and Theophrastus, scientific learning declined for a time. This branch of learning was not fostered by the Romans until later.

Pliny the Elder (A.D. 23–79) was a Roman general and a writer. He compiled 37 volumes of natural history. These books were a curious mixture of fact and fancy and remained for 15 centuries as a source of information regarding natural history.

Discorides (A.D. ?–40), a Greek physician, wrote a pharmacological account of plants that was very celebrated.

Galen (A.D. 130–200) was a Greek who lived in Rome. He was a physician, the last of the great biologists of ancient times. Dissection of human bodies was forbidden in Galen's time, and so animals had to be used in his studies. His books on anatomy were the standard for use in medical schools for about fifteen centuries.

IV. The Middle Ages

The Middle Ages, or medieval times, are usually designated as the time between the fall of the Roman Empire (A.D. 400) to the revival of learning about A.D. 1400.

A. The Dark Ages.—The early part of the Middle Ages is usually designated as the Dark Ages. After the time of Galen, all fields of learning suffered an eclipse. The period produced no great biologists. The church controlled learning; the appeal was to authority. All biological questions were referred to the ancient authorities; original investigation was at a standstill. In one controversy, a series of papers was published with respect to the number of teeth in a horse's mouth. In this instance, not one of the writers seems to have thought of examining an animal, but all were satisfied to quote the words of men who had died centuries before.

B. The Renaissance.—Beginning about A.D. 1350 and continuing through the sixteenth century, there was a great revival of art and learning. This revival, known as the *Renaissance,* was due largely to the abandonment of ancient authorities and to a renewal of the method employed by Aristotle, *i.e.,* personal observation.

Among the works published in Germany during this period were the "Herbals," which contained descriptions of the plants of western Europe. Also huge volumes containing all the information obtainable about animals, regardless of whether it was truth or fiction, were published at this time by the so-called *encyclopedists.*

The Renaissance is described as a period of great restlessness. During this time, there was an increasing knowledge of nature itself. This was brought about in part by the discovery and exploration of new countries through the Crusades and the travels of such men as *Marco Polo;* during the fifteenth century, the Portuguese made long voyages; America was discovered in 1492. It was not now possible to deal with the great amount of new information that was accumulating about plants and animals by studying ancient authorities.

One of the most important men of the late Renaissance was *Francis Bacon* (1561–1626). His greatness rests, not upon scientific achievement as such, but upon the fact that he believed in acquiring knowledge of nature by *observation and experiment.* His aim was to reform all human knowledge.

V. The Development of Biology since the Fifteenth Century

Since there is much overlapping of the work of men of the late Renaissance time of transition to the modern period, it will be convenient to consider the development of the various fields of biology about the fifteenth century.

A. Comparative Anatomy.—This subject is mentioned first among the biological subjects because of the leadership of Vesalius (Fig. 549) in the revival of teaching from first-hand observation. It was due to him that the teaching methods of Galen were discontinued after so many centuries.

Leonardo da Vinci (1452–1519) was a famous Italian artist, a mechanician, and a pioneer in the study of comparative anatomy.

Andreas Vesalius (1514–1564) was a Belgian anatomist (Fig. 549). Some of his ideas now seem strange, but his contribution was to return to first-hand observation by the dissection of the human body and the overthrow of authority. His book, "The Structure of the Human Body," was written by the time he was twenty-eight years of age.

Georges Cuvier (1769–1832), was a French scientist (Fig. 550) whose studies ranged over the entire animal kingdom. Besides a number of treatises on comparative anatomy, he wrote a book on the fossil remains of animals, which founded the science of vertebrate paleontology.

Richard Owen (1804–1892), an English anatomist, was also a paleontologist. He contributed much to our knowledge of the structure of

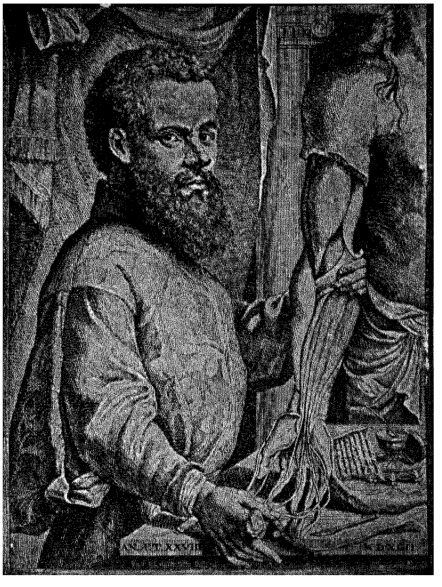


Fig. 549.—Andreas Vesalius, 1514–1564.

Fig. 550.—Georges Cuvier, 1769–1832. (From Locy, Biology and Its Makers, Henry Holt and Company, Inc.)

various types of animals. Of particular importance was the clear distinction he made between homologous and analogous organs.

B. Microscopic Anatomy.—In the early days of the development of the microscope, many amateurs became interested in the minute structures of living things. Following these were the microscopic anatomists, who made real contributions to the structures of plants and animals.

Robert Hooke (1635–1703), an Englishman, published in 1665 a description of the cell in his book "Micrographia" (page 30).

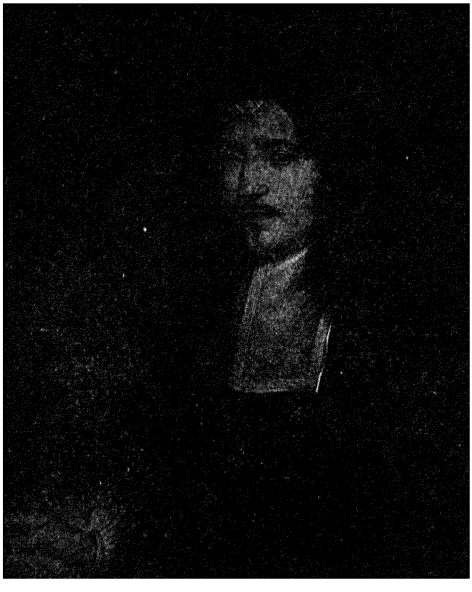


Fig. 551.—Marcello Malpighi, 1628–1694. (From Garrison, History of Medicine, W. B. Saunders Company.)

Anton van Leeuwenhoek (1632–1723) was a Dutchman who ground his own lenses and constructed over 200 microscopes (Fig. 15). With these he made many discoveries—of bacteria, Protozoa, and many other organisms not seen before by man. Although another Dutchman, *Hamm*, first observed animal sperm, Leeuwenhoek studied the spermatozoa of many animals. He described blood corpuscles first in the frog, later in man.

Jan Swammerdam (1637–1680), another Dutchman, made a careful study of the minute anatomy of insects, snails, and clams.

Marcello Malpighi (1628–1694), an Italian (Fig. 551), was a contemporary of Hooke, Leeuwenhoek, and Swammerdam. Probably his greatest discovery was demonstration of capillary circulation in the lungs. His figures on the minute anatomy of the silkworm are often reproduced.

Nehemiah Grew (1641–1712), an Englishman, was a pioneer in the study of microscopic plant tissues and one of the first plant histologists.

C. Embryology.—Aristotle made observations on the development of the chick; these were extended by Harvey. The development of the subject of embryology, however, had to wait upon two things, the perfecting of the microscope and the development of physiology and anatomy.

It was inevitable that many theories should arise, some of which seem fantastic in the light of modern embryology (page 671).

Hieronymus Fabrizio (1537–1619), an Italian, began the establishment of the science of embryology by describing, as best he could without a microscope, the development of the chick.

Caspar Frederich Wolff (1733–1794) was a German naturalist and physician. Some of the details of his comparisons are erroneous, but he was the first to compare plant and animal development. Although the theory of epigenesis was not new with Wolff, one of the most important of his contributions was to introduce this theory in the place of the preformation theory.

Karl Ernst von Baer (1792–1876), a Russian, is often called the *father of embryology*. He published notable papers on the development of the chick in 1832.

D. Systematic Biology.—It was natural that biologists should concern themselves with relationships of plants and animals from very early times. Work in this field was especially important during the Middle Ages, as old systems were changed and the basis for the new systems that we have today was established.

John Ray (1628–1705), an Englishman, used structure as a basis for classification of all living things. He was greatly in advance of his time.

Carolus Linnaeus (1707–1778), a Swedish scientist, (Fig. 39), was the most important figure of his time. "Systematic Biology" was his great work, and he attempted to describe all the existing species of plants and animals. He succeeded in listing 4,378 in the tenth edition of his greatest work, "Systema naturae." Perhaps his greatest contribution was the binomial system of nomenclature (page 69).

Asa Gray (1810–1888), an American, was a writer on systematic botany and American flora. In addition, he was a champion of Darwinism.

E. Natural History.—A large proportion of men included in other fields were also naturalists. The two names that follow represent a very large group.

Konrad von Gesner (1516–1565) was a Swiss. His complete work on plants was never published, but two large volumes containing 1,000 drawings appeared in 1751–1772. His "Historia animalia" in five volumes

is a compendium of all the knowledge of the sixteenth century regarding animals.

Louis Agassiz (1807–1873) was an American biologist, born in Switzerland, of French parents. His chief work was with fish, both recent and fossil.

F. Experimental Biology and Physiology.—The foundation for modern physiology was laid by the discovery of the human circulation of the blood by William Harvey, in 1628, and by the brilliant work of Johannes Müller, something more than 200 years later.

William Harvey (1578–1657) was an Englishman (Fig. 377). His book "Exercitatio anatomica de motu cordis et sanguinis in animalibus" ("An Anatomical Dissertation on the Movement of the Heart and Blood in Animals") was published in 1628. He proved by simple experiments that the blood flowed away from the heart in the arteries and to the heart in the veins. Perhaps the greatest contribution made by Harvey was that after his time biology became more and more an experimental science.

Francesco Redi (1626–1698), an Italian naturalist, performed a simple experiment (page 11) that proved that new organisms did not arise by spontaneous generation from nonliving substances.

Stephen Hales (1667–1761), an Englishman, was an early student of plant physiology. He determined by means of experiments the role that leaves play in the movements of fluids in plants.

Albrecht von Haller (1708–1777), of Switzerland, was a many-sided man, a poet, a botanist, and a physiologist. He summarized in easily accessible form all the known physiological facts of his time.

Jan Ingenhousz (1730–1799), of Holland, discovered a part of the process (photosynthesis) that occurs in green plants in the manufacture of food.

Lazaro Spallanzani (1729–1799), an Italian, used experimental methods in studies of regeneration, processes of fertilization, and other types of work.

Robert Brown (1773–1858), a Scotch physician, is credited with opening the field of plant physiology and genetics. He also discovered the importance of the cell nucleus in the cell in 1832.

Johannes Müller (1801–1858), a German, was the first great comparative physiologist. He published his "Handbuch der Physiologie des Menschens" ("The Handbook of Human Physiology") in 1833. He was the first to bring the facts of chemistry and physics to bear on physiology.

Julius Sachs (1832–1897), a German, made important contributions to experimental plant physiology. He had many brilliant pupils, among them the famous plant physiologist, *William Pfeffer* (1845–1920).

G. Microbiology.—Research in pure science is always important in the development of applied science. Sometimes men working in the meth-

ods of pure science are able to do work of great benefit to mankind. Three men may be mentioned here:

Louis Pasteur (1822–1896), a Frenchman (Fig. 4), was a chemist but was better known for his work in biology and preventive medicine. By proving that microorganisms (yeasts and bacteria) cause fermentation, he was able to suggest a method of preventing this process by heating substances high enough to kill these germs (pasteurization). He saved the silkworm industry of France (page 813), developed a method of treatment of *hydrophobia* (page 848), and, by conclusive experiments disproved the theory of spontaneous generation, belief in which had persisted for so long (page 11).

Robert Koch (1843–1906), a German, was the first to use aniline dyes in his studies with bacteria. He discovered the bacillus of tuberculosis and the microorganism of cholera.

Fritz Schaudinn (1871–1906), also a German, was a brilliant microbiologist. He did much work in the field of pure science, but his chief contributions were in working out the life history of the malaria parasite *Plasmodium* and other pathogenic Protozoa. With E. Hoffmann he discovered the causative agent of syphilis, the spirochete *Treponema pallida* (page 849).

H. Evolution.—As shown by work of the ancient Greeks, there was an idea, even in that far-off day, that species change or evolve. In the Middle Ages, the majority of biologists believed in the fixity of species and special creation (page 780). However, during this time, as the brief sketches of the prominent men of the time will show, there were ingenious explanations as to the causes of descent with change.

Comte Georges Louis Leclerc Buffon (1707–1788) expressed the ideas of many of his time regarding the origin or many different kinds of plants and animals. He realized the "struggle for existence"—that geographical isolation and natural selection are factors in evolution—and believed that changes due to action of the environment are inherited.

Erasmus Darwin (1731–1802) was an English country physician, the grandfather of Charles Darwin. His best known published work is his book "Zoonomia." In addition to descriptions of anatomy and coloration of animals in this book, he expresses views on evolution, one of these being his belief in the inheritance of acquired characters.

Jean Baptiste Lamarck (1744–1829), a Frenchman (Fig. 552), was the most famous advocate of the theory that acquired characters are inherited. His theory of organic evolution was the most complete up to that time.

Sir Charles Lyell (1797–1875), of England, a geologist, is included here because of the influence upon Charles Darwin of his ideas of evolution in geology.

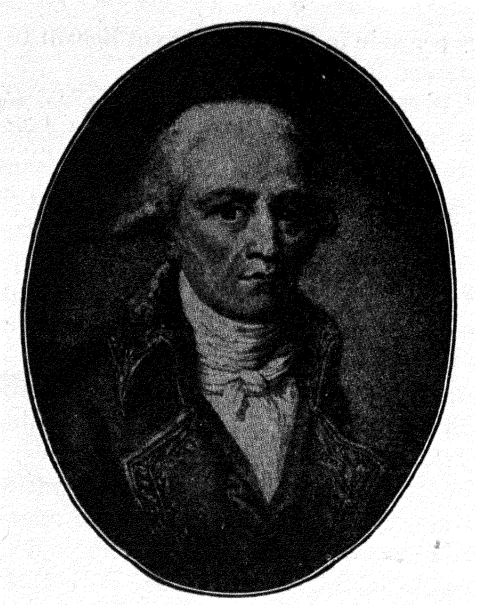


Fig. 552.—Jean Baptiste Lamarck, 1744–1829. (From Locy, Biology and Its Makers, Henry Holt and Company, Inc.)

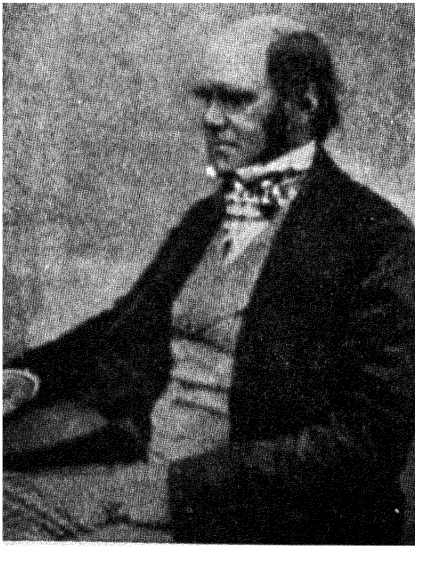


Fig. 553.—Charles Darwin, 1809–1882. (From Locy, Biology and Its Makers, Henry Holt and Company, Inc.)

Charles Darwin (1809–1882).—Most authorities agree that the publication in 1859 of "The Origin of Species by Means of Natural Selection," by Charles Darwin (Fig. 553) had a profound effect upon the thinking of that time. Darwin's ideas of natural selection and organic evolution (page 797) were not original with him but were the outgrowth of the ideas of his grandfather, Erasmus Darwin, and other men. However, for over 20 years he assembled with painstaking care the evidence for these theories, which he had collected on his travels.

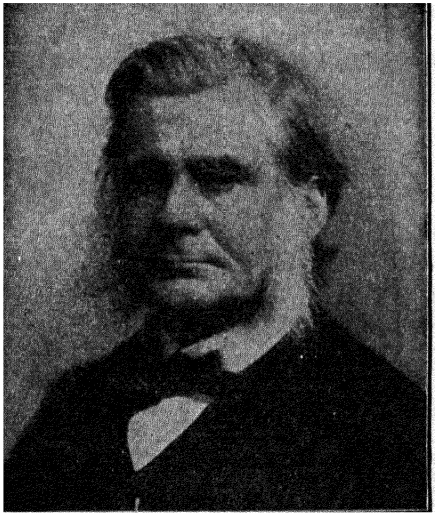


Fig. 554.—Thomas Henry Huxley, 1825–1895.

Alfred Russel Wallace (1822–1913), also an Englishman, wrote a paper setting forth practically the same views as Darwin on organic evolution (page 797).

Thomas Henry Huxley (1825–1895), an Englishman, was not only a great zoologist but also a master in writing English prose. Darwin was of a retiring disposition, and it was Huxley who was largely responsible for placing Darwin's theories before the public (Fig. 554).

I. Cytology and Genetics.—The fields of cytology and genetics are, of necessity, very closely related. The tremendous advance of the subject of genetics is due to the exact observations now possible to cytologists using greatly improved microscopes and delicate techniques. Although chromosomes had been observed as early as 1880, their behavior and their importance as the bearers of hereditary characters were not established until much later.

Matthias Jacob Schleiden (1804–1881) (Fig. 16) and *Theodor Schwann* (1810–1882), both Germans, formulated the cell theory in the publications of the results of their work during 1838–1839 (page 31).

Max Schültze (1825–1874), a German, established through extended research that *protoplasm is the fundamental substance* of both plants and animals.

Gregor Johann Mendel (1822–1884) was the son of German parents, born in what was at that time Austria (Fig. 466). He applied statistical methods to his work with peas and showed that characters did not blend in the germ cells of the hybrids but reappeared in definite proportions in a later generation (page 717).

August Weismann (1834–1914), also a German, stressed the fundamental difference between germ cells and somatic or body cells (page 798).

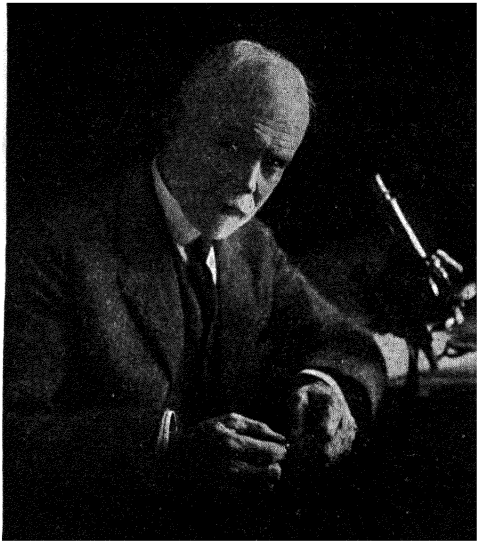


Fig. 555.—Edmund B. Wilson, 1856–1939.

Sir Frances Galton (1822–1911) was an Englishman who applied mathematical methods to the studies of human heredity (page 750).

Hugo De Vries (1848–1935), a Dutch botanist, was one of the three men who independently rediscovered the Mendelian law about 1900. He is famous for his work in plant breeding and genetics and for the formulation of *die Mutationstheorie* (page 740).

Edmund B. Wilson (1856–1939) was the foremost American cytologist of his time (Fig. 555). He began his work as an experimental biologist; his most important work had to do with cellular biology, particularly with chromosomes and their relation to heredity.

Thomas H. Morgan (1866–1945) is an American zoologist who recently received the Nobel prize for his work in heredity. With his associates, he has made an exhaustive study of heritable phenomena.

using the fruit fly *Drosophila melanogaster* as an experimental medium. He has added much to our knowledge of the mechanism of heredity. Before beginning his work in genetics, Morgan was an experimental embryologist of note.

VI. Biology Today

Biology today is an experimental science. That is to say that biologists are most concerned with trying to find by experimental methods the fundamental causes of biological phenomena. It was necessary that the natural world should first be described, classified, and correlated, as interpretation of natural phenomena is possible only with the information at hand.

Biology is progressing more rapidly at this time than at any other period in the world's history. In the United States, various institutions, such as the Rockefeller Institution for Medical Research, of New York City and Princeton, N.J., and professors of biology elsewhere are encouraged to carry on investigations that every year are adding to our knowledge of plants and animals.

Widely scattered over the United States are biological laboratories where scientists congregate in the summer to do research and exchange information and ideas. The greatest of these is the Marine Biological Laboratory, at Woods Hole, Mass. Among others are Mount Desert Island Laboratory, at Salsbury Cove, Me., biological laboratories of Cold Spring Harbor, L.I., Douglas Lake, Mich., La Jolla, Calif., and Mountain Lake, Va.

The United States government also encourages research in biology, particularly in those subjects that have a direct bearing on the improvements of plants and animals of interest to agriculture and animal industry. Bureaus of biological survey, plant industry, animal industry, and entomology are particularly important.

Biological progress is international in character, as the foregoing brief account shows. No attempt is made to evaluate the enormous amount of biological research now in progress in America, as well as in the rest of the world. Indeed, history in all fields of biology is developing so rapidly that even a specialist has difficulty in keeping up with all the work in his own field. Much of this work relates to the future well-being of humanity; all of it is concerned with a better understanding of living things. Biology is a great study; it is the study of life itself.

Questions

1. What evidence is there that there was a considerable body of biological information before the time of Aristotle?
2. What were some of the ideas held by biologists before the time of Aristotle?
3. Discuss the work of Aristotle.

4. Why is Galen an important figure of his time?
5. Give a reason for the decline of science during the Dark Ages.
6. What advantage had Vesalius over his predecessors in the study of the human body?
7. Why is Cuvier's work important?
8. What advances in biology had to await the development of the microscope?
9. What important contributions were made by Hooke? Leeuwenhoek? Swammerdam? Malpighi?
10. What men are associated with the development of embryology, and what were their chief contributions?
11. Who gave us the binomial system of nomenclature? What effect has this system had on the study of biology?
12. Beginning with William Harvey, give a brief account of the men associated with the development of physiology and their work.
13. What is meant by applied biology? Why would the French people consider Pasteur their greatest man? What important work was done by Koch? Schaudinn?
14. What views on the theory of evolution were held by Aristotle? Buffon? Erasmus? Darwin? Lamarck? Charles Darwin? What was Huxley's contribution to the study of evolution?
15. Why are cytology and genetics so closely related? Why was the formulation of the cell theory so important? Why was Max Schultze's work important?
16. Give an account of Mendel and his work.
17. Evaluate the work of Weismann, Galton, De Vries, E. B. Wilson, and T. H. Morgan in the development of the study of genetics.

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APPENDIX

The following table is a synopsis of communities adopted by a committee of the Ecological Society of America.[1]

I. Land Communities.

(*a*) *Forests with broad thin leaves.*

1. Continuously moist and evergreen.
   (*a*) Uniformly warm, affording habitats in six or more strata. (Tropical rain forests.)
2. Intermittently dry or cold, and deciduous.
   (*a*) Warm with distinct dry season. (Tropical deciduous forest.)
   (*b*) With cold winter, little winter shelter. (Temperate deciduous forest.)

(*b*) *Communities of evergreen forests of narrow, thick leaves.*

1. Moist conifer forest with little undergrowth.
2. Rainy conifer forest with shrub undergrowth.
3. Open, arid, conifer forest.

(*c*) *Communities of savanna and grassland.*

1. Tropical savanna (dry season) affording habitats in groves, thickets, forest margins, and grasslands.
2. Tropical steppe; large herds of mammals.
3. Temperate savanna; habitats in groves, thickets, forest margins, and grasslands.
4. Temperate steppe with cold or dry winters and usually large herds of mammals.
5. Arid, broken, bush-covered steppe with small herds of mammals.

(*d*) *Communities of winter rain* (forests with broad, thick leaves), *e.g.*, California semi-desert.

(*e*) *Communities of desert and semi-desert.*

1. Grass, cactus, tree semi-desert with grazing mammals (*e.g.*, South Texas semi-desert); succulent semi-desert; shrub-covered semi-desert.
2. Extreme desert without large diurnal mammals.

(*f*) *Arctic and Alpine lands.*

1. Tundra.
2. Alpine meadows.
3. Ice fields.

II. Communities of Waters and Shores.

(*a*) *Communities of the sea* (*Marine*).

1. Communities of the open sea (Pelagic).
   (*a*) Mid-oceanic communities.
   (*b*) Oceanic island communities.
   (*c*) Sargassum communities.
   (*d*) Coastal oceanic communities.
2. Communities of the sea bottom (Benthic).

[1] From Shull, "Principles of Animal Biology," McGraw-Hill Book Company, Inc., 1941.

3. Littoral communities
   (*a*) Communities of eroding shores; subdivisions based on exposure, bottom material, and latitude.
   (*b*) Communities of depositing shores; subdivisions as above plus vegetation.
   (*c*) Special communities: coral; tidepools; kelp.

III. Communities of the Sea Shores. Animals feeding in the sea and breeding on the land, or vice versa. Classification based on climate.

IV. Communities of the Fresh Waters.
   (*a*) *Communities of still waters.* Subdivisions based on size, depth, and vegetation: littoral, pelagic, benthic.
   (*b*) *Communities of turbulent waters.* Subdivisions based on character of water movement.
   (*c*) Swamps, marshes, etc.

THE 12 CRANIAL NERVES OF THE VERTEBRATES, THEIR ORIGIN, DISTRIBUTION, AND FUNCTION*

Number	Name	Origin	Distribution	Function
I	Olfactory	Olfactory lobe of forebrain	Lining of nose	Sensory
II	Optic	Second vesicle of forebrain	Retina of eye	Sensory
III	Oculomotor	Ventral region of midbrain	Muscles of eye	Motor
IV	Trochlearis (patheticus)	Dorsal region of the midbrain	Superior oblique muscle of eye	Motor
V	Trigeminal (trifacial)	Side of medulla (hindbrain)	Skin of face, mouth, and tongue and muscles of jaws	Largely sensory
VI	Abducens	Ventral region of medulla	External rectus muscle of eye	Motor
VII	Facial	Side of medulla	Chiefly to muscles of face	Largely motor
VIII	Auditory	Side of medulla	Inner ear	Sensory
IX	Glossopharyngeal	Side of medulla	Muscles of membranes of pharynx, and tongue	Sensory and motor
X	Vagus (pneumogastric)	Side of medulla	Posterior visceral arches, lungs, heart, stomach, and intestines	Sensory and motor
XI	Spinal accessory (not present in all vertebrates)	Side of medulla	Chiefly muscles of shoulder	Sensory and motor
XII	Hypoglossal (not present in all vertebrates)	Ventral region of medulla	Muscles of tongue and neck	Motor

* There is an old rhyme that may aid in remembering the order of the cranial nerves: "On old Olympus' tufted top, a Finn and German picked some hops."

The Composition of Foods

(Compiled from various sources; see bibliography at end of Chap. XXXIV)

Food	Measure	Weight, ounces	Calories	Protein, per cent	Fat, per cent	Carbohydrates, per cent	Ca	P	Fe	A	B	C	G
Meats and fish													
Beef, round	2½ × 2½ × ¾ in.	3 5	156	21 3	7 9		−	++	+	+	++	− to +	++
Bacon, smoked	4 slices	1 4	250	10 5	64 8		−	+	+	− to +	+ to ++	?	++
Lamb chops, broiled	2 chops, lean	2.4	244	21 7	29 9		−	++	++	− to +	++	?	+++
Fish													
Flounder, fresh	1 small	16 0	282	14 2	0 6		−	+	−	− to +	+	?	+
Salmon, canned	¾ cup	3 5	196	22 0	12 8		+	++	+	+	?	?	++
Liver, beef	3 × 3 × ¾ in.	4 0	150	20 4	4 5	1 7	−	++	+++	++ to +++	++	+	+++
Cereals													
Bread, white, with water	2 slices	1 4	100	9 2	1 3	53 1	+	+	−	?	+	−	?
Bread, whole wheat with water	1 slice	1 0	74	9 7	0 9	49 7	+	+	+	+	+++	?	+
Cornmeal	1 cup	5 0	504	9 2	1 9	75 4	−	+	−	− to +	+	−	?
Oatmeal	1 cup	2 6	298	16 1	7 2	67 5	+	++	++	− to +	++	−	+
Rice, brown	½ cup	3 5	351	8 0	0 3	79 0	+	++	+	+	++	−	+
Vegetables													
Beans, kidney, dried	½ cup	3 5	347	20 0	1 8	55 2	++	+++	+++	+	++	?	+
Beans, string, fresh	¾ cup	3 5	42	2 4	0 2	7 7	+	+	+	++	++	++	++
Cabbage, fresh	1 cup, chopped	3 1	28	1 4	0 2	5 3	+	+	−	+	++	+++	++
Carrots, fresh	¾ cup	3 5	45	1 2	0 3	9 3	+	+	−	+++	++	++	++
Cauliflower	1 cup, chopped	3 5	32	2 4	0 22	4 9	++	+	−	+	++	+	++
Lettuce	3 large leaves	1 9	10	1 2	0 2	2 9	+	+	+	+ to ++	++	++	++
Onions, fresh	1 medium	2 2	30	1 6	0 3	9 9	+	+	−	− to +	+	++	+
Peas, fresh	¾ cup	3 5	100	6 7	0 4	17 7	−	+	+	++	++	+++	++
Potatoes, sweet	1 medium	7 1	200	1 8	0 7	27 9	−	+	−	+++	++	++	+
Potatoes, white	1 medium	5 3	100	2 0	0 1	19 1	−	+	+	+	++	++	+
Spinach, fresh	1 cup	8 0	55	2 3	0 3	3 2	+	+	+	+++	+	++	++
Tomatoes, canned	⅔ cup	5 0	35	1 2	0 2	4 0	−	+	−	++	++	+++	+
Dairy products													
Butter	1 square	0 3	50	1 0	81 0		−	−	−	+++	−	−	−
Cheese, American	1 tablespoon	0 3	33	28 8	35 9	0 3	+++	+++	+	++ to +++	?	?	+
Eggs, whole	1 egg	1 6	68	13 4	10 5		+	++	++	+++	+ to ++	−?	+++
Milk, whole	1 cup	8 5	170	3 3	4 0	5 0	++	+	−	+++	++	+ (variable)	+++
Fruits and nuts													
Apples, fresh	1 medium	6 0	80	0 4	0 5	14 2	−	−	−	+	+ to ++	++	++
Bananas	1 medium	5 5	100	1 2	0 2	23 0	−	+	−	+ to ++	+ to ++	++	++
Grapefruit	½ large	10 0	100	0 5	0 2	10 1	−	+	−	+	++	+++	++
Grapes	20 grapes	3 5	100	1 3	1 6	19 2	−	+	−	+	+	− to +	+
Oranges	1 medium	7.5	80	0 8	0 2	11 6	+	−	−	+	++	+++	++
Pears, fresh	1 medium	2 8	50	0 7	0 4	15 8	−	−	−	?	++	+	++
Peanuts, shelled	20 kernels	0 6	100	25 8	38 6	24 4	+	++	+	+	++	?	+
Prunes, dried	4 medium	1 4	100	2.1		73 3	+	+	+	++	++	−	++

THE GEOGRAPHICAL REGIONS OF THE WORLD LIFE REALMS

1. Nearctic realm (Gr. *neo*, late or new + arctic). This includes North America, down to the edge of the Mexican Plateau, and Greenland.

2. Palearctic (Gr. *palaios*, ancient + arctic). This region includes Europe, Africa (north of the Tropic of Cancer), Asia (north of the Himalayas), and Japan. Many plants and animals found here are also found in the Nearctic. These two regions are sometimes united to form the Holarctic region (Gr. *holo*, whole + arctic).

3. Neotropical (Gr. *neo*, new or recent + tropical). This includes Central America, Mexico, South America, and the West Indies.

4. Ethiopian (Gr. *aithiops*, black face). This includes Africa (south of the Sahara Desert), southern Arabia, Madagascar, and adjacent islands.

5. Oriental (L. *orientalis*, eastern). This region includes Asia south of the Himalayas and that portion of the Malayan Archipelago, which lies northwest of Wallace's line. This line divides the Oriental and Australian regions. It passes east of the Philippines between the islands of Bali and Lombok and between Borneo and Celebes.

6. Australian (from L. *Terra Australis*, southern land) **region.** This includes Australia and adjacent islands as far west as Wallace's line. It includes also a great many small islands east of Australia. There are practically no higher mammals here, but there are a great many Marsupials.

7. Polynesian (Gr. *polys*, many; *nesos*, islands) **regions.** Made up of many oceanic islands of the tropical Pacific. Often included with the Australian region.

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